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PRICING STRATEGY AND COORDINATION MECHANISM OF DUAL-CHANNEL SUPPLY CHAIN BASED ON REFERENCE QUALITY EFFECT

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Abstract. The difference between the actual product quality experienced by consumers after shopping and the product reference quality expected before shopping usually has a significant effect on product demand and brand reputation. This paper considers a dual-channel supply chain composed of a manufacturer and a retailer. This investigation is on the influence of consumers' reference quality under centralized decision-making, decentralized decision-making Bertrand game, and decentralized decision-making Stackelberg game. Furthermore, in view of the influence of reference quality, this paper constructs cost-sharing contracts and two-part tariff contracts to discuss the consistency of the dual-channel supply chain. The results show that consumers' reference quality effect has a positive impact on the equilibrium price and profit of the dual-channel supply chain. Under normal circumstances, the dual-channel supply chain cannot achieve conformity. However, consistency can be achieved under the two-part tariff contract mechanism. Finally, numerical simulation is carried out for verification with numerical values.

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1. Introduction

With the development of e-commerce, third-party logistics and electronic payment technologies have become more and more mature. The dual-channel supply chain model is becoming more popular. Many traditional manufacturing companies have opened electronic direct sales channels. Due to changes in consumers' existing consumption habits, corporate marketing channels and traditional retail channels have also undergone corresponding changes. They can directly establish contracts with consumers to meet market demand. For example, Suning, Huawei, Gree and other companies have created their own online official stores. This enriches the way

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consumers shop and also meets their needs. Offline entities, such as RT-Mart, Corum, and TagHeuer, not only open online electronic direct sales channels, but also establish cooperative relationships with major e-commerce platforms. This allows consumers to make experiential consumption from online electronic direct sales channels, in addition to buying their favorite products offline. However, in recent years, many companies have suffered huge losses due to product quality issues. Examples include the Apple 12 mobile phone green screen event, the Samsung Galaxy Note 7 mobile phone battery explosion incident, and the fake bird's nest advertisement by Internet celebrities. These incidents have affected many companies and industries, and product quality issues have aroused widespread public concern. Therefore, if companies want to adapt to the new environment and survive in the fierce market competition, it is essential for them to formulate applicable, effective and feasible policies. Product pricing strategy and product quality level, as the product attributes most concerned by customers, determine the company's operating profit. Only by providing higher product quality than other competitors can companies attract and retain customers, and thus remain invincible in market competition. How to effectively improve product quality has become the focus of supply chain management theory and business community. In [19], the impact on market demand under the coordination of product quality level and retailer's promotion effort level is analyzed. In [40], the study is about how suppliers make production decisions and quality contract design issues to reduce quality risk sharing caused by information asymmetry. In [3], when studying supplier quality prevention decisions and seller quality evaluation decisions in the supply chain, product quality control strategies and product quality decision-making control models are formulated. In [6], it shows that in the internet environment, the sales channel selection of perishable product manufacturers will be affected by product price, perishable product freshness, and price and quality of competitive channels. In [18], the following questions are explained: the impact of quality improvement and advertising support on manufacturers' decision-making, and how to choose these two methods to increase their profit levels.

In addition to price, brand reputation, product quality, service level and other factors that affect consumer demand, consumer reference effect will also affect consumers' shopping behavior [25, 26]. Consumers cannot visually observe the comparison of quality and price. They continue to choose between products, but they know little about the consequences of the selected product, because it is difficult to obtain information on the product quality changes on the internet [32]. Therefore, when consumers buy products through online channels, the main factor that affects consumer choice is the quality effect of the product. The impact of quality and price reference effects on demand in the supply chain coordination research of quality improvement are investigated in [22], where products are divided into search products and experience products when discussing pricing, quality levels and advertising strategies and reference quality effects. Two different marketing strategies are obtained for different types of goods. In [20], a selection model is considered based on the generalized prospect theory. It is found that the reference quality has a significant effect on the value function. The optimal pricing of products is studied in [27], in which manufacturers and retailers carry out promotion activities under the influence of reference prices.

