International Business & Economics Studies
ISSN 2640-9852 (Print) ISSN 2640-9860 (Online)
Vol. 5, No. 3, 2023
www.scholink.org/ojs/index.php/ibes

Revised Paper

Pricing Decisions and Member Participation Conditions in the Platform Supply Chain with Seasonal Demand: A Game Theory-Based Analysis

Zhongmiao Sun[1*]

[1] School of Economics & Management, Shanghai Maritime University, Shanghai, 201306, China

[*] Zhongmiao Sun, Corresponding author

Received: June 18, 2023 Accepted: July 25, 2023 Online Published: July 28, 2023

doi:10.22158/ibes.v5n3p75 URL: http://dx.doi.org/10.22158/ibes.v5n3p75

Abstract

In a platform supply chain containing an sharing platform, a retailer, and two upstream factories, we consider the sales of two substitutable products and the constraints on the participation of non-platform members in the game, construct a dynamic game model of the platform supply chain with demand fluctuations due to seasonal changes, and use the inverse induction method to derive the thresholds for the participation of the retailer and factories in the game and the optimal price of each member, analyze the pricing decisions and participation game process among members. Our findings are as follows. (1) The threshold for the retailer to participate in the game during peak season is greater than that in the off-season, while the manufacturer's threshold is the opposite. (2) The platform should reduce commissions during peak season, factories should reduce wholesale prices, and the retailer should increase sales price. (3) The increase in price sensitivity coefficient, inventory cost and production cost are all detrimental to the platform, whereas an increase in the cross-price sensitivity coefficient is usually beneficial. (4) Whether it is the peak season or the off-season, the increase in demand fluctuations is bad for all chain members.

Keywords

platform supply chain, seasonal demand, threshold conditions, pricing decisions, game analysis

1. Introduction

In recent years, the platform supply chain has gradually sprung up. It realizes the connection between factories and retailers through sharing platforms, such as Ali 1688 platform (Sun et al., 2021). The sharing platform is mainly used to match transactions between the two sides, allocate or integrate the order demand of retailers, and spend some communication costs; Retailers can share the order demand to multiple factories through the sharing platform, so as to ensure timely delivery in the peak sales season; The factory can share and utilize the idle capacity through the sharing platform. In China, the sharing platform represented by Ali 1688 platform has developed rapidly. By 2021, the registered members of the platform have exceeded 100million, distributed in 34 provincial administrative regions and more than 3000 counties (cities) across the country. More than 10 million buyers participate in transactions every day, which has brought huge economic benefits to enterprises.

In the operation of the platform supply chain, it is very important for retailers to decide whether to participate in the order and determine their own sales price based on the wholesale price of the matching factory of the sharing platform. It is particularly important for factories to determine whether to participate in production and determine their own wholesale price based on the commission price of the sharing platform. For the sharing platform, it is very important to set a reasonable commission price in different sales seasons (i.e., off-season and peak season) to improve its profits. Based on this, in view of the participation and pricing problems in the platform supply chain, this paper considers the sales of two products, constructs a supply chain model under seasonal demand, and solves and analyzes the impact of pricing decisions and the optimal pricing strategy among the members of the supply chain.

2. Literature Review

Management experts and scholars have carried out a lot of research on pricing and replenishment in the supply chain. For example, Li et al. (2022) constructed a two-channel green supply chain model, explored the coordinated decision-making of pricing and promotion, and analyzed the impacts of after-sales service level, consumers' sensitivity to after-sales service, the level of green promotion efforts and the degree of free-riding on supply chain decision-making. Zhao and Song (2023) designed wholesale price and quality cost-sharing contracts to study the coordination of a dual-channel supply chain with loss-averse manufacturers and loss-averse retailers under quality control. Huang et al. (2021) studied the optimal pricing and replenishment strategy of perishable food supply chain under inflation. Adeinat et al. (2022) discussed supply chain pricing and inventory replenishment decisions with multiple geographically dispersed retailers. In addition, some scholars consider the game relationship of the cooperative members in the supply chain system, and study the pricing decisions of the members under different rights structures. For example, Jabarzare and Rasti-Barzoki (2020) considered a dual channel supply chain composed of a manufacturer and a packaging company, discussed how packaging companies affect product quality through packaging products. Liu et al. (2023) explored outsourcing strategies and their interactions between incumbent manufacturers and new entrants and common suppliers in supply chains and found that incumbents benefit from outsourcing to monopoly suppliers by new entrants and that it is rational and more profitable for incumbents to cooperate with new entrants. Unlike the above literature, the novelty of the current research is reflected in our study of the pricing and participation conditions for a three-stage platform supply chain, which has been rarely addressed in previous studies.

In reality, people's needs are often diversified (Akcay et al., 2010). For example, different consumer groups have different preferences for different styles of clothing, and retailers tend to order multiple styles of clothing or products to meet the diversified market demand. Some scholars have begun to pay attention to the research on the pricing strategy of multi product supply chain. For example, Bajwa et al. (2016) studied the joint pricing and production decision of a company producing multiple products. Tantiwattanakul and Dumrongsiri (2019) established a nonlinear bilevel programming model to study the coordination problem of a two-level decentralized supply chain composed of factories and retailers producing multiple products. Ma et al. (2018) considered that the market demand was affected by the price of two different products and the level of green manufacturing, and studied the pricing strategy of the supply chain of two factories and one retailer. Ma et al. (2021) studied the dynamic operational strategies of O2O supply chain and closed-loop supply chain based on the state changes of brand reputation, considering that consumers have a reference effect on product quality. However, although relevant studies consider the impact of multi product substitution on supply chain pricing decisions, they seldom consider the seasonal change of product demand, and generally assume that the demand function is non time-varying (Mahmoodi, 2019). Different from them, this paper considers the changes of product demand in peak and off-season sales, and studies the optimal pricing strategies of two kinds of replaceable products under seasonal demand.

To sum up, the current research on supply chain pricing strategy is mainly focused on the single product pricing strategy under non-seasonal demand, while the research on seasonal demand and multi product pricing strategy is rare. In addition, academic research usually studies the pricing strategy of the traditional supply chain from different angles, but with the development of Internet platforms, the platform supply chain is gradually rising, and has attracted the attention of relevant scholars, such as Zhang et al. (2023) on the channel mode selection of e-platform supply chain under secondary market conditions, and Zhang et al. (2022) on the selecting online distribution models for differentiated products in a platform supply chain. In this paper, for the problem of member participation and pricing decision of the platform supply chain, considering the sales of two products under seasonal demand, a decision model of the platform supply chain composed of one retailer, one sharing platform and two factories is established, and the optimal response strategy and optimal pricing strategy of each member of the supply chain are solved by using the inverse induction method in game theory, So as to study the impact of pricing decisions among members and the threshold of participating in the platform supply chain. The research in this paper can provide a reference for the members of the platform supply chain to participate in and make pricing decisions under the demand of off-season and peak season, and has a certain practical significance for improving the efficiency of enterprises.

3. Model Description and Assumptions

3.1 Model Description

Consider a platform supply chain consisting of a retailer, a sharing platform and two factories (see Figure 1). The retailer orders from the sharing platform, which shares and distributes the retailer's orders to the factory to achieve timely production and rapid delivery. The role of the sharing platform is mainly to match the transaction between the retailer and the factory, which requires a certain amount of communication costs. After the transaction is completed, the platform will charge a certain commission to the factory and free to the retailer (such as Ali 1688 platform, JD platform). This paper considers that retailers sell two kinds of products, which are replaceable in the market. For example, two styles of clothing, the retailer purchases products of unit Q from the sharing platform before the start of the sales cycle, and the sharing platform allocates the order quantity Q to two factories, in which the order quantity of product 1 received by factory f_1 is Q_1, and the order quantity of product 2 received by factory f_2 is Q_2.

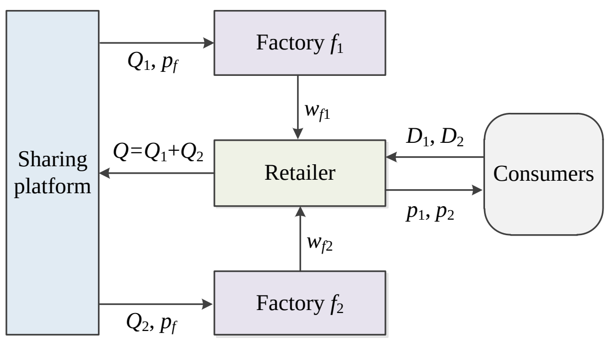


Figure 1. Platform Supply Chain Structure

During the operation of the platform supply chain, each member will participate in the transaction when it is profitable. For example, the retailer will judge whether it is profitable to order based on the wholesale price of the factory, while the factory will judge whether it is profitable and produce orders based on the commission price of the sharing platform. Therefore, whether the retailer and the factory participate in the sharing platform and conduct transactions depends on the participation constraints of the members, that is, the participation threshold condition (i.e., price critical point) for judging whether they are profitable when referring to the decision-making of the game opponent. For example, when the wholesale price of the factory is higher than a critical point, the retailer will be unprofitable, and the critical point of the wholesale price at this time is the participation threshold of the retailer based on the factory decision.

