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Pricing and Coordination in a Dual-Channel Supply Chain With Product Variety Under the Countervailing Power of the Retailer

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ABSTRACT To investigate pricing strategy and coordination mechanisms of the dual-channel supply chain with a retailer that has countervailing power to the manufacturer, we consider the effect of product variety in developing decentralized and centralized dual-channel supply chain game models. By solving these modes and comparing the results, we find the following: (i) The retailer's offline retail price is greater than the online retail price of the manufacturer when the retailer's market share is greater than the online market shares of the manufacturer under the centralized model. (ii) Online and offline product demand in a centralized supply chain increases with product variety. (iii) The relationship between offline retail price, wholesale price, and product variety depend on the threshold of the offline channel's market size. The wholesale price decreases with the countervailing power of the retailer. (iv) The relationship between offline retail price and demand in centralized and decentralized supply chains is related to the product variety threshold. Furthermore, manufacturer and total supply chain profit first rises and then declines, whereas the retailer's profit steadily increases with the degree of product variety. Two-part tariff pricing contracts can coordinate a decentralized model to obtain the same profit as that in a centralized model.

INDEX TERMS Dual-channel supply chain, product variety, countervailing power of the retailer, two-part tariff pricing contract.

I. INTRODUCTION

In recent years, consumer demand for products continues to show diversity trend due to personalization. To satisfy heterogeneous consumer needs and meet profit targets in different markets, manufacturers often use a product variety strategy. Different product variety strategies in a supply chain cause different results. A&K supplies coating components to market leaders such as BMW, Tesla, and automotive original equipment manufacturers. Due to the implementation of the product diversification strategy, A&K achieved more than 100% revenue growth [https://www.plex.com/about-plex/newsroom/press-releases/ak-finishing-achieves-record-growth.html]. On the contrary, as the largest consumer-goods company in China, Procter & Gamble, which has hundreds of brands, faces the risk of being removed from shelves because of the product variety strategy [1]. From these examples, we find investigating firms should adopt what degree of the product variety strategy is necessary.

This paper combines product variety strategy with the reality of retailers' growing countervailing power. The countervailing power of the retailer is the increasing bargaining power relative to the manufacturer. For example, large retailers can charge lower prices than small retailers when purchasing from the same manufacturers due to countervailing power. The bargaining power of retailers is increasing along with their countervailing power against manufacturers. Thus retailers can lower wholesale prices of manufacturers. Smith and Thanassoulis [14] find that large buyers will wield their countervailing power (obtain lower wholesale prices) if the upstream marginal cost drops. This paper's purpose is to discuss not only the necessity of the product variety strategy but also how the degree of product variety affects firms' profit

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under the countervailing power of the retailer. We consider both product variety strategy and the countervailing power of the retailer. The management implications of this paper help manufacturers make the better decisions on whether to cooperate with retailers and how to diversify products in the context of the retailer's growing countervailing power.

We focus on manufacturers that are able and willing to diversify their products. In this context, manufacturers always have multiple sales channels. The appearance, packaging, and quality of products also have a significant impact on sales. For instance, Unilever is in a fast-moving industry and diversifies its products to tap into segmented markets.

To solve this problem, we examine a supply chain composed of a manufacturer, a retailer and customers. In our model, the manufacturer offers lots of products that reach end consumers through online (e.g., the manufacturer's website) and offline (Through big supermarkets and other retailers like Wal-Mart) channels. Product distribution through the above channels does not affect the product's form, color, or quality [2]. To analyze the supply chain realistically, we study the countervailing power of the retailer in our paper. The countervailing power of the retailer is expressed by the discounts that the retailer can bargain for when purchasing products from the manufacturer. The manufacturer lowers the wholesale price to make the retailer order more when the retailer becomes more powerful.

The cooperation between the retailer and the manufacturer is another important issue in the supply chain. The aim of each firm is to maximize its profit. A two-part tariff pricing contract enables a retailer and manufacturer to cooperate to maximize the supply chain profit. We compare the centralized and decentralized dual-channel supply chain model. In particular, we calculate the total profit of the supply chain, retailer, and manufacturer in both cases. We then compare them to determine which scenario is more favorable for the supply chain and firms. In this paper, we consider the vertical cooperation [3]. Vertical cooperation increases supply chain efficiency through simultaneous decisions at different levels of the supply chain. A retailer and a manufacturer work together to achieve the goal of maximizing the overall profit of the supply chain when selling offline in the centralized mode [4]. In the decentralized model, each firm makes its own decision to maximize its interests.

In summary, this research makes two theoretical contributions: First, we identify the relationship between pricing and product variety in supply chain coordination. Second, this paper studies the countervailing power of the retailer's effect on the decision-making of the manufacturer in the supply chain. Few researches consider the double effect of product variety and the countervailing power of the retailer. Therefore, we examine how product variety and countervailing power of the retailer affect demand, price and profit of supply chain. As far as we know, there are few studies of centralized and decentralized dual-channel supply chain models that consider both product variety and the countervailing power of the retailer.

This paper answers the following questions:

(i) How does the degree of the product variety influence the decisions of the retailer and the manufacturer in the supply chain?

(ii) Can the product variety strategy improve the profits of the retailer and the manufacturer in the supply chain?

(iii) How does the degree of the countervailing power of the retailer affect the profits of the manufacturer and the retailer in the supply chain?

(iv) How can we coordinate the supply chain when considering product variety and countervailing power of the retailer?

The rest of this paper is organized as follows. In Section II, we review the relevant literature. Section III presents the problem description and model assumptions. Section IV characterizes the equilibrium results and provides the comparison of different scenarios. In Section V, we compare the equilibrium solutions and the relevant management significance is obtained. In Section VI, the decentralized model is regulated through the two-part tariff pricing contracts. Section VII reports the numerical experiments. The paper concludes in Section VIII and IX. Section B of the Supplementary Material provides the proofs for all theorems.

II. LITERATURE REVIEW

The product variety has aroused widespread attention and has produced a variety of analysis models. We review the literature from three aspects. The Section A of Section II reviews the literature on the countervailing power of the retailer. In Section B of Section II, we discuss the relevant literature on product variety. Finally, we discuss the distribution channel literature.