Most of the above-mentioned literature on supply chain pricing issues only take into account the consumer price reference effect. Only few studies have considered the impact of reference quality. Furthermore, there is little discussion about the dual-channel background. However, the influence of reference quality is becoming more and more important, directly affecting the decision-making of manufacturers and downstream retailers. Thus, this paper introduces the reference quality effect to enrich the existing literature, and aims to solve the following problems:

(i) How does the quality effect affect the equilibrium price and profit of the dual-channel supply chain?
(ii) What will happen to the equilibrium price and profit of each channel in the supply chain system when quality effect reference is ignored?
(iii) When making decisions under the influence of quality effect reference, which channel in the supply chain has higher prices and profits?
(iv) What impact will different coordination mechanisms have on the dual-channel supply chain when the impact of reference quality is taken into consideration?

To answer these questions, this paper considers the pricing problem of a dual-channel supply chain composed of a manufacturer and a retailer under the centralized decision-making game, the decentralized decision-making Bertrand game, and the decentralized decision-making Stackelberg game.

The rest of the paper is organized as follows: Section 2 reviews related papers in the literature. In Section 3, notations, model assumptions and problem description are introduced. Then, three different decision models are discussed and the results obtained are analyzed in Section 4. In Sections 5 and 6, the optimal pricing and profit comparison of the dual-channel supply chain under different coordination mechanisms are obtained. Examples using actual data are solved to verify the results. Finally, in Section 7, conclusions and some useful managerial insights for enterprises are revealed.

2. Literature review

In this section, a brief review of some related papers in the literature on dual-channel supply chains, influence of reference quality, and supply chain coordination mechanisms is given.

2.1. Dual-channel supply chain

Due to the rapid advancement of e-commerce, consumers' online shopping rate continues to increase, causing many manufacturers to sell products through retail channels and online direct sales channels [4]. These distribution systems are called dual channel supply chains [2]. This model is becoming a new development trend, it has changed the existing marketing channels, and has become a study hotspot in the field of supply chain management. Game theory methods are often used to study supply chain related issues. In [13], a dynamic pricing scheme of electric vehicle charging stations with photovoltaic system is proposed based on the Stackelberg game. In [31], Bayesian game theory is used to estimate the manufacturing cost and product premium of different product combinations. It is found in [42] that those horizontal mergers and acquisitions have unique characteristics in the impact of the dual-channel supply chain, and channel favoritism plays an important role in this influence. The optimal sales quantity and pricing of the dual-channel supply chain under three different modes, *i.e.*, MR, MRM, and MRMR, are discussed in [5]. The study in [37] suggests that manufacturers can effectively encourage physical stores to improve service levels, and expand product sales through the development of online direct sales channels. Physical stores can obtain lower wholesale prices, and hence ultimately increase the profitability of both parties. In [34], it is pointed out that the opening of online direct sales channels will reduce manufacturer's costs, and improve operating efficiency. At the same time, they can also increase the market share of the products and avoid the control of downstream physical stores. In [33], it is found that the manufacturer's dual-channel structure can attract more customers, so the manufacturer can always profit from the dual-channel structure. In [10], it is pointed out that for any given sales price, in the centralized decision-making process, the retailer's service strategy is determined by the profit margin of unit product sold through direct sales channels and retail channel. The manufacturer, in the decentralized model, will improve the service level of the direct sales channel, but will reduce quality improvement effort. In [30], the focus of the study is on the situation where manufacturers and retailers introduce online direct sales channels separately or at the same time. It is found that manufacturers can attract online consumers to purchase products in physical stores, which helps reduce double marginalization caused by the introduction of online direct sales channels. In [29], the study is on the best advertising investment strategy and profit balance of national brand manufacturers and retailers in the decomposition system and the integrated system.

2.2. Supply chain reference quality effect

When consumers buy products on the online platform, due to the asymmetry of information, they often estimate product quality based on factors such as brand reputation and past experience, that is, reference quality. If the actual quality of the received product is higher than the reference quality, consumers will increase their purchase demand for branded products, otherwise, they will reduce purchase demand. The kind of consumer behavior that usually exists in the purchase process is called the reference quality effect [17]. The current

