Research on dual-channel fresh food supply chain under the sharing of fresh-keeping costs

Fang Zhang[1,a], Xiaotian Qu[1,b*]

[1]School of Marketing Management, Liaoning University of Engineering and Technology, Xingcheng City, Huludao City, Liaoning Province

[a]Email: 1363662778@qq.com

*[b]Corresponding author Email:1582365028@qq.com

Abstract. This study is aimed at the secondary fresh supply chain composed of suppliers and retailers, based on the premise of the unified retail price of fresh products online and offline. At the same time, this paper considers that the demand for fresh products is affected by the freshness of the product, the level of online value-added services and the level of offline promotion, and introduces a cost-sharing contract. The research uses the Starkolberg game to build a centralized decision-making model (FC mode), a decentralized decision-making model with no shared cost of preservation (FS mode), and a decentralized decision-making model with shared preservation costs (FD mode). To explore whether the supplier bears the retailer's cost of fresh-keeping, the impact on the decision-making of suppliers and retailers, in order to achieve coordination among supply chain members. The research shows that: (1) The total demand and total profit of the supply chain in the FD model are larger than those in the FS model; (2) The fresh-keeping level of supply chain members in FD model is better than that in FS model. The fresh-keeping cost sharing contract is conducive to improving the fresh-keeping efforts of supply chain members, thereby improving the freshness of fresh products.

keywords: Consumer channel preference; Dual-channel supply chain; Fresh products; Cost sharing; Supply chain member coordinationa

1 Introduction

With the continuous expansion of market demand for fresh products and the development of e-commerce, various types of fresh supply chains have emerged as the times require. A large number of enterprises such as "Yonghui Supermarket", "Hema Fresh" and "Pagoda" have flooded into the e-commerce market. Competition among supply chain members and between online and offline channels has intensified, and consumers are paying more and more attention to the quality of products and services provided by each channel. Due to the perishable and fragile nature of fresh products, in order to maintain the freshness of the products when it is delivered to consumers, supply chain members need to make more efforts to preserve them. Compared with suppliers, retailers have to bear more fresh-keeping costs such as store fresh-keeping

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and storage fresh-keeping. The high cost of fresh-keeping can easily cause dissatisfaction among retailers and lead to conflicts among supply chain members. Under the circumstance that the retailer's fresh-keeping cost burden is increasing, how suppliers and retailers coordinate through cooperation contracts is an urgent problem to be solved by enterprises in the fresh food supply chain. Therefore, the research on the cost sharing of fresh-keeping in the dual-channel fresh supply chain is a topic worthy of discussion.

At present, scholars at home and abroad have carried out extensive research on the coordination of fresh product supply chain. Cai(2013) considered the fresh product supply chain composed of suppliers, retailers and third-party logistics service providers, and studied the coordination problem in the case of simultaneous quantity and value loss. Huo(2020) studied the agricultural product supply chain of a single channel, and considering the situation that the retail price and the retailer's promotion efforts have an impact on demand at the same time, and designed revenue sharing, cost sharing, and wholesale price discount contracts to maximize the benefits of the supply chain. Moon(2018) studied the coordination problem of secondary fresh food supply chain in which the fresh-keeping effort level of producers and the investment service level of retailers affected demand, and designed a revenue-sharing plus cost-sharing and incremental quantity discount to coordinate the supply chain. The above literature mainly studies the fresh supply chain of traditional channels, and does not conduct research on the fresh supply chain under the e-commerce model.

With the entry of fresh food enterprises into the field of e-commerce, the coordination between members of the dual-channel fresh food supply chain has attracted the attention of scholars at home and abroad, and some scholars have studied the factors affecting demand in the coordination of fresh food supply chains. Tang(2017) considered that time and temperature would affect the quality of fresh food, and then affect the market demand. Based on this, they studied the supply chain coordination under the coexistence of traditional channels and network channels. Devangan(2013) studied the supply chain coordination and optimization problem in which inventory quantity affects retailers' demand, stimulated demand with shelf space inventory, and designed a repurchase contract to achieve supply chain coordination and optimization. Sun(2015) designed a revenue-sharing contract based on the characteristics of fair concerns among supply chain members, considering the situation that demand is affected by product freshness and transportation losses. The study shows that when the wholesale price meets certain conditions, revenue sharing can effectively achieve supply chain coordination. Fei(2020) studied the coordination of green supply chain, established a game model in which manufacturers consider retailers' fairness and consumers' green awareness when investing in emission reduction technologies, and achieve supply chain coordination and optimization through revenue sharing contracts. The above-mentioned scholars' research on the influencing factors of demand mainly focuses on product quality, inventory, supply chain member willingness and consumer willingness.

Consumers' attention to the services of fresh enterprises and the freshness of fresh products has also attracted the attention of many scholars. Zhang(2015) conducted an empirical study on the factors affecting the purchase intention of fresh agricultural products under the O2O model, and the results showed that the service quality of fresh enterprises positively affects consumers' perceived value. Zhang(2015) conducted a study on the fresh supply chain in which manufacturers and retailers jointly invested in fresh-keeping efforts. The conclusion shows that joint investment in preservation efforts is beneficial to manufacturers, but it will damage the profits of retailers and the overall supply chain, thus introducing revenue sharing and cost sharing contracts to achieve supply chain coordination. Feng(2018) studied the situation that the market demand of fresh products is affected by the retail price and logistics level, and the manufacturers and retailers start a game to achieve the optimization of the fresh supply chain. Wang(2019) constructed a fresh supply chain model in which suppliers and retailers jointly invest in preservation and promotion efforts, and introduced a contract of sharing preservation costs and promotion costs. Research shows that cost sharing can effectively improve the interests of each member of the supply chain. Zou(2021) considered a fresh supply chain in which suppliers provide product preservation and distribution services and retailers provide value-added services, and designed a "two-way revenue sharing + cost sharing" contract to achieve coordination among members of the supply chain. Chen(2022) conducted research on the dual-channel supply chain of fresh food in which both suppliers and retailers have opened online channels, constructed a demand function affected by the level of suppliers' fresh-keeping efforts, and achieved supply chain coordination through cost allocation and benefit sharing. Yang(2017) studied that under the background that the demand for fresh agricultural products is affected by the price and the effort level of retailers, suppliers and retailers conduct a game to determine the optimal wholesale price.To sum up, it can be seen that the research on the coordination among fresh food e-commerce supply chain members has just started, and there is a lack of research that combines the cost of freshness with important factors such as promotion efforts and value-added services.