A. THE RETAILER'S COUNTERVAILING POWER IN A SUPPLY CHAIN

There is little literature related to the countervailing power of the retailer. As the retailer directly faces the end consumer, it can accurately predict market demand. For the same reason, the countervailing power of the retailer toward manufacturers is intense. Chen [5] constructs a competitive model for leading and marginal retailers. He proved the countervailing power of the retailer is indeed more favorable to consumers in the presence of marginal retailers. However, Chen's model is based on the assumption that products are homogeneous, so it does not reflect differentiation characteristics between retailers. Chen [6] argues that the existence of the countervailing power of the retailer reduces the product diversity. Erutku [7] extend Chen's model to build a vertical relationship model between two downstream retailers and an upstream supplier. He assumes that the retailers are competing on the product price. Based on this, the welfare effect of the countervailing power of the retailer was studied. Benton and Maloni [8] empirically tests how supplier satisfaction is affected by supply chain power. Inderst and Wey [9] consider that although the countervailing power of the retailer leads to the reduced profit of upstream suppliers, upstream companies strategically invest in technology to reduce costs or come up

with the new products when they anticipate the changes of the countervailing power of the retailer. Inderst and Shaffer [10] argue that retailers strengthen their bargaining power with upstream suppliers through mergers and that the increase in the countervailing power of the retailer weakens suppliers' enthusiasm for product innovation. Ellison and Snyder [11] uses empirical research to study the buyer counterweight of chain or independent drugstores, hospitals, and health maintenance organizations. He proves that consumer preference has a big impact on the formation of buyer counterweight. He refers to buyer power that is constantly increasing from the evolution of the vertical market as the countervailing power of the retailer. Inderst and Wey [12] consider that an increase in the countervailing power of the retailer leads to an increase in supplier costs, which reduces innovation incentives. Short-term effects include the influence of the countervailing power of the retailer on wholesale prices, consumer surplus, and retail prices. This part of their study is most relevant to this article. The sources of countervailing power of the retailer are varied. Inderst and Valletti [13] find that the source of countervailing power of the retailer is the external value selection's internal characteristic. Smith and Thanassoulis [14] examine vertical contracting through bargaining between downstream retailers and an upstream supplier. They find that the retailer uses countervailing forces if upstream marginal costs fall. Dana [15] and King [16] find that the source of buyer power is the internal characteristic of strategic behavior. Chen *et al.* [17] models buyer power as a downstream ability to obtain profit sharing or wholesale price discounts. He investigated the influence of buyer power on upstream and downstream enterprises, consumer surplus, and social welfare. Kim *et al.* [18] finds that referent power promotes the innovation performance of the supplier through social capital accumulation between the supplier and buyer. Ghadge *et al.* [19] aims to understand dependence scenarios after the risk-sharing contract and buyer-supplier power. Their research has developed a risk sharing contract of the supply chain to alleviate price volatility and demand uncertainty in the global business environment. Allain *et al.* [20] finds that the buying group enhances the countervailing power of the retailer and reduces the product variety. The retailers are even more profitable than full buying groups. Talay *et al.* [21] demonstrates that by extension of responsibilities and enforcing collaborations of fashion suppliers, the countervailing power of the retailer achieves.

B. THE ROLE OF PRODUCT VARIETY IN A SUPPLY CHAIN

Product variety undoubtedly plays a role in strengthening manufacturers' power to resist the countervailing power of the retailer. The results of Thonemann and Bradley [22] analysis show that by quantifying the impact of product variety on the performance of supply chain, the optimal product variety to offer can be determined. Conrad [23] delves into the reasons for horizontal product differentiation. The development of reasonable policies based on changes in individuals or society can increase the horizontal product differentiation. Hu's [24] paper proposes the models of product variety to assist in designing systems with robust performances. The models are developed to describe the product variety propagation in multi-echelon supply chains and multi-stage assembly systems. Wan *et al.* [1] empirically study the impact of product variety strategy on fill rate and sales. Rajagopalan and Xia [25] consider product variety strategy for horizontally differentiated products. Shi *et al.* [26] consider the quality levels of horizontally and vertically differentiated products for a manufacturer. They study the effects of the different customer distributions, customer heterogeneity on product quality decisions. Mayorga *et al.* [27] focus on a retailer that offers both vertically and horizontally differentiated products. Xiao *et al.* [28] examine the manufacturer who has direct and indirect channels. They addressed how product availability affects classification and inventory decisions. Syam and Bhatnagar [29] develops a model to determine the optimal product variety. Generally, the supply chain costs increase with the degree of the product variety. But he finds that this trend will be curbed by advanced manufacturing technologies such as modularization. Transchel *et al.* [30] examine a company's production quantity, pricing decisions, and assortment when the products have different quality. Federgruen and Hu [31] analyze a multi-product and multi-stage supply chain. The companies at each level participate in price competition. They characterize the price equilibrium for a sequential oligopoly model. Um *et al.* [32] finds that the product variety strategy influences customer service performance and supply chain cost when mediated by external and internal responsiveness capabilities. Chen *et al.* [33] analyze the manufacturer's product variety and detail production schedule (i.e., production sequence and batch sizes). Granero [34] shows that strategic of product variety can induce relevant inefficiencies. Specifically, the socially optimal level of quality can lead to excessive or insufficient product quality.

C. DISTRIBUTION CHANNELS SELECTION IN A SUPPLY CHAIN

The choice of distribution channels also plays an important role in a manufacturer's strategy under the countervailing power of the retailer. Chiang *et al.* [35] argue that the emergence of electronic direct channels increases profit for the manufacturer, reducing double marginalization in the downstream and upstream decision-making. Cai [36] finds that manufacturers can achieve Pareto improvements in profit by establishing electronic direct sales channels while selling products to traditional retailers. Retailers can also benefit from electronic sales channels. Khouja *et al.* [37] consider consumers that are loyal to retailer brands and find that the unit variable cost of products in electronic direct selling and traditional retail channels is an important factor affecting manufacturers' choice of electronic direct selling channels. Yoo and Lee [38] conduct research on a variety of hybrid channel strategies for manufacturers and found that manufacturers can achieve higher profits than increased e-retail channels by establishing their own electronic direct sales

channels. Rigby [39] argues that increasing manufacturers rid of the dependency on a single channel to meet consumers' online shopping needs. They combine traditional and electronic sales channels to establish a multi-channel distribution system. Kolay and Shalfer [40] considers that with the increase in the concentration of traditional retail markets, some larger retailers have increased the channel control and occupy a strong position in the supply chain, which has a significant effect on manufacturers' decision-making. The influence of supply chain dominance complicates the relationship between manufacturer and retailer. Liu *et al.* [41] finds that the optimal sales channel strategy is to distribute low-quality versions through retail channels and high-quality versions through direct sales channels. Matsui [42] proposes that a symmetric dual-channel distribution strategy will erode not only profit of the rival, but also its profit. Chen and Chen [43] points out the conditions for the retailer to choose a dual-channel structure. Yu *et al.* [44] investigates the impact of supply chain power structure on the optimal distribution channel strategy of the manufacturer. They find that the manufacturer is more inclined to grant sales channel control to a retailer who has high market power. Xia *et al.* [45] focus on how service competition affects the channel structure. He *et al.* [46] find the cost-saving strategies of remanufacturing can affect the different preferences of manufacturers and governments on channel structure. Jia and Li [47] study a supply chain involving self-run shops and e-retailer's online marketplace. Their results indicate that the platform fee and the order fulfillment cost show different impacts on supply chain decisions under different channel modes. Géraldine and Paule [48] investigate the effect of protecting the channels' diversity to meet the consumers' needs and avoid unsold food products. It also provides greater marketing opportunities for farmers. Yan *et al.* [49] find a coordination method for the agricultural product supply chain from the perspective of strategic consumer behavior. They find that the retailer's optimal order quantity decreases with the increase of wholesale price under the wholesale price contract coordination. Xu *et al.* [50] find that when the power of the platform is large, the wholesale price and cost-sharing contracts can coordinate the supply chain. Even if the power of platform is small, when the delivery time sensitivity is high, the supply chain can be coordinated by the cost sharing contract. Zhao *et al.* [51] find that the supply chain can be coordinated by linear quantity discount contract while the revenue sharing contract does not. They also find that supply chain coordination can be promoted by demand disruptions. Zhang *et al.* [52] propose the beneficial effects of revenue-sharing contracts in increasing the profit of supply chain and alleviating retail price competition. Hosseini-Motlagh *et al.* [53] propose an analytical scenario-based coordination model. By expanding the collection interruptions of the retailer, the retailers can invest more in corporate social responsibility efforts to make up for competitors' lower collections. The loss of the entire supply chain can be minimized.

