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CHANNEL STRUCTURES OF THIRD-PARTY PLATFORMS

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Abstract. The growing prominence of third-party (3P) platforms in the online retail sector has made the selection of an appropriate channel structure strategy a critical concern for manufacturers, 3P platforms, and retailers operating within this environment. We construct a Stackelberg game model with the manufacturer as the leader, evaluating four channel structures: (A) reselling and retailer agency selling, (B) agency selling and retailer agency selling, (C) reselling and agency selling, and (D) reselling, agency selling, and retailer agency selling. The supply chain can adopt two pricing strategies: uniform pricing (UP) and differential pricing (DP). Research indicates that expanding the number of channels may not always enhance profitability for suppliers and supply chain participants. Under strategy UP, the 3P platform opts for structure B, whereas the retailer favors structure C. Incorporating agency selling is advantageous for the manufacturer; however, structure A represents the least beneficial option for the supply chain. Under strategy DP, a substantial portion of the pareto optimal region is present. Intense competition and reduced agency fees lead both the supply chain as a whole and individual member to prefer structure A. The addition of a reselling or retailer agency channel boosts the manufacturer's profits, and benefits the 3P platform, while structure D emerges as the least favorable option for the retailer. Furthermore, under strategy DP, structure C is rendered obsolete, signifying the retailer's essential role in the supply chain to the advantage of all involved parties. This study advances the scholarly understanding of sales models and platform economies by offering valuable insights into the decision-making processes of manufacturers, third-party (3P) platforms, and retailers regarding channel structure choices in a 3P platform environment.

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1. Introduction

In 2022, retail sales in China's online retail market stood at \$2.01 trillion[1]. The major 3P platforms (JD.com, Taobao, Tiktok and Pinduoduo) have combined sales of more than \$500 billion[2]. In 2022, the U.S. e-commerce

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[1] https://www.chinainternetwatch.com/30910/retail-sales/.

[2] https://www.sohu.com/a/658407153_289979.

market also achieved strong growth, with sales exceeding \$1 trillion[3]. Amazon platform sales were \$242.9 billion[4]. 3P platforms have become the primary online channel for consumer shopping [1]. Almost all products in China have retail channels on 3P platforms. They allow manufacturers to skip traditional intermediaries (retailers), engage directly with consumers, and share profits with 3P platforms based on percentage fees, known as agency selling [2]. This retail model is standard on Amazon and Taobao, for example. Manufacturers can also sell their products wholesale to 3P platforms that sell to consumers, referred to as reselling. The reselling model is now one of the significant retail models, with reselling business on JD accounting for more than 70% of total business[5]. Manufacturers can also wholesale their products to traditional large retailers (*e.g.*, Walmart and Suning) or smaller retailers conducting reseller business on 3P platforms, which is called retailer agency selling.

Many brands on JD (Examples include Dell, Sony and Samsung) sell through agency selling, reselling, and retailer agency selling. However, some brands don't do so. Apple, for example, does not open an agency selling on JD, and Haier does not open a reselling on Taobao. The number and structure of channels within the same 3P platform profoundly affect how manufacturers, 3P platforms, and retailers' benefit. Therefore, it is necessary to study the structure of retail channels in different situations.

Within the 3P platform, there are three potential retail channels: (i) Reselling channel. Manufacturers wholesale products to the 3P platform, which subsequently sells these products to consumers. (ii) Agency selling. Manufacturers sell products directly to consumers on the 3P platform, paying a commission to the platform. (iii) Retailer agency selling. Manufacturers wholesale products to retailers, who then sell these products directly to consumers on the 3P platform, also paying a commission to the platform.

Based on different combinations of three retail channels, this paper considers four channel structures: (i) Structure A. Opening a reselling channel and a retailer agency selling channel; (ii) Structure B. Opening an agency selling channel and a retailer agency selling channel; (iii) Structure C. Opening an agency selling channel and a reselling channel; (iv) Structure D. Opening an agency selling channel, a reselling channel, and a retailer agency selling channel. The degree of competition (degree of substitutability) within the same platform becomes more pronounced than the cross-platform competition, making it a key factor in determining channel structure. The impact of agency fees on agency selling and retailer agency selling is significant, making it another core factor.

This paper also considers the pricing strategy. In order to reduce channel conflict and maintain a strong brand, one of the supply chain's strategies is to adopt a uniform pricing strategy (UP), where prices are the same across all channels. In order to maximize profit, supply chain members can decide their own selling price to maximize profit, that is, differential pricing strategy (DP). Table 1 shows the pricing strategies of products with different structures in practice. It is worth noting that there are no examples of structure C, because manufacturers generally believe that increasing the number of channels (wholesale products to retailers on the 3P platform) always increases profits. However, the results refute this view. There are situations in which the manufacturer is more profitable in structure C than in other structures, so structure C should be within the scope of our discussion.

Vertical competition exists in strategy UP. Vertical competition refers to the game between the manufacturer and the other two players in wholesale price decision. The double marginalization problem arises from the intense vertical competition. there is not only vertical competition but also horizontal competition in strategy DP. Horizontal competition refers to the competition between the manufacturer and the other two players in the selling price decision. The inherent differences between the two strategies may lead to different equilibrium. That is, the pricing strategy affects how the supply chain chooses its channel structure. Therefore, the choice of channel structure for supply chain members under different pricing strategies is one of the important issues to be addressed in this paper.

[3] https://www.digitalcommerce360.com/article/us-ecommerce-sales/.

[4] https://ir.aboutamazon.com/news-release/news-release-details/2023/Amazon.com-Announces-Fourth-Quarter-Results/default.aspx.

[5] Xue yunkui. See the business model of Ali, JD, Amazon, Meituan, and Pinduoduo. https://www.mbachina.com/html/ckgsb/20220901/479581.html.2022-9-3.

TABLE 1. Pricing comparison of various products.

Structure	Product	Manufacturer's price	3P Platform's price	Retailer's price	Pricing strategy
A	The Mi Band 7	¥230[1]	None	¥200[2]	DP
	Huawei P60 Pro	¥6988[1]	None	¥6988[2]	UP
B	Apple iPhone 14	None	¥5399[3]	¥5399[4]	UP
	Apple Wired Headphone	None	¥129[3]	¥110[4]	DP
C			None		
D	Phone (Redmi Note 12)	¥2299[5]	¥2299[3]	¥2299[4]	UP
	SONY Earphone (WF-C500)	¥399[5]	¥419[3]	¥385[4]	DP

Notes. Source: Data collected from 3P platforms (JD.com, Tmall.com) in April 2023. (1)The manufacturer's store on Taobao; (2)The retailer's store on Taobao; (3)The 3P platform's store on JD; (4)The retailer's store on JD; (5)The manufacturer's store on JD.

By capturing two decision variables, the degree of competition and agency fees, this paper investigates the following questions under the constraints of the same platform:

(i) Does increasing the number of channels always increase the profits of manufacturers and 3P platforms? (ii) How should manufacturers, 3P platforms, and retailers choose their channel structure under different pricing strategies? (iii) What channel structure shifts can improve revenue for manufacturers, 3P platforms, and retailers, and under what circumstances? (iv) Under what circumstances are the choices of supply chain members consistent?

A Stackelberg game model with the manufacturer as the leader is developed to answer the above questions. The manufacturer in the model can own an agency selling and reselling; the retailer can own a retailer agency selling. This leads to four channel structures that can be selected. Two pricing strategies (Strategy UP and strategy DP) are considered. This paper first discusses how supply chain members can choose (optimize) the channel structure under strategy UP and then discusses how supply chain members can choose (optimize) the channel structure under strategy DP. The main findings of this paper are as follows.

Adding channels can potentially reduce profits for the manufacturer and 3P platform. In strategy UP, adding a retailer agency selling channel minimizes the manufacturer's earnings in high competition and low agency fee. This is because increasing the number of channels under high competition increases horizontal channel competition and leads to lower aggregate demand, and lower agency fees make the 3P platform less influential, and the manufacturer more favorable in structure C. Moving from structure A to structure D is a superior strategy for the manufacturer. In strategy DP, high competition leads the manufacturer to choose structure A. Increasing a reselling or retailer agency channel can increase profits. Shifting from structure B or C to structure D is the optimal strategy for the manufacturer. In strategy UP, the optimal channel structure for the 3P platform is structure C. The strategic preference is to remove the retailer from the supply chain. High competition and agency fees can make structure D the worst choice. In strategy DP, in most cases, the 3P platform chooses structure D. Moving from structure B or C to structure D is the optimal strategy for the 3P platform. Structure D is a mediocre choice for the retailer. Increasing the number of channels in most cases is detrimental to the retailer. In strategy UP, the optimal choice for the retailer is structure B. Low competition and agency fees allow it to benefit from the increase in the agency selling channel. In strategy DP, structure D is the worst choice, and the retailer's preference for horizontal channel competition depends on the level of competition and agency fees. Increasing the number of channels for the supply chain does not improve total profits in many cases.

The analysis shows that the pareto region exists in strategy DP. Increased competition or lower agency fees induce supply chain members to choose structure A. No supply chain member would choose structure C under strategy DP. The retailer would benefit both supply chain members and the supply chain as a whole.

The remainder of this study is organized as follows. We review the relevant literature in Section 2. Then the model is constructed in Section 3. The choice of channel structure for supply chain members under strategies UP and DP is discussed in Sections 4 and 5, respectively. Finally, conclusions are given in Section 6. All proofs are provided in the appendix.

2. Literature review

This paper builds on the contributions of 3P platform retail models, distribution channel design and supply chain pricing strategies. Next, we review here the studies most relevant to the work.

The rapid growth of e-tailing has made 3P platforms a significant selling channel for manufacturers and retailers. With this comes the exploration of retailing models on 3P platforms, where there are currently two main models of agency selling and reselling. Scholars have studied the advantages and disadvantages of these two models mainly in the early stages. For example, Hagiu and Wright [3] argue that the choice between agency selling or reselling depends mainly on whether the supplier or intermediary has more important information related to the best customization of each specific product marketing campaign. Abhishek *et al.* [2] find that 3P platforms tend to agency selling when sales in online channels negatively impact demand in the traditional channel, while 3P platforms prefer reselling when sales in the online channel materially stimulate demand in in the conventional channel. Ha *et al.* [4] examine the case of opening both agency selling and reselling. Yan *et al.* [5] examine when manufacturers could benefit from introducing an agency selling channel. Fu *et al.* [6], on the other hand, argue that a supplier distributing products through a physical retailer needs to be cautious about participating in the marketplace of e-tailers through reselling as a strategy. Hu *et al.* [7] investigate the interaction between supplier market entry strategies and retailer sales model choices. Wu *et al.* [8] examine the impact of manufacturer entry and agency models on online platform channel structures. Specifically, they analyzed the strategic sales model decisions of two competing online platforms in the context of manufacturer entry and two types of agency models. Gilbert *et al.* [9] explore the optimal sales format for suppliers within a dominant platform context. Another important issue in this area is how to choose a sales model considering different influencing factors, such as information sharing [10–12], order fulfillment costs [13], branded products [14, 15], competitive manufacturers [16, 17], carbon emission reduction [18], logistics services [19, 20], blockchain [21], and live-streaming [22].

This study also deals with distribution channel design. Distribution channel design has been one of the popular directions for researchers. The work of Ingene and Parry [23] summarize the early achievements in this area. Cai [24] investigates the impact of channel structure and channel coordination on suppliers, retailers, and the entire supply chain. Mantin *et al.* [25] analyze how supply chain members are affected by the introduction of online retailers into third-party marketplaces, and showed that the behavior has opposite effects on online retailers and manufacturers. Chen *et al.* [26] study the impact of manufacturers opening new retail channels on the supply chain and found that increasing the number of direct channels always benefits manufacturers.

Zhen *et al.* [27] study the attribution of 3P platform channels under different pricing strategies. Yenipazarli [28] centers on the strategic channel selection by brand manufacturers for product distribution, considering varying price points and quality tiers. Hao and Yang [29] investigate the decision-making process within supply chains during live streaming selling, focusing on the choice between two sales models: reselling and agency selling. Tang *et al.* [30] explore the impact of information sharing on suppliers' and 3P platforms' decisions regarding consignment sales *versus* reselling. Dai *et al.* [31] investigate the effects of unobservable promotional service distribution channel design. Mao *et al.* [32] examine the mechanisms and conditions under which retailers and manufacturers collaborate with third-party platforms. Additional literature examines how specific factors affect channel choices, such as sales tax [33], organizational structure [34], remanufacturers [35], and retention of physical channels [36].

In a Stackelberg game, the leader's decision-making process is predicated on predicting the follower's reaction function. Extensive literature indicates that such interactions complicate market dynamics and introduce strategic dimensions, thereby providing a unique perspective on inter-firm competition, as evidenced by refer-

TABLE 2. Differences between this paper and most related papers.