In view of this, on the basis of existing research, this paper considers the situation in which the online and offline fresh-keeping efforts, online value-added services, and offline promotion services jointly affect demand in the dual-channel fresh food supply chain, explore the coordination and optimization of the fresh food supply chain under the retailer's fresh-keeping cost sharing contract, and discuss how the members of the supply chain can achieve the best interests, analyze the factors that affect the interests of each member of the supply chain and the overall interests of the supply chain, in order to provide reference for the decision-making of each member of the supply chain.

2 Materials and Methods

2.1 Problem description

The dual-channel supply chain of fresh products studied in this paper is a secondary supply chain composed of a fresh product supplier and a fresh product retailer. Online channels are direct sales by suppliers, while offline channels are sold by suppliers to retailers at wholesale prices, and then by retailers to consumers. As shown in Figure

1, in the e-commerce environment, suppliers will take advantage of online advantages to provide consumers with value-added services e, including recommendations, consultation, after-sales and other issues, while retailers will promote fresh products offline to increase sales. In the process of product circulation, suppliers and retailers are jointly responsible for the preservation of products.

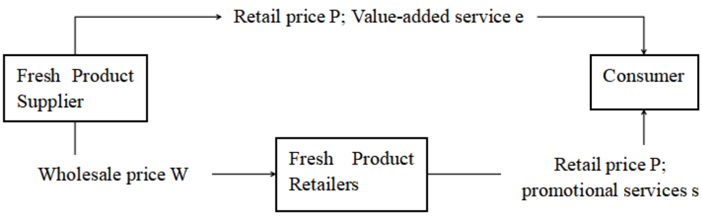

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Fig. 1. Dual-channel supply chain of fresh product

Assume that in the fresh supply chain, the supplier is the leader and the retailer is the follower. In order to ensure the freshness of products delivered to consumers and avoid retailers' dissatisfaction due to high fresh-keeping costs, suppliers take the initiative to share retailers' fresh-keeping costs. Considering that suppliers and retailers are mostly decentralized decision-making in real life, this paper only compares the impact of whether suppliers share the retailer's preservation cost on the decision-making of supply chain members under decentralized decision-making. In order to verify the necessity of sharing the cost of fresh-keeping, a centralized decision-making model and a decentralized decision-making model were designed to compare. Based on this, this paper considers: (1) the centralized decision-making model of suppliers and retailers (FC model);2) Suppliers and retailers make decentralized decision-making, and the cost of fresh-keeping is independently borne by suppliers and retailers (FS model); (3) Suppliers and retailers decentralize decision-making, and suppliers bear θ times the retailer's fresh-keeping costs (FD model).

2.2 Model Assumptions

Assumption 1: The fresh products considered in this paper are not specific seasonal products, but traditional fresh products, so it is assumed that the supply of fresh products is relatively stable, and the wholesale prices and market prices are relatively stable. In order to make the calculation more convenient, it is assumed that other costs in the circulation process of fresh products are 0. Even if they are not 0, it will not affect the conclusions of this paper.

Assumption 2: Assuming that the market demand of fresh products is independent of price. When consumers buy fresh products, online channels are mainly affected by the level of value-added services and product freshness of suppliers, while offline channels are mainly affected by retailers' promotion level and product freshness.

From this, the online channel demand function and offline channel demand function can be obtained as follows:

$$D_1 = A + \alpha\lambda_1 - \beta\lambda_2 + \gamma e \quad (1)$$

$$D_2 = 1 - A + \alpha\lambda_2 - \beta\lambda_1 + \rho s \quad (2)$$

Among them, subscript 1 represents online channels, and subscript 2 represents offline channels; A represents the consumer's preference for online channels; and $0 \leq A \leq 1$; α and β represent the influence coefficient of the freshness of the product on the demand of this channel and the cross-influence coefficient of the demand of the alternative channel, and $0 \leq \beta \leq \alpha \leq 1$; λ represents the freshness of the product; γ represents the influence coefficient of the supplier's value-added service level on the demand of online channels;e represents the supplier's value-added service level; ρ represents the influence coefficient of the retailer's promotion level on offline channel demand; s represents the retailer's promotion level.

Assumption 3: The value-added service cost that the supplier needs to pay to provide the value-added service level is:$C(e)=ne^2/2$, where n is the value-added service cost coefficient.

Assumption 4: The promotion cost that retailers need to pay to provide the level of promotion service is:$C(s)=ks^2/2$, where k is the cost coefficient of promotion service.

Assumption 5: Suppliers and retailers must pay corresponding costs to improve product freshness both online and offline. The fresh-keeping cost of the supplier is:$C(\lambda_1)=\varphi_1\lambda_1^2/2$; the fresh-keeping cost of the retailer is: $C(\lambda_2)=\varphi_2\lambda_2^2/2$, where are the online fresh-keeping effort cost coefficient and the offline fresh-keeping effort cost coefficient, respectively.