Based on the existing literature, this paper transforms for manufacturers' traditional sales channels, develops electronic sales channels, and brings friction and coordination to dual-channel sales. The product variety is added to the supply chain model as an essential variable of product demand. The influence of product variety in dual-channel sales is analyzed. We also consider the impact of the countervailing power of the retailer. A pricing strategy and coordination contracts have a significant effect. This is a win-win situation for both the retailer and the manufacturer.

This paper makes the following contributions. First, this paper combines product variety with the countervailing power of the retailer to analyze their interactive impact on the dual-channel supply chain. Previous papers have respectively studied the importance of the retailers' countervailing power and the influence of product diversification strategies on the supply chain. As far as we know, no one has previously considered a combination of retailers' countervailing power and product diversity strategies. Our paper considers the impact of product diversification from the perspective of retailers' countervailing power. Therefore this paper is more detailed and closed to the real situation than previous articles. Second, combining the fact that more and more firms sell products to customers directly through the website, we consider offline and online channels. So this paper contributes to both literature and practice. This deepens the previous research and increases the research difficulty.

III. MODEL DESCRIPTION AND ASSUMPTIONS

This section develops the supply chain models in two different situations. According to the problems to be discussed, we define the parameters and put forward some assumptions.

A. MODEL DESCRIPTION

As described in the Introduction, a manufacturer realistically sells products in two channels. The first channel is offline indirect sales. The manufacturer sells products to a retailer. The retailer determines the retail price. Then retailer sells the products to the consumer. The second channel is online direct sales. The manufacturer sells products to consumers through online channels. The degree of product variety affects cost, price, demand, and the profits of the supply chain members. Thus, investigating the degree of product variety when managers make decisions in their supply chain operations is necessary.

Fig. 1 and Fig. 2 show the general structure of centralized and decentralized supply chain, which are composed of the manufacturer, the retailer, and consumers. A retailer and a manufacturer work together when selling offline in the centralized model. Consumers choose to obtain products from online or offline sales channels under the centralized model. In the decentralized model, each firm makes its own decision to maximize its interests. Consumers choose to obtain products from online sales channels or the offline retailer under the decentralized model. All notations used are summarized in Table 2.

TABLE 1. Our paper comparing with other papers.

	The retailer's countervailing power	Product variety	Dual-channel supply chain	Supply chain coordination	Centralized & decentralized decision	Game theory -Stackelberg	Pricing strategy
Chen et al. (2003)	√					√	√
Inderst et al. (2011)	√			√		√	√
Chen et al. (2016)	√						√
Allain et al. (2020)	√	√				√	√
Talay (2020)	√						
Conrad et al. (2005)		√	√			√	√
Rajagopalan et al. (2012)		√		√	√	√	√
Xiao et al. (2014)		√	√			√	√
Transchel et al.(2016)		√				√	√
Um et al. (2017)		√					
Cai (2010)			√	√	√	√	
Chen et al. (2017)			√	√		√	√
He et al. (2019)			√	√	√	√	√
Liu et al. (2010)			√	√	√	√	√
Jia et al. (2020)48			√			√	√
Our work	√	√	√	√	√	√	√

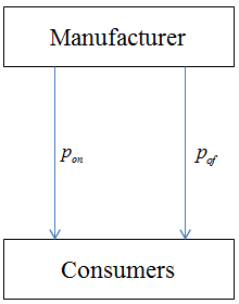

FIGURE 1. Centralized supply chain framework.

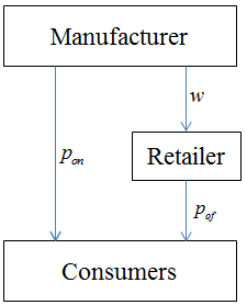

FIGURE 2. Decentralized supply chain framework.

B. MODEL ASSUMPTIONS

Assumption 1: A larger Δ indicates greater product diversification. To simplify, this paper focuses on the situation where $0 < \Delta < 1$. The investment cost of the manufacturer to implement a product variety strategy is expressed by function $\varphi(\Delta)$. This paper models the relationship between the degree of product variety and investment cost as a quadratic function, meaning that the cost increases with increases in the degree of product variety. Assume $\varphi(\Delta) = k\Delta^2/2$, where k represents the cost of implementing product variety [55, 56]. It measures the efficiency of differentiation. The larger κ is, the lower the efficiency of product variety.

Assumption 2: The countervailing power of the retailer is expressed by price discounts. A retailer with countervailing power bargains with the manufacturer and obtains price discounts λ. Thus, the retailer's wholesale price is $(1-\lambda)\,w$. The larger λ is, the stronger the countervailing power of the retailer [5], [56].

Assumption 3: The market demand function is a linear function of price. The offline product demand function is $q_{of} = s\alpha - \beta p_{of}/\Delta + f p_{on}/\Delta$ and the online product demand function is $q_{on} = (1-s)\alpha - \beta p_{on}/\Delta + f p_{of}/\Delta$ [57], [58]. In these equations, α is divided into two parts. s represents the market share ratio of offline retail channels; thus,

TABLE 2. Notations.

Symbols	Definition
Decision variables	
w	Wholesale price of the product
p_{of}	Offline retail unit price of the product
p_{on}	Online retail unit price of the product
Parameters	
c	Marginal unit cost of producing a product
q_{of}	Order quantity of the offline retailer
q_{on}	Order quantity of the online customer
Δ	Degree of product variety
α	Market size
s	Market share of the offline retail channels
β	Price-demand elasticity of online channel
f	Price-demand elasticity of offline channel
λ	Degree of the countervailing power of the retailer
k	Product variety cost factor
Derived functions	
π_M	Target profit function of the manufacturer
π_R	Target profit function of the retailer
π_{MR}	Target profit function of the supply chain
Indexes	
Superscript	
$*$	The equilibrium solution
Subscript	
d	The supply chain in the decentralized model
c	The supply chain in the centralized model
DT	The supply chain with a two-part tariff pricing contract
R	The retailer
M	The manufacturer

$1-s$ denotes the market share ratio of online channels, where $s \in (0, 1)$. $\beta > f$ indicates the customers' demand in the online channel is more sensitive to the price in this channel than the price in the offline channel. For instance, compared with offline sales prices, the customers in online channel are more sensitive to online retail prices because Internet can transfer information to them rapidly [59].