Literature	Decision-maker	3P platform	Differential pricing	Single market	Retailer agency selling	Problem
[2]	M, R	No	No	Yes	No	Agency selling or reselling.
[4]	M, R	No	No	Yes	No	Agency selling, reselling or both.
[7]	M, R	No	No	No	No	The traditional, consignment, or in-marketplace selling modes.
[17]	Two Ms, R	No	No	Yes	No	Agency selling or reselling.
[32]	M, R	Yes	No	No	No	Whether and how the manufacturer and the retailer collaborate with the 3P platform.
[27]	M, R	Yes	Yes	No	No	Who should introduce the 3P platform channel.
This paper	M, 3P, R	Yes	Yes	Yes	Yes	The optimal channel structure for the manufacturer, the 3P platform, and the retailer within the 3P platform.

Notes. M, 3P, R represent the manufacturer, the 3P platform, and the retailer, respectively.

ences [37–39]. Analyzing the Stackelberg game, particularly within the context of distribution channel design, offers profound insights into how firms develop optimal strategies through strategic interactions in competitive markets. Therefore, we employ this game theory in this article.

This paper is related to the literature on pricing strategies for multichannel supply chain. Considerable literature discusses differential pricing, uniform pricing. dynamic pricing, price matching, and price delegation [27]. Uniform pricing strategy is believed to reduce channel conflict and benefits the firm [40, 41], as well as to maintain strong brands by avoiding consumer perceptions of price unfairness that arise from price differentiation. On the other hand marketing and economics research has concluded that differential pricing strategy can bring additional profits to firms [42]. Many retailers practice differential pricing between channels and this number increases over time [43]. Some literatures examine manufacturers' pricing strategies in the supply chain [44] and retailers' pricing strategies in the supply chain [45]. Cai *et al.* [46] investigate the advantages and disadvantages of uniform and differentiated pricing strategies under different costs and demand. Xu *et al.* [47] study the pricing strategy of a two-stage supply chain consisting of a supplier and two retailers. In this case, the retailers can choose to operate separately from the online and offline channels and adopt a differential pricing strategy, or they can choose to integrate the channels and adopt a unified pricing strategy. Hao and Yang [29] examine the effect of three distinct pricing strategies–uniform high, uniform low, and differentiated – on the live streaming selling supply chain. Zhou *et al.* [48] developed two game-theoretic models with both exogenous and endogenous pricing strategies within a supply chain consisting of manufacturers and e-commerce platforms. These models aim to investigate the influence of shopping convenience and privacy concerns on decision-making processes. Most of the above literatures focus on the pricing strategy choice of the supply chain. Some literatures examine the application of game theory to stabilize market environments, thereby facilitating the development of enhanced pricing management strategies [49–51]. This paper studies the joint decision of pricing strategy and channel structure in a supply chain consisting of a manufacturer, a 3P platform, and a retailer. The similarities and differences between this paper and other related studies are presented in Table 2.

In fact, the share of independent retailers in 3P platforms is sizable, and the above literature does not consider the involvement of retailers in sales. This paper considers both channels of retailer agency selling (retailers sell products wholesale from manufacturers and sell them on 3P platforms through an agency selling model) on the

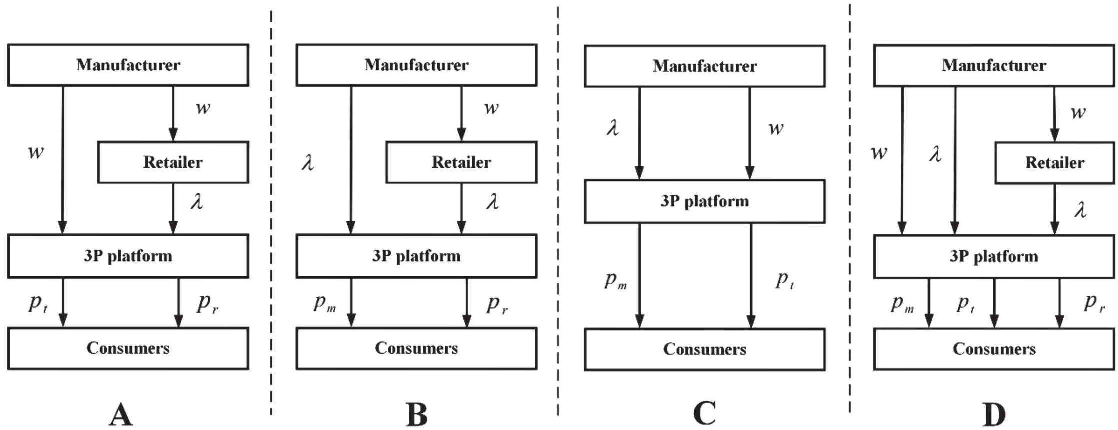

Figure 1. Four types of structures in the supply chain.

basis of agency selling and reselling. The complexity of the three-party interaction makes this study necessary. This paper explores the issue of designing the channel structure for manufacturer, 3P platform and retailer in the same 3P platform. This study adds to the literature in three ways. First, this paper explores the issue of channel structure design for manufacturers, 3P platforms and retailers on the same platform under different pricing strategies. This is not addressed in the previous literature. Second, this paper provides the decisions of different subjects on channel structure under different pricing strategies and obtain the selection thresholds between channel structures. Third, the results provide managerial insights into the channel structure design and pricing strategy selection of firms in the same 3P platform. For example, under strategy DP, a high degree of competition and low agency fees cause all supply chain members to choose structure A, *i.e.*, the 3P platform does not participate in direct retailing.

3. The model

Consider a supply chain consisting of a manufacturer (he), a third-party (3P) platform (she), and a retailer (it). The goal of members is to maximize their own profits. The manufacturer produces the product at a fixed marginal cost, normalized to zero for ease of exposition [27]. The manufacturer can sell the product directly through the 3P platform at a price p_m (agency selling). The 3P platform receives a percentage of his revenue in return. The 3P platform can buy the product from the manufacturer at wholesale price ω and sell it to the consumer through its platform at a price p_t (reselling). The retailer can likewise purchase products from the manufacturer at a wholesale price ω and sell them to consumers through the 3P platform at a price p_r (retailer agency selling). The 3P platform also receives a percentage of its revenue. In this paper, the 3P platform is assumed to charge the same proportion of revenue to manufacturers and retailers at λ. And the proportion is an exogenous variable known before the parties make their decisions. The decision variables are the degree of competition and agency fees.

In the supply chain, the manufacturer can profit by wholesaling products to the 3P platform and retailer or selling products directly on the 3P platform. The 3P platform can earn profits by collecting agency fees from the manufacturer and retailer and selling products now. The retailer can only make profits by selling products to consumers.

According to the above description, the supply chain can be divided into four channel structures, as shown in Figure 1. A particular utility function is used to obtain the demand function in different channel structures, which has been widely used in related studies [10, 18, 25]. The function is specified as follows:

$$U = \sum_{i=m,t,r} \left(\alpha_i d_i - \frac{b{d_i}^2}{2} - p_i d_i \right) - \theta d_m d_r - \theta d_m d_t - \theta d_r d_t. \tag{1}$$

In the formula, m, t and r represent the manufacturer, 3P platform, and retailer, respectively. d_i is the product demand of the channel. α_i is the basic demand of each channel. b represents the rate of change of marginal utility. $\theta(0 < \theta < 1)$ represents the substitutability between channels, which positively correlated with substitutability and negatively correlated with aggregate demand. For simplicity and ease of analysis, α_i and b are normalized to 1 regarding the assumptions of studies using the same model [2, 34].

The demand function for each channel is obtained when the utility function is maximized. In structure A, the manufacturer does not sell the product directly to the consumer, so $d_m = 0$. The profit formula for the three parties is as follows:

$$\pi_m^A = w(d_t + d_r), \quad \pi_t^A = (p_t - w)d_t + \lambda p_r d_r, \quad \pi_r^A = (1-\lambda)p_r d_r - w d_r. \tag{2}$$

In structure B, the 3P platform does not sell the product directly to the consumer, so there is $d_t = 0$. The profit formula for the three parties is as follows:

$$\pi_m^B = (1-\lambda)p_m d_m + w d_r, \quad \pi_t^B = \lambda(p_m d_m + p_r d_r), \quad \pi_r^B = (1-\lambda)p_r d_r - w d_r. \tag{3}$$

In structure C, there is no retailer participation in the supply chain, so $d_r = 0$. The profit equation for the other two parties is as follows:

$$\pi_m^C = (1-\lambda)p_m d_m + w d_t, \quad \pi_t^C = \lambda p_m d_m + (p_m - w)d_t. \tag{4}$$

In structure D, all three parties can sell the product directly and the profit equation is as follows:

$$\begin{aligned} \pi_m^D &= (1-\lambda)p_m d_m + w(d_t + d_r) \\ \pi_t^D &= \lambda(p_m d_m + p_r d_r) + (p_t - w)d_t \\ \pi_r^D &= (1-\lambda)p_r d_r - w d_r. \end{aligned} \tag{5}$$

In this paper, the manufacturer is the leader, the 3P platform is the second leader by its scale, and the retailer is the follower. Under strategy UP, the manufacturer first determines the wholesale price ω. The 3P platform determines the retail price p_t in structure A, and the retailer matches it. The retailer determines the retail price p_r in structure B, and the manufacturer corresponds it. The 3P platform determines the retail price p_t in structure C, and the manufacturer matches it. In structure D, the platform determines the retail price, and the manufacturer and retailer match the retail price of the platform.

Under strategy DP, the three players can set retail prices that maximize their profits. In structure A, the manufacturer first determines the wholesale price ω, then the 3P platform and the retailer simultaneously choose the selling prices p_t and p_r. In structure B(C), the manufacturer first determines the wholesale price ω and the retail price p_m, and then the retailer (3P platform) determines the selling price $p_r(p_t)$. In structure D, the manufacturer determines the wholesale price and the retail price p_m. Then the 3P platform and the retailer simultaneously determine the sales prices p_t and p_r. Table 3 summarizes all the parameters discussed in this article.

4. Uniform pricing strategy

When the supply chain adopts strategy UP, the optimal wholesale and retail prices under the four structures are solved by the inverse induction method, as shown in Table 2. The i in superscript represents the structure type, the u represents strategy UP, and the d represents strategy DP.The m, t, r in subscript means the supply

TABLE 3. Notations.

Parameters	Definitions
d_i	Demand of product, $i = m, t, r$
λ	Commission rate
α_i	Basic demand of channel, $i = m, t, r$
b	Rate of change in marginal utility
θ	Substitutability between channels
π_j^i	Profit of manufacturer, 3P platform or retailer under different strategies and structure channels, $i = A, B, C, D, j = m, t, r$
$m/t/r$	Manufacturer/3P platform/Retailer
Decision variables	
ω	Wholesale price of product
p_i	Sales price of product, $i = m, t, r$

chain member and mtr represents the supply chain as a whole. In this section, to ensure that the retailer is profitable, there is an assumption as follows:

$$0 < \lambda < \frac{1}{9}\left(\sqrt{13} - 2\right). \tag{6}$$

4.1. Demand

Utilizing equation (1), the utility maximization function is used to derive the demand function for each distribution channel. Within structure A, the manufacturer refrains from direct sales to consumers, setting $d_m = 0$. The demand functions for the remaining two entities are obtained as follows:

$$d_t = \frac{\alpha(1-\theta) - p_t + \theta p_r}{1-\theta^2}, \quad d_r = \frac{\alpha(1-\theta) - p_{\mathrm{r}} + \theta p_t}{1-\theta^2}. \tag{7}$$

In structure B, the 3P platform does not engage in direct sales to consumers; consequently, $d_t = 0$. The demand functions for the remaining parties can be derived as follows:

$$d_m = \frac{\alpha - \theta\alpha - p_m + \theta p_r}{1-\theta^2}, \quad d_r = \frac{\alpha - \theta\alpha - p_r + \theta p_m}{1-\theta^2}. \tag{8}$$

In structure C, the retailer does not participate in the supply chain, thus $d_r = 0$. The demand functions for the remaining two parties can be derived as follows:

$$d_m = \frac{\alpha - \theta\alpha - p_{rn} + \theta p_t}{1-\theta^2}, \quad d_t = \frac{\alpha - \theta\alpha - p_t + \theta p_m}{1-\theta^2}. \tag{9}$$

In structure D, all three parties have the capability to directly sell products. The respective demand functions can be obtained as follows:

$$\begin{aligned} d_m &= \frac{(1-\theta)\alpha - (1+\theta)p_m + \theta p_t + \theta p_r}{(1-\theta)(1+2\theta)} \\ d_t &= \frac{(1-\theta)\alpha - (1+\theta)p_t + \theta p_m + \theta p_r}{(1-\theta)(1+2\theta)} \\ d_r &= \frac{(1-\theta)\alpha - (1+\theta)p_{\mathrm{r}} + \theta p_m + \theta p_t}{(1-\theta)(1+2\theta)}. \end{aligned} \tag{10}$$

