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DYNAMIC PRICING STRATEGIES FOR DUAL-CHANNEL SUPPLY CHAIN OF NEARLY EXPIRED FOODS UNDER DIFFERENT POWER STRUCTURES

Abstract:

With the change of consumers' concepts, the popularity of online shopping and the strong publicity of online platforms, nearly expired food is more and more accepted by consumers. Since nearly expired food is featured with lower selling price as it approaches the shelf life, this paper investigates the dynamic pricing strategy of expired food in two stages. At the same time, considering that different supply chain power structures also have different impacts on the pricing of nearly expired food, this paper will explore the dual-channel dynamic pricing strategies under different power structures. In this paper, the dynamic pricing model of the two-channel supply chain of nearly expired food is constructed under manufacturers' dominance and mixed dominance of manufacturers and network platforms respectively, and the two-stage optimal pricing and optimal profit are solved according to the game theory. It is found that there exists a two-stage optimal pricing strategy to maximize supply chain profits. The two-stage pricing of nearly expired food in the dual-channel under the mixed dominance is smaller than that under the manufacturer's dominance. The total manufacturer profit and total retailer profit of both stages are larger in the manufacturer-dominated dual-channel supply chain model, but the manufacturer's profit from online channel sales is higher in the mixed-power-dominated model than in the manufacturer-power-dominated model. Suppliers of nearly expired food can choose the appropriate channel to sell according to the product characteristics. Finally, by solving the centralized decision-making model for the dual-channel supply chain of nearly expired food, it is obtained that under the centralized decision-making, although the pricing in both stages is lower than the decentralized decision-making mentioned above, the total profit of the supply chain is the highest, which indicates that manufacturers and retailers can achieve higher profits by developing revenue-sharing contracts, reducing channel competition, and adopting cooperative pricing.

Keywords:

nearly expired food; dynamic pricing; dual-channel supply chain; power structures

1 Introduction

Under the publicity of social media and the change of people's consumption habits, consumers are becoming more accepting of nearly expired food and are more willing to buy it at lower prices. How to better set the price and sales strategy of expired food has become the key for retailers and suppliers to get greater profitability. Besides, the rise of online shopping platforms has expanded consumers' shopping channel. Due to the low transaction costs associated with online shopping as well as the cheap cost of comparing similar products, more and more strategic customers are evaluating online and offline products before making a purchase, which has made the corporate marketing landscape more difficult. In the supply chain system, manufacture were previously in a leading position due to their core technologies. However, with the continuous development of network platforms and the further improvement of people's demand for online channel shopping, the dominant force among channels gradually shifts from manufacturing enterprises to online platforms. Therefore, we construct a dual-channel supply chain under the manufacturer dominated traditional supply chain and network platform dominated network channel to find a solution to the problem of how to dynamically set the sales price and differentiate between online and offline products in order to maximize the interests of manufacturers and retailers.

2 literature review

In this section, we review more past studies related to our research in addition to those cited in Section 1. We focus on supply chain power structures, consumer strategy-based behavior, and supply chain dynamic pricing strategies.

There is not much direct exploration of the factors influencing the demand for nearly expired food. Adventitious foods are a type of nearly expired food and also have the characteristics of some perishable goods, so in order to obtain as much useful information as possible, the concept of suboptimal foods is included in the review. Theresa et al[29] conducted a systematic literature review, using a fixed search term and 2004–2019 as timespan. They found there are two main factors affecting the consumption of suboptimal food, quality issues and price discounts. Jessica et al[30-31] set up a pricing scheme based on shelf-life proximity to examine the effects of product characteristics, purchasing habits, personal preferences, and the salesperson's communication style on purchasing decisions.