Based on the work of Bowley [58], we find the product diversity and the product substitution degree change in the opposite direction. In general, the increase of product variety drives up the total demand, which is consistent with the situation where firms implement the product diversity strategy to stimulate demands. For instance, A&K achieves the purpose of increasing demand due to the execution of product variety strategy[https://www.plex.com/about-plex/newsroom/press-releases/ak-finishing-achieves-record-growth.html], as proved by calculating the centralized model (Corollary 2) and examples under the decentralized model (FIG. 6 and FIG. 7) respectively.

Assumption 4: Information between the retailer and manufacturer is symmetrical [60]. The manufacturer is the leader of the Stackelberg game and the retailer is the follower in the supply chain [61].

IV. MODELS

In a centralized model, the manufacturer's profit is supply chain's total profit, which is product sales revenue minus production costs and the cost of implementing the product diversification strategy. The manufacturer's profit includes online and offline channel sales in a decentralized model, t. The retailer's unit profit is the wholesale minus retail prices.

A. MODEL FOR A CENTRALIZED DUAL-CHANNEL SUPPLY CHAIN

First, we consider the centralized mode to explore the implementation of the cooperation between the retailer and the manufacturer plays a role in the supply chain. The upstream manufacturer and downstream retailer are regarded as a unit in the centralized model. The manufacturer's profit is the total profit of the supply chain. c indicates the centralized dual-channel decision scenario. The manufacturer uses dual channels: offline and online product sales. The manufacturer implements a product diversification strategy to satisfy heterogeneous consumer needs.

The profit of the manufacturer is the supply chain's total profit in a centralized supply chain. The objective function of the manufacturer of this case is as follows:

$$\begin{aligned}\max \pi_{MR} = {} & (p_{on} - c)\left[(1-s)\alpha - \beta p_{on}/\Delta + f p_{of}/\Delta\right] \\ & + \left(p_{of} - c\right)\left[s\alpha - \beta p_{of}/\Delta + f p_{on}/\Delta\right] - k\Delta^2/2 \end{aligned} \tag{1}$$

The aim of the manufacturer is to maximize its profit. The manufacturer decides p_{of} and p_{on}. We use backward induction to solve the model.

Theorem 1: In a centralized scenario, the decision variables and profits of the retailer and manufacturer are as follows:

$$p_{of}^{c*} = \frac{s\alpha\beta + (1-s)\alpha f}{2(\beta^2 - f^2)}\Delta + \frac{c}{2},$$
$$p_{on}^{c*} = \frac{s\alpha f + (1-s)\alpha\beta}{2(\beta^2 - f^2)}\Delta + \frac{c}{2},$$

and

$$\pi_{MR}^{c*} = \left[\frac{s\alpha f\Delta+(1-s)\alpha\beta\Delta}{2\left(\beta^2-f^2\right)}-\frac{c}{2}\right]\frac{(1-s)\alpha\Delta+(f-\beta)c}{2\Delta} + \left[\frac{s\alpha\beta\Delta+(1-s)\alpha f\Delta}{2\left(\beta^2-f^2\right)}-\frac{c}{2}\right]\frac{s\alpha\Delta+(f-\beta)c}{2\Delta}-\frac{1}{2}k\Delta^2.$$

The Hessian matrix of Eq. (1) is $\begin{bmatrix}-2\beta/\Delta & 2f/\Delta\\ 2f/\Delta & -2\beta/\Delta\end{bmatrix}$; we can obtain $4(\beta^2-f^2)/\Delta^2>0$ from the equivalent relationship between the negative definition of the Hessian matrix and the quadratic function. If $4(\beta^2-f^2)/\Delta^2>0$, (1) ensures a strictly concave function. The supply chain has a unique solution under the centralized model.

The proof of this theorem is shown in the Appendix.

Corollary 1: If $1/2\le s<1, p_{of}^{c*}\ge p_{on}^{c*}; 0<s<1/2$, $p_{of}^{c*}<p_{on}^{c*}$.

When $1/2\le s<1$, the optimal offline retail price is greater than the optimal online retail price when the market share of the offline channels is greater than the online market share under a centralized decision. When $0<s<1/2$, the market share of the online channels is greater than the offline channels, and the optimal online selling price is also greater than the offline. Thus, the manufacturer should consider its online market share when making online pricing decisions and take effective measures to increase its market share, online prices, and profit.

Corollary 2: $\partial q_{of}/\partial\Delta>0$, $\partial q_{on}/\partial\Delta>0$.

Online and offline demand increases with increases in the degree of product diversity. More products meet the needs of consumers, thus demand increases. It indicates that the manufacturer is willing to engage in a product diversity strategy. Thus, it increases consumer market demand to maximize its profit.

Corollary 3: If $s\ge 2(\beta+f)/\alpha-f/(\beta-f)$, then p_{of}^{c*} increases with Δ; otherwise, p_{of}^{c*} decreases.

The offline retail price increases when product variety increases if the market share of offline retail channels is above the threshold. However, if the market share of offline channels is below the threshold, the offline retail price decreases even if product variety increases. Thus, the retailer attracts more consumers to purchase and expands its market share. When the market share of offline channels is above the threshold, more people will buy, and they are willing to pay more for product diversity.

This section studies the centralized dual-channel decision-making model and obtains the equilibrium solution for online retail price, offline retail price, and manufacturer profit. Next, the decentralized dual-channel decision-making model is discussed.

B. DECENTRALIZED DUAL-CHANNEL SUPPLY CHAIN MODEL

The retailer and manufacturer are individual members of the supply chain different from centralized model. Each member makes decisions to maximize their profit under decentralized decision-making. The manufacturer's profit includes online and offline channel sales profit. The profit of the retailer is the profit from offline channel sales. The manufacturer is the leader, followed by the retailer.

The profit function of the retailer, the manufacturer, and the supply chain are in the following.

The profit of the retailer is determined as follows:

$$\max\pi_R=\left[p_{of}-(1-\lambda)\,w\right]\left[s\alpha-\beta p_{of}/\Delta+fp_{on}/\Delta\right] \quad (2)$$

The manufacturer's profit is determined as follows:

$$\begin{aligned}\max\pi_M &= (p_{on}-c)\left[(1-s)\alpha-\beta p_{on}/\Delta+fp_{of}/\Delta\right]\\ &\quad+\left[(1-\lambda)w-c\right]\left[s\alpha-\beta p_{of}/\Delta+fp_{on}/\Delta\right]-k\Delta^2/2 \quad (3)\end{aligned}$$

The total supply chain is determined as follows:

$$\begin{aligned}\max\pi_{MR} &= (p_{on}-c)\left[(1-s)\alpha-\beta p_{on}/\Delta+fp_{of}/\Delta\right]\\ &\quad+(p_{of}-c)\left[s\alpha-\beta p_{of}/\Delta+fp_{on}/\Delta\right]-k\Delta^2/2 \quad (4)\end{aligned}$$

The game has two stages. In the first stage the manufacturer determines its online selling price and the wholesale price. In the second stage the retailer determines its retail price. We use the backward induction method to solve the model. The superscript d represents the decentralized dual-channel decision scenario. The following theorem is obtained through mathematical calculations.