In the sales cycle of [0, T], each member will make the optimal decision with the goal of maximizing their own profits under the condition of meeting the participation constraints and ensuring profits. We consider a three-stage dynamic game. In the first stage, the sharing platform decides the commission price p_f and announces it to the factory. In the second stage, the factory f_i (i=1, 2) decides the wholesale price w_{fi} and feedback it to the retailer by the sharing platform. In the third stage, the retailer decides the sales price p_i of the product. This paper mainly studies the influence of pricing decisions among members of the platform supply chain under different demand conditions, the participation threshold conditions of retailer and factories, and the optimal pricing strategy of each member.

3.2 Basic Assumptions

The construction of the dynamic game model of the platform supply chain is based on the following assumptions:

(1) Assuming that the demand functions for the retailer to sell two types of products are:

$$D_i(p_i, p_j, t) = (\alpha_i - \beta p_i + \gamma p_j) \cdot e^{\lambda t} \tag{1}$$

where α_i, α_j>0; β>γ>0; α_i and α_j represent the potential market demand for products i and j respectively; β indicates the price sensitivity coefficient of demand; γ indicates the cross-price sensitivity coefficient (Zhao et al., 2014); Referring to the demand function of Maihami et al. (2012), we use $\lambda \neq 0$ to represent the seasonal factor, which reflects the seasonal demand change of products. If λ>0, the market is the peak sales season, if λ<0, the market is the off-season; p_i and p_j represent the sales prices of product i and product j respectively; i=1, 2, j=3-i.

(2) Assuming that the factory can deliver goods on time before the start of the sales cycle, the inventory of the retailer's product i at time t is $I_i(t)$, and the inventory status changes to $\overline{I_i}(t) = -D_i(p_i,\ p_j,\ t)$, the inventory of product i at time 0 is $I_i(0)=Q_i$, and the inventory of product i at the end of the sales cycle T is 0, that is, $I_1(T)=I_2(T)=0$.

(3) Assuming that the unit time cost of the platform is c_{sp}, the unit inventory cost of the retailer is h, and the unit production cost of factory f_i is c_{fi}.

Based on the above assumptions, the retailer's inventory model is:

$$I_i(t) = Q_i - \int_0^t D_i(p_i, p_j, \tau) d\tau = \int_t^T D_i(p_i, p_j, \tau) d\tau \tag{2}$$

The profit functions of retailer, sharing platform and factory f_i in the platform supply chain can be expressed as:

$$\pi_r = \int_0^T [\sum_{i=1}^{2} ((p_i - w_{fi}) \cdot D_i(p_i, p_j, t) - h \cdot I_i(t))] dt \tag{3}$$

$$\pi_{sp} = p_f \cdot Q - 2c_{sp} \cdot T \tag{4}$$

$$\pi_{fi} = (w_{fi} - c_{fi} - p_f) \cdot Q_i \tag{5}$$

4. Model Formulation

Seasonal demand means that the demand for some goods changes due to seasonal changes. Generally, the demand for these goods decreases gradually in the off-season, while the demand continues to increase in the peak season. For example, the transaction of seasonal fashion clothing and other commodities on Ali 1688 platform. According to the model assumptions, when the seasonal factor λ<0, it means the sales off-season; when the seasonal factor $\lambda>0$, it means the sales peak season. From the demand function of equation (1), it can be seen that under the same sales price, the demand rate in the off-season will be less than that in the peak season, which is consistent with the actual situation. At this time, the demand of product *i* will change dynamically with time. The goal of each member of the platform supply chain is to maximize their own profits. The model in this section is constructed:

$$\max \pi_{sp} = \max_{p_f^s}[p_f \cdot \sum_{i=1}^{2}((\alpha_i - \beta p_i + \gamma p_j)\cdot(e^{\lambda T}-1)/\lambda) - 2c_{sp}\cdot T] \quad (6)$$

$$\max \pi_{fi} = \max_{w_{fi}}[(w_{fi} - c_{fi} - p_f)\cdot(\alpha_i - \beta p_i + \gamma p_j)\cdot(e^{\lambda T}-1)/\lambda] \quad (7)$$

$$\begin{aligned}\max \pi_r = \max_{p_i, p_j}[\sum_{i=1}^{2}((p_i - w_i + h/\lambda)\cdot(\alpha_i - \beta p_i + \gamma p_j)\cdot(e^{\lambda T}-1)/\lambda \\ -The^{\lambda T}(\alpha_i - \beta p_i + \gamma p_j)/\lambda)]\end{aligned} \quad (8)$$

Member participation constraints: $p_i > w_{fi} > c_{fi} + p_f$

Based on the dynamic game model of the platform supply chain with member participation constraints under the above seasonal demand, this section will use the game theory method to gradually analyze the impact of pricing decisions among members and the participation threshold conditions of the retailer and factories, and give the optimal pricing strategy of each member.

5. Model Analysis

5.1 Member Participation Constraints in the Platform Supply Chain

After obtaining the wholesale price information decided by the factory, the retailer will first determine whether to participate in the game. Under the participation constraint of ensuring its own profitability, it will make the optimal sales price response. Firstly, the participation threshold condition and optimal response strategy of the retailer based on factory f_i decision are derived and analyzed. According to equation (8), the determinant of the Hessian matrix of the retailer's profit function π_r with respect to p_i and p_j under seasonal demand can be obtained:

$$|H| = \begin{vmatrix} \frac{\partial^2 \pi_r}{\partial p_i^2} & \frac{\partial^2 \pi_r}{\partial p_i \partial p_j} \\ \frac{\partial^2 \pi_r}{\partial p_j \partial p_i} & \frac{\partial^2 \pi_r}{\partial p_j^2} \end{vmatrix} = \begin{vmatrix} \frac{-2\beta\cdot(e^{\lambda T}-1)}{\lambda} & \frac{2\gamma\cdot(e^{\lambda T}-1)}{\lambda} \\ \frac{2\gamma\cdot(e^{\lambda T}-1)}{\lambda} & \frac{-2\beta\cdot(e^{\lambda T}-1)}{\lambda} \end{vmatrix} \quad (9)$$

It can be obtained from (9), $|H_1| = -2\beta\cdot(e^{\lambda T}-1)/\lambda < 0$ and $|H_2| = 4(e^{\lambda T}-1)\cdot(\beta^2-\gamma^2)/\lambda > 0$, that is, the Hessian matrix is negative definite. When the retailer meets the participation condition $p_i > w_{fi}$, there is a unique (p_i^*, p_j^*) to maximize the profit of the retailer, which will be obtained together with $\frac{\partial \pi_r}{\partial p_i} = 0$ and $\frac{\partial \pi_r}{\partial p_j} = 0$:

$$p_i^*(w_{fi}) = \frac{\alpha_i\beta + \alpha_j\gamma}{2(\beta^2 - \gamma^2)} + \frac{hM}{2} + \frac{w_{fi}}{2} \tag{10}$$

where $M = \frac{Te^{\lambda T}}{e^{\lambda T} - 1} - \frac{1}{\lambda}$.

Since $p_i^*(w_{fi}) > w_{fi}$ when the retailer participates in the game, the threshold value condition $(w_{fi})_{th}$ of the retailer's participation in the game under seasonal demand can be obtained by combining equation (32):

$$(w_{fi})_{th} = \frac{(\alpha_i\beta + \alpha_j\gamma)}{(\beta^2 - \gamma^2)} + \frac{hM}{2} \tag{11}$$

The threshold value condition $(w_{fi})_{th}$ of the retailer's participation in the game refers to the critical point of the maximum wholesale price that the retailer can accept when it refers to the wholesale price determined by the factory under seasonal demand. Obviously, when $w_{fi} \geq (w_{fi})_{th}$, the retailer cannot make profits and will not participate in the game of platform supply chain under seasonal demand; when $w_{fi} < (w_{fi})_{th}$, the optimal sales price response of retailer product i is equation (10). According to equation (2), we have $Q_i = \int_0^T D_i(p_i, p_j, \tau)d\tau$. So, the optimal order quantity response of product i under seasonal demand is:

$$Q_i^*(w_{fi}, w_{fj}) = \frac{e^{\lambda T} - 1}{2\lambda} \cdot (\alpha_i - \beta(w_{fi} + hM) + \gamma(w_{fj} + hM)) \tag{12}$$

Based on the above derivation and analysis, Proposition 1 can be obtained.

Proposition 1. *In the platform supply chain with seasonal demand, we get a threshold for the retailer to participate in the game based on the factory f_i decision is* $(w_{fi})_{th} = (\alpha_i\beta + \alpha_j\gamma)/(\beta^2 - \gamma^2) + hM/2$. *Also, we find that when $w_{fi} \geq (w_{fi})_{th}$, the retailer will not participate in the game; when $w_{fi} < (w_{fi})_{th}$, the retailer's optimal responsive sales price for product i is* $(\alpha_i\beta + \alpha_j\gamma)/2(\beta^2 - \gamma^2) + hM/2 + w_{fi}/2$ *and the optimal responsive order quantity is* $(e^{\lambda T} - 1) \cdot (\alpha_i - \beta(w_{fi} + hM) + \gamma(w_{fj}^S + hM))/2\lambda$.