2.3 Model parameters and variables

Table 1. Description of main parameters and variables

Parameters and Variables	meaning
θ	Percentage of suppliers' co-guarantee of fresh-keeping costs
w	Product wholesale price
P	Product online and offline unified retail price
$\lambda_1^{FC*}, \lambda_1^{FS*}, \lambda_1^{FD*}$	Optimal online preservation effort level under FC, FS, FD models
$e^{FC*}, e^{FS*}, e^{FD*}$	Optimal value-added service level of suppliers under FC, FS, FD models
$D_1^{FC*}, D_1^{FS*}, D_1^{FD*}$	Optimal online demand in FC, FS, FD model
$\pi_1^{FC*}, \pi_1^{FS*}, \pi_1^{FD*}$	Optimal online profit in FC, FS, FD model
$\pi^{FC*}, \pi^{FS*}, \pi^{FD*}$	The optimal profit of supply chain under FC, FS, FD model

Table 2. Description of main parameters and variables

Parameters and Variables	meaning
$\lambda_2^{FC*}, \lambda_2^{FS*}, \lambda_2^{FD*}$	Optimal offline preservation effort level of FC, FS, FD models
$s^{FC*}, s^{FS*}, s^{FD*}$	Optimal promotion effort level of retailers under FC, FS, FD models
$D_2^{FC*}, D_2^{FS*}, D_2^{FD*}$	FC, FS, FD model offline optimal demand
$\pi_2^{FC*}, \pi_2^{FS*}, \pi_2^{FD*}$	FC, FS, FD model offline optimal profit
$D^{FC*}, D^{FS*}, D^{FD*}$	Optimal demand of supply chain under FC, FS, FD model

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3 Results & Discussion

3.1 Centralized Decision Making (FC model)

Under the FC model, the suppliers and retailers are taken as a whole, and decisions are made based on the maximum benefit of the overall supply chain. At this time, the profit function of the overall supply chain is:

$$\pi = \mathrm{P}(D_1 + D_2) - \frac{\varphi_1\lambda_1^2}{2} - \frac{\varphi_2\lambda_2^2}{2} - \frac{ne^2}{2} - ks^2/2 \tag{3}$$

The Hessian matrix H(1) is:

$$H(1) = \begin{bmatrix} -\varphi_1 & 0 & 0 & 0 \\ 0 & -\varphi_2 & 0 & 0 \\ 0 & 0 & -n & 0 \\ 0 & 0 & 0 & -k \end{bmatrix}$$

The Hessian matrix is negative definite, and the objective function π can be obtained as a concave function. Taking the first-order partial derivative of (3), the optimal online freshness preservation level λ_1^{FC*}, the optimal offline freshness preservation level λ_2^{FC*}, the optimal online value-added service level e^{FC*}, and the optimal offline promotion level s^{FC*} in the FC model can be obtained as follows:

$$\lambda_1^{FC*} = \frac{P(\alpha-\beta)}{\varphi_1} \tag{4}$$

$$\lambda_2^{FC*} = \frac{P(\alpha-\beta)}{\varphi_2} \tag{5}$$

$$e^{FC*} = \frac{\gamma P}{\omega} \tag{6}$$

$$s^{FC*} = \frac{\rho P}{k} \tag{7}$$

Bringing (4), (5), (6), and (7) into the demand functions (1), (2) and the profit function (3), the optimal demand and maximum profit online and offline under the centralized decision-making model can be obtained, details as follows:

$$D_1^{FC*} = A + \frac{P\gamma^2}{\omega} + \frac{\alpha P(\alpha-\beta)}{\varphi_1} - \frac{\beta P(\alpha-\beta)}{\varphi_2} \tag{8}$$

$$D_2^{FC*} = 1 - A + \frac{P\rho^2}{K} + \frac{\alpha P(\alpha-\beta)}{\varphi_2} - \frac{\beta P(\alpha-\beta)}{\varphi_1} \tag{9}$$

$$\pi^{FC*} = \frac{P^2(\varphi_1+\varphi_2)(\alpha-\beta)^2}{2\varphi_1\varphi_2} + \frac{P^2\gamma^2}{2\omega} + \frac{P^2\rho^2}{2k} + P \tag{10}$$

3.2 The cost of preservation is not shared and decentralized decision-making (FS model)

In the FS model, suppliers and retailers pursue their own interests, and the profit functions of suppliers and retailers are as follows:

$$\pi_1^{FS} = PD_1 + WD_2 - \frac{\varphi_1\lambda_1^2}{2} - \frac{ne^2}{2} \tag{11}$$

$$\pi_2^{FS} = (P - W)D_2 - \frac{\varphi_{2\lambda_2^2}}{2} - \frac{ks^2}{2} \tag{12}$$