According to studies in the literature that have looked at strategic consumer behavior, Consumers can be divided into two categories: myopic and strategic. Myopic consumers are generally considered to purchase when the price of a product is lower than their psychological expectations. Coase was the first to propose strategic consumer behavior in 1972 [1]. Cachon and Swinney classified consumers into myopic, discount-seeking, and strategic types, and explored the advantages of obtaining additional inventory quickly when demand information is updated[2]. Liu and Ryzin investigated how firms can adjust their inventories to induce consumers to purchase goods earlier for greater profits in the presence of strategic consumers[3]. Bi et al. explored the dynamic pricing of two brand substitutes based on strategic consumers[4]. Wu and Ran et al explore the overall impact of consumer’s strategic buying behavior on a pricing strategy and identifies conditions where fixed pricing, strategic high pricing, or high-low pricing is the best approach[23]. Wei and Zhang took an operator's perspective of exploring how to identify coping strategies to offset the adverse effects of strategic consumer behavior from three aspects: pricing, inventory, and corporate marketing messages respectively[5]. Wang and Ma et al. compared the profits of operators with and without rapid response in different proportions of strategic consumer environments[6]. Chen and Zha et al. build a model for designing two-stage dynamic pricing strategies when the seller faces strategic consumers in the presence of a reference price effect[24]. Xu and Li constructed a consumer choice model relying on network channel risk and retail channel search cost to discuss optimal vendor decision-making and channel efficiency in a dual-channel supply chain under consumer behavior[7]. Guan and Ren developed a dynamic pricing strategy model with two-stage normal and clearance prices to explore the relationship between optimal price and maximum profit and consumer reliance on historical price and other factors[8]. Li et al. studied the dynamic pricing strategy of two retailers in a competitive environment from the perspective of strategic customer behavior[9]. Ye and Sun discussed the optimal order quantity decision and optimal profit under two different demand function expressions in a strategic consumer environment[10]. Some retailers discussed whether the retailers could earn more profits when they provide a very long price protection policy in the presence of strategic consumers.[21-22,26] Liu et al. discussed whether a firm selling two consecutive generations of old and new products using dynamic pricing or commitment pricing could achieve more profits[11]. Shum et al. discussed when products undergo cost reductions over their product life cycles, retailer's optimal pricing decisions in the presence of strategic consumers[27]. Yu et al. investigated the effect of information generated by consumers about product quality evaluations and other information on manufacturers' dynamic pricing in the presence of strategic consumers[12]. Chen and Tan introduced the dynamic game of multiple retailers in their study of dynamic pricing considering strategic consumers and analyzed the dynamic game pricing process among multiple retailers[13]. Kabul et al. extended the study of strategic consumers to the supply chain level to explore the pricing problem of supply chain members[14]. Cui et al. investigated the effect of inventory disclosure on strategic consumers' purchase decisions and found that disclosing inventory levels motivates consumers to make purchase decisions when inventory is lower, and out-of-stock may occur[15]. Papanastasiou et al. discussed how the presence of social learning affects the strategic interaction between a dynamic-pricing monopolist and a forward-looking consumer population in a two-stage model[28]. Qiu and Li discussed how online retailers choose inventory disclosure strategies and make optimal pricing and inventory decisions in a market with strategic consumers by analyzing purchase behavior [16]. Chen and Guan discussed the impact of return strategies on consumers' purchase decisions and online retailers' operational decisions when strategic consumers are uncertain about product valuation and have expected regret [17]. Aflaki et al. developed a model of endogenous time preferences to explore whether consumer actually benefit from the strategic behavior[25].Scholars have analyzed the impact of strategic consumers' purchase decisions in terms of "action regret" and "abandonment regret," two types of regret that may arise in strategic consumers' purchase behavior [18-20].

From the existing literature, we can find that studies based on consumer types and behaviors are mainly aimed at discussing how companies can maximize profits when strategic consumers exist in terms of pricing and inventory decisions. Few scholars have explored the dynamic pricing of products and the overall profitability of the supply chain from the supply chain level when different types of consumers are present in dual channels. In this paper, we discuss the dynamic pricing of products in two stages of the dual-channel supply chain in terms of the magnitude of consumer utility and measuring the demand of each channel under different power structures.

3 the model

In this section, we present the problem setting and the description of the key model assumptions.

Table 1. Notations

Symbol	Description
i	The selling period ($i = 1$ represents the full-price period, $i = 2$ represents the salvage period)
p_{ji}	Unit retail price of different sales periods and different channels (j=r represents the physical sales channel, j=e represents the online sales channel)
θ	The fraction of myopic consumers ($0< \theta < 1$)
v	Consumer's valuation for a product, with uniform distribution for $v \in [0,1]$
α	Discount factor for online consumer valuation ($0< \alpha < 1$)
β	Discount factor for salvage consumer valuation ($0< \beta < 1$)

c	Manufacturer's unit production cost
ω	The unit wholesale price of products
μ	Strategic consumers' probability of obtaining product during the salvage period ($0 < \mu < 1$)
d_{ji}	The demand of different sales periods and different channels(*j=r, e ; i =1,2*)
h	Commissions charged by online platforms on unit products

We consider a model of a dual-channel supply chain consisting of a single manufacturer and a single retailer. The manufacturer produces the product and sells it to the retailer at ω price. Then the retailer sells the product to the consumers. The manufacturer also sells the product to consumers directly through online sales platforms. At the same time, the online platform will charge the manufacturer a commission for the sale of each product. Both of them sell the product over two periods. In the full-price period, the retailer sells at price p_{r1}, and the manufacturer sells at price p_{e1}. In the salvage period, the retailer sells at price p_{r2}, and the manufacturer sells at price p_{e2}. To meet the conditions for the existence of dual channels, we stipulate that the price is subject to the following conditions $p_{r1} > p_{e1} > p_{r2} > p_{e2}$; we can deduce that $1 > r > \beta > 0$. The specific model can be referred to in Table 1. The channel structures is shown in Fig.1.

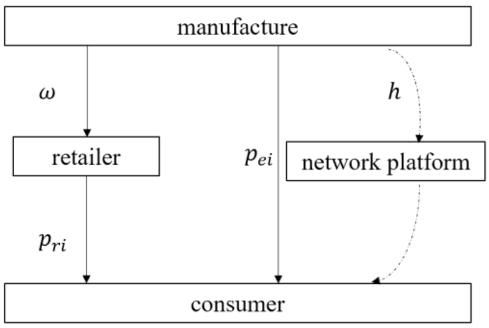

Fig. 1. Model structure diagram

3.1 model assumptions

(1) Manufacturers produce and sell a single product in a two-channel supply chain, and consumers buy the same quality of product at the same stage through both channels.