4.2. Equilibrium results

The reverse induction method is utilized to analyze Structure A and resolve the game. In the subsequent phase, given the wholesale price w, the 3P platform tackles problem

$$\max_{p_t}(p_t - w)d_t + \lambda p_r d_r. \tag{11}$$

By forecasting the optimal response function of the 3P platform, the manufacturer addresses the following problem:

$$\max_{w} w(d_t + d_v). \tag{12}$$

By solving for the equilibrium wholesale price w from the problem and substituting it into the best response function of the 3P platform, obtaining the following equilibrium decision:

$$w_m^{Aw} = \frac{\alpha(1+\lambda)}{2}, \quad p^{Ax} = \frac{3\alpha}{4}. \tag{13}$$

The retailer matches the price of the 3P platform, by substituting the equilibrium decisions back to the profit functions to obtain

$$\begin{aligned} \pi_m^{Au} &= \frac{\alpha^2(1+\lambda)}{4(1+\theta)}, \quad \pi_t^{Au} = \frac{\alpha^2(1+\lambda)}{16(1+\theta)} \\ \pi_r^{Au} &= \frac{\alpha^2(1-5\lambda)}{16(1+\theta)}, \quad \pi_{mtr}^{Au} = \frac{3\alpha^2}{8(1+\theta)}. \end{aligned} \tag{14}$$

Then considering structure B, the backward induction method is applied. Given the wholesale price w, the retailer solves problem

$$\max_{p_r}(1-\lambda)p_r d_r - w d_r. \tag{15}$$

By forecasting the optimal response function of the retailer, the manufacturer addresses the following problem:

$$\max_{w}(1-\lambda)p_r d_m + w d_r. \tag{16}$$

By solving for the equilibrium wholesale price w from the problem and substituting it into the best response function of the retailer, obtaining the following equilibrium decision:

$$w_m^{Bu} = \frac{\alpha(1-\lambda)}{3}, \quad p^{Bu} = \frac{2\alpha}{3}. \tag{17}$$

The manufacturer matches the price of the retailer, by substituting the equilibrium decisions back to the profit functions to obtain

$$\begin{aligned} \pi_m^{Bu} &= \frac{\alpha^2(1-\lambda)}{3(1+\theta)} \, \pi_t^{Bu} = \frac{4\alpha^2\lambda}{9(1+\theta)} \\ \pi_r^{Bu} &= \frac{\alpha^2(1-\lambda)}{9(1+\theta)} \, \pi_{mtr}^{Bu} = \frac{4\alpha^2}{9(1+\theta)}. \end{aligned} \tag{18}$$

The solution process in structure C mirrors that of structure A, resulting in the following equilibrium decisions:

$$w_m^{Cu} = \frac{\alpha(1+\lambda)^2}{3+\lambda}, \quad p^{Cu} = \frac{\alpha(2+\lambda)}{3+\lambda}. \tag{19}$$

The manufacturer matches the price of the 3P platform, by substituting the equilibrium decisions back to the profit functions to obtain

$$\begin{aligned} \pi_{\mathrm{co}}^{C_u} &= \frac{\alpha^2}{(1+\theta)(3+\lambda)} \pi_t^{Cu} = \frac{\alpha^2(1+\lambda)}{(1+\theta)(3+\lambda)^2} \\ \pi_{\mathrm{mtr}}^{\alpha} &= \frac{2\alpha^2(2+\lambda)}{(1+\theta)(3+\lambda)^2}. \end{aligned} \tag{20}$$

The solution process in structure D mirrors that of structure A, resulting in the following equilibrium decisions:

$$w_m^{Du} = \frac{2\alpha(1+2\lambda)^2}{5+7\lambda}, \quad p^{Du} = \frac{\alpha(7+11\lambda)}{2(5+7\lambda)}. \tag{21}$$

The manufacturer and the retailer match the price of the 3P platform, by substituting the equilibrium decisions back to the profit functions to obtain

$$\begin{aligned} \pi_m^{Du} &= \frac{9\alpha^2(1+\lambda)^2}{4(1+2\theta)(5+7\lambda)}, \quad \pi_t^{Du} = \frac{9\alpha^2(1+2\lambda)(1+\lambda)^2}{4(1+2\theta)(5+7\lambda)^2} \\ \pi_r^{Du} &= \frac{9\alpha^2(1+\lambda)\left(1-4\lambda-9\lambda^2\right)}{4(1+2\theta)(5+7\lambda)^2}, \quad \pi_{mtr}^{Du} = \frac{9\alpha^2\left(7+18\lambda+11\lambda^2\right)}{4(1+2\theta)(5+7\lambda)^2}. \end{aligned} \tag{22}$$

4.3. Insights on price, demand and profit

First, analyze how decision variables in different structures affect the prices and profits of manufacturers, 3P platforms, and retailers in the following lemma:

Lemma 1.

$$\begin{aligned} &\text{(i)} \quad \frac{\partial w_m^{iu}}{\partial \theta} = 0, \frac{\partial p^{iu}}{\partial \theta} = 0 \ (i = A, B, C, D). \\ &\text{(ii)} \quad \frac{\partial w_m^{Au}}{\partial \lambda} > 0, \frac{\partial w_m^{Bu}}{\partial \lambda} < 0, \frac{\partial w_m^{Cu}}{\partial \lambda} > 0, \frac{\partial w_m^{Du}}{\partial \lambda} > 0. \\ &\text{(iii)} \quad \frac{\partial p^{Au}}{\partial \lambda} = \frac{\partial p^{Bu}}{\partial \lambda} = 0, \frac{\partial p^{Cu}}{\partial \lambda} > 0, \frac{\partial p^{Du}}{\partial \lambda} > 0. \end{aligned}$$

Lemma 1(i) shows that wholegale and retail prices are not influenced by competition in all channel structures. The reason is that the degree of competition mainly affects demand, which is equal across channels under strategy UP, leading to a linear correlation between demand and $1/1+\theta$ (or $1/1+2\theta$). It only affects final profit, not wholesale and retail prices. Lemma 1(ii) shows a positive correlation between wholesale price and agency fee in structure A, C, and D and a negative correlation in structure B. The reason is that when the agency fee increases, the manufacturer increases profits in structures A, C, and D by raising the wholesale price. In structure B, the manufacturer's revenue from retailers can be shared alone, and consumer revenue needs to be shared with 3P platforms. The manufacturer's lower wholesale price can lead to increased retailer channel demand and more retailers' profits. Usually, retail prices need to be increased accordingly to cope with the loss of unit profit when agency fees are increased. However, Lemma 1(iii) shows that retail prices are not affected by agency fees in structures A and B. The reason is that in structure A, the retail price is set by a 3P platform that can directly increase the profit received from the retailer by increasing the agency fees and does not need to increase the profit received from the consumer by increasing the retail price. In structure B, the increase in the agency fee is accompanied by a decrease in the wholesale price, so there is no need to increase the retail price.

Another important finding is that high agency fees in structures C and D lead to double marginalization by increasing wholesale and retail prices. This is because there are agency selling and reselling in structures C and D. When both exist, the manufacturer is the leader in wholesale prices, and the 3P platform is the leader in agency fees. Two-leader system in the game intensifies the degree of competition and eventually leads to a double marginalization situation. In structures A and B, although high agency fees raise wholesale prices, they do not impact retail prices, so there is no double marginalization.

Lemma 2.

$$\text{(i)} \quad \frac{\partial \pi_j^{iu}}{\partial \theta} < 0 \ (i = A, B, C, D; j = m, t, r, mtr).$$
$$\text{(ii)} \quad \frac{\partial \pi_m^{Au}}{\partial \lambda} > 0, \frac{\partial \pi_t^{Au}}{\partial \lambda} > 0, \frac{\partial \pi_r^{Au}}{\partial \lambda} < 0, \frac{\partial \pi_{mtr}^{Au}}{\partial \lambda} = 0.$$
$$\text{(iii)} \quad \frac{\partial \pi_m^{Bu}}{\partial \lambda} < 0, \frac{\partial \pi_t^{Bu}}{\partial \lambda} > 0, \frac{\partial \pi_r^{Bu}}{\partial \lambda} < 0, \frac{\partial \pi_{mtr}^{Bu}}{\partial \lambda} = 0.$$
$$\text{(iv)} \quad \frac{\partial \pi_m^{Cu}}{\partial \lambda} < 0, \frac{\partial \pi_t^{Cu}}{\partial \lambda} < 0, \frac{\partial \pi_{mtr}^{Cu}}{\partial \lambda} < 0.$$
$$\text{(v)} \quad \frac{\partial \pi_m^{Du}}{\partial \lambda} > 0, \frac{\partial \pi_t^{Du}}{\partial \lambda} > 0, \frac{\partial \pi_r^{Du}}{\partial \lambda} < 0, \frac{\partial \pi_{mtr}^{Du}}{\partial \lambda} < 0.$$

Lemma 2(i) shows that profits under any structure are negatively related to the degree of competition. This echoes the findings of Lemma 1(i). The high level of competition leads to lower demand from all parties, resulting in lower profits. Lemma 2(ii) shows that in structure A, higher agency fees benefit the manufacturer and the 3P platform to the detriment of the retailer, with no impact on overall supply chain profits. This means the manufacturer does not prevent the 3P platform from setting higher agency fees because high agency fees raise the manufacturer's profits, when only the retailer is at a disadvantage. The conclusions of Lemmas 2(iii) and 2(ii) are similar. Only the manufacturer is affected by the agency fee becomes the opposite. In structure B, a high agency fee set by the 3P platform hurts both the manufacturer and the retailer. Still, because the 3P platform is not involved in product sales at this point, the structural disadvantage prevents the manufacturer from constraining the 3P platform from raising the agency fee. Lemma 2(iv) shows that in structure C, profits are all negatively related to the degree of competition. It suggests that the 3P platform should set the agency fee to zero, which would benefit itself, the manufacturer and the supply chain. The conclusion of Lemma 2(v) is similar to Lemma 2(ii) as well, with the difference that in structure D, the profitability of the supply chain is negatively influenced by agency fees. The retailer's position remains inferior due to the lack of pricing power. Still, the agency fees should be lower than in structure B, considering the benefits of the whole supply chain.

Lemma 3. $w_m^{Bu} < w_m^{Cu} < w_m^{Du} < w_m^{Au}, p^{Bu} < p^{Cu} < p^{Du} < p^{Au}$.

Lemma 3 shows that the wholesale and retail prices are in the same order of magnitude, with the largest in structure A and the smallest in structure B. The reason is that the manufacturer has no direct retail channel in structure A, and profits come entirely from 3P platforms and retailers. Hence, it tries to maximize profits by raising wholesale prices, and 3P platforms set high retail prices to cope with high wholesale prices. In structure B, the retail price is determined by the retailer and the supply chain is mainly led by the manufacturer, which is less competitive than the dual leader structure in the other three structures. The conclusion also shows that structure A has the most severe double marginalization problem, while structure B has the most moderate one.

Lemma 4. *(i)* $d_m^D < d_m^C < d_m^B$. *(ii) if* $\lambda < \frac{1-4\theta}{1+8\theta}, d_t^A < d_t^D < d_t^C, d_r^A < d_r^D < d_r^B$; *if* $\frac{1-4\theta}{1+8\theta} < \lambda, d_t^D < d_t^A < d_t^C, d_r^D < d_r^A < d_r^B$. *(iii)* $\theta_1 = \frac{7-\lambda}{13+29\lambda}, \theta_2 = \frac{7+8\lambda+9\lambda^2}{13+20\lambda-9\lambda^2}$; *if* $0 < \theta < \theta_1, d^A < d^C < d^B < d^D$; *if* $\theta_1 < \theta < \theta_2, d^A < d^C < d^D < d^B$; *if* $\theta_2 < \theta < 1, d^A < d^D < d^C < d^B$.

Lemma 4(i) shows that the manufacturer's consumer demand is the largest in structure B and the smallest in structure D. This is due to the absolute dominance of the manufacturer in structure B, where low retail prices can lead to high profits and high demand. In structure D, all three parties have direct retail channels, and horizontal competition is more intense than in the other structures, resulting in lower demand.

Lemma 4(ii) shows that 3P platforms and retailers demand the same characteristics. Structure C (B) has the highest demand. Structure A has the lowest demand when the agency fee is below the threshold, and structure D has the lowest demand above the threshold. The above findings suggest that increasing the number of horizontal channels can sometimes increase demand. When agency fees are low, increasing the manufacturer's agency sales channel (Structure A to structure D) can increase the demand for 3P platforms and retailers. However, increasing the retailer resale channel (Structure C to structure D) or the manufacturer resale channel (Structure B to structure D) does not increase demand from 3P platforms or retailers.

The intuition is that increasing the number of channels tends to increase aggregate demand, but Lemma 4(iii) shows that this is not always the case. Adding agency selling (Structure A to structure D) and reselling at low levels of competition (Structure C to structure D, structure B to structure D) always raises aggregate demand. However, adding reselling at higher levels of competition decreases aggregate demand, implying that increasing the number of channels is not always beneficial for supply chain demand.