In FS model, suppliers and retailers play a Stackelberg game. In the first stage, suppliers formulate the online fresh-keeping effort level λ_1^{FS} and value-added service level e^{FS}. On this basis, retailers make decisions on the offline fresh-keeping effort level λ_2^{FS} and promotion effort level s^{FS}. Taking (12) for the first and second partial derivatives of λ_2 and s, we get: $d\pi_2 FS/d\lambda_2>0$, $d^2\pi_2^{FS}/d\lambda^2_2<0$; $d\pi_2^{FS}/ds>0$, $d^2\pi_2^{FS}/ds^2>0$. Therefore, (12) has a maximum value for λ_2 and s, respectively setting their first-order derivatives equal to zero to obtain:

$$\lambda_2^{FS*} = \frac{\alpha(P-W)}{\varphi_2} \tag{13}$$

$$s^{FS*} = \frac{\rho(P-W)}{k} \tag{14}$$

Substituting (13) and (14) into (11), the Hessian matrix H(2) can be obtained as:

$$H(2) = \begin{bmatrix} -\varphi_1 & 0 \\ 0 & n \end{bmatrix}$$

Obviously, the Hessian matrix is negative definite, and the objective function π_1^{FS} is negative definite, so the function (11) has a maximum value for λ_1^{FS} and e^{FS}. Taking the first-order derivation of (11) and making it equal to zero, the online optimal fresh-keeping level λ_1^{FS*} and the online optimal value-added service level e^{FS*} can be obtained, as follows:

$$\lambda_1^{FS*} = \frac{\alpha P-\beta W}{\varphi_1} \tag{15}$$

$$e^{FS*} = \frac{\gamma P}{n} \tag{16}$$

Substitute (13), (14), (15), (16) into (1), (2), (11), (12), the optimal online and offline demand, the maximum online and offline profit and the total profit of the supply chain under the FS model can be obtained. The solution is as follows:

$$D_1^{FS*} = A + \frac{P\gamma^2}{n} + \frac{\alpha(\alpha P-\beta W)}{\varphi_1} - \frac{\alpha\beta(P-W)}{\varphi_2} \tag{17}$$

$$D_2^{FS*} = 1 - A + \frac{\rho^2(P-W)}{k} + \frac{\alpha^2(P-W)}{\varphi_2} - \frac{\beta(\alpha P-\beta W)}{\varphi_1} \tag{18}$$

$$\pi_1^{FS*} = W + A(P-W) + \frac{\gamma^2 P^2}{2n} + \frac{\rho^2 W(P-W)}{k} + \frac{\alpha(P-W)(\alpha W-\beta P)}{\varphi_2} + \frac{(\alpha P-\beta W)^2}{2\varphi_1} \tag{19}$$

$$\pi_2^{FS*} = (P-W)\left(1 - A - \frac{\beta(\alpha P-\beta W)}{\varphi_1}\right) + \frac{\rho^2(P-W)^2}{2k} + \frac{\alpha^2(P-W)^2}{2\varphi_2} \tag{20}$$

$$\pi^{FS*} = \frac{\alpha(\varphi_1+\varphi_2)(\alpha(P^2-W^2)-2\beta P^2)}{2\varphi_1\varphi_2} + \frac{2\beta PW(\alpha\varphi_1+\beta\varphi_2)}{2\varphi_1\varphi_2} + \frac{\gamma^2 P^2}{2n} + \frac{\rho^2(P^2-W^2)}{2k} + P \tag{21}$$

Theorem 1: Compared with the FC model, the total profit of the supply chain in the FS model shows a downward trend.

Prove:

$$\pi^{FC*} - \pi^{FS*} = \frac{k\varphi_1(\alpha W-\beta P)^2 + \beta^2 k\varphi_2(P-W)^2 + \varphi_1\varphi_2\rho^2 W^2}{2k\varphi_1\varphi_2} > 0$$

From Theorem 1, it can be seen that the overall profit of the supply chain is higher under centralized decision-making, but in real life, suppliers and retailers are mostly in a state of decentralized decision-making, and it is difficult to achieve the effect of centralized decision-making. As the leader of the fresh food supply chain, a reasonable contract mechanism can be introduced to achieve the overall coordination of the supply chain and the optimization of the interests of each member.

3.3 Retailers share decentralized decision-making for fresh-keeping costs (FD model)

In the FD model, the dominant supplier takes the initiative to share the retailer's fresh-keeping costs, which can prompt retailers to provide more fresh-keeping efforts, thereby improving the freshness of fresh products reaching consumers, thereby increasing sales. In this model, suppliers and retailers make decisions with the goal of maximizing their own interests, As follows:

$$\pi_1^{FD} = PD_1 + WD_2 - \frac{\varphi_1\lambda_1^2}{2} - \frac{\theta\varphi_2\lambda_2^2}{2} - \frac{ne^2}{2} \tag{22}$$

$$\pi_2^{FD} = (P-W)D_2 - \frac{(1-\theta)\varphi_2\lambda_2^2}{2} - \frac{ks^2}{2} \tag{23}$$

Under the FD model, suppliers and retailers engage in a two-stage game. The game sequence of the two is as follows: the supplier formulates the online fresh-keeping level λ_1 of fresh products, the online value-added service level e, and the retailer's share of fresh-keeping cost ratio θ. Based on this retailer formulates the offline preservation level λ_2 and promotion level s. Taking (23) for the first-order and second-order partial derivatives of λ_2 and s, we can get: $d\pi_2^{FD}/d\lambda_2>0$, $d^2\pi_2^{FD}/d\lambda_2^2<0$; $d\pi_2^{FD}/ds>0$, $d^2\pi_2^{FD}/ds^2>0$. Therefore (23) has a maximum value for λ_2 and s, and the solution is:

$$\lambda_2^{FD*} = \frac{\alpha P-\beta W}{\varphi_2(1-\theta)} \tag{24}$$

$$s^{FD*} = \frac{\rho(P-W)}{k} \tag{25}$$

Substitute (24), (25) back into (22), find the first-order partial derivative of (22) with respect to λ_1, e, θ and make it equal to zero. The optimal online preservation level λ_1^{FD*}, the optimal online value-added service level e^{FD*} and the optimal preservation cost sharing ratio θ^{FD*}can be obtained. As follows:

$$\lambda_1^{FD*} = \frac{\alpha P-\beta W}{\varphi_1} \tag{26}$$

$$e^{FD*} = \frac{\gamma P}{n} \tag{27}$$

$$\theta^{FD*} = \frac{3\alpha W-\alpha P-2\beta P}{\alpha P-2\beta P+\alpha W} \tag{28}$$