(2) The total mass consumers in the whole market for the model is assumed to be one. Among them, the fraction of myopic consumers is θ, and the fraction of strategic consumers is $1-\theta$. Myopic consumers purchase only during the full-price period because these consumers are simply shortsighted. Furthermore, strategic consumers have to decide when they'll make a purchase.

(3) Both consumers value the goods as v with uniform distribution in the full-price period. The utility obtained by consumers through physical channels for purchasing products is $U_{ri} = v - p_{ri} (i = 1,2)$. Consumers have certain preferences for products sold through online channels, and we show it by setting preference coefficients α. The utility obtained by consumers through online channels for purchasing products is $U_{ei} = \alpha v - p_{ei} (i = 1,2)$.

(4) Considering the time value, we discount the salvage period and set the valuation discount factor parameter β. When strategic consumers wait for the salvage period to buy a product, there is a certain probability that the product will be sold out. We set μ to describe the probability that strategic consumers will obtain the product during the salvage period.

3.2 consumer purchase decision

Consumers will choose the offline channel when the utility generated by the purchase through the offline channel is greater than the utility of the purchase through the online channel. myopic consumers purchase only during the full-price period because these consumers are simply shortsighted. Furthermore, strategic consumers have to decide when they'll make a purchase. They realize the goods might be sold at a reduced cost during the salvage period. They will compare their surplus from purchases made during the full-price period with their surplus from purchases made during the salvage period to choose when to buy in order to maximize individual predicted surplus. Of course, both myopic consumers and strategic consumers will evaluate online and offline prices and select the most affordable option. The consumer utility functions for different channels are as follows:

$$u_{r1} = v - p_{r1}, u_{e1} = \alpha v - p_{e1}, u_{r2} = \mu\left(\beta v - p_{r2}\right), u_{e2} = \mu\left(\alpha\beta v - p_{e2}\right)$$

According to the utility functions, we can calculate the equilibrium points between online and offline channel.
Myopic consumers' dual-channel purchase decision equilibrium point:

$$u_{r1} = u_{e1} \Rightarrow v_{s1} = \frac{p_{e1} - p_{r1}}{-1+\alpha}$$

Myopic consumers' online purchase and non-purchase decision equilibrium point:

$$u_{e1} = 0 \Rightarrow v_{s2} = \frac{p_{e1}}{\alpha}$$

The purchase decision of myopic consumers in the full-price stage is shown in Fig.2.

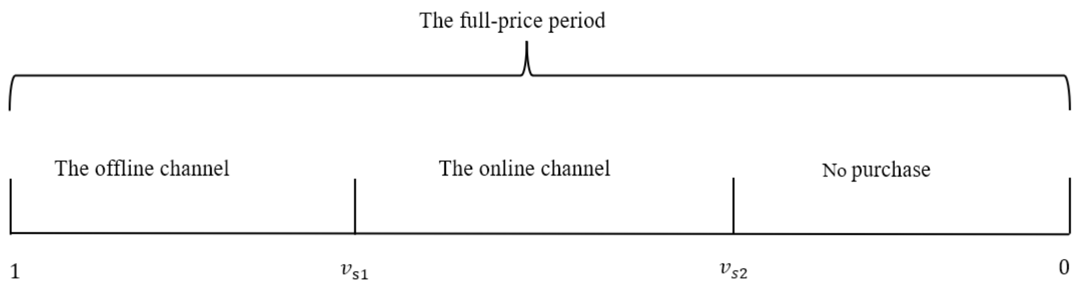

Fig. 2. The myopic consumers' decision in the full-price stage

Strategic consumers' dual-channel purchase decision equilibrium point:

$$u_{r1} = u_{e1} \Rightarrow v_{h1} = \frac{p_{e1} - p_{r1}}{-1+\alpha}$$

Strategic consumers' full-price period online purchase and salvage period offline purchase decision equilibrium point:

$$u_{e1} = u_{r2} \Rightarrow v_{h2} = \frac{p_{e1} - \mu p_{r2}}{\alpha - \beta\mu}$$

Strategic consumers' salvage period online purchase and offline purchase decision equilibrium point:

$$u_{r2} = u_{e2} \Rightarrow v_{h3} = \frac{p_{e2} - p_{r2}}{\left(-1+\alpha\right)\beta}$$

Strategic consumers' salvage period online purchase and non-purchase decision equilibrium point:

$$u_{e2} = 0 \Rightarrow v_{h4} = \frac{p_{e2}}{\alpha\beta}$$

The two-stage purchase decision of strategic consumers is shown in Fig.3.