4.4. Manufacturer's decision under Strategy DP

The choice of a structure by the supply chain members depends mainly on the magnitude of profit. The analysis of the manufacturer's choice of the four structures under different levels of agency fees and competition yields the following proposition:

Proposition 1. *When* $\lambda < 1/7$, *if* $\theta < \theta_3, \pi_m^{Au} < \pi_m^{Bu} < \pi_m^{Cu} < \pi_m^{Du}$; *if* $\theta_3 < \theta < \theta_4, \pi_m^{Au} < \pi_m^{Bu} < \pi_m^{Du} < \pi_m^{Cu}$; *if* $\theta_4 < \theta < 1, \pi_m^{Au} < \pi_m^{Du} < \pi_m^{Bu} < \pi_m^{Cu}$. *When* $1/7 < \lambda < (\sqrt{13} - 2)/9$, *if* $\theta < \theta_3$, $\pi_m^{Bu} < \pi_m^{Au} < \pi_m^{Cu} < \pi_m^{Du}$; *if* $\theta_4 < \theta < 1$, $\pi_m^{Bu} < \pi_m^{Au} < \pi_m^{Du} < \pi_m^{Cu}$. $\theta_3 = \frac{7+35\lambda+45\lambda^2+9\lambda^3}{13-7\lambda-45\lambda^2-9\lambda^3}, \theta_4 = \frac{7+46\lambda+55\lambda^2}{13-38\lambda+83\lambda^2}$.

The four regions in Figure 2 represent each of the four cases in Proposition 1. The manufacturer's optimal choice is structure C, when the agency fee is low, and competition is high. Under high competition, increasing the number of channels increases horizontal channel competition. It leads to lower demand, and the lower agency fee makes the 3P platform less influential, so structure C becomes the optimal structure at this time. The manufacturer's optimal choice in the other cases is structure D because his profits benefit from the total product demand. Under low competition, aggregate demand benefits from the number of channels, so manufacturers prefer structure D with the highest number of channels. When agency fees are high, adding retailer agency sales (Structure C to structure D) enables manufacturers to gain a large portion of wholesale profits without loss, maximizing the benefit.

Structure B is the worst choice for the manufacturer when the agency fee is high ($\lambda > 1/7$). This is because the 3P platform does not participate in the game and only charges agency fees, from which the manufacturer cannot earn profits and to which it has to pay high agency fees. In the other cases, the manufacturer has the lowest yield in structure A. The reason is that the manufacturer does not participate in the game and only earns wholesale profits and loses retail profits. It means that the manufacturer always benefits from opening a retail channel, and it is not a wise choice to be only a "traditional supplier".

In region I of Figure 2, the manufacturer's profit in structure D is lower than in structure B. Therefore, increasing the manufacturer's resale channel (Structure B to structure D) is profit-damaging for the manufacturer in the case of high competition and low agency fees. Another finding is that as agency fees gradually increase, the profit order of manufacturers in structure B decreases until they rank last. The reason why this happens is apparent. In structure B, the 3P platform is not involved in gaming and direct retailing, and the manufacturer receives zero profit from her, so the negative impact of the agency fees increase is higher for the manufacturer than for the other three structures.

4.5. 3P platform's decision under Strategy DP

The intuitive perception is that adding new channels to a 3P platform can increase her profits because she can charge agency fees for the new channels. But in some cases, the opposite is true.

Lemma 5. $\pi_t^{Cu} > \max\{\pi_t^{Bu}, \pi_t^{Au}, \pi_t^{Du}\}$.

Lemma 5 shows that under strategy UP, the optimal choice of the 3P platform is not affected by the structure, which is always structure C. This indicates that it is more advantageous for the 3P platform to pull both parties

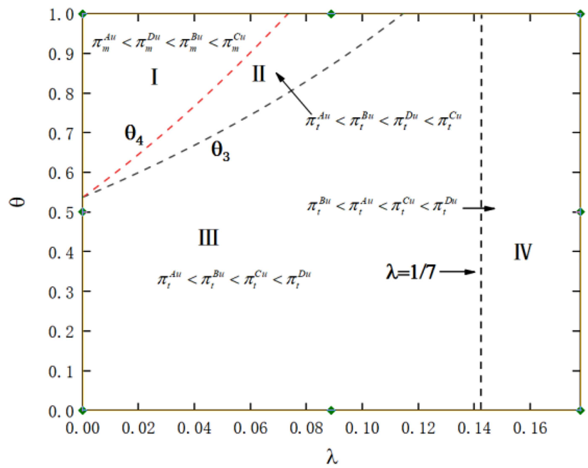

FIGURE 2. Profits ranking of the manufacturer's channel structures.

into the game than not participating in the game itself (Structure B) and not participating in direct retailing by the manufacturer (Structure A). Adding the channel (Structure D) can increase agency fees revenue and horizontal channel competition, causing the manufacturer to raise wholesale prices to capture more vertical channel benefits. The 3P platform then raise prices to mitigate steep channel competition, leading to severe double marginalization. Another possibility is that agency fees are capped at a lower level to make the retailer profitable. When agency fees continue to increase, the optimal choice of channel structure by the 3P platform may change, and we continue to analyze this issue in the subsequent differential pricing strategy.

Proposition 2. *When* $\lambda < 9/55$, *if* $0 < \theta < \theta_5, \pi_t^{Bu} < \pi_t^{Au} < \pi_t^{Du} < \pi_t^{Cu}$; *if* $\theta_5 < \theta < \theta_6, \pi_t^{Bu} < \pi_t^{Du} < \pi_t^{Au} < \pi_t^{Cu}$, *if* $\theta_6 < \theta < 1, \pi_t^{Du} < \pi_t^{Bu} < \pi_t^{Au} < \pi_t^{Cu}$. *When* $\frac{1}{7} < \lambda < \frac{1}{9}\left(\sqrt{13} - 2\right)$, *if* $0 < \theta < \theta_6, \pi_t^{Au} < \pi_t^{Bu} < \pi_t^{Du} < \pi_t^{Cu}$; *if* $\theta_6 < \theta < \theta_5, \pi_t^{Au} < \pi_t^{Du} < \pi_t^{Bu} < \pi_t^{Cu}$; *if* $\theta_5 < \theta < 1, \pi_t^{Du} < \pi_t^{Au} < \pi_t^{Bu} < \pi_t^{Cu}$.
$\theta_5 = \frac{11+38\lambda+23\lambda^2}{14+32\lambda+26\lambda^2}, \theta_6 = \frac{622\lambda^3+715\lambda^2+76\lambda-81}{81-476\lambda-1835\lambda^2-1406\lambda^3}$.

The regions in Figure 3 represent the profit ranking results in Proposition 2. When the agency fees is low, the worst choice for the 3P platform is structure B, which is consistent with intuitive judgment. The reason is the profit of 3P platform comes only from the agency fees, and the negative impact of lowering the agency fees is the greatest for the 3P platform. The results find that the profit performance of the 3P platform in structure D is worse under high competition and even worst when the agency fees is higher. This implies that adding agency selling (Structure A to structure D) or retailer agency selling (Structure B to structure D) is a poor choice for the 3P platform at this time.

4.6. Retailer's decision under Strategy DP

Continue to explore the retailer's choice of channel structure in different situations. The availability of pricing power and the degree of horizontal channel competition emerge as major influencing factors (Fig. 4).

Proposition 3. *If* $0 < \theta < \theta_7, \pi_r^{Au} < \pi_r^{Du} < \pi_r^{Bu}$; *if* $\theta_7 < \theta < 1, \pi_r^{Du} < \pi_r^{Au} < \pi_r^{Bu}$. $\theta_7 = \frac{11-53\lambda-167\lambda^2-79\lambda^3}{14-2\lambda-134\lambda^2-166\lambda^3}$.

For the retailer, structure B is the optimal choice. The reason is that the retailer has the pricing power over the price in structure B, and there is not much competitive pressure in the horizontal channel. With low agency fees and low levels of competition, structure D is more favorable to the retailer than structure A. This suggests that when the retailer does not have pricing power, pulling the manufacturer into horizontal channel competition may benefit them.

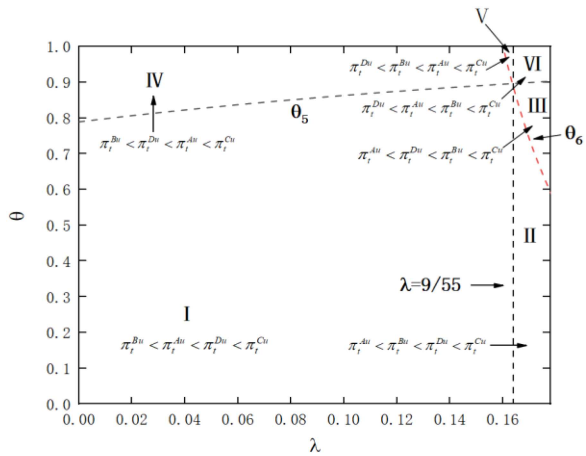

FIGURE 3. Profit ranking of the 3P platform's channel structure.

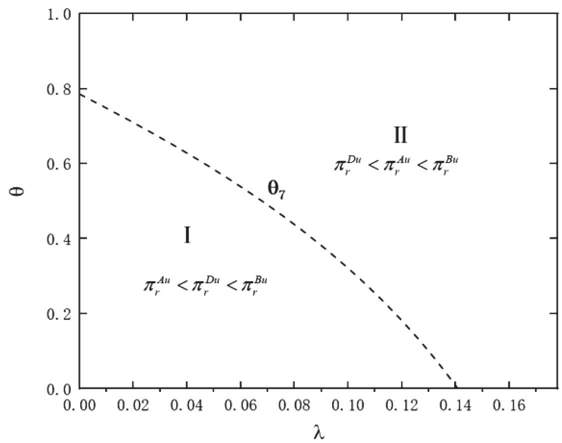

FIGURE 4. Profit ranking of the retailer's channel structure.

4.7. Supply chain's decision under Strategy DP

After analyzing the channel structure selection of supply chain members, this part selects the channel structure from the perspective of the supply chain as a whole.

Proposition 4. *If* $0 < \theta < \theta_8, \pi^{Au} < \pi^{Cu} < \pi^{Bu} < \pi^{Du}$*; if* $\theta_9 < \theta < 1, \pi^{Au} < \pi^{Du} < \pi^{Cu} < \pi^{Bu}$. $\theta_8 = \frac{167+338\lambda+107\lambda^2}{233+782\lambda+677\lambda^2}$, $\theta_9 = \frac{167+516\lambda+582\lambda^2+364\lambda^3+99\lambda^4}{233+804\lambda+762\lambda^2+28\lambda^3-99\lambda^4}$.

The regions in Figure 5 represent the findings in Proposition 4. Proposition 4 shows that the optimal choice for the supply chain at low levels of competition is structure D. This is consistent with the intuitive judgment that increasing the number of channels constantly improves the overall profitability of the supply chain. At high levels of competition, the supply chain should prefer structure B. It means that if the substitutability between channels is too high, the 3P platform should not be involved in the game, and it is in the overall interest of the supply chain to make her charge only agency fees.

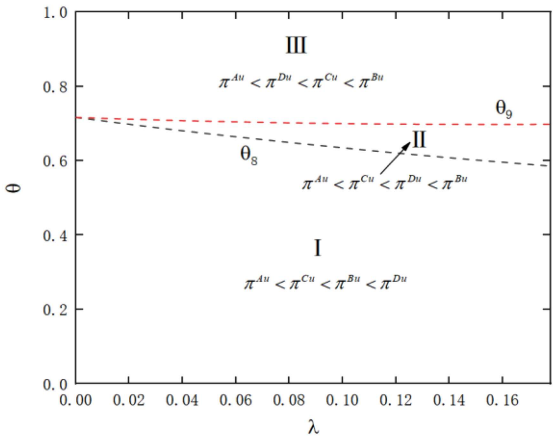

FIGURE 5. Profit ranking of the supply chain's channel structure.

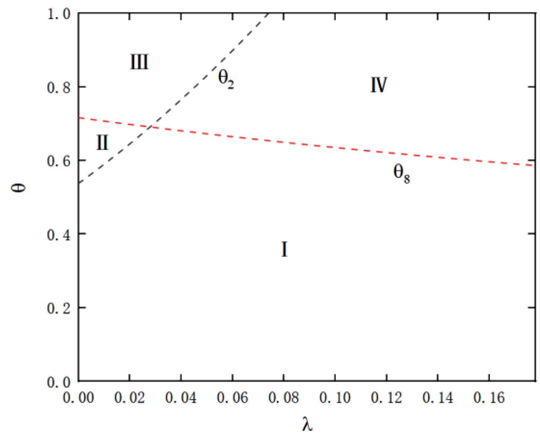

FIGURE 6. Choice of joint channel structure for manufacturer and supply chain.

Another finding is that agency fees have little effect on how supply chains choose channel structure. This suggests that the impact of increasing agency fees is broadly consistent across all structures, with none of the supply chain profit sensitivity to agency fees being prominent.