Substitute

$$\lambda_2^{FD*} = \frac{\alpha P+\alpha W-2\beta P}{2\varphi_2} \tag{29}$$

Substitute (25), (26), (27), (28), (29) into (1), (2), (22), (23) to get:

$$D_1^{FD*} = A+\frac{\gamma^2 P}{n}+\frac{\alpha(\alpha P-\beta W)}{\varphi_1}-\frac{\beta(\alpha P+\alpha W-2\beta P)}{2\varphi_2} \tag{30}$$

$$D_2^{FD*} = 1-A+\frac{\beta(\alpha P-\beta W)}{\varphi_1}+\frac{\rho^2(P-W)}{k}-\frac{\alpha(\alpha P+\alpha W-2\beta P)}{2\varphi_2} \tag{31}$$

$$\pi_1^{FD*} = W+A(P-W)+\frac{\rho^2 Q(P-W)}{k}+\frac{\gamma^2P^2}{2n}+\frac{(\alpha P-\beta W)^2}{2\varphi_1}+\frac{\alpha^2(P-W)^2}{8\varphi_2}+\frac{\beta P(\beta P-\alpha P-\alpha W)}{2\varphi_2} \tag{32}$$

$$\pi_2^{FD*} = (1-A)(P-W)+\frac{\alpha^2(P^2-W^2)}{4\varphi_2}+\frac{2\rho^2(P-W)^2}{4k}-\frac{\alpha\beta P(P-W)(\varphi_1+\varphi_2)}{2\varphi_1\varphi_2}+\frac{\rho^2 W(P-W)}{\varphi_1} \tag{33}$$

$$\pi^{FD*} = P+\frac{\gamma^2 P}{2n}+\frac{\rho^2(P^2-W^2)}{2k}+\frac{3\alpha^2P^2+4\beta^2P^2-\alpha^2W^2-8\alpha\beta P^2+2\alpha^2PW)}{8\varphi_2}+\frac{\alpha^2P^2-\beta^2W^2-2\alpha\beta P^2+2\beta^2PW)}{2\varphi_1} \tag{34}$$

4 model Results Analysis

Corollary **1:**

$$\lambda_1^{FS} = \lambda_1^{FD*}, \lambda_2^{FD*} > \lambda_2^{FS*}, \Delta\lambda_2 = \lambda_2^{FD*} - \lambda_2^{FS*}, \frac{\partial\Delta\lambda_2}{\partial P} > 0, \quad \frac{\partial\Delta\lambda_2}{\partial W} > 0, \quad \frac{\partial\Delta\lambda_2}{\partial \alpha} > 0, \quad \frac{\partial\Delta\lambda_2}{\partial \beta} < 0, \quad \frac{\partial\Delta\lambda_2}{\partial \varphi_2} < 0$$

It can be seen from Corollary 1 that under the FS model and the FD model, the online fresh-keeping efforts of the suppliers are equal, but the offline fresh-keeping efforts of the retailers under the FD model are greater than those of the FS model. It can be seen that: (1) Suppliers bear part of the offline fresh-keeping costs, which improves the retailers' enthusiasm for fresh-keeping, thereby improving the freshness of offline fresh products, and thus increasing sales. (2) The offline freshness preservation level of retailers is proportional to the wholesale price W and the influence coefficient α of the freshness preservation level on this channel. It is inversely proportional to the online and offline unified retail price P, the cross-influence coefficient β of the preservation level on alternative channels, and the offline channel preservation cost coefficient φ_2. As the leader of the supply chain, suppliers can improve the preservation technology, reduce the preservation cost of products, actively promote the preservation of fresh products by using value-added services, and increase consumers' attention to the preservation level. At the same time, it will improve the cooperation with retailers in fresh-keeping, stimulate consumers to buy products with higher fresh-keeping levels, and further increase the sales of fresh products.

Corollary 2:

$$s^{FS*} = s^{FD*}, \frac{\partial s^{FD*}}{\partial P} > 0, \quad \frac{\partial s^{FD*}}{\partial \rho} > 0, \quad \frac{\partial s^{FD*}}{\partial W} > 0, \frac{\partial s^{FD*}}{\partial k} > 0$$

From Corollary 2, it can be seen that the level of retailer's promotion efforts has nothing to do with whether the supplier bears the cost of fresh-keeping, so the level of retail's fresh-keeping efforts in FS model and FD model are equal. And it is positively related to the influence coefficient ρ of the retailer's promotion effort level on demand and the unified online and offline retail price P, and it is negatively related to the wholesale price W and the offline channel promotion cost coefficient k. If the level of promotion is to be further increased, a new dynamic mechanism or contract needs to be introduced. For example, the use of new media such as big data and the Internet can make promotions more targeted, increase consumers' attention to new media channels, and make them willing to pay for new media channels with higher freshness and more satisfactory promotional services. At the same time, it can improve the efficiency of promotion, save the cost of promotion, and increase the sales of fresh products.