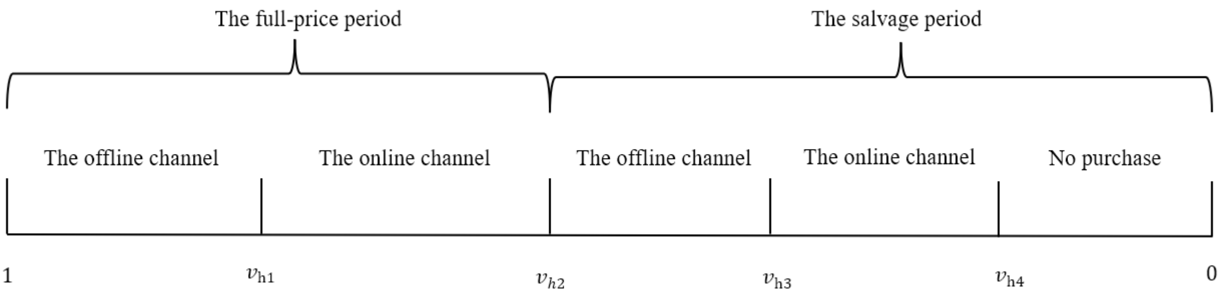

Fig.3. The strategic consumers' decision in two stage purchase decision

3.3 demand function and profit function

According to the above text, we can easily work out the demand functions in each stage as follows:

$$d_{r1}=\theta\int_{v_{s1}}^{1}dv+(1-\theta)\int_{v_{h1}}^{1}dv=\theta(1-v_{s1})+(1-\theta)(1-v_{h1})=\left(1-\frac{p_{e1}-p_{r1}}{-1+\alpha}\right)$$

$$d_{e1}=\theta\int_{v_{s2}}^{v_{s1}}dv+(1-\theta)\int_{v_{h2}}^{v_{h1}}dv=\theta\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}}{\alpha}\right)+\left(1-\theta\right)\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\right)$$

$$d_{r2}=(1-\theta)\int_{v_{h3}}^{v_{h2}}dv=\left(1-\theta\right)\left(\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}-\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}\right)$$

$$d_{e2}=(1-\theta)\int_{v_{h4}}^{v_{h3}}dv=\left(1-\theta\right)\left(\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}-\frac{p_{e2}}{\alpha\beta}\right)$$

Assuming the demand is sufficiently big enough that the manufacturer's product will be sold out in both sales periods and there is no backlog of goods. If the strategic consumer chooses to wait for the price of the goods to be reduced, there is a certain probability that he or she will not be able to buy the discounted product in the salvage period. The demand function for each channel in each period is shown below:

$$\pi_{r1}=d_{r1}\left(p_{r1}-\omega\right),\quad \pi_{m1}=d_{r1}\left(\omega-c\right)+d_{e1}\left(p_{e1}-h-c\right)$$

$$\pi_{r2}=d_{r2}\left(p_{r2}-\omega\right),\pi_{m2}=d_{r2}\left(\omega-c\right)+d_{e2}\left(p_{e2}-h-c\right)$$

4 Analysis of optimal pricing strategies under different power structure

We construct a dynamic pricing model for the dual-channel supply chain of nearly expired food under Manufacturer Stackelberg (MS) and Network platform Stackelberg (HS), and a comparison and analysis of the optimal dynamic pricing and inventory policies for different power structures is performed.

4.1 The optimal pricing strategies under MS

Under MS, manufacturer act as the leader and takes the retailer's response functions into consideration to decide its optimal pricing strategies. The backward induction method used in solving Stackelberg game problems is adopted to pursue the optimal decisions. That is, the follower's problem is first focused to get the optimal response functions on any given leader's decisions. Then, with the follower's optimal response functions, the leader's problem will be solved. According to the method, the retailer's pricing and the network platform's pricing are solved firstly in MS, then we can calculate the manufacture's optimal pricing.

4.1.1 Salvage period

Manufacturer's decision model:

$$Max\prod\nolimits_{r2}^{MS}=\left(1-\theta\right)\left(\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}-\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}\right)\left(p_{r2}-\omega\right)$$

$$s.t.0\le\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}\le\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\le 1$$

Since $\frac{\partial^2\pi_{r2}^{MS}}{\partial p_{r2}{}^2}=\frac{2(-1+\theta)}{(-1+\alpha)\beta}<0$, the problem can be converted into solving a convex optimization problem.

$$Max\prod\nolimits_{m2}^{MS}=\left(1-\theta\right)\left(\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}-\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}\right)\left(\omega-c\right)+\left(1-\theta\right)\left(\frac{p_{e2}-p_{r2}}{\left(-1+\alpha\right)\beta}-\frac{p_{e2}}{\alpha\beta}\right)\left(p_{e2}-h-c\right)$$

Solving the above model, we find the optimal pricing $(p_{r2}^{MS*},p_{e2}^{MS*})$ for the offline channel and online channel during the salvage period. Since the analytic solution for optimal profit $(\Pi_{r2}^{MS*},\Pi_{m2}^{MS*})$ is complex, it will be explored in the numerical analysis section.