Structure A is the worst option for the supply chain in any case. Combined with the conclusion in Proposition 1, the manufacturer should participate in direct retailing, considering its profit or the overall profit of the supply chain. In Region III, structure D is even less profitable than structure C. The damage of high competition level to the overall gain of the supply chain is undeniable.

4.8. Choice of channel structure by supply chain members

Based on the previous section, it can be concluded that under strategy UP, the 3P platform must choose structure C and the retailer must choose structure B. Figure 6 and Table 2 summarize the optimal choice of the channel structure by the manufacturer and the supply chain.

According to Table 4, the results find that no region can make all members of the supply chain choose the same structure. No region can achieve Pareto optimality for all supply chain members. However, for the manufacturer and the 3P platforms only, choosing structure C in region II and region III can achieve Pareto

TABLE 4. Choice of joint channel structure for manufacturer and supply chain.

Region	Optimal choice (manufacturer)	Optimal choice (supply chain)
I	D	D
II	C	D
III	C	B
IV	D	B

optimality. This suggests that under high competition, the 3P platform should reduce agency fees to achieve the best for both parties, and the manufacturer should not cooperate with retailers. The retailer and the other two parties do not have regions to achieve Pareto optimum, but the supply chain can complete Pareto optimum in regions III and IV. The 3P platform and the supply chain do not have regions to achieve Pareto optimality. This explains to some extent that increasing the profit of the 3P platform will sacrifice the benefit of the supply chain as a whole.

In regions I and IV, the optimal choices of supply chain members are entirely different. This indicates a severe conflict in the supply chain in these regions. The manufacturer wants to increase the number of channels, and the other two parties prefer to work with the manufacturer alone.

Under a low competition, the change in agency fees cannot make the manufacturer change their optimal choice. Combined with the conclusion of Lemma 2(v), the 3P platform should set the high agency fees to increase her profit.

5. Differential pricing strategy

This section continues to analyze strategy DP. In structure A, the manufacturer first determines the wholesale price w, then the 3P platform and the retailer simultaneously determine the selling prices p_t and p_r. In structure B(C), the manufacturer determines the wholesale price w and the retail price p_m. Then the retailer (3P platform) determines the selling price $p_r(p_t)$. In structure D, the manufacturer determines the wholesale price w and the retail price p_m. Then the platform and the retailer simultaneously determine the retail prices p_t and p_r. The profit equations for each party in the four structures are the same as strategy UP, and the optimal solutions for the four structures are obtained by reverse induction as follows:

$$w^{Ad} = \frac{\alpha(1-\lambda)(4+\theta(2-\lambda-\theta\lambda))}{4(2+\theta-\lambda)} \tag{23}$$

$$p_t^{Ad} = \frac{\alpha\left(8(3-2\lambda)+2\theta\left(4+5\lambda-\lambda^2\right)-\theta^2\left(10+\lambda-5\lambda^2\right)-\theta^3\left(4+5\lambda+\lambda^2\right)\right)}{4(2+\theta-\lambda)(4-\theta^2(1+\lambda))}$$

$$p_r^{Ad} = \frac{\alpha\left(8(3-\lambda)+2\theta(4-\lambda)-\theta^2\left(10+\lambda-\lambda^2\right)-\theta^3\left(4+\lambda-\lambda^2\right)\right)}{4(2+\theta-\lambda)(4-\theta^2(1+\lambda))}$$

$$w^{Bd} = \frac{\alpha(1-\lambda)}{2}, \quad p_m^{Bd} = \frac{\alpha}{2}, \quad p_r^{Bd} = \frac{\alpha(3-\theta)}{4} \tag{24}$$

$$w^{Cd} = \frac{\alpha(1-\theta\lambda)}{2}, \quad p_m^{Cd} = \frac{\alpha}{2}, \quad p_t^{Cd} = \frac{\alpha(3-\theta)}{4} \tag{25}$$

$$w^{Dd} = \frac{\alpha(1-\lambda)\left(4+\theta(10-3\lambda)+\theta^2(6-5\theta)\right)}{4(1+\theta)(2+\theta(3-\lambda)-\lambda)} \tag{26}$$

$$p_m^{Dd} = \frac{\alpha}{2}$$

$$p_t^{Dd} = \frac{\alpha\big(24 - 16\lambda + 2\theta\big(36 - 15\lambda - \lambda^2\big) + 3\theta^2\big(18 - 5\lambda + \lambda^2\big) + 3\theta^3\lambda(3-\lambda)\big)}{4(4 + 8\theta + \theta^2(3-\lambda))(2 + \theta(3-\lambda) - \lambda)}$$

$$p_r^{Dd} = \frac{\alpha\big(24 - 8\lambda + \theta(72 - 26\lambda) + \theta^2\big(54 - 27\lambda + \lambda^2\big) + 3\theta^3\lambda(3-\lambda)\big)}{4(4 + 8\theta + \theta^2(3-\lambda))(2 + \theta(3-\lambda) - \lambda)}.$$

5.1. Insights on price, demand and profit

Like strategy UP, analyzing price, demand and profit for the Strategy DP's channel structure helps improve management insights. To reduce length, only conclusions that are counterintuitive or cannot be informed by intuition are summarized, without elaborating on consistent findings. In addition, in actual operation, 3P platforms are not too high for agency fees ($\lambda < 0.5$), and the subsequent analysis builds on a reasonable level of agency fees.

Lemma 6. *(i) For structure A,* $\frac{\partial w_m^{Ad}}{\partial \theta} < 0, \frac{\partial w_m^{Ad}}{\partial \lambda} < 0, \frac{\partial p_r^{Ad}}{\partial \lambda} < 0$. *(ii) For structure B,* $\frac{\partial w_m^{Bd}}{\partial \theta} = 0, \frac{\partial w_m^{Bd}}{\partial \lambda} < 0, \frac{\partial p_m^{Bd}}{\partial \theta} = 0, \frac{\partial p_m^{Bd}}{\partial \lambda} = 0, \frac{\partial p_r^{Bd}}{\partial \lambda} = 0$. *(iii) For structure C,* $\frac{\partial w_m^{Cd}}{\partial \theta} < 0, \frac{\partial w_m^{Cd}}{\partial \lambda} < 0, \frac{\partial p_m^{Cd}}{\partial \theta} = 0, \frac{\partial p_m^{Cd}}{\partial \lambda} = 0, \frac{\partial p_t^{Cd}}{\partial \lambda} = 0$. *(iv) For structure D,* $\frac{\partial w_m^{Dd}}{\partial \lambda} < 0, \frac{\partial p_m^{Dd}}{\partial \theta} = \frac{\partial p_m^{Dd}}{\partial \lambda} = 0, \frac{\partial p_t^{Dd}}{\partial \lambda} < 0, \frac{\partial p_r^{Dd}}{\partial \lambda} > 0$.

Lemma 6(i) shows that wholesale price and the level of competition are negatively related in Structure A. The reason is that the high level of competition increases horizontal channel competition between the 3P platform and retailer, resulting in lower retail price for both parties and wholesale price for the manufacturer to drive up demand. Another finding is that the manufacturer's wholesale and the retailer's price is negatively related to agency fees. This suggests that retailers respond to agency fees not by raising retail prices to increase unit profits but by lowering the cost to increase demand. The wholesaler responds to the retailer's behavior by reducing the wholesale price.

The similar findings of Lemmas 6(ii) and 6(iii) are related to the similarity of their channel structures. The only difference is that the wholesale price in structure B is independent of the degree of competition, while structure C is negatively correlated.

Lemma 6(iv) shows that wholesale price is negatively related to 3P platform and agency fees, manufacturer's retail price is unrelated to both, and retailer's retail price is positively related to agency fees. The above scenario indicates that with high agency fees, the manufacturer and 3P platform are willing to lower their wholesale or retail price to increase their benefits. In contrast, retailers behave oppositely.

Lemma 7. *(i) For structure A,* $\frac{\partial d_t^{Ad}}{\partial \lambda} > 0$. *(ii) For structure B,* $\frac{\partial d_m^{Bd}}{\partial \lambda} = \frac{\partial d_r^{Bd}}{\partial \lambda} = \frac{\partial d_{mtr}^{Bd}}{\partial \lambda} = 0$. *For structure C,* $\frac{\partial d_m^{Bd}}{\partial \lambda} = \frac{\partial d_t^{Bd}}{\partial \lambda} = \frac{\partial d_{mtr}^{Bd}}{\partial \lambda} = 0$. *(iii) For structure D,* $\frac{\partial d_m^{Dd}}{\partial \lambda} > 0, \frac{\partial d_t^{Dd}}{\partial \lambda} > 0$.

Lemma 7(i) shows that increasing agency fees in structure A can increase demand from 3P platforms. The reason is that retailers raise retail prices to offset the impact of high agency fees, which shifts direction to the 3P platform. Lemma 7(ii) illustrates that in structures B and C, the demand of supply chain members and the overall market are not affected by agency fees. This suggests that 3P platforms can still benefit from higher agency fees in structures B and C, even if they need the product to secure a market share. Lemma 7(iii) shows that high agency fees in structure D raise demand from the manufacturer and the 3P platform. It is mainly because the retailer's price increases with higher agency fees, leading to a shift in direction for the other two parties.

Lemma 8. *(i) For structure A,* $\frac{\partial \pi_m^{Ad}}{\partial \theta} > 0, \frac{\partial \pi_m^{Ad}}{\partial \lambda} < 0, \frac{\partial \pi_{mtr}^{Ad}}{\partial \theta} > 0 (\lambda < 0.99)$. *(ii) For structure B,* $\frac{\partial \pi_{mtr}^{Bd}}{\partial \lambda} = 0$*; For structure C,* $\frac{\partial \pi_{mtr}^{Cd}}{\partial \lambda} = 0$.

Lemma 8(i) shows that in structure A, the manufacturer's profit is positively related to the degree of competition, negatively associated with the agency fees, and the total supply chain profit is positively related to the degree of competition. The above findings are inconsistent with intuition, probably because the manufacturer

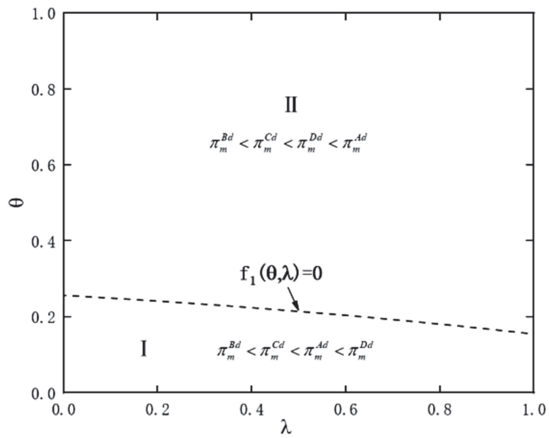

FIGURE 7. Profit ranking of manufacturers' channel structure.

does not participate in the game in structure A. A high degree of competition enables the other two parties to lower price and increase demand, expanding the manufacturer's wholesale and total supply chain gains. Raising agency fees moves the situation in the opposite direction, resulting in a loss of interest for manufacturers.

Lemma 8(ii) shows that in structures B and C, total profit is not affected by agency fees, which is consistent with the finding of constant total demand in Lemma 7(ii). It implies that structures B and C can better reduce the harmful effects of high agency fees.

Lemma 9. *(i)* $w_m^{Bd} < w_m^{Dd} < w_m^{Ad} < w_m^{Cd}$. *(ii)* $p_m^{Bd} = p_m^{Cd} = p_m^{Dd} = \frac{\alpha}{2}$. *(iii)* $p_t^{Dd} < \min\{p_t^{Ad}, p_t^{Cd}\}$. *(iv)* $\max\{p_r^{Bd}, p_r^{Dd}\} < p_r^{Ad}$. *(v)* $d_{mtr}^{Ad} < d_{mtr}^{Cd} = d_{mtr}^{Bd} < d_{mtr}^{Dd}$.

Lemma 9(i) shows that structure B has the lowest wholesale price while structure C has the highest. It indicates that adding (removing) the reselling channel raises (lowers) the wholesale price, drawing (adding) the agency selling channel extends (decreases) the wholesale price, and adding (reducing) the retailer agency selling falls (raises) the wholesale price.

Lemma 9(ii) shows that when the manufacturer is involved in direct retailing, his retail price remains constant. The manufacturer's retail price is more stable under strategy DP than strategy UP. According to Lemma 9(iii), the 3P platform in structure D has the lowest price. The 3P platform responds to horizontal channel competition by lowering the price because she also has a profit from agency fees. Lemma 9(iv) shows that the retailer in structure A has the highest price. Because in structure A, the retailer and the 3P platform have only horizontal channel competition, which is lower than in structures B and D. The findings of Lemma 9(v) are consistent with the intuition that total demand always increases when the number of channels increases. When horizontal channel competition weakens, aggregate demand at high retail prices is minimal.