Proposition 1 clarifies that the impact of factory f_i on retailer's pricing and ordering decisions in the platform supply chain with seasonal demand. In this case, the retailer should consider the impact of seasonal factor on the wholesale price decision of the factory, so as to correctly make the judgment of participating in the game, and should also consider the impact of seasonal factor on its response strategy. M reflects the influence of seasonal factor on the retailer's optimal response decision and participation threshold judgment. At this time, when the retailer refers to the wholesale price w_{fi} determined by the factory f_i, the retailer will judge whether to participate in the platform supply chain and order based on the wholesale price w_{fi} under seasonal demand. When the wholesale price w_{fi} determined by the factory f_i is higher than the acceptable threshold $(w_{fi})_{th}$ of the retailer, the retailer will refuse to order product i; When the wholesale price w_{fi} determined by the factory f_i does not exceed the threshold value condition $(w_{fi})_{th}$ acceptable to the retailer, the retailer will make the optimal sales price response to its wholesale price w_{fi} as $p_i^*(w_{fi})$, and the optimal sales price response $p_i^*(w_{fi})$ increases with the increase of the wholesale price w_{fi}. Similarly, from equation (12), we can see that the optimal order quantity response $Q_i^*(w_{fi}, w_{fj})$ of product i under seasonal demand decreases with the increase of wholesale price w_{fi}, and increases with the increase of wholesale price $(w_{fi})_{th}$. In addition, the retailer's participation threshold $(w_{fi})_{th}$, the optimal sales price response $p_i^*(w_{fi})$ and the optimal order quantity response $Q_i^*(w_{fi}, w_{fj})$ of product i all depend on the size of seasonal factor λ. The retailer's participation condition, and the optimal pricing and ordering decision will also be adjusted in the peak and low sales seasons.

Next, under the seasonal demand, the factory f_i will determine whether to participate in the game and carry out order taking production by referring to the commission price information published on the sharing platform, so as to make the optimal wholesale price response. The corresponding expression of $p_j^*(w_{fj})$ can also be written according to equation (10), and it and equation (10) can be substituted into equation (7), so that the profit function π_{fi} of factory f_i can find the first and second derivatives of w_{fi} respectively:

$$\frac{d\pi_{fi}}{dw_{fi}} = \frac{e^{\lambda T}-1}{2\lambda}\cdot[(\alpha_i - \beta(2w_{fi} + hM - c_{fi} - p_f) + \gamma(w_{fj} + hM))] \tag{13}$$

$$\frac{d^2\pi_{fi}}{dw_{fi}^{\ 2}} = -\beta\cdot\frac{e^{\lambda T}-1}{\lambda} \tag{14}$$

Because β>0 and $(e^{\lambda T}-1)/\lambda > 0$, therefore, when factory f_i participates in the game, its profit function π_{fi} is the concave function of w_{fi}, and the existence of w_{fi} maximizes the profit of factory f_i, let $\frac{d\pi_{fi}}{dw_{fi}} = 0$, we can get:

$$w_{fi}^*(w_{fj}, p_f) = \frac{\alpha_i}{2\beta} - \frac{hM - c_{fi} - p_f}{2} + \frac{\gamma(w_{fj} + hM)}{2\beta} \tag{15}$$

In the same way:

$$w_{fj}^*(w_{fi}, p_f) = \frac{\alpha_j}{2\beta} - \frac{hM - c_{fj} - p_f}{2} + \frac{\gamma(w_{fi} + hM)}{2\beta} \tag{16}$$

Simultaneous (15) and (16) can obtain:

$$w_{fi}^*(p_f) = \frac{2\beta\alpha_i + 2\beta^2 c_{fi} + \gamma\alpha_j + \beta\gamma c_{fj}}{4\beta^2 - \gamma^2} - \frac{(\beta-\gamma)hM}{2\beta-\gamma} + \frac{\beta p_f}{2\beta-\gamma} \tag{17}$$

When the participation constraint $w_{fi}>c_{fi}+p_f$ is satisfied, the factory f_i under seasonal demand will participate in the game. Combined with equation (17), the participation threshold $(p_f)_{th1}$ of factory f_i when making commission price decision based on sharing platform can be obtained:

$$(p_f)_{th1} = \frac{2\beta\alpha_i + (\gamma - 2\beta^2)c_{fi} + \gamma\alpha_j + \beta\gamma c_{fj}}{(\beta-\gamma)\cdot(2\beta+\gamma)} - hM \tag{18}$$

At this time, when $p_f \geq (p_f)_{th1}$, factory f_i cannot guarantee its own income; when $p_f<(p_f)_{th1}$, the optimal wholesale price response of factory f_i is equation (17).

Based on the above derivation and analysis, Proposition 2 can be obtained.

Proposition 2. *In the platform supply chain with seasonal demand, we get a threshold for the factory* f_i

to participate in the game based on the sharing platform decision is $(p_f)_{th1} = (2\beta\alpha_i + (\gamma - 2\beta^2)c_{fi} + \gamma\alpha_j + \beta\gamma c_{fj}) / ((\beta-\gamma)\cdot(2\beta+\gamma)) - hM$ *. Also, we find that* $p_f \geq (p_f)_{th1}$*, the factory* f_i *will not participate in the game; when* $p_f < (p_f)_{th1}$*, the optimal response wholesale price of factory fi is* $(2\beta\alpha_i + 2\beta^2 c_{fi} + \gamma\alpha_j + \beta\gamma c_{fj}) / (4\beta^2 - \gamma^2) - hM(\beta-\gamma)/(2\beta-\gamma) + \beta p_f / (2\beta-\gamma)$.

Proposition 2 illustrates the seasonal demand of the platform supply chain and the impact of the sharing platform on the pricing decision of factory f_i. In this case, the factory f_i should consider the impact of seasonal factor on the commission price decision of the sharing platform, so as to correctly make the judgment of participating in the game, and should also consider the impact of seasonal factor on its wholesale price response. M reflects the influence of seasonal factor on the optimal wholesale price response and participation threshold condition of factory f_i. At this time, when the factory f_i refers to the commission price p_f decided by the sharing platform, the factory f_i will also determine whether to participate in the platform supply chain and carry out production based on the commission price p_f. When the commission price p_f decided by the sharing platform is higher than the acceptable threshold $(p_f)_{th1}$ of factory f_i, factory f_i will not accept orders for production; When the commission price p_f decided by the sharing platform is lower than the acceptable threshold $(p_f)_{th1}$ of factory f_i, factory f_i will make the optimal wholesale price response $w_{fi}^*(p_f)$ to its commission price p_f, and the optimal wholesale price response $w_{fi}^*(p_f)$ will increase with the increase of commission price p_f. In addition, the participation threshold $(p_f)_{th1}$ and the optimal wholesale price response $w_{fi}^*(p_f)$ of factory f_i are related to seasonal factor, and the participation decision and optimal wholesale price response decision of factory f_i will be different in the peak and off-season sales.

Next, according to the optimal wholesale price response $w_{fi}^*(p_f)$ of factory f_i under seasonal demand, similarly, it analyzes whether the retailer should participate in the game indirectly by observing the commission price announced by the sharing platform to the factory, and studies the optimal pricing response and order quantity response of retailers when making decisions with reference to the sharing platform. According to Proposition 1, when $w_{fi} < (w_{fi})_{th}$, retailers will participate in the game. According to equation (17), let $w_{fi}^*(p_f) < (w_{fi})_{th}$:

$$(p_f)_{th2} = \frac{(2\beta-\gamma)(\beta\alpha_i + \gamma\alpha_j)}{\beta(\beta^2-\gamma^2)} - \frac{2\beta\alpha_i + 2\beta^2 c_{fi} + \gamma\alpha_j + \beta\gamma c_{fj}}{\beta(2\beta+\gamma)} + \frac{hM(4\beta-3\gamma)}{2\beta} \quad (19)$$

$(p_f)_{th2}$ is the maximum commission price for the retailer to judge whether it can make profits when it indirectly refers to the commission price of the sharing platform under seasonal demand. When $p_f < (p_f)_{th2}$, the optimal sales price response of retailer product i can be obtained by substituting equation (17) into equation (10):

$$p_i^*(p_f) = \frac{\alpha_i\beta + \alpha_j\gamma}{2(\beta^2-\gamma^2)} + \frac{w_{fi}^*(p_f)}{2} + \frac{hM}{2} \quad (20)$$

According to equation (17), the corresponding expression of $w_{fj}^*(p_f)$ can also be written, and it and equation (17) can be substituted into equation (12) to obtain the optimal order quantity response of product i when the retailer participates in the game under seasonal demand as follows:

$$Q_i^*(p_f) = \frac{e^{\lambda T} - 1}{2\lambda} \cdot (\alpha_i - \beta(w_{fi}^*(p_f) + hM) + \gamma(w_{fj}^*(p_f) + hM)) \tag{21}$$

According to the above derivation and analysis, Proposition 3 can be obtained.