$$\begin{cases}p_{r2}^{MS*}=-\dfrac{\left(c+h-c\alpha\right)\left(\alpha-\beta\mu\right)+\alpha\left(2+\alpha-3\beta\mu\right)\omega-2\left(-1+\alpha\right)\beta p_{e1}}{\alpha\left(-4+\alpha+3\beta\mu\right)}\\ p_{e2}^{MS*}=\dfrac{\left(-1+\beta\mu\right)\left(2\left(c+h-c\alpha\right)+3\alpha\omega\right)+\left(-1+\alpha\right)\beta p_{e1}}{-4+\alpha+3\beta\mu}\end{cases}$$

4.1.2 Full-price period

Manufacturer's decision model:

$$Max\prod\nolimits_{r(sum)}^{MS}=\left(1-\frac{p_{e1}-p_{r1}}{-1+\alpha}\right)\left(p_{r1}-\omega\right)+\prod\nolimits_{r2}^{MS*}$$

$$s.t.0\le\frac{p_{e1}-p_{r1}}{-1+\alpha}\le 1$$

$$Max\prod\nolimits_{m(sum)}^{MS}=\prod\nolimits_{m2}^{MS*}+\left(1-\frac{p_{e1}-p_{r1}}{-1+\alpha}\right)\left(\omega-c\right)+(\theta\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}}{\alpha}\right)$$

$$+\left(1-\theta\right)\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\right))\left(p_{e1}-h-c\right)$$

$$s.t.\begin{cases}0\le\dfrac{p_{e1}-p_{r1}}{-1+\alpha}\le 1\\ 0\le\dfrac{p_{e1}}{\alpha}\le\dfrac{p_{e1}-p_{r1}}{-1+\alpha}\le 1\\ 0\le\dfrac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\le\dfrac{p_{e1}-p_{r1}}{-1+\alpha}\le 1\end{cases}$$

The optimal pricing and profits of retailers and manufacturers in the full-price period are also solved by constructing the Lagrangian function and the KKT condition. The analytic solutions are also shown in the numerical analysis section.

4.2 The optimal pricing strategies under HS

Under NS, network platform acts as the leader and takes the manufacture's response functions into consideration to decide its optimal commission pricing h in online channel. While in the offline channel, Manufacture also acts as the leader. Manufacture first determines the wholesale price ω to retailer, and the retailer determines the selling price p_{ri}.

4.2.1 Salvage period

$$Max\prod\nolimits_{r2}^{NS}=(1-\theta)\left(\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}-\frac{p_{e2}-p_{r2}}{(-1+\alpha)\beta}\right)(p_{r2}-\omega)$$

$$s.t.0\le\frac{p_{e2}-p_{r2}}{(-1+\alpha)\beta}\le\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\le 1$$

$$Max\prod\nolimits_{m2(on)}^{NS}=(1-\theta)\left(\frac{p_{e2}-p_{r2}}{(-1+\alpha)\beta}-\frac{p_{e2}}{\alpha\beta}\right)(p_{e2}-h-c)$$

$$s.t.0\le\frac{p_{e2}}{\alpha\beta}\le\frac{p_{e2}-p_{r2}}{(-1+\alpha)\beta}\le 1$$

Solving the above model, we find the optimal pricing $(p_{r2}^{HS*},p_{e2}^{HS*})$ and the optimal profit $(\Pi_{r2}^{HS*},\Pi_{m2}^{HS*})$ for the offline channel and online channel during the salvage period.

$$\begin{cases} p_{r2}^{NS*}=\dfrac{-(c+h)(\alpha-\beta\mu)+2\alpha(-1+\beta\mu)\omega+2(-1+\alpha)\beta p_{e1}}{\alpha(-4+\alpha+3\beta\mu)} \\ p_{e2}^{NS*}=\dfrac{(-1+\beta\mu)(2(c+h)+\alpha\omega)+(-1+\alpha)\beta p_{e1}}{-4+\alpha+3\beta\mu} \end{cases}$$

$$\begin{cases} \pi_{r2}^{NS*}=-\dfrac{(-1+\theta)(-1+\beta\mu)\begin{pmatrix}(c+h)(\alpha-\beta\mu)+\alpha(-2+\alpha+\beta\mu)\omega\\ -2(-1+\alpha)\beta p_{e1}\end{pmatrix}^2}{(-1+\alpha)\alpha\beta(\alpha-\beta\mu)(-4+\alpha+3\beta\mu)^2} \\ \pi_{m2on}^{NS*}=\dfrac{(-1+\theta)\left((c+h)(-2+\alpha+\beta\mu)+\alpha(1-\beta\mu)\omega+(\beta-\alpha\beta)p_{e1}\right)^2}{(-1+\alpha)\alpha\beta(-4+\alpha+3\beta\mu)^2} \end{cases}$$

4.2.2 Full-price period

In this period, our objective is to maximize the sum of the profits of two periods, we use the optimal pricing and the optimal profit to solve the model.