5.2. Manufacturer's decision under Strategy DP

Similar to the previous section, the manufacturer's choice of the four structures is first analyzed under strategy DP with different agency fees and levels of competition.

Proposition 5. *If* $0 < \lambda < \left[f_1(\theta,\lambda)=0\right], \pi_m^{Bd} < \pi_m^{Cd} < \pi_m^{Ad} < \pi_m^{Dd}$, *if* $\left[f_1(\theta,\lambda)=0\right] < \lambda < 1, \pi_m^{Bd} < \pi_m^{Cd} < \pi_m^{Dd} < \pi_m^{Ad}$.

The two areas in Figure 7 represent the two scenarios in Proposition 5. The intuition is that adding channels leads to higher profits for the manufacturer because the manufacturer can earn profits from all channels (wholesale profits or sales profits). The low competition obtained from Figure 7 is consistent with this conclusion.

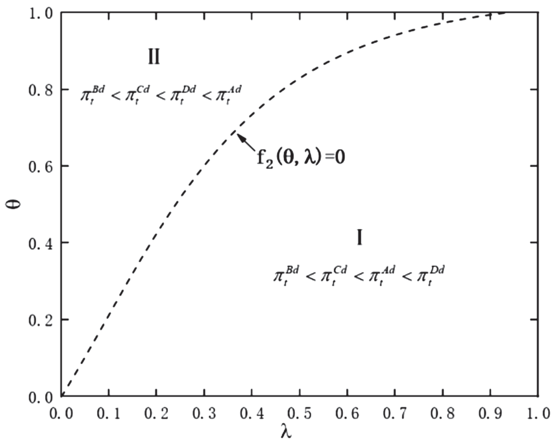

FIGURE 8. Profit ranking of 3P platform's channel structure.

Still, as the level of competition increases, structure A replaces structure D as optimal, breaking the intuitive judgment. It means that the manufacturer should not open the agency selling channel in the high competition. Not participating in the game is the best choice.

The manufacturer's profit in structure B is lower than in structure C. This finding suggests that it is wiser to work with the retailer than with the 3P platform. Another result is that agency fees have little to no impact on the manufacturer's decisions, which the manufacturer's supply chain leadership position may determine.

5.3. 3P platform's decision under Strategy DP

The 3P platform's choice of channel structure is similar to that of the manufacturer.

Proposition 6. *If* $0 < \lambda < [f_2(\theta, \lambda)=0], \pi_t^{Bd} < \pi_t^{Cd} < \pi_t^{Ad} < \pi_t^{Dd}$*; if* $[f_2(\theta, \lambda)=0] < \lambda < 1, \pi_t^{Bd} < \pi_t^{Cd} < \pi_t^{Dd} < \pi_t^{Ad}$.

Proposition 6 and Figure 8 enable us to obtain that the optimal choice for the 3P platform is structure D, given the level of competition and low agency fees, and structure A is the most profitable under other conditions. Similar to Proposition 5, increasing the number of channels (structure A to structure D) does not necessarily increase the profitability of the 3P platform, although the 3P platform can also gain from all channels.

The profit of structure C is lower than that of structure A, which indicates that it is more advantageous to compete with the retailer than with the manufacturer in the horizontal channel. Structure B has the lowest profits, meaning the 3P platform always benefits from participating in the game. In addition, the 3P platform has the same favorable channel structure transformation as the manufacturer in different regions.

5.4. Retailer's decision under Strategy DP

Continue discussing the retailer's choice of channel structure under strategy DP. Proposition 7 is represented in Figure 9.

Proposition 7. *If* $0 < \lambda < [f_3(\theta, \lambda)=0], \pi_r^{Dd} < \pi_r^{Ad} < \pi_r^{Bd}$*; if* $[f_3(\theta, \lambda)=0] < \lambda < 1, \pi_r^{Dd} < \pi_r^{Bd} < \pi_r^{Ad}$.

Proposition 7 shows that structure D becomes the worst choice for the retailer. The best choice for retailers is structure B, when competition is low and agency fees are high. In other cases, the best option is structure A. These findings suggest that increasing the number of horizontal channels reduces the retailer's profitability in the supply chain. When competition is high, the retailer is more willing to compete with the 3P platform in horizontal channels than the manufacturer. This is because in structure B, a high level of competition causes the manufacturer to focus on vertical channel competition, and the retailer will face severe double competition.

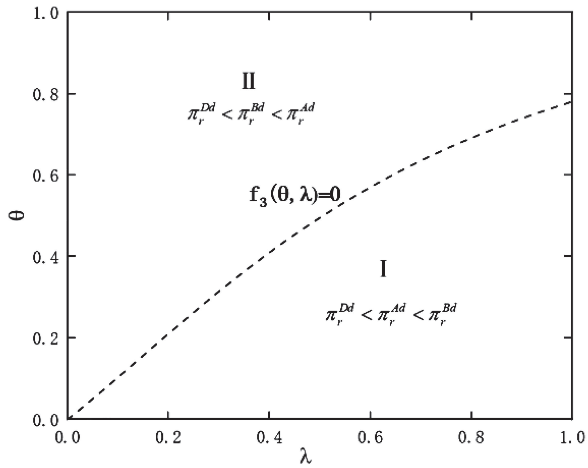

FIGURE 9. Profit ranking of retailer's channel structure.

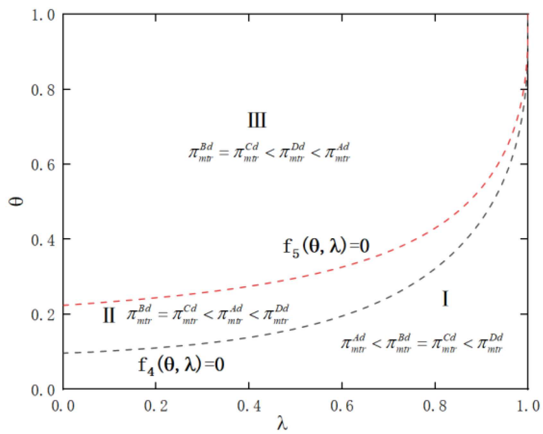

FIGURE 10. Profit ranking of supply chain's channel structure.

5.5. Supply chain's decision under Strategy DP

Similar to strategy UP, the selection of channel structure is made from the perspective of the entire supply chain. Figure 10 represents Proposition 8.

Proposition 8. *If* $0 < \lambda < [f_4(\theta,\lambda) = 0]$, $\pi_{mtr}^{Ad} < \pi_{mtr}^{Bd} = \pi_{mtr}^{Cd} < \pi_{mtr}^{Dd}$ *; if* $[f_4(\theta,\lambda) = 0] < \lambda < [f_5(\theta,\lambda) = 0]$ $\pi_{mtr}^{Bd} = \pi_{mtr}^{Cd} < \pi_{mtr}^{Ad} < \pi_{mtr}^{Dd}$*; if* $[f_5(\theta,\lambda) = 0] < \lambda < 1$, $\pi_{mtr}^{Bd} = \pi_{mtr}^{Cd} < \pi_{mtr}^{Dd} < \pi_{mtr}^{Ad}$.

It is observed from Proposition 8 and Figure 10 that as competition increases, the optimal choice of the supply chain changes from structure D to structure A and the worst choice changes from structure A to structure B (or structure C). Increasing the number of channels does not necessarily increase the overall profitability of the supply chain, which is consistent with the results under strategy UP. The most significant difference with strategy UP is that the profit of structure A is very much affected by the degree of competition, which shifts directly from the lowest yield under low competition to the highest profit under high competition. This indicates that structure A is subject to the least negative effect of the degree of competition. Region III is much larger than the other two regions, so the manufacturer can benefit the most from the supply chain by not participating

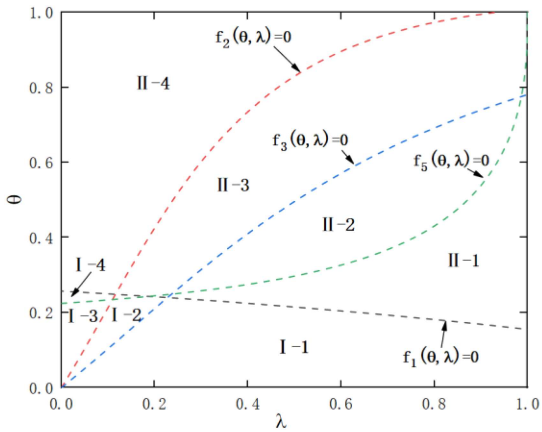

FIGURE 11. Optimal choice of channel structure by supply chain members and supply chain.

TABLE 5. Optimal choice of supply chain members and supply chain (see Fig. 11 for regions).

Region	Manufacturer	3P platform	Retailer	Supply chain
I-1	D	D	B	D
I-2	D	D	A	D
I-3	D	A	A	D
I-4	D	A	A	A
II-1	A	D	B	D
II-2	A	D	B	A
II-3	A	D	A	A
II-4	A	A	A	A

in direct retailing in most cases. A similar finding to strategy UP is that when the level of agency fees is low, agency fees have less impact on the profit ranking of the four structures and the primary influence remains the degree of competition.

5.6. Choice of channel structure by supply chain members

The optimal choices of channel structure for supply chain members and the entire supply chain are summarized, as shown in Figure 11 and Table 4. For ease of analysis, three insignificant regions have been filtered out.

Unlike strategy UP, the Strategy DP can effectively mitigate internal conflicts in the supply chain. From Figure 11 and Table 5, it can be seen that both supply chain members and the supply chain can achieve Pareto optimality in region II-4 (the most extensive area). It indicates that in most cases, everyone prefers that manufacturers do not participate in direct retailing, and there is no conflict among supply chain members. The premise is that the 3P platform sets a lower agency fee, so the supply chain can achieve Pareto optimization based on the assumption that the 3P platform sacrifices the agency fee profit.

There is no Pareto area for everyone when competition is low. But for the other three parties except for the retailer, regions I-1, I-2 and I-3 are Pareto regions. It is well understood because increasing channels enables the manufacturer to improve their wholesale profits and 3P platform to increase agency fee profits, thus increasing total supply chain profits.

Structure C does not maximize profit for any party, which is different from strategy UP. In strategy UP, structure C is always the optimal choice for the 3P platform, and the manufacturer also chooses structure C in some cases. This indicates that the retailer is essential in the supply chain under the Strategy DP, and pulling retailers into the game always increases profits for all parties. Retailers are also always willing to participate in direct retailing because they do not gain any profit if they do not participate. Thus, Proposition 9 can be obtained.

Proposition 9. *Under the Strategy DP, the supply chain does not choose structure C. Retail must participate in retailing.*

In practice, structure B is hardly chosen by the supply chain. The most critical decision for the supply chain is whether to select structure A or structure D. This suggests that the manufacturer either does not participate in direct retailing or opens all channels to obtain higher profits and reduce conflicts between parties.

6. Conclusions and managerial implications

The growing strength of 3P platforms makes the question of how to choose the channel structures within them quite significant. This paper investigates the preferences of manufacturers, 3P platforms, and retailers for channel structures within 3P platforms under uniform and differential pricing strategies and favorable shifts. For this purpose, this paper constructs a Stackelberg game model with the manufacturer as the leader and analyze four channel structures. By comparing the decisions and benefits of the different structures, guiding outcomes of the supply chain members on the channel structure are derived.

6.1. Conclusions

Supply chain members' choice of channel structure is profoundly influenced by two key parameters: the degree of competition and agency fees. For the manufacturer, expanding distribution channels can potentially diminish profits. The research conducted by Arya *et al.* [53] and Ha *et al.* [4] suggests that when the manufacturer establishes reselling channel under existing agency selling, it typically leads to mutually beneficial outcomes for the manufacturer. This is consistent with the conclusion. In strategy UP, adding retailer agency selling channel under high competition and low agency fees reduces the manufacturer's profits, but adding agency selling makes it profitable. In strategy DP, the optimal choice depends mainly on the degree of competition. Agency selling should not be established with high competition, while structure D is optimal with low competition. Adding reselling channel or retailer agency channel can increase profits. For the 3P platform, while it benefits from multiple channels, an increase in the number of channels does not guarantee higher profits and may prove to be a suboptimal strategy. Previous studies have shown that agency selling alleviate double marginalization, benefiting platforms [3,29,52]; however, this paper reveals a subtle deviation from these findings. In strategy UP, the best strategic preference is to keep the supply chain free of the retailer. Structure D with high competition and agency fees becomes the 3P platform's most unfavorable choice. In strategy DP, structure D is the best choice in most cases. Adding reselling or retailer agency selling can benefit. Increasing the number of channels for the retailer is terrible in most cases. Strategy UP chooses structure B. Low competition and low agency fees enable it to benefit from the increasing agency selling channel. In strategy DP, structure D is the worst choice. The retailer's preference to compete with horizontal channels depends on the level of competition and agency fees. For the supply chain, increasing the number of channels does not improve total profits every time. Consistent with Zhen and Xu's conclusion [27], an increase in agency fees exacerbates double marginalization. Intense channel competition reduces channel demand, diminishing the benefits of expanding channels.