Proposition 3. *In the platform supply chain with seasonal demand, based on the decision-making of the shared platform, we have the threshold for retailer to participate in the game as* $(p_f)_{th2}$ *(i.e., Equation (19)). Also, we find that when* $p_f \geq (p_f)_{th2}$*, the retailer will not participate in the game; when* $p_f < (p_f)_{th2}$*, the retailer's optimal responsive sales price for product i is* $(\alpha_i\beta + \alpha_j\gamma)/2(\beta^2 - \gamma^2) + (w_{fi}^*(p_f) + hM)/2$ *, and the optimal responsive order quantity is* $Q_i^*(p_f)$ *(i.e., Equation (21)).*

It can be seen from Proposition 3 that the seasonal demand of the platform supply chain and the impact of the sharing platform on the pricing and ordering decisions of the retailer. In this case, the retailer should consider the impact of seasonal factor on the commission price decision of the sharing platform, so as to correctly make the judgment of participating in the game, and should also consider the impact of seasonal factor on its own response decision. M captures the effect of the seasonal factor λ on retailer's optimal response and participation threshold condition when making platform commission-based price decisions. At this time, when the commission price p_f decided by the sharing platform is higher than the critical point $(p_f)_{th2}$, the excessive commission price p_f will cause the optimal wholesale price decision of factory f_i under seasonal demand to exceed the threshold value condition $(w_{fi})_{th}$ acceptable to the retailer, which indirectly leads to the retailer not ordering product i; When the commission price p_f decided by the sharing platform is lower than the critical point $(p_f)_{th2}$, the retailer will make the optimal sales price response $p_i^*(p_f)$ to the commission price pf decided by the sharing platform. In addition, the retailer's participation threshold $(p_f)_{th2}$, the optimal sales price response $p_i^*(p_f)$ of product i and the optimal order quantity response $Q_i^*(p_f)$ are related to seasonal factor λ. Retailers should adjust their participation decision and pricing and order response decision based on different sales seasons.

5.2 Optimal Pricing Decisions of the Platform Supply Chain

Based on the model derivation and analysis in Section 5.1, the optimal pricing strategy of each member of the platform supply chain under seasonal demand and meeting the participation constraints is further solved. The corresponding expression of $p_j^*(p_f)$ can also be written according to equation (20), and it and equation (20) can be substituted into equation (6), so that the profit function π_{sp} of the sharing platform can calculate the first and second derivatives of p_f respectively:

$$\frac{d\pi_{sp}}{dp_f} = \frac{e^{\lambda T} - 1}{2\lambda} \cdot [\frac{\beta(\alpha_i + \alpha_j) - \beta(\beta - \gamma)(c_{fi} + c_{fj})}{2\beta - \gamma} - \frac{4\beta(\beta - \gamma)}{2\beta - \gamma} \cdot p_f] \tag{22}$$

$$\frac{d^2\pi_{sp}}{dp_f^{\,2}} = -\frac{e^{\lambda T} - 1}{\lambda} \cdot \frac{2\beta(\beta - \gamma)}{2\beta - \gamma} \tag{23}$$

Since $\frac{d^2\pi_{sp}}{dp_f^{\,2}} < 0$, the profit function π_{sp} of the sharing platform is a concave function of p_f, the existence of p_f^* maximizes the profit of the sharing platform, let $\frac{d\pi_{sp}}{dp_f}=0$, so that the optimal commission price of the sharing platform under seasonal demand can be obtained:

$$p_f^*=\frac{\alpha_i+\alpha_j}{4(\beta-\gamma)}-\frac{c_{fi}+c_{fj}}{4}-\frac{hM}{2} \tag{24}$$

By substituting equation (23) into equation (17), the optimal wholesale price of factory f_i under seasonal demand can be obtained:

$$w_{fi}^*=\frac{2\beta\alpha_i+2\beta^2c_{fi}+\gamma\alpha_j+\beta\gamma c_{fj}}{4\beta^2-\gamma^2}-\frac{(\beta-\gamma)hM}{2\beta-\gamma}+\frac{\beta p_f^*}{2\beta-\gamma} \tag{25}$$

By substituting equation (23) into equations (20) and (21), the optimal sales price and optimal order quantity of retailer product *i* under seasonal demand can be obtained:

$$p_i^*=\frac{\alpha_i\beta+\alpha_j\gamma}{2(\beta^2-\gamma^2)}+\frac{hM}{2}+\frac{w_{fi}^*}{2} \tag{26}$$

$$Q_i^*=\frac{e^{\lambda T}-1}{\lambda}(\alpha_i-\beta p_i^*+\gamma p_j^*) \tag{27}$$

Under the seasonal demand, the premise for the platform supply chain to realize the transaction is that retailers and factories participate in the game at the same time. Therefore, according to the participation constraint in the model, namely $p_i>w_{fi}>c_{fi}+p_f$, and combined with the analysis of Propositions 1-3, we can get the constraint conditions for the platform supply chain to reach the transaction: $0<p_f^*<\min((p_f)_{th1}, (p_f)_{th2})$, $p_f^*+c_{fi}<w_{fi}^*<(w_{fi})_{th}$.

Based on the above derivation and analysis, Proposition 4 can be obtained.

Proposition 4. *In the platform supply chain with seasonal demand, when the conditions of participation constraints are satisfied, the optimal pricing strategies of each member of the platform supply chain are p_f^* (i.e., Equation (24)), w_{fi}^* (i.e., Equation (25)), and p_i^* (i.e., Equation (26)), respectively; and the optimal order quantity of retailer's product i is Q_i^* (i.e., Equation (27)).*

Proposition 4 shows that for the seasonal demand of the platform supply chain, on the basis of meeting the participation constraints of retailer and factories, each member of the supply chain will participate in the platform supply chain with the goal of maximizing their own profits. The optimal pricing strategy of each member depends on the size of seasonal factor. For example, the optimal decision of each member in the off-season is different from that in the peak season. *M* reflects the impact of seasonal factor λ on pricing decisions of members.

6. Expanded Analysis: Non-Seasonal Demand (λ=0)

Non-seasonal demand (denoted by *N*) means that the demand for some commodities is not affected by seasonal changes, and the demand for these commodities is usually stable, such as non-seasonal commodity trading on Ali 1688 platform. In this case, the seasonal factor $\lambda=0$. In the sales cycle of [0, *T*], the demand rate of product *i* does not change with time. Based on the model description and symbol description in Section 3, this section will build a dynamic game model of platform supply chain considering participation constraints under non-seasonal demand (i.e., λ=0), and gradually solve and analyze the impact of pricing decisions among members by using the backward induction method. At the same time, we will study the threshold conditions of the retailer and factories participating in the game, and finally derive the optimal pricing decisions of members. The model is constructed as follows:

$$\max \pi_{sp}{}^{N} = \max_{p_f{}^N}[p_f{}^N \cdot \sum_{i=1}^{2}((\alpha_i - \beta p_i{}^N + \gamma p_j{}^N)\cdot T) - 2c_{sp}\cdot T] \tag{28}$$

$$\max \pi_{fi}{}^{N} = \max_{w_{fi}{}^N}[(w_{fi}{}^N - c_{fi}{}^N - p_f{}^N)\cdot(\alpha_i - \beta p_i{}^N + \gamma p_j{}^N)\cdot T] \tag{29}$$

$$\max \pi_{r}{}^{N} = \max_{p_i{}^N, p_j{}^N}[\sum_{i=1}^{2}((p_i{}^N - w_{fi}{}^N - \frac{hT}{2})\cdot(\alpha_i - \beta p_i{}^N + \gamma p_j{}^N)\cdot T)] \tag{30}$$

After obtaining the wholesale price information of the factory decision, the retailer will first determine whether to participate in the game. Under the participation constraint of ensuring its own profitability, it will make the optimal sales price response. According to equation (30), the determinant of the Hessian matrix of the retailer's profit function $\pi_r{}^N$ with respect to $p_i{}^N$ and $p_j{}^N$ under non-seasonal demand can be obtained:

$$\left|H^N\right| = \begin{vmatrix} \frac{\partial^2 \pi_r{}^N}{\partial p_i{}^2} & \frac{\partial^2 \pi_r{}^N}{\partial p_i{}^N \partial p_j{}^N} \\ \frac{\partial^2 \pi_r{}^N}{\partial p_j{}^N \partial p_i{}^N} & \frac{\partial^2 \pi_r{}^N}{\partial p_j{}^{N2}} \end{vmatrix} = \begin{vmatrix} -2\beta T & 2\gamma T \\ 2\gamma T & -2\beta T \end{vmatrix} \tag{31}$$

It can be obtained from (31), $\left|H_1{}^N\right| = -2\beta T < 0$ and $\left|H_2{}^N\right| = 4T^2\cdot(\beta^2-\gamma^2) > 0$, that is, the Hessian matrix is negative definite. When the retailer meets the conditions $p_i{}^N > w_{fi}{}^N$ of participating in the game, there is a unique ($p_i{}^{N*}$, $p_j{}^{N*}$) to maximize the profit of the retailer, which will be available together with $\frac{\partial \pi_r{}^N}{\partial p_i{}^N} = 0$ and $\frac{\partial \pi_r{}^N}{\partial p_j{}^N} = 0$:

$$p_i{}^{N*}(w_{fi}{}^N) = \frac{\alpha_i\beta + \alpha_j\gamma}{2(\beta^2-\gamma^2)} + \frac{hT}{4} + \frac{w_{fi}{}^N}{2} \tag{32}$$