$$Max\prod\nolimits_{r(sum)}^{HS}=\left(1-\frac{p_{e1}-p_{r1}}{-1+\alpha}\right)(p_{r1}-\omega)+\prod\nolimits_{r2}^{HS*}$$

$$s.t.0\le\frac{p_{e1}-p_{r1}}{-1+\alpha}\le 1$$

$$Max\prod_{m(sum-online)}^{HS} = \theta\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}}{\alpha}\right)\left(p_{e1}-h-c\right)$$
$$+\left(1-\theta\right)\left(\frac{p_{e1}-p_{r1}}{-1+\alpha}-\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\right)\left(p_{e1}-h-c\right)+\prod_{m2(on)}^{HS*}$$
$$s.t.\begin{cases} 0<\dfrac{p_{e1}}{\alpha}<\dfrac{p_{e1}-p_{r1}}{-1+\alpha}<1 \\ 0<\dfrac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}<\dfrac{p_{e1}-p_{r1}}{-1+\alpha}<1 \end{cases}$$

$$Max\prod_{m(sum)}^{HS} = Max\prod_{m(sum-online)}^{HS} + Max\prod_{m(sum-offline)}^{HS}$$

By taking the derivative of the profit function, the optimal pricing $(p_{r1}^{HS*}, p_{e1}^{HS*})$ and the optimal profit $(\prod_{r1}^{HS*}, \prod_{m1}^{HS*})$ for the full-price period dominated by the online platform could be calculated. Since the analytical solution expression is too complicated, we will analyze the dynamic pricing and optimal profit of dual-channel supply chain under different power structure through numerical analysis.

4.3 Numerical analysis

We now give a numerical study to investigate the analytical results. The related parameters are assumed as follows: the online consumer valuation discount factor $\alpha = 0.9$, the salvage period food discount factor $\beta = 0.6$, the factor that strategic consumers' probability of obtaining product during the salvage period $\mu = 0.8$, the fraction of myopic consumers $\theta = 0.5$, $c = 0.3$, we will show the numerical analysis in the following tables .

Tabel 2. The optimal pricing strategies under MS

p_{r1}^{MS*}	p_{e1}^{MS*}	p_{r2}^{MS*}	p_{e2}^{MS*}	$\prod_{r2}^{MS*}$	$\prod_{m2}^{MS*}$	$\prod_{r(sum)}^{MS*}$	$\prod_{m(sum)}^{MS*}$
0.677	0.653	0.617	0.613	0.004	-0.067	0.061	0.083

Tabel 3. The optimal pricing strategies under HS

p_{r1}^{HS*}	p_{e1}^{HS*}	p_{r2}^{HS*}	p_{e2}^{HS*}	$\prod_{r2}^{HS*}$	$\prod_{m2(on)}^{HS*}$	$\prod_{m2}^{HS*}$	$\prod_{r(sum)}^{HS*}$	$\prod_{m(sum-online)}^{HS*}$	$\prod_{m(sum)}^{HS*}$
0.586	0.472	0.463	0.437	0.0504	0.0126	-0.193	0.0524	0.0714	-0.176

From Tabel 3 and Tabel 4, we can see that the optimal pricing in both period under MS is higher than the optimal pricing under HS. The salvage period products under HS are more favorable, and the products have a greater price reduction from the full-price period to the salvage period. The profit of each member of the supply chain and the total profit of the supply chain are higher under the manufacture's power structure.