Corollary 3:

$$e^{FS*} = e^{FD*}, \frac{\partial e^{FD*}}{\partial \gamma} > 0, \quad \frac{\partial e^{FD*}}{\partial P} > 0, \frac{\partial e^{FD*}}{\partial n} > 0$$

It can be seen from Corollary 3 that: (1) The value-added service level of the supplier under FS mode and FD mode does not change with whether the supplier bears the retailer's preservation cost; (2) e is positively related to the influence coefficient γ of value-added service level on online demand and the unified retail price P of online and offline, and negatively correlated with the value-added service cost coefficient n . With the increase of online and offline sales prices and the influence coefficient of service demand, the level of value-added services also shows a positive trend of increasing. At this time, it is more effective to adopt an enhancement strategy. By raising prices to balance the cost of preservation and the cost of value-added services, it can ensure its own profits. But in the long run, price stability is the key to the stable development of the supply chain, and price adjustment is a short-term approach, not a long-term strategy. Suppliers should improve the stickiness between consumers and online value-added services by providing more diversified value-added services, such as recipe formulation, health guidance, cooking online demonstrations, etc. At the same time, increase the influence coefficient of value-added service demand, thereby increasing the sales of fresh products and ensuring the stable and lasting growth of suppliers' online profits.

Corollary 4:

$$D_1^{FD*} < D_1^{FS*}, D_2^{FD*} > D_2^{FS*}, \quad D_1^{FD*} + D_2^{FD*} > D_1^{FS*} + D_2^{FS*}$$

It can be seen from Corollary 4 that the online demand for fresh products in the FD model is smaller than that in the FS model, while the offline demand is greater than that in the FS model. Since the decrease in online demand in FD model is smaller than the increase in online model, the total demand in FD model is greater than that in FS model. This shows that suppliers' sharing of retailers' offline fresh-keeping costs plays a positive role in the overall demand of the supply chain, which motivates retailers to make more fresh-keeping efforts, resulting in higher offline sales levels. Aggregate demand can show an upward trend even as online demand decreases.

Corollary 5:

$$\pi_1^{FD*} > \pi_1^{FS*}, \pi_2^{FD*} > \pi_2^{FS*}, \pi^{FD*} > \pi^{FS*}$$

It can be seen from Inference 5 that although the online demand in FD model is smaller than that in FS model (Inference 4), the increase in offline demand is greater than the decrease in online demand. Therefore, in the FD model, the profit of the supplier is higher than that in the FS model. For retailers, profits have also improved due to improved preservation levels. Therefore, in the FD model, the profits of both suppliers and retailers have increased, and obviously the profits of the entire supply chain have also increased significantly. Both the supplier and the retailer are willing to reach a contract to improve the level of freshness, thereby increasing each other's profits, realizing Pareto improvement, and the FD model is better than the FS model.

Corollary 6:

$$\frac{\partial \lambda_1^{FD*}}{\partial \alpha} > 0, \quad \frac{\partial \lambda_1^{FD*}}{\partial \beta} < 0, \quad \frac{\partial \lambda_1^{FD*}}{\partial P} > 0, \frac{\partial \lambda_1^{FD*}}{\partial W} < 0, \frac{\partial \lambda_1^{FD*}}{\partial \varphi_1} < 0, \frac{\partial \lambda_2^{FD*}}{\partial \alpha} > 0, \frac{\partial \lambda_2^{FD*}}{\partial \beta} < 0, \frac{\partial \lambda_2^{FD*}}{\partial W} > 0, \frac{\partial \lambda_2^{FD*}}{\partial \varphi_2} < 0, \frac{\partial \lambda_2^{FD*}}{\partial P} > 0, (\alpha > 2\beta); \quad \frac{\partial \lambda_2^{FD*}}{\partial P} < 0, (\alpha < 2\beta)$$

It can be seen from Inference 6 that: (1) For suppliers in the FD model, the direct influence coefficient α of the freshness level on the channel and the online and offline wholesale price P have a positive impact on their freshness level. The cross-influence coefficient β of fresh-keeping level on alternative channels, the wholesale price of fresh products W, and the fresh-keeping cost coefficient φ_1 of online channels negatively affect the fresh-keeping level. Therefore, suppliers can adjust their own preservation level and online value-added service level according to consumers' preference for online and offline channels, and improve the preservation level and reduce the cost of preservation through higher preservation technology. Take advantage of online advantages to provide consumers with more value-added services to promote sales. (2) For retailers, the direct influence coefficient α of the fresh-keeping level on this channel positively affects their fresh-keeping level. The cross-influence coefficient β of fresh-keeping level on alternative channels, the wholesale price of fresh products W and the fresh-keeping cost coefficient of online channels φ_2 negatively affect the fresh-keeping level. Therefore, retailers can also adjust their own freshness level according to consumers' preference for different channels. At the same time, it can also provide more targeted promotions and promotions according to the needs of consumers, reduce promotion costs, improve promotion levels, and then increase offline sales.

Corollary 7:

$$\frac{\partial \theta^{FD*}}{\partial \alpha} > 0, \quad \frac{\partial \theta^{FD*}}{\partial \beta} < 0, \quad \frac{\partial \theta^{FD*}}{\partial P} < 0, \frac{\partial \theta^{FD*}}{\partial W} > 0$$

It can be seen from Corollary 7 that: (1) The proportion of FD model suppliers sharing the retailer's fresh-keeping cost increases with the increase of the direct influence coefficient α of the fresh-keeping effort level on the channel and the wholesale price W of fresh products. It decreases with the increase of the cross-influence coefficient β of fresh-keeping efforts on alternative channels and the online and offline retail prices P of fresh products. (2) The greater the direct influence coefficient of product freshness level on this channel, the higher the wholesale price of fresh products, and the greater the proportion of freshness preservation costs that suppliers are willing to bear for retailers. The cross-influence coefficient of the fresh-keeping level on alternative channels, and the greater the online and offline retail price of the product, the smaller the proportion of the fresh-keeping cost that the supplier is willing to bear for the retailer. For suppliers, raising wholesale prices will boost their own profits. For retailers, although the increase in wholesale prices will promote the sharing of fresh-keeping costs by suppliers, it will also lead to a decrease in profits. Therefore, increasing the wholesale price to achieve greater profits can easily lead to imbalances in the supply chain and undermine the healthy and stable development of the supply chain. It is more acceptable to adjust the sharing ratio according to consumers' preferences for both online and offline channels.