literature mainly focuses on the reference price effect and the low-carbon effect, and rarely mentions the reference quality effect. In [36], it is pointed out that customers' decisions are influenced by the selling price. Customers will compare the selling price of a product with other prices (such as reference price) to make decisions. The price competition between two competing retailers and one manufacturer, and the price competition between two competing manufacturers and one retailer are, respectively, discussed in [8,44] under the green supply chain. In [39], a differential game model is established for decentralized and centralized decision-making of manufacturers and retailers under the reference price effect. With reference to the low-carbon effect, Stackelberg game is used in [9] to explain the pricing and profit issues of the power plant supply chain. In [15], a carbon emission-dependent demand function is set up to demonstrate the impact of consumer low-carbon effects on emissions and supply chain performance. Revenue sharing contracts and quantity discount contracts are used to ensure the conformity of the supply chain. It is assumed in [35] that consumers are environmentally conscious and pay attention to the carbon footprint of products. On this basis, the study is on the retailer-led supply chain emission reduction strategy and conformity mechanisms. The conformity of the low-carbon supply chain is discussed in [43] under the advertising and easement cost-sharing contract, where retailers have fairness issues and consumers have low-carbon preferences. At present, it is relatively mature to discuss the pricing issues of dual-channel supply chain from different reference effects, which is of great help in studying the impact of reference quality effects on the dual-channel supply chain. With the improvement of people's living standards, residents' income has gradually increased, and the impact of prices on consumers has decreased. Consumers are beginning to pay more attention to product quality. Therefore, product quality has become an important attribute that consumers will consider when purchasing products. In [11], the product quality strategy formulation problem taking into account the reference quality effect is considered. In [16], the influence of the reference quality effect on the corporate price strategy, quality strategy and profit are analyzed, and the investigation shows that the reference quality effect can improve the cost-effectiveness of the product. In [12], by taking into consideration of the reference quality effect, the impacts of short-sighted and forward-looking behaviors of supply chain members on product quality, price strategies and profits are investigated. The results obtained show that the strategies of supply chain members are inseparable from consumer behavior factors. However, recent studies on the reference quality effect mainly focus on the price reference effect, although the reference quality effect is an important factor affecting consumers' purchasing decisions. Incorporating the reference quality effect into the supply chain to further enrich the existing theoretical research is of practical significance.

2.3. Supply chain coordination mechanism

Currently, relevant studies on supply chain coordination mechanisms mainly focus on revenue sharing contracts, cost-sharing contracts and two-part tariff contracts. In [14], the best incentives for end customers and the best profits for supply chain members in terms of concentration, decentralization, and revenue sharing contracts are determined. In [41], based on the demand for consumer utility, two different competitive power structures with and without horizontal coordination are compared. Under the revenue sharing contract, the equilibrium order quantity decision and optimal profit under the centralized and decentralized settings are obtained. In [38], the study aims to find the conditions that should be met by network operating costs in the dual-channel fresh agricultural product supply chain. A revenue sharing contract is proposed to make up for the retailer's loss so as to achieve a win-win situation. In [7], with the help of a revenue sharing contract, the cooperative relationship and risk sharing mechanism between suppliers and retailers are analyzed. In [28], the impact of myopia behavior on the reference quality effect under a revenue sharing contract is studied. In [43], the joint decision-making of supply chain emission reduction and advertising is studied when retailers have fairness concerns, and the coordination of supply chain is realized by designing reasonable cost-sharing contracts. In [17], when consumers have green preferences, the effect of cost-sharing contracts on product greenness, product prices, and supply chain members' income is discussed. In [23], the issue of contract conformity and contract selection in a supply chain composed of a single manufacturer and two competing retailers is considered. In [1], a model is constructed to analyze different pricing structures. The study finds that, within a certain range, manufacturers tend to provide profit-maximizing two-part tariff contracts, rather than quantity discount contracts. Compared with wholesale

TABLE 1. Brief review of related papers in the literature.

	Supply chain		Coordination contract		Reference effect		Function status	
	Single	Dual	With	Without	Consider	Not consider	static	dynamic
Cao [5]		√		√		√	√	
Chen [10]		√		√	√		√	
Gosh [17]		√	√			√	√	
Zhu [44]		√		√	√		√	
Chen [8]		√		√		√	√	
Wang [35]		√	√		√		√	
Zhou [43]		√	√			√	√	
Gavious [16]	√			√	√			√
Dey [14]	√		√			√	√	
Liu [28]		√	√		√			√
This paper		√	√		√		√	

price contracts, the complex contracts proposed in [24] can coordinate the supply chain, achieve optimal channel benefit, and achieve a win-win situation for node enterprises.