4.3.1 The impact of parameter θ on optimal pricing and profitability of different supply chain power structure

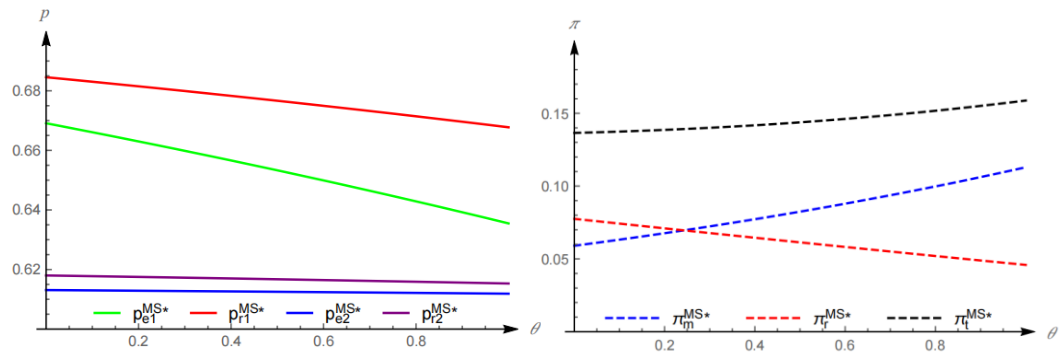

Fig.4. The optimal dynamic pricing and profit under MS with different θ

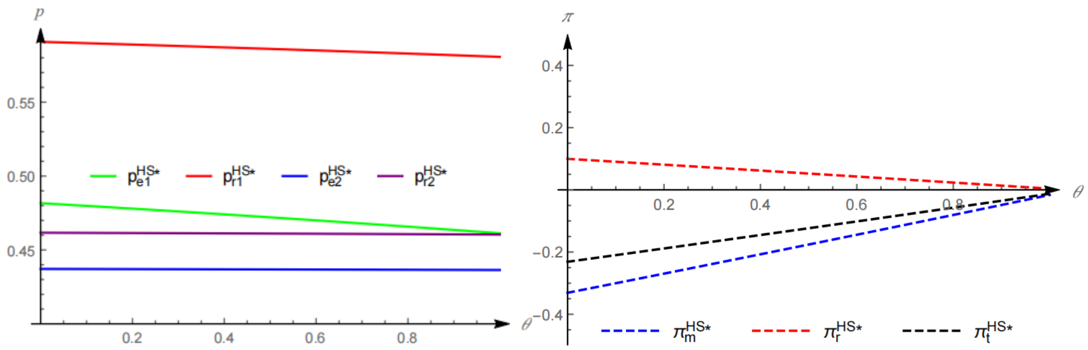

Fig.5. The optimal dynamic pricing and profit under HS with different θ

From Figure 4 and Figure 5, we can see that as the proportion of myopic consumers increases, the price in the first period in the dual-channel supply chain of nearly expired foods all decrease. While under MS, the product price decreases much more than that under HS. Since myopic consumers only purchase products in the full-price period, as the proportion of myopic consumers increases, manufacturers hope to attract more consumers to make purchases in the full-price period by lowering the price of product. Under the above two supply chain power structure models, the retailer has low bargaining power and can only be passive in pricing, and is in a weak position in the competition. In the HS model, the manufacturer loses its online pricing power and the total manufacturer profit is lower than in the MS model.

The total profit of retailers in both periods is decreasing with the increase in the proportion of myopic consumers. The increase in the manufacturer's profit and total supply chain profit implies that the increase in the proportion of myopic consumers has a contributing effect on the sales of nearly expired foods. Manufacturers can stimulate consumers to make purchases through marketing methods such as promotions, advertisements, and realistic offers.

4.3.2 The impact of parameter β on optimal pricing and profitability of different supply chain power structure

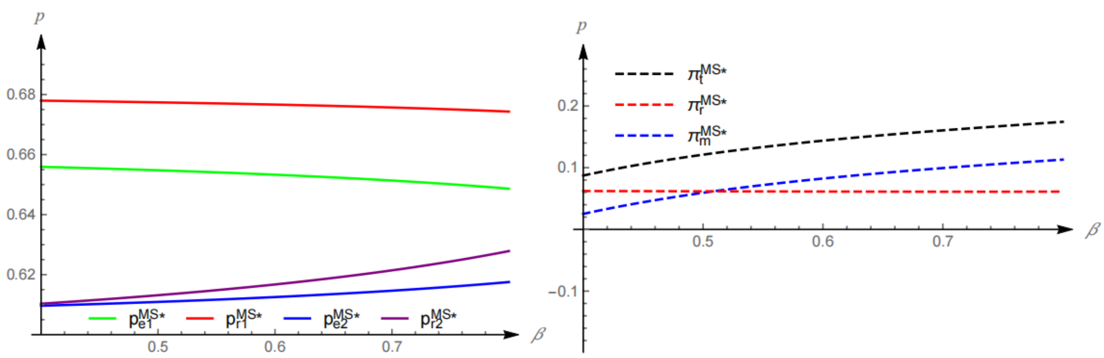

Fig.6. The optimal dynamic pricing and profit under MS with different β

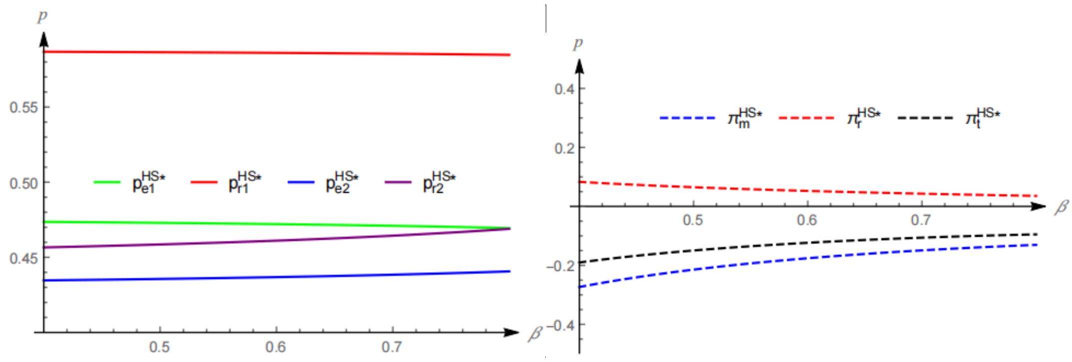

Fig.7. The optimal dynamic pricing and profit under HS with different β

With reference to related studies and retailers' discounting efforts in dealing with nearly expired foods, we set the value range of β in [0.4,0.8] when discussing the discount coefficients for nearly expired foods. From Figure 4 and Figure 5, we can see that as β increases, both online and offline pricing for the full-price period decreases, and both online and offline pricing for the salvage period increases. Both the decrease in online pricing in the first period and the increase in offline pricing in the second period are larger than the increase or decrease in pricing in other channels over the same period. In both dual-channel supply chain structures, the total profit of the retailer decreases slightly as β increases, but the total profit of both the manufacturer and the supply chain increases.