5 Numerical Analysis

Based on the above theoretical basis, in order to more intuitively verify the validity of the model, the influence of the online and offline preservation cost coefficient, online value-added service cost coefficient and offline promotion cost coefficient on the profit and demand of the fresh food supply chain was examined. This paper refers to previous studies [6, 10, 12] for parameter settings, as follows: W=12, P=15, A=0.5, α=0.6, β=0.3, φ_1=8, φ_2=6, ρ=0.2, γ=0.5, k=10, n=10; The calculation results are shown in the figure.

5.1 The influence of φ_1,φ_2,k, n on the profit of the supply chain under the FS and FD models

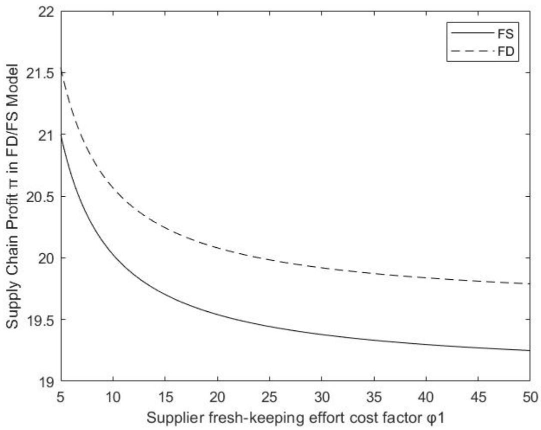

Photo credit:Original

Fig. 2. The impact of φ_1 on the profit of the supply chain under the FS and FD models

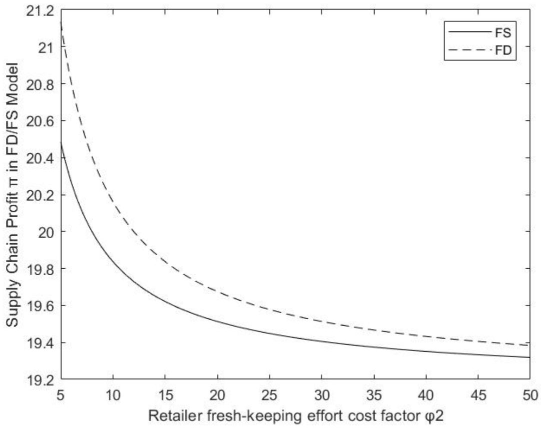

Photo credit:Original

Fig. 3. The impact of φ_2 on the profit of the supply chain under the FS and FD models

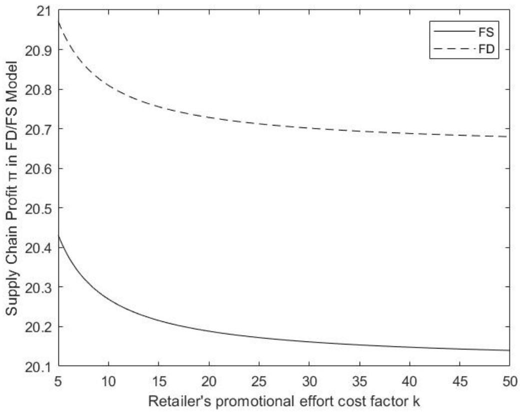

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Fig. 4. The influence of k on the profit of the supply chain under the FS and FD models

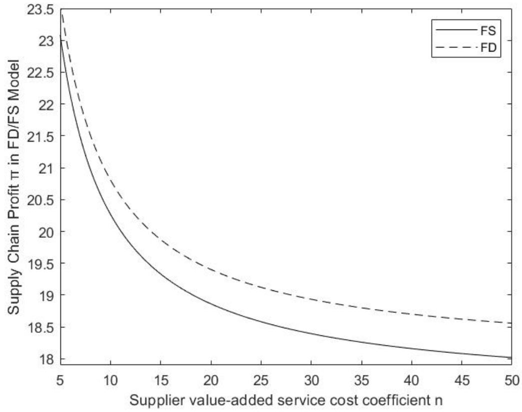

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Fig. 5. The influence of n on the profit of the supply chain under the FS and FD models

It can be seen from Figures 2 、3、4 and 5 that with the increase of the online fresh-keeping cost coefficient φ_1, the offline fresh-keeping cost coefficient φ_2, the offline promotion cost coefficient k, and the online value-added service cost coefficient n, the profit of the supply chain under both the FS model and the FD model shows a downward trend. However, the profit of the FD model supply chain is always above the FS model. Therefore, for the fresh supply chain, the FD model is a better choice. If they want to further increase the profits of the supply chain, suppliers can take advantage of the network to provide more value-added services and improve service quality; retailers can conduct targeted promotions based on consumer psychology to improve the effectiveness of promotions. On the whole, both suppliers and retailers need to introduce more advanced preservation transportation and packaging technologies to improve preservation levels, reduce preservation costs, and increase profits.