The above is a brief summary of current research in the area of supply chain coordination mechanism, see Table 1. So far, there are few papers for which the reference quality effect is included in the dual-channel supply chain. Particularly, no basic theoretical results have been reported. Most of the papers in the literature that consider the reference quality effect are for the case of a single channel, or are with focus on the dynamic analysis of the supply chain. There is a lack of consideration and discussion at the static level. In addition, there are few papers that take into account the selection of a suitable coordination mechanism. Due to the problems mentioned above, it motivates the research of this paper.

3. SYMBOLS AND ASSUMPTIONS

This paper considers a dual supply chain composed of a manufacturer and a retailer, the relationship structure diagram is shown in Figure 1. For this dual-channel supply chain, it is assumed that information between the manufacturer and the retailer is complete. The manufacturer bears the cost of product quality improvement, distributes products to the retailer at wholesale prices, and sells products directly to customers through online platforms. In this model, the retailer only sells products to consumers through retail channels. Consumers can obtain product quality information in advance through product advertisements and offline physical stores, and then decide to purchase the products and and choose appropriate purchase channels.

Hypothesis 1. The manufacturer provides products with a quality level of q and a cost of C, which are sold at a unit price p_m through direct sales channels. The retailer obtains the product with the unit product price of w ($p_m > w$) from the manufacturer. The unit price of the product sold by the retailer to the consumer is p_r. The cost of sales per unit of product is c, and the quality cost is $C = q^2$.

Hypothesis 2. Taking into account the randomness of the two-channel market demand, by using the reference quality equation for products given in [43], the demand functions D_r and D_m of the two channels are:

$$D_r = ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q) \tag{3.1}$$

$$D_m = (1-a)k - \beta_2 p_m + \lambda p_r + \delta q + \alpha_2. \tag{3.2}$$

Here, a is the distribution ratio of the total demand in the traditional channel market; k is the total scale of market demand; β_1 and β_2 are, respectively, the influence coefficients of the demand functions p_r and p_m; λ is the elasticity coefficient of the influence of the sales price between the two channels; δ is the mass elasticity

TABLE 2. The symbols used in this paper are listed below.

Notation	Description
a	The proportion to the total scale of the traditional channel market demand distribution
k	Total market demand
β_1	Retail channel price elasticity coefficient
β_2	Price elasticity coefficient of online direct sales channels
δ	Mass elasticity coefficient
λ	The elasticity coefficient of the influence of the sales price between the two channels
α_1	The elasticity coefficient being considered by retail channels as the reference quality effect
α_2	The elasticity coefficient being considered by online direct sales channels as the reference quality effect
w	Unit wholesale price
c	Unit production cost
q	Product quality
C	Manufacturer's cost of quality
p_r	Retailer price
p_m	Manufacturer price
q_{r0}	Product quality expected by consumers in retail channels
q_{m0}	Consumers' expected product quality in online direct sales channels

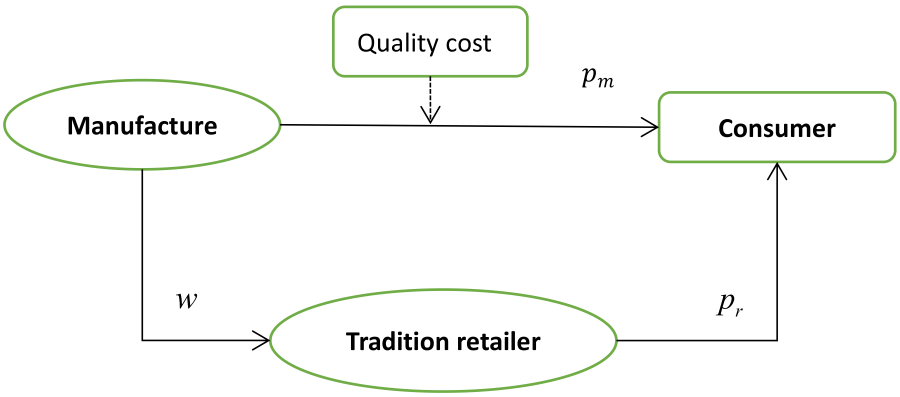

FIGURE 1. Supply chain model diagram.

coefficient; α_1 and α_2 are, respectively, the elasticity coefficients of retail channels and online direct sales channels when the reference quality effect is taken into consideration; q_{r0} is the consumers' expectation of product quality of the product purchased in retail channels; q_{m0} is customers' expectation of product quality of the product purchased from online direct sales channels, see Table 2.