Considering the participation constraint, that is, $p_i{}^{N*}(w_{fi}{}^N) > w_{fi}{}^N$, combining equation (32), the threshold value condition of retailer's participation in the game can be obtained:

$$(w_{fi}{}^N)_{th} = \frac{(\alpha_i\beta + \alpha_j\gamma)}{(\beta^2-\gamma^2)} + \frac{hT}{2} \tag{33}$$

The threshold condition $(w_{fi}{}^N)_{th}$ of retailer's participation in the game refers to the critical point of the maximum wholesale price that retailer can accept when they refer to the wholesale price determined by the factory under non seasonal demand. According to equation (2), we have

$Q_i^N = \int_0^T D_i^N(p_i^N, p_j^N, \tau)d\tau$, the optimal order quantity response of retailer product *i* is:

$$Q_i^{N*}(w_{fi}^N, w_{fj}^N) = \frac{T}{2}(\alpha_i - \beta w_{fi}^N + \gamma w_{fj}^N - \frac{Th}{2}(\beta - \gamma)) \quad (34)$$

Next, we will analyze whether the factory participates in the game and takes orders for production with reference to the commission price information published on the sharing platform, so as to make the optimal wholesale price response. According to equation (10) the corresponding expression for $p_j^{N*}(w_{fj}^N)$ can also be written, substitute it and equation (32) into equation (29), so that the profit function π_{fi}^N of factory f_i under non-seasonal demand can find the first and second derivatives of w_{fi}^N respectively:

$$\frac{d\pi_{fi}^N}{dw_{fi}^N} = [(\alpha_i - \beta w_{fi}^N + \gamma w_{fj}^N - \frac{Th(\beta-\gamma)}{2}) - \beta(w_{fi}^N - c_{fi} - p_f^N)] \cdot \frac{T}{2} \quad (35)$$

$$\frac{d\pi_{fi}^N}{dw_{fi}^N} = [(\alpha_i - \beta w_{fi}^N + \gamma w_{fj}^N - \frac{Th(\beta-\gamma)}{2}) - \beta(w_{fi}^N - c_{fi} - p_f^N)] \cdot \frac{T}{2} \quad (36)$$

Since $\frac{d^2\pi_{fi}^N}{dw_{fi}^{N^2}} < 0$, when the factory f_i meets the condition $w_{fi}^N > p_f^N + c_{fi}$ of participating in the game, its profit function π_{fi} is the concave function of w_{fi}^N, and there is w_{fi}^{N*} to maximize the profit of factory f_i, so that $\frac{d\pi_{fi}^N}{dw_{fi}^N} = 0$, we can get:

$$w_{fi}^{N*}(w_{fj}^N, p_f^N) = \frac{1}{2\beta}(\alpha_i + \gamma w_{fj}^N - \frac{Th(\beta-\gamma)}{2}) + \frac{1}{2}(c_{fi} + p_f^N) \quad (37)$$

$$w_{fj}^{N*}(w_{fi}^N, p_f^N) = \frac{1}{2\beta}(\alpha_j + \gamma w_{fi}^N - \frac{Th(\beta-\gamma)}{2}) + \frac{1}{2}(c_{fj} + p_f^N) \quad (38)$$

Joining equations (37) and (38) yields:

$$w_{fi}^{N*}(p_f^N) = \frac{1}{2\beta-\gamma} \cdot (\alpha_i + \frac{\gamma\alpha_j}{2\beta} - \frac{\gamma Th(\beta-\gamma)}{4\beta} + \frac{\gamma c_j}{2} + \beta c_i) + \frac{2\beta+\gamma}{2(2\beta-\gamma)} \cdot p_f^N \quad (39)$$

Considering the participation constraint, that is, $w_{fi}^N > c_{fi} + p_f^N$, combining equation (39), we can get the threshold value condition of factory f_i participating in the game:

$$(p_f^N)_{th1} = \frac{2}{(2\beta-3\gamma)}(\alpha_i + \frac{\alpha_j\gamma}{2\beta} - \frac{\gamma Th(\beta-\gamma)}{4\beta} + \frac{\gamma c_{fj}}{2} + (\gamma-\beta)c_{fi}) \quad (40)$$

The threshold value condition $(p_f^N)_{th1}$ of factory f_i participating in the game refers to the critical point of the maximum commission price that can be accepted when the factory refers to the commission price decided by the sharing platform under non-seasonal demand. Under the premise of factory profits, factory f_i will make the optimal wholesale price response, that is, equation (39).

Furthermore, based on the optimal wholesale price response $w_{fi}^{N*}(p_f^N)$ of factory f_i, we will analyze whether the retailer should participate in the game indirectly by observing the commission price announced by the sharing platform to the factory, and study the optimal pricing response and order quantity response when retailer make decisions with reference to the sharing platform. When ${w_{fi}}^N < ({w_{fi}}^N)_{th}$, the retail will participate in the game. According to equation (39), let ${w_{fi}}^{N*}({p_f}^N) < ({w_{fi}}^N)_{th}$, we can get:

$$({p_f}^N)_{th2} = \frac{2}{(2\beta+\gamma)}(\alpha_i + \gamma\alpha_j / 2\beta - \frac{\gamma Th(\beta-\gamma)}{4\beta} + \frac{\gamma c_{fj}}{2} + \beta c_{fi} + ({w_{fi}}^N)_{th} \cdot (2\beta-\gamma)) \quad (41)$$

The threshold value condition $({p_f}^N)_{th2}$ at which the retailer participates in the game is the maximum commission price at which the retailer can judge whether it can profit or not when it indirectly refers to the commission price of the sharing platform's decision under non-seasonal demand. By substituting equation (39) into equation (32), the optimal sales price response of retailer product *i* can be obtained.

$$\begin{aligned} {p_i}^{N*}({p_f}^N) = {} & \frac{\alpha_i\beta + \alpha_j\gamma}{2(\beta^2-\gamma^2)} + \frac{hT}{4} + \frac{1}{2(2\beta-\gamma)} \cdot (\alpha_i + \frac{\gamma\alpha_j}{2\beta} - \frac{\gamma Th(\beta-\gamma)^2}{4\beta} + \frac{\gamma c_{fj}(\beta-\gamma)}{2} \\ & + \beta c_{fi}) + \frac{2\beta+\gamma}{4(2\beta-\gamma)} \cdot {p_f}^N \end{aligned} \quad (42)$$

According to equation (39) the corresponding expression for ${w_{fj}}^{N*}({p_f}^N)$ can also be written, substituting it and equation (39) into equation (34), the optimal response order quantity of product *i* when the retailer participates in the game is:

$$\begin{aligned} {Q_i}^{N*}({p_f}^N) = {} & \frac{T}{2} \cdot [\frac{(\beta^2 + (\beta-\gamma)^2)\alpha_i + \gamma\beta\alpha_j}{2\beta(2\beta-\gamma)} + \frac{\beta-\gamma}{2(2\beta-\gamma)} \cdot (\frac{\gamma Th(\beta-\gamma)}{2\beta} - c_{fi} + c_{fj}) - \frac{Th}{2} \\ & (\beta-\gamma) - \frac{(\beta-\gamma)(2\beta+\gamma)}{2(2\beta-\gamma)} \cdot {p_f}^N] \end{aligned} \quad (43)$$

Based on the above analysis, we further obtain the optimal pricing strategy of each member of the platform supply chain under non-seasonal demand and meeting the member participation constraints. According to equation (42), the expression of ${p_j}^{N*}({p_f}^N)$ can also be written accordingly, substitute it and equation (42) into equation (28), and let the profit function ${\pi_{sp}}^N$ of the sharing platform calculate the first and second derivatives of ${p_f}^N$ respectively:

$$\begin{aligned} \frac{d{\pi_{sp}}^N}{d{p_f}^N} = {} & [\frac{\beta(\beta+\gamma)(\alpha_1+\alpha_2) + (\beta-\gamma)^2(\alpha_1+\alpha_2+\gamma Th)}{2\beta(2\beta-\gamma)} - Th(\beta-\gamma) - \frac{2(\beta-\gamma)(2\beta+\gamma)}{(2\beta-\gamma)} \\ & \cdot {p_f}^N] \cdot \frac{T}{2} \end{aligned} \quad (44)$$

$$\frac{d^2{\pi_{sp}}^N}{d{p_f}^{N^2}} = -\frac{(\beta-\gamma)(2\beta+\gamma)}{(2\beta-\gamma)} \quad (45)$$

Because $\frac{d^2{\pi_{sp}}^N}{d{p_f}^{N^2}} < 0$, the profit function ${\pi_{sp}}^N$ of the sharing platform is a concave function of ${p_f}^N$, ${p_f}^{N*}$ exists to maximize the profit of the sharing platform, so that the optimal commission price of the sharing platform can be obtained as follow:

$${p_f}^{N*} = \frac{1}{2(2\beta+\gamma)} \cdot [\frac{(\beta(\beta+\gamma) + (\beta-\gamma)^2)(\alpha_i+\alpha_j)}{2\beta(\beta-\gamma)} + \frac{\gamma Th(\beta-\gamma)}{2\beta} - Th(2\beta-\gamma)] \quad (46)$$

The optimal wholesale price of the factory f_i can be obtained by substituting the optimal commission price of the sharing platform into equation (39).