Theorem 2: The decision variables and profit of the retailer, manufacturer, and supply chain are as follows:

$$\begin{aligned}
p_{of}^{d*} &= \frac{s\alpha\beta+(1-s)\alpha f}{2(\beta^2-f^2)}\Delta+\frac{s\alpha\Delta+fc}{4\beta}+\frac{c}{4},\\
p_{on}^{d*} &= \frac{s\alpha f+(1-s)\alpha\beta}{2(\beta^2-f^2)}\Delta+\frac{c}{2},\\
w^{d*} &= \frac{s\alpha\beta+(1-s)\alpha f}{2(\beta^2-f^2)(1-\lambda)}\Delta+\frac{c}{2(1-\lambda)},\\
\pi_R^{d*} &= \frac{[s\alpha\Delta+(f-\beta)c]^2}{16\beta\Delta},\\
\pi_M^{d*} &= \left[\frac{s\alpha f+(1-s)\alpha\beta}{2\left(\beta^2-f^2\right)}\Delta-\frac{c}{2}\right]\\
&\quad\times\left[\frac{f^2c+\beta fc-2\beta^2c}{4\beta\Delta}+\frac{s\alpha f}{4\beta}+\frac{(1-s)\alpha}{2}\right]\\
&\quad+\left[\frac{s\alpha\beta\Delta}{2\left(\beta^2-f^2\right)}+\frac{(1-s)\alpha f\Delta}{2\left(\beta^2-f^2\right)}-\frac{c}{2}\right]\\
&\quad\times\frac{s\alpha\Delta+(f-\beta)c}{4\Delta}-\frac{1}{2}k\Delta^2, \text{ and}\\
\pi_{MR}^{d*} &= \left[\frac{s\alpha f+(1-s)\alpha\beta}{2(\beta^2-f^2)}\Delta-\frac{c}{2}\right]\\
&\quad\times\left[\frac{f^2c+\beta fc-2\beta^2c+s\alpha f\Delta}{4\beta\Delta}+\frac{(1-s)\alpha}{2}\right]\\
&\quad+\left[\frac{s\alpha\beta+(1-s)\alpha f}{2(\beta^2-f^2)}\Delta+\frac{s\alpha\Delta}{4\beta}+\frac{fc}{4\beta}-\frac{3c}{4}\right]\\
&\quad\times\frac{s\alpha\Delta+(f-\beta)c}{2\Delta}-\frac{1}{2}k\Delta^2.
\end{aligned}$$

Proof: The proof of the theorem is similar to Theorem 1; thus, it is not repeated here.

Corollary 4: If $s \geq \frac{4\beta(\beta+f)}{\alpha(3\beta+f)}$, then $p_{of}^{d^*}$ increases with Δ; otherwise, $p_{of}^{d^*}$ decreases.

The offline retail price increases as product variety increases when the market share of offline channels is above the threshold. When the market share of offline channels is below the threshold, the offline retail price decreases even if product variety is enhanced; thus, the retailer expands its market share and attracts more consumers to purchase. When the market share of offline channels is above the threshold, more consumers will purchase the product and are willing to pay higher prices for product diversity.

Corollary 5: Wholesale prices w^{d^*} increase with the countervailing power of the retailer λ.

This is a counter-intuitive finding. In the decentralized model, the manufacturer enhances product diversity to maximize its profit when the retailer's countervailing power increases. The manufacturer's resistance increases the wholesale price because of the development of different sales channels and other methods to counter the increasingly powerful retailer. Corollary 5 indicates that it is wrong to intuitively believe that the wholesale price will decline when the retailer's bargaining power increases.

Corollary 6: If $s \geq 2(\beta + f)/\alpha - f/(\beta - f)$, then w^{d^*} increases with Δ; otherwise, w^{d^*} decreases with Δ.

When the market share of offline retail channels is above the threshold, the wholesale price increases with product variety; otherwise, the wholesale price decreases. When the market share of the offline channel is below the threshold, the offline selling price must be reduced to expand market share and attract more consumers. Thus, the retailer requires the manufacturer to reduce the wholesale price to ensure the retailer's profit. When the market share of offline channels is above the threshold, more people will buy; thus, they want to pay higher prices for product diversity. Then, the manufacturer raises wholesale prices to obtain more profit.

This section examines decentralized dual-channel decision-making and obtains a balanced solution for online retail price, offline retail price, and wholesale prices as well as for each member of supply chain's profits. The next section compares centralized and decentralized dual channels and discusses managerial insights.

V. MODEL COMPARISON AND CORRESPONDING ANALYSIS

In Section 4, by analyzing decentralized and centralized dual-channel models, we obtained equilibrium solutions in both models for each member of supply chain's profits. Next, the following theorems are derived by comparing overall profit, retail price, and product demand in each model.

Theorem 3: $\pi_{MR}^{c^*} > \pi_{MR}^{d^*}$.

This shows that overall supply chain profit under centralized model outweighs the profit under decentralized decision-making. Thus, cooperation between the retailer and the manufacturer is conducive to the development of a supply chain. Increased cooperation reduces the cost of procurement and production information asymmetry and optimizes the entire supply chain. The retailer provides timely feedback on demand to the manufacturer to avoid manufacturer inventory backlog or low inventory caused by the bullwhip effect. Also the information about market need provided timely by the retailer helps the manufacturer adjust its online product price and production, coordinating the dual-channel supply chain.

Theorem 4: If $\Delta \leq \frac{(\beta-f)c}{s\alpha}$, then $p_{of}^{d^*} \leq p_{of}^{c^*}$; otherwise, $p_{of}^{d^*} > p_{of}^{c^*}$.

The offline retail price under decentralized model is less than that under centralized model when the degree of product variety is below the threshold; however, the offline selling price under the decentralized model is higher. When the degree of product variety is below the threshold, cost increases with the product variety. The manufacturer sets the offline selling price under centralized model. Thus, it increases the offline selling price to compensate for the additional cost. In the decentralized scenario, the retailer is not willing to wholesale a variety of similar products, which lowers the retail price. When product variety is above the threshold, the manufacturer must set pricing at a lower level due to the scale effect. The retailer wholesales more products under the decentralized model, so the retail price rises.

Theorem 5: If $\Delta \leq \frac{(f-\beta)c}{s\alpha-4(\beta-f)}$, then $q_{of}^{d^*} \geq q_{of}^{c^*}$; otherwise, $q_{of}^{d^*} < q_{of}^{c^*}$.

Offline demand under decentralized model is greater than that under decentralized model when the degree of product diversity is below the threshold; otherwise, offline demand in the decentralized mode is less than offline demand in the centralized mode because the retailer is closer to customers and better understands their preferences. The retailer can promote products to customers and increase sales. The retailer is unwilling to wholesale additional products when product variety is above the threshold. Demand increases when there are more choices online.