5.2 Influence of φ_1,φ_2 ,k, n on supply chain demand under FS, FD, models

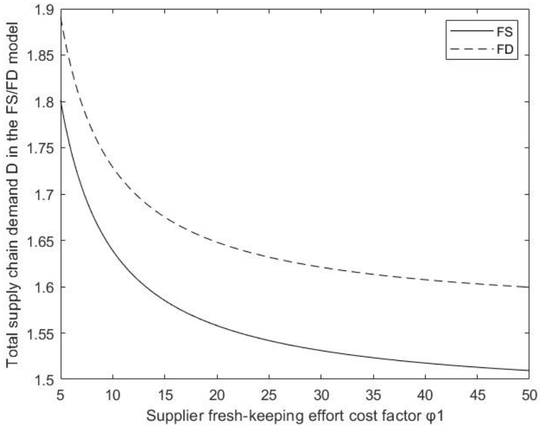

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Fig. 6. Influence of φ_1 on supply chain demand under FS and FD models

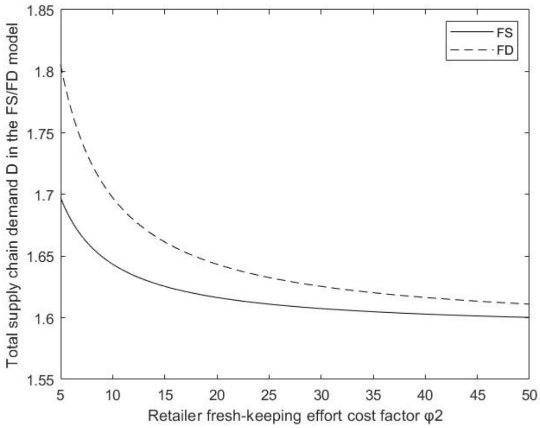

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Fig. 7. Influence of φ_2 on supply chain demand under FS and FD models

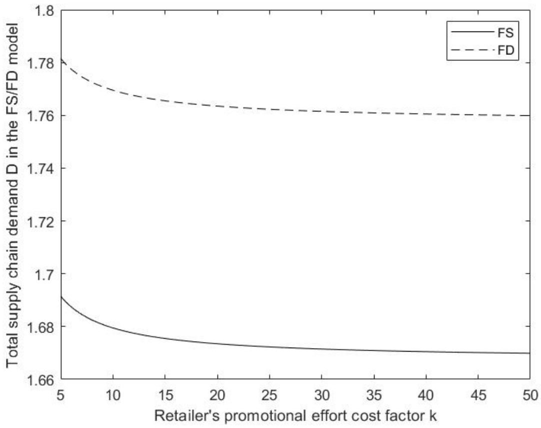

Photo credit:Original

Fig. 8. The influence of k on supply chain demand under FS and FD models

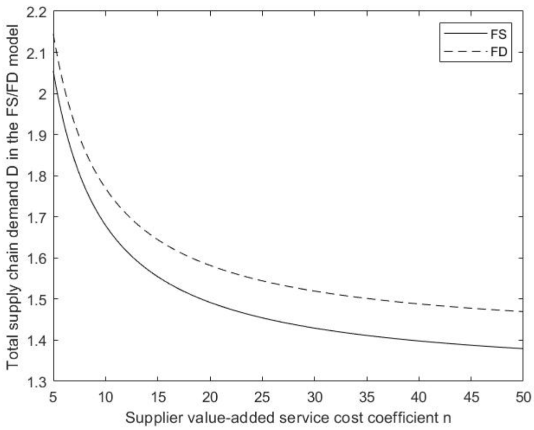

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Fig. 9. The influence of n on supply chain demand under FS and FD models

It can be seen from Figure 6、7、8 and 9 that with the increase of the online fresh-keeping cost coefficient φ_1, the offline fresh-keeping cost coefficient φ_2, the offline promotion cost coefficient k, and the online value-added service cost coefficient n. The demand in the supply chain under both the FS model and the FD model shows a downward trend, and the FD model is always higher than the FS model. This further confirms that the FD model is better for the fresh supply chain as a whole. However, for suppliers and retailers, if they want to increase demand and improve profits, they also need to take the above measures to reduce the cost of fresh-keeping, provide better services to increase consumer welfare, and then increase the overall demand of the fresh-food supply chain.

6 Conclusions

This paper aims at the secondary supply chain composed of suppliers and retailers, and takes the premise of unified price online and offline, considers that the market demand for fresh products is affected by the level of online and offline product preservation, the level of value-added services of online suppliers and the level of promotional services of offline retailers, construct a centralized decision-making model (FC model), a decentralized decision-making model with non-shared preservation costs (FS model), and a decentralized decision-making model with shared preservation costs (FD model), and solve them separately. The research shows that: (1) The total demand and total profit of the supply chain in the FD model are larger than those in the FS model. (2) The fresh-keeping level of supply chain members in FD model is better than that in FS model. The fresh-keeping cost sharing contract is conducive to improving the fresh-keeping efforts of supply chain members, thereby improving the freshness of fresh products.

Fresh product suppliers can take advantage of online advantages to provide more complete value-added services and increase consumers' attention to the freshness level of fresh products. At the same time, strengthen the cooperation with retailers in fresh-keeping, and realize the improvement of the overall profit of the supply chain. Fresh product retailers can take advantage of offline direct contact with consumers to better grasp consumer psychology, provide more targeted and effective promotional activities, and increase consumers' willingness to buy. At the same time, learn advanced fresh-keeping packaging technology, improve the freshness of fresh products, so as to increase the sales volume of fresh products, and then achieve the purpose of increasing profits.

Consumers seek higher-quality fresh products, and the preservation of products requires the joint efforts of suppliers and retailers. This paper only considers the effect of freshness of fresh products on the level of efforts of both suppliers and retailers, and does not consider that the freshness of products will also be lost over time, which will be the focus of further research.

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