$$w_{fi}^{N*} = \frac{1}{2\beta-\gamma}\cdot[\frac{(\alpha_i+\alpha_j)(\beta+\gamma)}{8(\beta-\gamma)}+\frac{\alpha_i(9\beta-\gamma)+\alpha_j(\beta+3\gamma)-\gamma Th(\beta-\gamma)}{8\beta} + \gamma c_{fj}+\beta c_{fi}]-\frac{Th}{4} \quad (47)$$

By substituting the optimal commission price of the sharing platform into equations (42) and (43) respectively, the optimal sales price and optimal order quantity of the retailer's product i can be obtained.

$$p_i^{N*} = \frac{\alpha_i\beta+\alpha_j\gamma}{2(\beta^2-\gamma^2)}+\frac{1}{2(2\beta-\gamma)}\cdot[\frac{(\alpha_i+\alpha_j)(\beta+\gamma)}{8(\beta-\gamma)}+\frac{\alpha_i(9\beta-\gamma)+\alpha_j(\beta+3\gamma)-\gamma Th(\beta-\gamma)}{8\beta} + \gamma c_{fj}+\beta c_{fi}]+\frac{Th}{8} \quad (48)$$

$$Q_i^{N*} = \frac{T}{2}\cdot[\frac{(\beta^2+(\beta-\gamma)^2)\alpha_i+\gamma\beta\alpha_j}{2\beta(2\beta-\gamma)}+\frac{\beta-\gamma}{2(2\beta-\gamma)}\cdot(\frac{\gamma Th(\beta-\gamma)}{2\beta}-c_{fi}+c_{fj})-\frac{Th}{2}(\beta-\gamma) - \frac{(\beta-\gamma)(2\beta+\gamma)}{2(2\beta-\gamma)}\cdot p_f^{*}] \quad (49)$$

Under the non-seasonal demand, the premise for the platform supply chain to realize the transaction is that the retailer and the factories participate in the game at the same time. Therefore, according to the constraints in the model, that is, combined with the game analysis, the constraints for the platform supply chain to achieve the transaction under the non-seasonal demand can be obtained: $0<p_f^{N*}<\min((p_f^N)_{th1}, (p_f^N)_{th2})$, $p_f^{N*}+c_{fi}<w_{fi}^{N*}<(w_{fi}^N)_{th}$.

7. Numerical Analysis

This paper focuses on member participation and pricing decisions in the platform supply chain under seasonal demand, but due to the complexity of the calculation results, it is not possible to directly compare and analyze the relationship between the participation threshold value conditions of the retailer and factories and the optimal pricing of each member in the off-season and peak season. In view of this, this section will use numerical calculation method to simulate the model, so as to further explore the impact of peak and off-season sales on the platform supply chain's participation threshold conditions, pricing decisions and profits. At the same time, taking the peak sales season as an example, the impacts of the price sensitivity coefficient β, cross-price sensitivity coefficient γ, unit inventory cost h and unit production cost c_{fi} of factory f_i on the decision-making and profit of each member of the platform supply chain are analyzed. The parameters are set as follows: T=10, α_i=95, α_j=105, c_{fj}=32, c_{sp}=5, and the benchmark values of β, γ, h and c_{fi} are 0.75, 0.15, 5 and 30, respectively. At the same time, take λ=(-0.3, 0.3) to depict the off-season and the sales season, respectively.

Table 1. Member Participation Conditions and Pricing Decisions in Peak and Off-Season Sales

Seasonal demand	$(w_{fi})_{th}$	$(p_f)_{th1}$	$(p_f)_{th2}$	p_f^*	w_{fi}^*	p_i^*
Off-season sales	168	120	219	61	115	145
Peak season sales	179	98	276	50	100	148

Table 1 shows the optimal prices of each member of the platform supply chain and the conditions for the retailer and factory f_i to participate in the platform supply chain during the peak and off-season sales. It can be seen from the table that the optimal sales price of retailer product i is higher in the peak season than in the off-season, while the optimal wholesale price w_{fi}^* of factory f_i and the optimal commission price p_f^* of sharing platform are lower in the peak season than in the off-season. Generally, the retailer will increase the order quantity during the peak sales season. When the order quantity increases, the factory f_i and sharing platform will appropriately reduce the optimal price to maximize their profits. In the peak sales season, $(w_{fi})_{th}$=179, which means that when the wholesale price of factory f_i is lower than 179, the retailer can make the optimal sales price response based on the wholesale price of factory f_i, and when the wholesale price of factory f_i is higher than 179, the retailer will refuse to order. In addition, it can be seen from Table 1 that the conditions $(w_{fi})_{th}$ and $(p_f)_{th2}$ for retailer's participation in the platform supply chain are larger in the peak season than that in the off-season, which indicates that the retailer has more orders in the peak season, while the factory's supply capacity is in short supply at this time, so the wholesale price threshold and the platform's commission threshold are both high; The threshold condition $(p_f)_{th1}$ of factory f_i participating in the platform supply chain is smaller in the peak season than in the off-season, which indicates that in the peak season, due to the large order quantity and the limited production capacity of the factory, in order to stimulate the production capacity of the factory, the commission threshold of the platform is relatively reduced, so that the factory can actively participate in the operation of the platform supply chain.

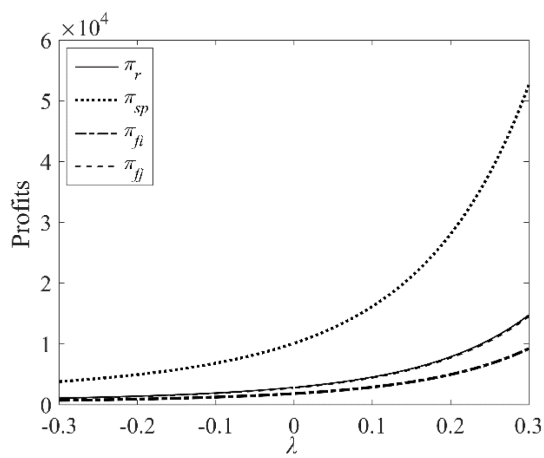
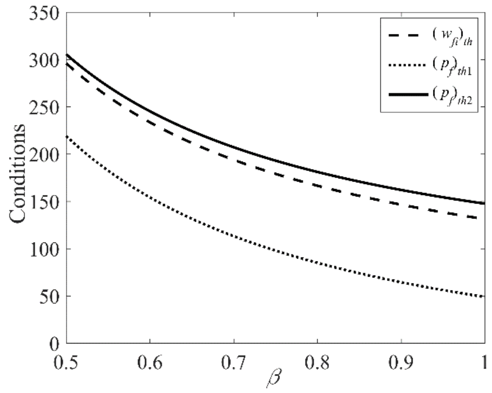
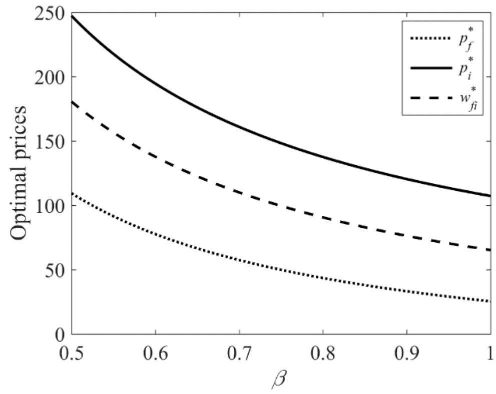


Figure 2. Impact of Seasonal Factor λ on the Profits of Members of the Platform Supply Chain

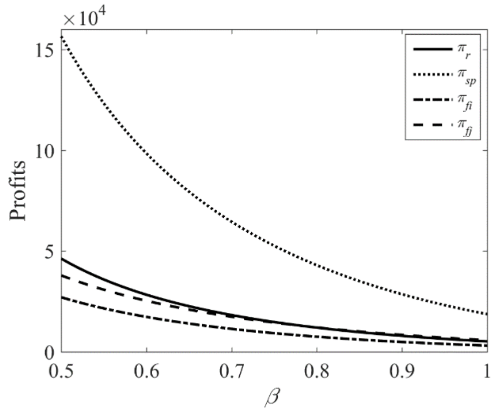
Figure 2 shows the profit trajectory of each member of the platform supply chain with seasonal factor λ. It can be seen from the figure that when the market demand changes from the off-season to the peak season, the profit of each member will gradually rise, which is consistent with the reality. Due to the large market demand in the peak season, the profits of the retailer, sharing platform and factories will all be significantly increased.