The analysis shows that there is no pareto area in strategy UP, but a significant portion of the Pareto area exists in strategy DP. As competition increases and agency fees decrease, supply chain members hope that the manufacturer does not open agency selling channel.

6.2. Managerial implications

The research has management implications for the 3P platform, the manufacturer and the retailer engaged in platform retailing. First, the optimal channel structure of under different pricing strategies is provided. The degree of competition and agency fee are important factors influencing the choice. Under strategy UP, the manufacturer can open reselling channel to maximize profits. This conclusion is supported by practical evidence. On the JD platform, manufacturers commonly establish reselling channels for brands that implement the strategy UP. Examples include the appliance company Haier, the mobile phone manufacturer Xiaomi, and the computer manufacturer Lenovo. The best option for both the 3P platform and the retailer is to work with the manufacturer alone. Under strategy DP, the revenue maximization channel structure is greatly affected by the degree of competition. Under high competition, when the manufacturer gives up the agency selling, the profit of the three are maximized.

This indicates that for product categories characterized by high competition and the potential for strategy DP, manufacturers should avoid initiating agency selling channels. Notable examples include personal care products and sporting goods, where brands such as Procter & Gamble in personal care and Spalding in sporting goods have exclusively established reselling channels on platforms like JD.com. These instances provide anecdotal support for the findings. Second, this paper gets the shift in the structure of the channels through which members of the supply chain can achieve revenue growth. For example, under strategy UP, with the reduction of agency fees, it is better for the manufacturer to cooperate with the retailer alone than to cooperate with the 3P platform alone or give up agency selling. This indicates that 3P platforms reducing agency fees may not incentivize manufacturers to enhance their cooperation. Instead, it may promote collaboration between manufacturers and retailers. Third, this paper gets to know in what case the supply chain member's choice is consistent. Under strategy UP, horizontal competition between the 3P platform and the retailer makes the design of channel structure of supply chain inconsistent. Under strategy DP, the differential price alleviates the conflicts within the supply chain. In most cases, the manufacturer's abandonment of agency selling can make the supply chain members' choice consistent. Another finding is that structure C should not be in the consideration of any party under strategy DP. A retailer in the supply chain can benefit all parties. This discovery aligns with industry practices; on 3P platforms, most products are sold through retailer agency selling channels, resulting in price variations compared to other channels.

Some limitations of this paper allow for a clear direction for future research. First, the model assumes that the manufacturer is the leader. However, the 3P platform may be the leader in practice due to its strong position, such as JD.com. The resulting decision structure may change some conclusions. Secondly, it is assumed that the agency fees of the 3P platform is fixed. However, the platform may apply different agency fees to the manufacturer or retailer who opens other selling channels. This can cause the results to vary. A potential solution is to consider the factor of differentiated agency fees in the model. Third, since the 3P platform becomes a retailer in the resale channel, she may put more effort into marketing, logistics, on the reselling side compared to other channels, thus causing demand variation. Future research plans aim to address this issue by distinguishing the states of the 3P platform. Finally, considering the objectives of sustainable supply chain management within the context of the supply chain represents a future research direction.

Appendix A.

A.1. Proof of optimal solution (UP strategy)

A.1.1. Structure A

In structure A, the manufacturer does not sell the product directly to the consumer, so $d_m = 0$. The profit formula for the three parties is as follows: $\pi_m^A = w(d_t + d_r)$, $\pi_t^A = (p_t - w)d_t + \lambda p_r d_r, \pi_r^A = (1-\lambda)p_r d_r - wd_r$.

Since $\frac{\partial^2 \pi_t^A}{\partial {p_t}^2} = -\frac{2(1+\lambda)}{1+\theta} < 0, \pi_t^A$ is concave in p_t. Let $\frac{\partial \pi_t^A}{\partial p_t} = 0$, we have $p_t = \frac{w+\alpha+\alpha\lambda}{2+2\lambda}$, substitute it into $\pi_m^A = w(d_t + d_r)$. Since $\frac{\partial^2 \pi_m^A}{\partial w^2} = -\frac{2}{(1+\theta)(1+\lambda)} < 0, \pi_m^A$ is concave in w. Let $\frac{\partial \pi_m^A}{\partial w} = 0$, we have $w = \frac{\alpha(1+\lambda)}{2}$, substitute it into $p_t = \frac{w+\alpha+\alpha\lambda}{2+2\lambda}$ to get $p_t = \frac{3\alpha}{4} = p_r$.

A.1.2. Structure B

In structure B, the third-party platform does not sell the product directly to the consumer, so there is $d_t = 0$. The profit formula for the three parties is as follows: $\pi_m^B = (1-\lambda)p_m d_m + wd_r, \pi_t^B = \lambda(p_m d_m + p_r d_r), \pi_r^B = (1-\lambda)p_r d_r - wd_r$.

Since $\frac{\partial^2 \pi_r^B}{\partial {p_r}^2} = -\frac{2(1-\lambda)}{1+\theta} < 0, \pi_r^B$ is concave in p_r. Let $\frac{\partial \pi_r^B}{\partial p_r} = 0$, we have $p_r = \frac{1}{2}\left(\alpha + \frac{w}{1-\lambda}\right)$ substitute it into $\pi_m^B = (1-\lambda)p_m d_m + wd_r$. Since $\frac{\partial^2 \pi_m^B}{\partial w^2} = -\frac{3}{2(1+\theta)(1-\lambda)} < 0, \pi_m^B$ is concave in w. Let $\frac{\partial \pi_m^B}{\partial w} = 0$, we have $w = \frac{\alpha(1-\lambda)}{3}$, substitute it into $p_r = \frac{1}{2}\left(\alpha + \frac{w}{1-\lambda}\right)$ to get $p_r = \frac{2\alpha}{3} = p_m$.

A.1.3. Structure C

In structure C, there is no retailer participation in the supply chain, so $d_r = 0$. The profit equation for the other two parties is as follows: $\pi_m^C = (1-\lambda)p_m d_m + wd_t$, $\pi_t^C = \lambda p_m d_m + (p_m - w)d_t$.

Since $\frac{\partial^2 \pi_t^C}{\partial {p_t}^2} = -\frac{2(1+\lambda)}{1+\theta} < 0, \pi_t^C$ is concave in p_t. Let $\frac{\partial \pi_t^C}{\partial p_t} = 0$, we have $p_t = \frac{w+\alpha+\alpha\lambda}{2(1+\lambda)}$, substitute it into $\pi_m^C = (1-\lambda)p_m d_m + wd_t$. Since $\frac{\partial^2 \pi_m^C}{\partial w^2} = -\frac{3+\lambda}{2(1+\theta)(1+\lambda)^2} < 0, \pi_m^C$ is concave in w. Let $\frac{\partial \pi_m^C}{\partial w} = 0$, we have $w = \frac{\alpha(1+\lambda)^2}{3+\lambda}$, substitute it into $p_t = \frac{w+\alpha+\alpha\lambda}{2(1+\lambda)}$ to get $p_t = \frac{\alpha(2+\lambda)}{3+\lambda} = p_m$.

A.1.4. Structure D

In structure D, all three parties can sell the product directly and the profit equation is as follows: $\pi_m^D = (1-\lambda)p_m d_m + w(d_t + d_r), \pi_t^D = \lambda(p_m d_m + p_r d_r) + (p_t - w)d_t$, $\pi_r^D = (1-\lambda)p_r d_r - wd_r$.

Since $\frac{\partial^2 \pi_t^D}{\partial {p_t}^2} = -\frac{2(1+2\lambda)}{1+2\theta} < 0, \pi_t^D$ is concave in p_t. Let $\frac{\partial \pi_t^D}{\partial p_t} = 0$, we have $p_t = \frac{w+\alpha+2\alpha\lambda}{2(1+2\lambda)}$, substitute it into $\pi_m^D = (1-\lambda)p_m d_m + w(d_t + d_r)$. Since $\frac{\partial^2 \pi_m^D}{\partial w^2} = -\frac{5+7\lambda}{2(1+2\theta)(1+2\lambda)^2} < 0, \pi_m^D$ is concave in w. Let $\frac{\partial \pi_m^D}{\partial w} = 0$, we have $w = \frac{2\alpha(1+2\lambda)^2}{5+7\lambda}$, substitute it into $p_t = \frac{w+\alpha+2\alpha\lambda}{2(1+2\lambda)}$ to get $p_t = \frac{\alpha(7+11\lambda)}{2(5+7\lambda)} = p_m = p_r$.

A.2. Proof of optimal solution (DP strategy)

A.2.1. Structure A

In structure A, the manufacturer first determines the wholesale price w, then the thirdparty platform and the retailer simultaneously choose the selling prices p_t and p_r. The profit formula for the three parties is as follows: $\pi_m^A = w(d_t + d_r), \pi_t^A = (p_t - w)d_t + \lambda p_r d_r$, $\pi_r^A = (1-\lambda)p_r d_r - wd_r$.

Since $\frac{\partial^2 \pi_t^A}{\partial {p_t}^2} = -\frac{2}{1-\theta^2} < 0, \pi_t^A$ is concave in p_t. Since $\frac{\partial^2 \pi_r^A}{\partial {p_r}^2} = -\frac{2(1-\lambda)}{1-\theta^2} < 0, \pi_r^A$ is concave in p_r. Let $\frac{\partial \pi_t^A}{\partial p_t} = 0, \frac{\partial \pi_r^A}{\partial p_r} = 0$, we have $p_t = \frac{\alpha(1-\theta)(1-\lambda)(2+\theta+\theta\lambda)+w(2+\theta-2\lambda+\theta\lambda)}{(1-\lambda)(4-\theta^2(1+\lambda))}, p_t = \frac{\alpha(1-\lambda)\left(2-\theta-\theta^2\right)+w(2+\theta-2\lambda+\theta\lambda)}{(1-\lambda)(4-\theta^2(1+\lambda))}$, substitute them into $\pi_m^A = w(d_t + d_r)$. Since $\frac{\partial^2 \pi_m^A}{\partial w^2} = -\frac{4(2+\theta-\lambda)}{(1-\theta)(1-\lambda)(4-\theta^2(1+\lambda))} < 0, \pi_m^A$ is concave in w. Let $\frac{\partial \pi_m^A}{\partial w} = 0$, we have $w = \frac{\alpha(1-\lambda)(4+\theta(2-\lambda-\theta\lambda))}{4(2+\theta-\lambda)}$, substitute it into p_t, p_r to get

$$
\begin{aligned}
p_t &= \frac{\alpha\left(8(3-2\lambda) + 2\theta\left(4+5\lambda-\lambda^2\right) - \theta^2\left(10+\lambda-5\lambda^2\right) - \theta^3\left(4+5\lambda+\lambda^2\right)\right)}{4(2+\theta-\lambda)(4-\theta^2(1+\lambda))} \\
p_r &= \frac{\alpha\left(8(3-\lambda) + 2\theta(4-\lambda) - \theta^2\left(10+\lambda-\lambda^2\right) - \theta^3\left(4+\lambda-\lambda^2\right)\right)}{4(2+\theta-\lambda)(4-\theta^2(1+\lambda))}.
\end{aligned}
$$

The manufacturer's profit is $\pi_m^A = \frac{\alpha^2(1-\lambda)\left(4+2\theta-\theta\lambda-\theta^2\lambda\right)^2}{8(1-\theta)(2+\theta-\lambda)(4-\theta^2(1+\lambda))}$. The third-party platform's profit is

$$\alpha^2\left(\begin{array}{c}\theta^7\lambda^2\left(3+\lambda-3\lambda^2-\lambda^3\right)\\ +64\left(1+3\lambda-4\lambda^2+\lambda^3\right)\\ +32\theta\left(2+13\lambda-10\lambda^2+2\lambda^3\right)\\ +\theta^6\lambda\left(4+23\lambda+11\lambda^2-7\lambda^3+\lambda^4\right)\\ -4\theta^2\left(8-44\lambda+23\lambda^2-25\lambda^3+7\lambda^4\right)\\ -4\theta^3\left(16+22\lambda+34\lambda^2-34\lambda^3+9\lambda^4\right)\\ +\theta^4\left(-28-56\lambda-103\lambda^2+41\lambda^3-13\lambda^4+3\lambda^5\right)\\ +\theta^5\left(-4+4\lambda+17\lambda^2+15\lambda^3-9\lambda^4+5\lambda^5\right)\end{array}\right).$$

The retailer's profit is

$$\pi_m^A = \frac{\alpha^2(1-\theta)(1-\lambda)\left(8+\theta(8-6\lambda)-8\lambda-\theta^3\lambda(1+\lambda)+\theta^2\left(2+\lambda+\lambda^2\right)\right)^2}{16(1+\theta)(2+\theta-\lambda)^2\left(4-\theta^2(1+\lambda)\right)^2}.$$

A.2.2. Structure B

In structure B, the manufacturer first determines the wholesale price w and the retail price p_m, and then the retailer determines the selling price p_r. The profit formula for the three parties is as follows: $\pi_m^B = (1-\lambda)p_m d_m + w d_r, \pi_t^B = \lambda(p_m d_m + p_r d_r), \pi_r^B = (1-\lambda)p_r d_r - w d_r$.