VI. TWO-PART PRICING CONTRACT FOR THE SUPPLY CHAIN COORDINATION

In Section 5, the efficiency loss in the decentralized supply chain is verified by comparing its supply chain profit to that under centralized decision-making. Thus, the manufacturer has an incentive to improve supply chain profit via contract, which requires effective cooperation among supply chain members. According to the responsibilities and obligations for production of the manufacturer, the manufacturer should sign a contract with the retailer. By signing the contract, the manufacturer strengthens cooperation with the retailer in the supply chain and transfer part of their profit to obtain greater profit. Two-part tariff pricing contracts have been widely used in practice. This section studies the use of two-part tariff pricing contracts to improve overall supply chain profit.

The two-part tariff pricing contract refers that a fixed fee F is given from the retailer to the manufacturer to make

the supply chain's profit reach the profit under a centralized scenario. Meanwhile, the retailer and the manufacturer make more profit

$$\max \pi_R^{DT} = \left[p_{of}^c - (1-\lambda)\, w^c\right]\left[s\alpha - \beta p_{of}^c/\Delta + f p_{on}^c/\Delta - \beta + f\right] - F \tag{5}$$

$$\max \pi_M^{DT} = \left(p_{on}^c - c\right)\left[(1-s)\,\alpha - \beta p_{on}^c/\Delta + f p_{of}^c/\Delta\right] + [(1-\lambda)\,\mathrm{w} - c]\left[s\alpha - \beta p_{of}^c/\Delta + f p_{on}^c/\Delta\right] - \frac{k\Delta^2}{2} + F \tag{6}$$

According to the rules of the game between the retailer and the manufacturer and the contract's observability, this paper uses backward induction to obtain the equilibrium product wholesale and retail prices under the two-part tariff pricing contract. We can obtain that

$$w^{DT*} = \frac{s\alpha f^2 + (1-s)\alpha\beta f}{2\beta(\beta^2 - f^2)(1-\lambda)} + \frac{c}{(1-\lambda)} + \frac{fc}{2\beta(1-\lambda)},$$

$$p_{of}^{DT*} = \frac{s\alpha\beta + (1-s)\alpha f}{2(\beta^2 - f^2)}\Delta + \frac{c}{2}, \text{ and}$$

$$p_{on}^{DT*} = \frac{s\alpha f + (1-s)\alpha\beta}{2(\beta^2 - f^2)}\Delta + \frac{c}{2}$$

Theorem 6: If $F_2 < F < F_1$, then $\pi_M^{DT} > \pi_M^d$, $\pi_R^{DT} > \pi_R^d$. Where

$$F_1 = \frac{3\left[s\alpha\Delta + (f-\beta)\,c\right]^2}{16\beta\Delta},$$

$$F_2 = \left[\frac{s\alpha f + (1-s)\alpha\beta}{2(\beta^2 - f^2)}\Delta - \frac{c}{2}\right]\frac{f^2 c - \beta f c + s\alpha f\Delta}{4\beta\Delta} + \left[\frac{s\alpha\beta + (1-s)\alpha f}{2(\beta^2 - f^2)}\Delta + \frac{fc}{\beta} - \frac{c}{2}\right]\frac{s\alpha\Delta + (f-\beta)\,c}{4\Delta}$$

Theorem 6 shows that the profits of supply chain's each member are improved by Pareto compared with the decentralized model when F is in the range of (F_2, F_1) under a two-part tariff pricing contract. Then, the supply chain's total expected profits achieve the optimal levels under centralized decision, which indicates the contract can achieve full coordination. Thus, it is better to strengthen cooperation to obtain more profit and distribute profits according to the contract.

This section shows that the profitability of manufacturer and retailer are increased under centralized and decentralized sales through a two-part tariff pricing contract, which has management implications. The manufacturer actively designs a two-part pricing contract and cooperates with the retailer. The retailer also helps the manufacturer diversify products by developing its strengths.

VII. NUMERICAL EXPERIMENTS

To verify our research conclusions and further analyze the effect on the main parameters in the supply chain, this paper set the following parameters for each member of the supply chain: $\alpha = 1, \beta = 1, f = 0.75, \mathrm{s} = 0.5, \mathrm{c} = 0.2, \Delta = 0.5$. To focus on the primary research aim, namely, highlight the impact of product diversification on the supply chain, by referring to related literature, we believe the value set like this is reasonable, we thus set alpha and Beta to 1. Conclusions are drawn by studying the effects of product variety parameters on prices and overall supply chain profit. The results of our experiments are shown in Figs. 3-10.

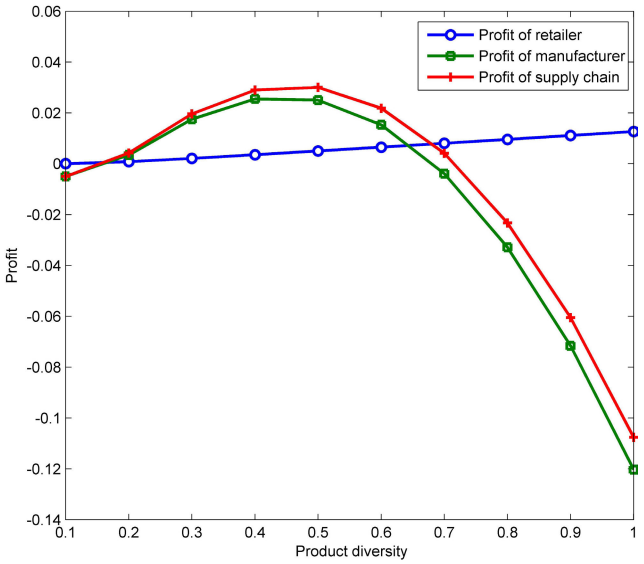

FIGURE 3. Total profit for retailer, manufacturer, and supply chain vs. the degree of product variety under the decentralized model.

Fig.3 demonstrates that the retailer's profit increases, whereas the profit of the manufacturer and total supply chain first increase and then decrease with increases in the degree of product variety. The increase in product variety will increase offline demand, thus increasing the retailer's profit. For the manufacturer, the increase in product variety leads to an increase in product demand, which increases short-term profit, but as product variety continues to increase, the marginal profit of the manufacturer cannot compensate for the marginal additional costs, thus profit decreases. The higher product variety is not better. The manufacturer should develop a reasonable degree of product variety based on current market conditions and the cost of product variety to achieve optimal profit. The retailer is always willing to accept a product variety strategy, and thus it always profits from product variety.

Fig.4 shows that under different degrees of product variety, the supply chain profit in the centralized model is always greater than that in the decentralized model, proving the rationality of Theorem 1. The manufacturer should strengthen cooperation with the retailer to form a strategic alliance. As the diversification of products increases, supply chain profit first rises and then falls in both models. The demand for products increases as the variety of products increases, which expands profit in the short term. The marginal profit of the manufacturer cannot compensate for the marginal costs when product variety continues to increase; thus, profit declines.