(a) Effect of price sensitivity coefficient β on the member participant conditions



(b) Effect of price sensitivity coefficient β on optimal pricing decisions of chain members

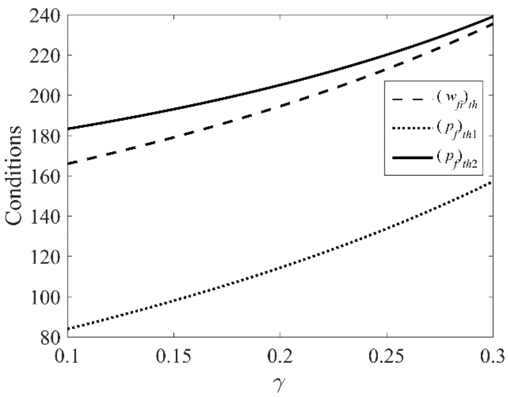


(c) Effect of price sensitivity coefficient β on the profits of chain members

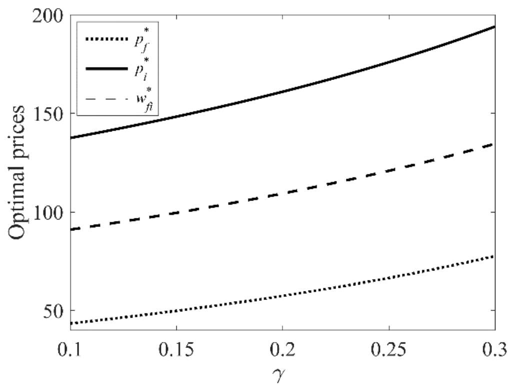
Figure 3. Sensitivity Analysis of Price Sensitivity Coefficient β

Figure 3 reveals the impact of price sensitivity coefficient on the participation threshold condition of the retailer and factories, and the optimal pricing and profit of each member during the peak sales season. It can be seen from the figure that the participation threshold of the retailer and factories, the optimal price of each member and the profit of each member in the platform supply chain decrease with the increase of the price sensitivity coefficient. When the price sensitivity coefficient increases, for the retailer, reducing the sales price can ensure the stability of market demand. Similarly, factories need to reduce the wholesale price to ensure the unchanged order quantity, and the sharing platform also needs to reduce the commission price to ensure the matching between retailer and factories. As the price of each member decreases, but the order quantity does not increase, the profit of each member will decrease with the increase of the price sensitivity coefficient. That is to say, when the price sensitivity coefficient increases, it will be unfavorable to the members of the platform supply chain.

Figure 4 shows the impact of the cross-price sensitivity coefficient on the participation threshold of the retailer and factories and the optimal pricing and profit of each member during the peak sales season. It can be seen from the figure that the participation threshold conditions of retailer and factories and the optimal price and profit of each member increase with the increase of cross price sensitivity coefficient. Because the cross-price sensitivity coefficient represents the replaceability of two products, for the retailer, when the sales price of one product is increased, the sales of another product will be stimulated. The greater the cross-price sensitivity coefficient, the stronger the degree of substitution, and the greater the stimulation. Therefore, the retailer can maximize its profit by increasing the sales price, and factory f_i will also increase the wholesale price to maximize its profit. The corresponding sharing platform will also increase the commission price. It can be seen that the stronger the degree of substitution of the two products, the more favorable it will be to the members of the supply chain.

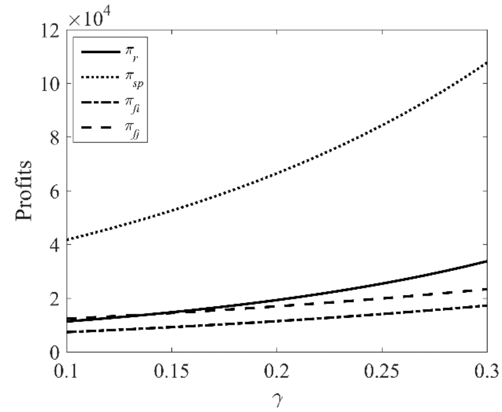


(a) Effect of cross-price sensitivity coefficient γ on the member participant conditions



(b) Effect of cross-price sensitivity coefficient γ on optimal pricing decisions of chain members

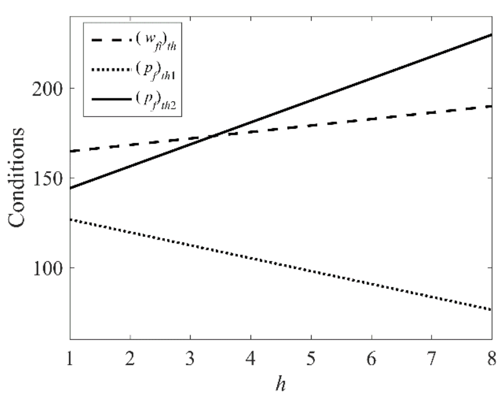
Published by SCHOLINK INC.



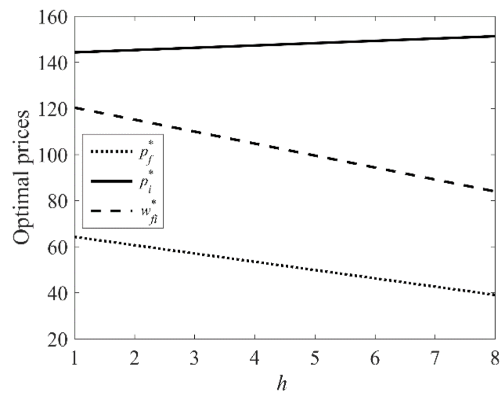
(c) Effect of cross-price sensitivity coefficient γ on the profits of chain members

Figure 4. Sensitivity Analysis of Cross-Price Sensitivity Coefficient γ

Figure 5 shows the impact of unit inventory cost on the participation threshold conditions of the retailer and factories, and the optimal pricing and profit of each member during the peak sales season. When the unit inventory cost increases, it can be seen from Figure 5 (a) that the participation condition of the retailer will increase, while the participation condition of factory will decrease. It can be seen from Figure 5 (b) that the optimal sales price of the retailer will increase, while the optimal wholesale price of factory and the optimal commission price of sharing platform will decrease accordingly. This shows that because the unit inventory cost directly affects the profit of retailer, the rise of its own inventory cost will lead to the increase of sales price, and also lead to the increase of the threshold value condition of participating in the platform supply chain. As can be seen from Figure 5 (c), the profit of each member of the platform supply chain decreases with the increase of unit inventory cost. That is to say, the increase of retailer's unit inventory cost will not be conducive to the profits of all members.

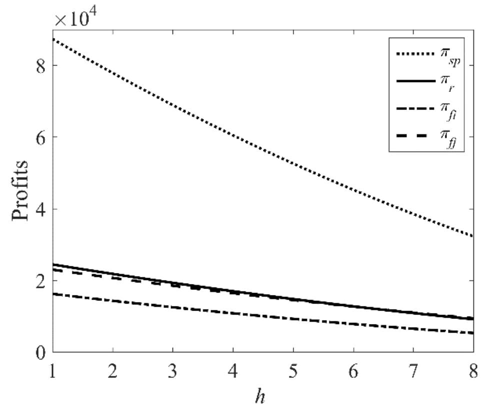


(a) Effect of the unit inventory cost h on the member participant conditions



(b) Effect of the unit inventory cost h on optimal pricing decisions of chain members

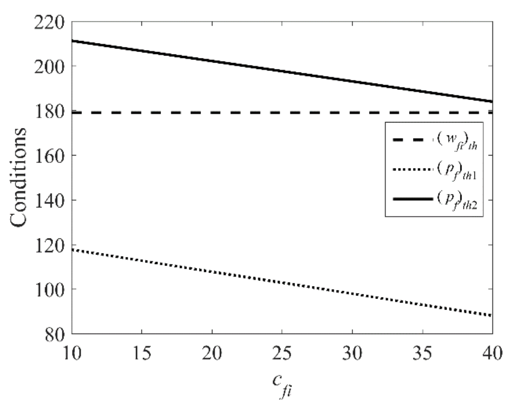
Published by SCHOLINK INC.



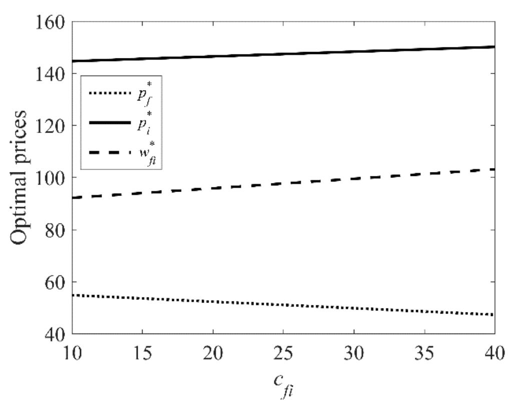
(c) Effect of the unit inventory cost h on the profits of chain members

Figure 5. Sensitivity Analysis of the Unit Inventory Cost *h*

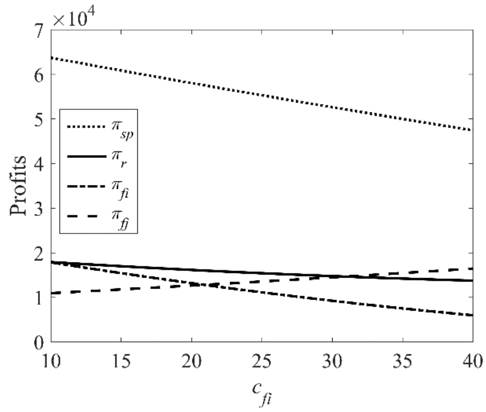
Figure 6 shows the impact of the unit production cost c_{fi} of factory f_i on the participation threshold conditions of the retailer and factories and the optimal pricing and profit of each member during the peak sales season. When the unit production cost c_{fi} increases, it can be seen from Figure 6 (a) that the participation threshold condition of the retailer when referring to the factory f_i decision remains unchanged, while the threshold of the retailer and the factory f_i reference platform decision tends to decrease; From Figure 6 (b), we can see that the optimal sales price of the retailer and the optimal wholesale price of factory f_i will increase, while the commission price of the sharing platform will decrease; It can be seen from Figure 6 (c) that the profits of retailer, factory f_i and sharing platform will decrease, while the profit of factory f_j will increase. As the unit production cost of factory f_i increases, the retailer will increase the order quantity of substitute product j, which will correspondingly increase the profit of factory f_j.