A feasible solution requires that the sales price, demand, and profit per unit are positive for all parties involved. We first relax these constraints and find the optimal solution to the relaxed problem by reverse induction.

Since $\frac{\partial^2\pi_r^B}{\partial {p_r}^2} = -\frac{2(1-\lambda)}{1-\theta^2} < 0, \pi_r^B$ is concave in p_r. Let $\frac{\partial\pi_r^B}{\partial p_r} = 0$, we have $p_r = \frac{1}{2}\left(\alpha-\alpha\theta+\theta p_m+\frac{w}{1-\lambda}\right)$, substitute it into $\pi_m^B = (1-\lambda)p_m d_m + w d_r$. To ensure that the optimal w and p_m exist, we attempt to find the region in which the Hessian matrix is negative definite. The Hessian matrix can be written as follows:

$$H = \begin{pmatrix}\frac{\partial^2\pi_m^B}{\partial w^2} & \frac{\partial^2\pi_m^B}{\partial w\partial p_m}\\ \frac{\partial^2\pi_m^B}{\partial p_m\partial w} & \frac{\partial^2\pi_m^B}{\partial {p_m}^2}\end{pmatrix} = \begin{pmatrix}-\frac{1}{(1-\theta^2)(1-\lambda)} & \frac{\theta}{1-\theta^2}\\ \frac{\theta}{1-\theta^2} & -\frac{\left(2-\theta^2\right)(1-\lambda)}{1-\theta^2}\end{pmatrix}.$$

$M_1 = \frac{\partial^2\pi_m^B}{\partial w^2} = -\frac{1}{(1-\theta^2)(1-\lambda)} < 0$. $M_1 = |H| = \frac{2}{1-\theta^2} > 0$. Then the Hessian matrix is negative definite, then π_m^B is jointly concave in w and p_m. Let $\frac{\partial\pi_m^B}{\partial w} = 0$ and $\frac{\partial\pi_m^B}{\partial p_m} = 0$, we have $w = \frac{\alpha(1-\lambda)}{2}, p_m = \frac{\alpha}{2}$. We substitute them into $p_r = \frac{1}{2}\left(\alpha-\alpha\theta+\theta p_m+\frac{w}{1-\lambda}\right)$, we have $p_r = \frac{\alpha(3-\theta)}{4}$.

The manufacturer's profit is $\pi_m^B = \frac{\alpha^2(3+\theta)(1-\lambda)}{8(1+\theta)}$.

The third-party platform's profit is $\pi_t^B = \frac{\alpha^2\lambda(7+\theta)}{16(1+\theta)}$.

The retailer's profit is $\pi_r^B = \frac{\alpha^2(1-\theta)(1-\lambda)}{16(1+\theta)}$.

The profit of supply chain is $\pi_{mtr}^B = \frac{\alpha^2(7+\theta)}{16(1+\theta)}$.

A.2.3. Structure C

In structure C, the manufacturer first determines the wholesale price w and the retail price p_m, and then the third-party platform determines the selling price p_t. The profit formula for the two parties is as follows: $\pi_m^C = (1-\lambda)p_m d_m + w d_t, \pi_t^C = \lambda p_m d_m + (p_m - w)d_t$.

Same as structure B, we first relax these constraints and find the optimal solution to the relaxed problem by reverse induction.

Since $\frac{\partial^2\pi_t^C}{\partial {p_t}^2} = -\frac{2}{1-\theta^2} < 0, \pi_t^C$ is concave in p_t. Let $\frac{\partial\pi_t^C}{\partial p_t} = 0$, we have $p_t = \frac{1}{2}(w+\alpha-\alpha\theta+\theta p_m(1+\lambda))$, substitute it into $\pi_m^C = (1-\lambda)p_m d_m + w d_t$. To ensure that the optimal w and p_m exist, we attempt to find the region in which the Hessian matrix is negative definite. The Hessian matrix can be written as follows:

$$H=\begin{pmatrix}\frac{\partial^2\pi_m^C}{\partial w^2} & \frac{\partial^2\pi_m^C}{\partial w\partial p_m}\\ \frac{\partial^2\pi_m^C}{\partial p_m\partial w} & \frac{\partial^2\pi_m^C}{\partial {p_m}^2}\end{pmatrix}=\begin{pmatrix}-\frac{1}{1-\theta^2} & \frac{\theta(1-\lambda)}{1-\theta^2}\\ \frac{\theta(1-\lambda)}{1-\theta^2} & -\frac{(1-\lambda)\left(2-\theta^2-\theta^2\lambda\right)}{1-\theta^2}\end{pmatrix}.$$

$M_1=\frac{\partial^2\pi_m^C}{\partial w^2}=-\frac{1}{1-\theta^2}<0$. $M_1=|H|=2-2\theta^2>0$. Then the Hessian matrix is negative definite, then π_m^C is jointly concave in w and p_m. Let $\frac{\partial\pi_m^C}{\partial w}=0$ and $\frac{\partial\pi_m^C}{\partial p_m}=0$, we have $w=\frac{\alpha(1-\theta\lambda)}{2}, p_m=\frac{\alpha}{2}$. We substitute them into $p_t=\frac{1}{2}(w+\alpha-\alpha\theta+\theta p_m(1+\lambda))$, we have $p_t=\frac{\alpha(3-\theta)}{4}$.

The manufacturer's profit is $\pi_m^C=\frac{\alpha^2(3+\theta-2\lambda-2\theta\lambda)}{8(1+\theta)}$. The third-party platform's profit is $\pi_t^C=\frac{\alpha^2(1+4\lambda-\theta+4\theta\lambda)}{16(1+\theta)}$. The profit of supply chain is $\pi_{msr}^C=\frac{\alpha^2(7+\theta)}{16(1+\theta)}$.

A.2.4. Structure D

In structure D, the manufacturer determines the wholesale price w and the retail price p_m. Then the third-party platform and the retailer simultaneously determine the sales prices p_t and p_r. The profit formula for the three parties is as follows: $\pi_m^D=(1-\lambda)p_m d_m+w(d_t+d_r)$, $\pi_t^D=\lambda(p_m d_m+p_r d_r)+(p_t-w)d_t\pi_r^D=(1-\lambda)p_r d_r-wd_r$.

Since $\frac{\partial^2\pi_t^D}{\partial {p_t}^2}=-\frac{2(1+\theta)}{(1-\theta)(1+2\theta)}<0, \pi_t^D$ is concave in p_t. Since $\frac{\partial^2\pi_r^D}{\partial {p_r}^2}=-\frac{2(1+\theta)(1-\lambda)}{(1-\theta)(1+2\theta)}<0, \pi_r^D$ is concave in p_r. Let $\frac{\partial\pi_t^D}{\partial p_t}=0, \frac{\partial\pi_r^D}{\partial p_r}=0$, we have

$$p_t=\frac{\begin{pmatrix}-w(1+\theta)(\theta(-3+\lambda)+2(-1+\lambda))\\ -p_m\theta(2+3\theta)\left(-1+\lambda^2\right)\\ +\alpha(-1+\theta)(2+\theta(3+\lambda))\end{pmatrix}}{((-4-8\theta+\theta^2(-3+\theta))(-1+\lambda))}$$

$$p_r=\frac{-\left(\begin{pmatrix}-2p_m\theta-3p_{mn}\theta^2-2w-5\theta w-3\theta^2 w\\ -2\alpha-\alpha\theta+3\alpha\theta^2+2p_m\theta\lambda+2p_m\theta^2\lambda\\ +\theta w\lambda+\theta^2 w\lambda+2\alpha\lambda+\alpha\theta\lambda-3\alpha\theta^2\lambda\end{pmatrix}\right)}{((-1+\lambda)(-4-8\theta-3\theta^2+\theta^2\lambda))}$$

substitute them into $\pi_m^D=(1-\lambda)p_m d_m+w(d_t+d_r)$.

Same as structure B, we relax these constraints and find the optimal solution to the relaxed problem by reverse induction.

To ensure that the optimal w and p_m exist, we attempt to find the region in which the Hessian matrix is negative definite. The Hessian matrix can be written as follows:

$$\begin{pmatrix}-\frac{4(1+\theta)(-2-3\theta+\theta\lambda+\lambda)}{(1-\lambda)(1-\theta)(1+2\theta)(-4-8\theta-3\theta^2+\theta^2\lambda)} & \frac{4\theta(1+\theta)(-2-3\theta+\theta\lambda+\lambda)}{(1-\theta)(1+2\theta)(-4-8\theta-3\theta^2+\theta^2\lambda)}\\ \frac{4\theta(1+\theta)(-2-3\theta+\theta\lambda+\lambda)}{(1-\theta)(1+2\theta)(-4-8\theta-3\theta^2+\theta^2\lambda)} & \frac{2\begin{pmatrix}4-12\theta(-1+\lambda)-4\lambda\\ +\theta^2(7-10\lambda+3\lambda^2)\\ +\theta^3(-3-2\lambda+5\lambda^2)\end{pmatrix}}{(1-\theta)(1+2\theta)(-4-8\theta-3\theta^2+\theta^2\lambda)}\end{pmatrix}$$

$$M_1=\frac{\partial^2\pi_m^D}{\partial w^2}=-\frac{4(1+\theta)(-2-3\theta+\theta\lambda+\lambda)}{(1-\lambda)(1-\theta)(1+2\theta)(-4-8\theta-3\theta^2+\theta^2\lambda)}<0.$$

$M_1=|H|>0$. Then the Hessian matrix is negative definite, then π_m^D is jointly concave in w and p_m. Let $\frac{\partial\pi_m^D}{\partial w}=0$ and $\frac{\partial\pi_m^D}{\partial p_m}=0$, we have $w=\frac{\alpha(1-\lambda)\left(4+\theta(10-3\lambda)+\theta^2(6-5\theta)\right)}{4(1+\theta)(2+\theta(3-\lambda)-\lambda)}, p_m=\frac{\alpha}{2}$. We substitute them into p_t and p_r, we have:

$$p_t=\frac{\alpha\left(24-16\lambda+2\theta\left(36-15\lambda-\lambda^2\right)+3\theta^2\left(18-5\lambda+\lambda^2\right)+3\theta^3\lambda(3-\lambda)\right)}{4(4+8\theta+\theta^2(3-\lambda))(2+\theta(3-\lambda)-\lambda)},$$

$$p_r=\frac{\alpha\left(24-8\lambda+\theta(72-26\lambda)+\theta^2\left(54-27\lambda+\lambda^2\right)+3\theta^3\lambda(3-\lambda)\right)}{4(4+8\theta+\theta^2(3-\lambda))(2+\theta(3-\lambda)-\lambda)}.$$

We substitute them into π_m^D, π_t^D and π_r^D, we have

$$\pi_m^D = \frac{-((\alpha^2(-1+\lambda)(-8(-4+\lambda)-56\theta(-3+\lambda)+10\theta^4(-3+\lambda)^2+\theta^2(328 - 142\lambda+3\lambda^2)+\theta^3(282-154\lambda+11\lambda^2)))}{(8(1+\theta)(1+2\theta)(-4-8\theta+\theta^2(-3+\lambda))(-2+\theta(-3+\lambda)+\lambda)))}$$

$$\begin{aligned}\pi_t^D = {} & (\alpha^2(4\theta^7(-3+\lambda)^4(-1+4\lambda)+64(1+7\lambda-8\lambda^2+2\lambda^3) \\ & +2\theta^6(-3+\lambda)^2(-66+562\lambda-228\lambda^2+21\lambda^3)+32\theta(14+129\lambda-134\lambda^2+32\lambda^3) \\ & -4q^2(-296-3972\lambda+3815\lambda^2-913\lambda^3+15\lambda^4)-4\theta^3(-320-8274\lambda+7550\lambda^2-1918\lambda^3+93\lambda^4) \\ & +\theta^4(-60+40256\lambda-36251\lambda^2+10281\lambda^3-909\lambda^4+7\lambda^5) \\ & +\theta^5(-1404+28548\lambda-26565\lambda^2+8693\lambda^3-1115\lambda^4+31\lambda^5)))/(16(1+\theta)(1+2\theta)(4+8\theta \\ & -\theta^2(-3+\lambda))^2(-2+\theta(-3+\lambda)+\lambda)^2)\end{aligned}$$

$$\pi_r^D = \frac{(-1+\theta)\alpha^2(-1+\lambda)(8+\theta(32-30\lambda)+2\theta^3(-3+\lambda)^2-8\lambda+\theta^2(42-35\lambda+\lambda^2))^2}{16(1+\theta)(1+2\theta)(4+8\theta-\theta^2(-3+\lambda))^2(-2+\theta(-3+\lambda)+\lambda)^2}.$$

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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