It suggests that with β increases, consumers perceive the difference between regular and nearly expired food to be smaller, and at the same time their acceptance of nearly expired food increases. For food companies, different sales strategies can be formulated according to the different attitudes of consumers towards nearly expired foods. For foods that are still highly valued at the salvage period, companies can lengthen the sales cycle, allow some products to enter the salvage period, and sell them with higher sales volume and lower pricing, so that the total members of the supply chain can still obtain higher total profits. For food products with lower valuation at the end-of-life stage, firms should minimize the number of products entering the salvage period.

5 Analysis of optimal pricing strategies under centralized decision making

Under centralized structure, the retailer and the manufacturer set the selling prices of full-price period products and salvage period products based on maximizing the whole supply chain's interests. In this section, we will compare the optimal pricing under the centralized model with the pricing strategy under decentralized model by solving for the optimal pricing.

5.1 The optimal pricing strategies under centralized decision-making model

5.1.1 Salvage period

Supply chain's decision model:

$$Max\prod_{t2}^{C}=(1-\theta)\left(\frac{p_{e2}-p_{r2}}{\beta-\alpha\beta}+\frac{p_{e1}-\mu p_{r2}}{\alpha-\beta\mu}\right)(p_{r2}-c)+\frac{(-1+\theta)(-p_{e2}+\alpha p_{r2})}{(-1+\alpha)\alpha\beta}(p_{e2}-h-c)$$

We obtain the Hessian matrix by finding the second-order partial derivative of the profit function. We can conclude that the profit function is strictly concave. We can also get the optimal price and the optimal profit:

$$\begin{cases} p_{r2}^{*} = -\dfrac{-c\alpha - \beta p_{e1}}{2\alpha} \\ p_{e2}^{*} = \dfrac{1}{2}\left(c + h + \beta p_{e1}\right) \end{cases}$$

5.1.2 Full-price period

Supply chain's decision model:

$$Max\prod\nolimits_{t(sum)}^{C} = \frac{\left(\alpha + \alpha\beta\left(-1+\theta\right)\mu - \beta\theta\mu\right)p_{e1} + \alpha\left(-\alpha+\beta\mu\right)p_{r1} + \alpha\left(-1+\alpha+\theta-\alpha\theta\right)\mu p_{r2}}{\left(-1+\alpha\right)\alpha\left(\alpha-\beta\mu\right)}\left(p_{e1} - h - c\right) + \left(1 - \frac{p_{e1} - p_{r1}}{-1+\alpha}\right)\left(p_{r1} - c\right) + \prod\nolimits_{t2}^{C*}$$

We obtain the Hessian matrix by finding the second order partial derivative of the profit function. Then we can also get the optimal price and the optimal profit, since the analytic solution expression for the price is complex. We will conduct a comparison of optimal pricing between different models through numerical analysis in the next section.

5.2 Numerical analysis

Tabel 4. The optimal pricing strategies under centralized decision making

p_{r1}^{C*}	p_{e1}^{C*}	p_{r2}^{C*}	p_{e2}^{C*}	$\prod_{t2}^{C*}$	$\prod_{t(sum)}^{C*}$
0.45	0.442	0.398	0.376	0.152	0.157

From Tabel 4, we can see that all the optimal pricing strategies under centralized decision-making model are lower than decentralized model. The profit of each member of the supply chain and the total profit of the supply chain are higher under centralized decision-making than the total profit of the supply chain under decentralized decision-making. This suggests that centralized decision-making mitigates the double marginal effect of the supply chain to a greater extent, which indicates that manufacturers and retailers can achieve higher profits by developing revenue-sharing contracts, reducing channel competition, and adopting cooperative pricing.

6 Conclusion

This paper studies the dual-channel dynamic pricing strategies of nearly expired foods under different power structures. We provide a game theoretic framework from manufacture Stackelberg, network platform Stackelberg to explore the effect of supply chain power structure. The analyses show that different power structure have a significant impact on the members' pricing strategies. The conclusions are as follows:

(1) There exists a two-stage optimal pricing strategy to maximize supply chain profits. The two-stage pricing of nearly expired food in the dual-channel under the network platform dominance is smaller than that under the manufacturer dominance.

(2) The total manufacturer profit and total retailer profit of both stages are larger in the manufacturer-dominated dual-channel supply chain model, but the manufacturer's profit from online channel sales is higher in the mixed-power-dominated model than in the manufacturer-power-dominated model.

(3) Although the pricing under the centralized decision-making in both stages is lower than the decentralized

decision-making mentioned above, the total profit of the supply chain is the highest, which indicates that manufacturers and retailers can achieve higher profits by developing revenue-sharing contracts, reducing channel competition, and adopting cooperative pricing.

(4) As the proportion of myopic consumers and consumers positive attitude toward nearly expired food increase, manufacturers are able to sell more products in the first stage at lower product pricing, resulting in greater profitability throughout the sales process. Suppliers of nearly expired food could stimulate consumers to make purchases through marketing methods such as promotions, advertisements, and realistic offers.

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