(a) Effect of the unit production cost c_{fi} on the member participant conditions



(b) Effect of the unit production cost c_{fi} on optimal pricing decisions of chain members



(c) Effect of the unit production cost c_{fi} on the profits of chain members

Figure 6. Sensitivity Analysis of the Unit Production Cost c_{fi}

8. Conclusions and Management Implications

Taking the platform supply chain as the research object, considering that it is composed of a retailer, a sharing platform and two factories, this paper constructs a dynamic game model of the platform supply chain under seasonal demand by using game theory, and gradually solves and analyzes the impact of pricing decisions among members of the supply chain, the threshold conditions of retailer and factories participating in the platform supply chain, and the optimal pricing strategy by using the inverse induction method. Finally, through numerical simulation, the impact of peak and off-season sales on the participation, pricing and profit of platform supply chain members is further analyzed, and the sensitivity of price sensitivity coefficient, cross price sensitivity coefficient, unit inventory cost and unit production cost of factory f_i is analyzed.

8.1 Main Conclusions

Through theoretical analysis and numerical simulation, the following main conclusions can be drawn:

(1) The optimal pricing decisions of each member of the supply chain will be different in the peak season and the off-season. For the retailer, the optimal sales price should be appropriately increased in the peak season compared with the off-season to maximize its profit. For factories and sharing platform, the optimal price in the peak season is lower than that in the low season.

(2) The impact of peak and off-season sales on retailer's and factories' participation in decision-making is different. The threshold condition for retailer to participate in the platform supply chain is larger in the peak season than in the off-season, while the threshold for factories to participate in the platform supply chain is smaller in the peak season than in the off-season.

(3) The effects of key parameters such as seasonal factor, price sensitivity coefficient, cross-price sensitivity coefficient and unit inventory cost are given. The participation threshold of retailer and factories and the optimal price and profit of each member decrease with the increase of price sensitivity coefficient, but increase with the increase of cross-price sensitivity coefficient.

8.2 Management Implications

According to the above main conclusions, the following management implications can be obtained:

1) Managers of platforms, retailers and factories should strategically adjust their optimal pricing decisions according to seasonal changes in product demand. When the off-season turns to the peak season, it is suggested that the managers of retailers should raise the sales price of products, which will help to improve the profitability of retail enterprises; The managers of the factories should reduce the wholesale price of products, so as to obtain more ordering opportunities and improve the profit of the factory; The managers of the platform should take the opportunity to reduce commissions, promote capacity utilization, meet more demands and obtain more profits.

2) Managers of retailers and factories should decide whether to participate in the transaction on the sharing platform according to the seasonal changes of product demand and the corresponding threshold conditions, and the managers of the platform can also better match the transaction between the two sides according to the threshold conditions of retailers and factories. The managers of retailers should actively participate in the platform during the peak sales season to obtain additional capacity, meet more ordering demands and avoid missing sales opportunities, while the managers of factories should actively participate in the platform during the off-season to obtain production opportunities and make full use of idle capacity. Platform managers can encourage more factories to participate in the peak sales season and more retailers to participate in the low sales season by reducing commissions or providing subsidies, based on the participation threshold conditions of factories and retailers obtained in this paper, so as to achieve more matching between idle capacity and demand and improve the profitability of the platform.

3) The changes of seasonal factor, price sensitivity coefficient, cross price sensitivity coefficient, unit inventory cost and unit production cost will affect the optimal decisions and profits of platforms, retailers and factories. It is suggested that relevant decision makers refer to the research results of parameter sensitivity analysis in this paper, fully consider the influence of changes in market factors when making the optimal pricing decision, and adjust the optimal decision of the enterprise at any time, so as to reduce the operation risk of the enterprise and improve the profitability of the enterprise.

8.3 Limitations and Future Research

This research still has some limitations, and can be expanded in the following aspects in the future. First. this paper mainly studies the pricing problem of the platform supply chain, and the next step can be explored and researched for the platform supply chain coordination. Second, this paper only considers one retailer, but in the future, we can consider multiple retailers and multiple factories transacting on the sharing platform, and study how the sharing platform can effectively distribute or integrate orders. Third. the competition between multiple sharing platforms can be further studied.

Acknowledgement

The author is grateful to the Editor and anonymous reviewers for their very valuable comments and suggestions. The author declares that there was no funding for this research paper.

References

Adeinat, H., Pazhani, S., Mendoza, A., & Ventura, J. A. (2022). Coordination of pricing and inventory replenishment decisions in a supply chain with multiple geographically dispersed retailers. *International Journal of Production Economics*, *248*, 108461. https://doi.org/10.1016/j.ijpe.2022.108461

Akçay, Y., Natarajan, H. P., & Xu, S. H. (2010). Joint Dynamic Pricing of Multiple Perishable Products Under Consumer Choice. *Management Science*, *56*(8), 1345-1361. https://doi.org/10.1287/mnsc.1100.1178

Bajwa, N., Sox, C. R., & Ishfaq, R. (2016). Coordinating pricing and production decisions for multiple products. *Omega*, *64*, 86-101. https://doi.org/10.1016/j.omega.2015.11.006

Huang, X., Yang, S., & Wang, Z. (2021). Optimal pricing and replenishment policy for perishable food supply chain under inflation. *Computers & Industrial Engineering*, *158*, 107433. https://doi.org/10.1016/j.cie.2021.107433

Jabarzare, N., & Rasti-Barzoki, M. (2020). A game theoretic approach for pricing and determining quality level through coordination contracts in a dual-channel supply chain including manufacturer and packaging company. *International Journal of Production Economics*, *221*, 107480. https://doi.org/10.1016/j.ijpe.2019.09.001

Li, M., Shan, M., & Meng, Q. (2022). Pricing and promotion efforts strategies of dual-channel green supply chain considering service cooperation and free-riding between online and offline retailers. *Environment, Development and Sustainability*, *12*, 1-21. https://doi.org/10.1007/s10668-022-02845-y

Liu, B., Huang, L., Zhang, R., & Hu, C. (2023). Strategic outsourcing decisions of new entrant and competing incumbent manufacturer in a supply chain with common supplier. *Journal of Industrial and Management Optimization*, *19*(8), 5842-5868. https://doi.org/10.3934/jimo.2022197

Ma, D. Q., Hu, J. S., & Wang, W. H. (2021). Differential game of product–service supply chain considering consumers' reference effect and supply chain members' reciprocity altruism in the online-to-offline mode. *Annals of Operations Research*, *304*(1-2), 263-297. https://doi.org/10.1007/s10479-021-04032-0

Ma, P., Zhang, C., Hong, X., & Xu, H. (2018). Pricing decisions for substitutable products with green manufacturing in a competitive supply chain. *Journal of Cleaner Production*, *183*, 618-640. https://doi.org/10.1016/j.jclepro.2018.02.152

Mahmoodi, A. (2019). Joint pricing and inventory control of duopoly retailers with deteriorating items and linear demand. *Computers & Industrial Engineering*, *132*, 36-46. https://doi.org/10.1016/j.cie.2019.04.017

Maihami, R., & Nakhai Kamalabadi, I. (2012). Joint pricing and inventory control for non-instantaneous deteriorating items with partial backlogging and time and price dependent demand. *International Journal of Production Economics*, *136*(1), 116-122. https://doi.org/10.1016/j.ijpe.2011.09.020

Sun, Z., Xu, Q., & Liu, J. (2021). Pricing and replenishment decisions for seasonal and nonseasonal products in a shared supply chain. *International Journal of Production Economics*, *233*, 108011. https://doi.org/10.1016/j.ijpe.2020.108011

Tantiwattanakul, P., & Dumrongsiri, A. (2019). Supply chain coordination using wholesale prices with multiple products, multiple periods, and multiple retailers: Bi-level optimization approach. *Computers & Industrial Engineering*, *131*, 391-407. https://doi.org/10.1016/j.cie.2019.03.050

Zhang, Z., Xu, H., Chen, K., Zhao, Y., & Liu, Z. (2023). Channel mode selection for an e-platform supply chain in the presence of a secondary marketplace. *European Journal of Operational Research*, *305*(3), 1215-1235. https://doi.org/10.1016/j.ejor.2022.06.064

Zhang, Z., Xu, H., Ke, G. Y., & Chen, K. (2022). Selecting online distribution modes for differentiated products in a platform supply chain. *International Journal of Production Economics*, *244*, 108384. https://doi.org/10.1016/j.ijpe.2021.108384

Zhao, C., & Song, J. (2023). Coordination of dual-channel supply chain considering differential pricing and loss-aversion based on quality control. *Journal of Industrial and Management Optimization*, *19*(4), 2507-2527. https://doi.org/10.3934/jimo.2022053

Zhao, J., Wei, J., & Li, Y. (2014). Pricing decisions for substitutable products in a two-echelon supply chain with firms' different channel powers. *International Journal of Production Economics*, *153*, 243-252. https://doi.org/10.1016/j.ijpe.2014.03.005