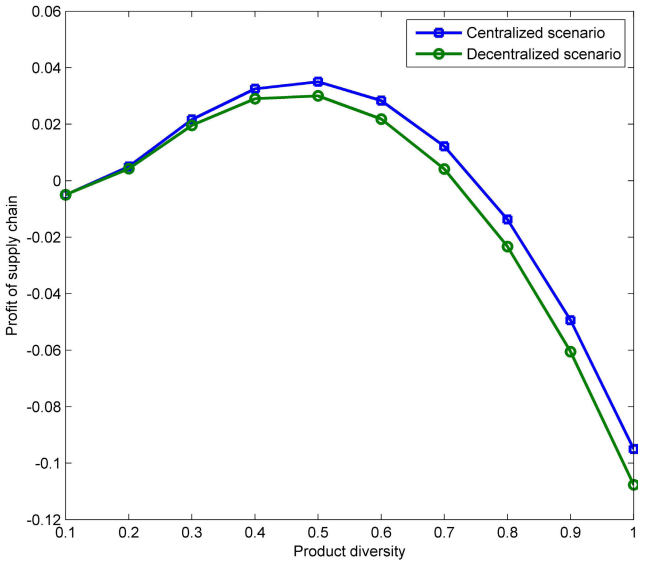

FIGURE 4. Supply chain profit vs. product variety under centralized and decentralized models.

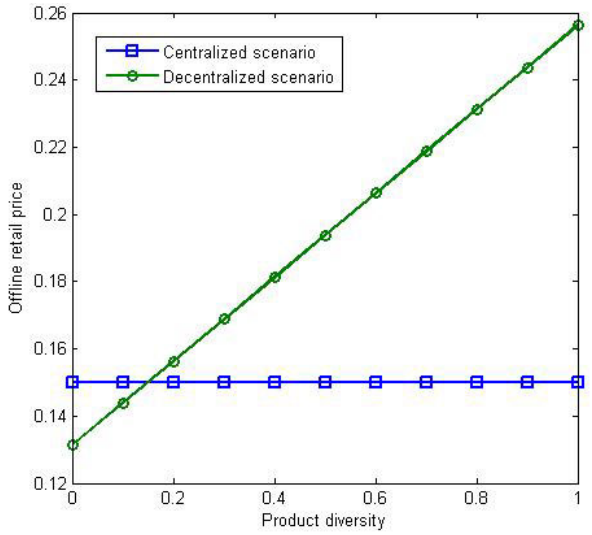

FIGURE 5. Offline retail price vs. product variety under centralized and decentralized models.

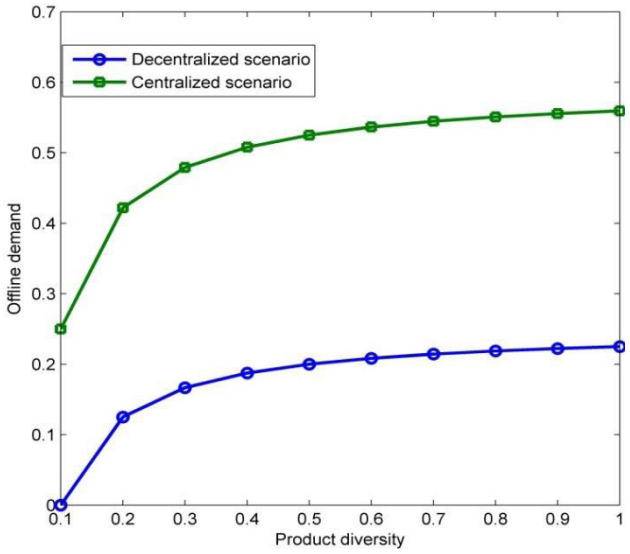

FIGURE 6. Offline demand vs. product variety under centralized and decentralized models.

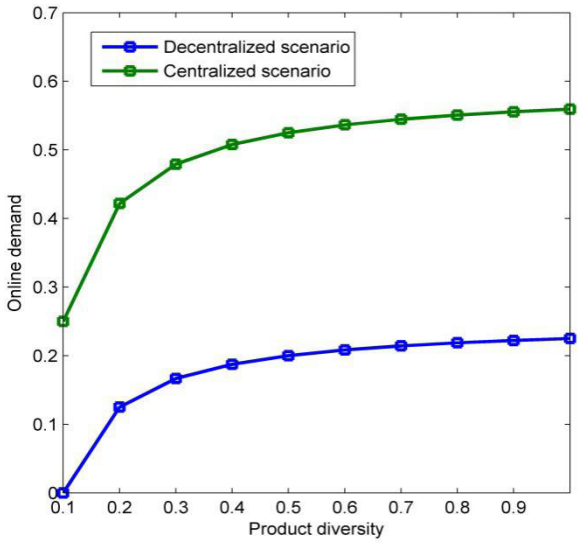

FIGURE 7. Online demand vs. product variety under centralized and decentralized models.

This demonstrates that the manufacturer must be cautious about making product variety decisions, not blindly diversify. The manufacturer seeks optimal diversification within a reasonable range to maximize profit whether in a decentralized or centralized supply chain.

Fig.5 indicates that the centralized offline selling price is higher than the decentralized offline selling price within a specific range. Beyond that range, the decentralized offline selling price is higher than the centralized offline retail price. This proves the rationality of Theorem 5. There is still an increase in cost when the degree of product variety is below a certain level. The manufacturer increases the offline retail price to compensate for that increase in cost. It prices products similar to the centralized model. The retailer is unwilling to wholesale a variety of similar products, which lowers the retail price under decentralized decision-making. When product variety is above the threshold, the manufacturer independently decides to lower the price in the centralized model, and the retailer wholesales more products. Thus, the retail price increases in the decentralized model because the manufacturer obtains economies of scale. This indicates that the manufacturer should carry out a product variety strategy. Only by diversifying can the manufacturer fight a strong retailer and increase the offline retail price of its products.

Fig.6 and **Fig.7** illustrate that marginal demand decreases as product variety increases when the market continues to improve and consumer demand is continuously met in centralized and decentralized modes. Thus, the manufacturer cannot continuously diversify its products. Marginal need will be reduced even if product diversification increases.

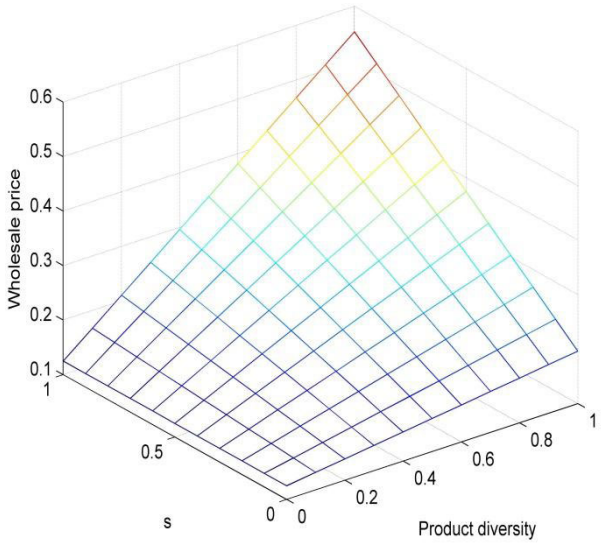

FIGURE 8. Wholesale price vs. product variety and market share of the offline retail channels in a decentralized supply chain.

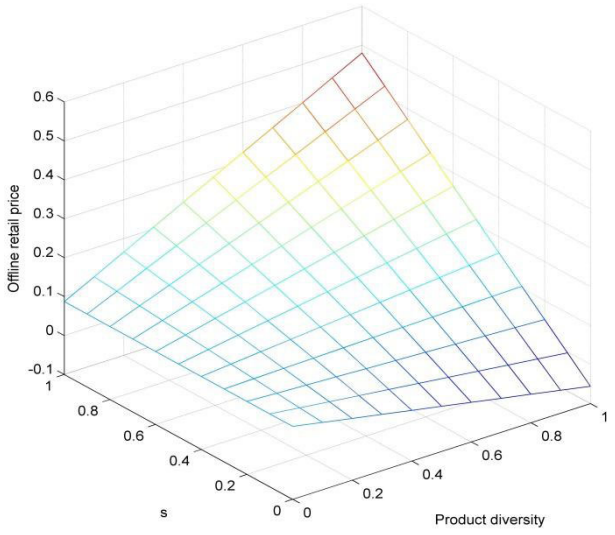

FIGURE 9. Offline retail price vs. product variety and market share of the offline retail channels in a decentralized supply chain.

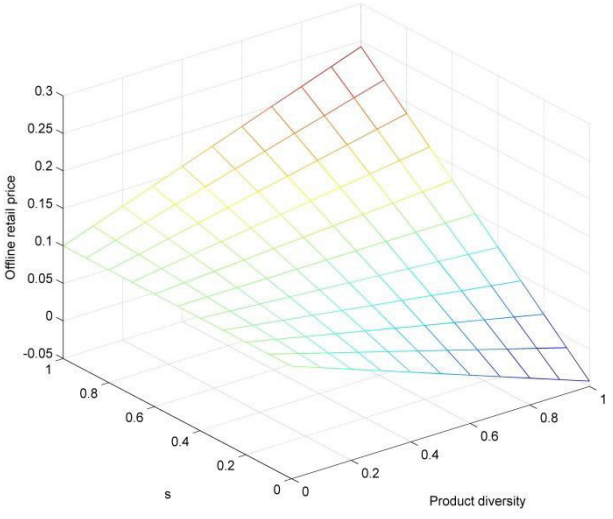

FIGURE 10. Offline retail price vs. product variety and market share of the offline retail channels in a centralized supply chain.

This means that the manufacturer must learn from the retailer or through other means and strengthen its understanding of consumer needs to meet more needs.

Fig.8 shows that wholesale price decreases with increases in product variety when s is below the threshold; otherwise, wholesale prices increase. The offline retail price must be reduced to expand the market share and attract more consumers to buy products when the market share of offline channels is below the threshold value. In this case, the retailer requires the manufacturer to reduce the wholesale price to ensure profit. More people buy the product; thus, customers want to pay higher prices for product diversity when the market share of offline channels is above the threshold. Then, the manufacturer will increase wholesale prices to obtain more profit. The manufacturer should engage in strategic product differentiation if it wants to increase the wholesale price of its products.

Fig.9 and **Fig.10** indicate that offline retail price decreases with increases in product variety when s is below the threshold; otherwise, the offline retail price increases. The offline retail price must be reduced to expand market share and attract more consumers to purchase even if product variety is enhanced when the market share of offline channels is below the threshold value. More people buy the product; thus, they want to pay higher prices for product diversity when the market share of offline channels is above the threshold. This indicates that the manufacturer should make product variety decisions according to the market share of offline retail channels to increase offline retail prices.

VIII. MANAGERIAL INSIGHTS

This study provides essential managerial insights for manufacturers and retailers. The manufacturer can enhance product variety through technological and quality innovations. The manufacturer should make product variety decisions cautiously based on factors such as production cost and market capacity, and not blindly develop products. Blind diversification will result in a decline in total profit of the manufacturer and supply chain. In addition, the manufacturer actively launches online sales, moderately diversifies products, and strengthens cooperation with the retailer; ultimately enhancing the supply chain's overall profit under centralized decision-making when considering product variety and the countervailing power of the retailer.

The implication for the retailer. The finds of this paper indicate the retailer can cooperate with the manufacturer instead of countering to the manufacturer. The distribution of profit through two-part tariff pricing contracts makes retailer profits greater than profits under decentralized decision-making. The product variety strategy benefits the retailer. Thus, the retailer can cooperate with a manufacturer to implement a better

product differentiation strategy. The retailer can cooperate with the manufacturer as well as other retailers. The retailer can actively launch sales channels to enhance the countering power to the manufacturer.

IX. CONCLUSION AND FUTURE RESEARCH

This section is divided into two parts: the conclusions of the paper and the suggestions for future research.

Main findings. This paper investigates a two-echelon supply chain consisting of a retailer and a manufacturer, and considers the influence of product variety under the countervailing power of the retailer. We examine two cases: 1) the manufacturer and the retailer cooperate in the offline channel (the centralized supply chain), 2) the manufacturer does not cooperate with the retailer in the offline channel (the decentralized supply chain). Moreover, through two-part tariff pricing contracts we coordinate the supply chain successfully. To find the optimal profit of the supply chain, we compare the performance of centralized and decentralized models. In the end, we conduct numerical experiments to prove our results.

The main conclusions are as follows:

(i) Product variety strategy likes a double-edged sword. The greater product variety is not necessarily better. The manufacturer's profit will rise and then decline as the degree of product variety increases continuously. Product differentiation within a reasonable range is beneficial to the manufacturer and supply chain's total profits. As product variety increases, retailer profit increases because retailers are closer to consumers and better understand consumer needs than the manufacturer.

(ii) The enhancement of the countervailing power of the retailer stimulates the increase of the wholesale price of products, but it affects neither the profits of the retailer, manufacturer, nor that of supply chain. We always argue that an increase in the countervailing power of the retailer makes the retailer dominate the manufacturer and bargain for better pricing. However, the manufacturer can carry out product differentiation strategies and/or expand sales channels, which can successfully help him to balance his loss for the increase of the countervailing power of the retailer.

(iii) The increase in product variety is significant to the improvement of product price and market demand. Thus, it can increase the manufacturer's profit and enhance his ability to negotiate with the retailer in the face of the retailer's increasing counterweight. However, the product variety is not the only factor that affects pricing and demand. The results show that price and demand vary independently from the degree of product variety depending on the size of the market. So the firm needs to pay attention to more factors besides the product variety.

(iv) The manufacturer can use a two-part tariff pricing contract to reasonably redistribute the overall supply chain profit by strengthening cooperation with the retailer. Even after transferring some fixed costs, the manufacturer still obtains more profit because overall supply chain profit reaches optimized through cooperation under the decentralized model. Total supply chain profit under centralized decision making situation is greater than that under decentralized situation.

Research limitations and the future work. In recent years, more and more scholars have paid attention to exploring the impact of information symmetry on supply chain. This paper does not take account of information asymmetry. It is believed that this factor will exert some influence on how to deal with pricing and coordination in a dual-channel supply chain. Therefore, information asymmetry is considered the next direction of our further research on dual-channel supply chain with product variety under the countervailing power of the retailer.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this article, and it is the original research that has not been published previously, and not under consideration for publication elsewhere.

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