Hypothesis 3. Customers who shop in retail channels can better understand product quality. For customers who shop through online sales platforms, they can also learn about product quality through advertisements and physical stores. However, only few people who shop online will learn about product quality through these methods. Therefore, the reference quality effect of retail channels should be greater than that of direct sales channels. In addition, when customers make a purchase decision, they will be affected by the sales prices of the two channels and the price factors of their own channels. The price factors of their own price channels will dominate. Therefore, $\delta > \alpha_1 > \alpha_2 > \beta_1 > \beta_2 > \lambda > 0$. The profit functions of the retailer, the manufacturer,

and the dual-channel supply chain are, respectively, given below:

$$\Pi_r = (p_r - w)[ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q)] \tag{3.3}$$

$$\begin{aligned}\Pi_m = {} & (p_m - c)[(1-a)k - \beta_2 p_m + \lambda p_r + \delta q + \alpha_2(q_{m0} - q)] \\ & + (w - c)[ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q)] - q^2\end{aligned} \tag{3.4}$$

$$\begin{aligned}\Pi_c = {} & (p_m - c)[(1-a)k - \beta_2 p_m + \lambda p_r + \delta q + \alpha_2(q_{m0} - q)] \\ & + (p_r - c)[ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q)] - q^2.\end{aligned} \tag{3.5}$$

4. Pricing strategies of dual-channel supply chain under different decision-making modes

4.1. Pricing strategy of dual-channel supply chain under centralized decision-making

For centralized decision-making in a dual-channel supply chain, the manufacturer and the retailer as a whole make centralized decision-making. The following proposition is obtained through taking the partial derivatives with respect to p_r and p_m, and then setting them to equal to zero.

Proposition 4.1. *The optimal prices of the manufacturer and the retailer under the centralized decision-making of the dual-channel supply chain are:*

$$p_r^* = \frac{(1-a)\lambda k + ak\beta_2 + (\lambda + \beta_2)\delta q + c\big(\beta_1\beta_2 - \lambda^2\big) + \beta_2\alpha_1(q_{r0} - q) + \lambda\alpha_2(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} \tag{4.1}$$

$$p_m^* = \frac{(1-a)\beta_1 k + ak\lambda + (\lambda + \beta_1)\delta q + c\big(\beta_1\beta_2 - \lambda^2\big) + \lambda\alpha_1(q_{r0} - q) + \beta_1\alpha_2(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2}. \tag{4.2}$$

Proposition 4.2. *Consider the situation where the actual quality of the product purchased by the consumer is greater than the consumer's expected initial reference quality effect, and the price is an increasing function of the reference quality effect. In this case, consumers can accept an appropriate price increase. On the other hand, for the case when the actual quality of the product purchased by the consumer is lower than the initial reference quality effect expected by the consumer, and the price is a decreasing function of the reference quality effect. In this case, the merchant should lower the price appropriately in order to obtain a higher sales volume.*

Proof. Consider the case when q_{r0} and q_{m0} are greater than q. Then,

$$\frac{\partial p_m^*}{\partial \alpha_1} = \frac{\lambda(q_{r0} - q)}{2\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_m^*}{\partial \alpha_2} = \frac{\beta_1(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} > 0,$$

$$\frac{\partial p_r^*}{\partial \alpha_1} = \frac{\beta_2(q_{r0} - q)}{2\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_r^*}{\partial \alpha_2} = \frac{\lambda(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} > 0.$$

For the case when q_{r0} and q_{m0} are less than q, we have

$$\frac{\partial p_m^*}{\partial \alpha_1} = \frac{\lambda(q_{r0} - q)}{2\beta_1\beta_2 - 2\lambda^2} < 0, \qquad \frac{\partial p_m^*}{\partial \alpha_2} = \frac{\beta_1(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} < 0,$$

$$\frac{\partial p_r^*}{\partial \alpha_1} = \frac{\beta_2(q_{r0} - q)}{2\beta_1\beta_2 - 2\lambda^2} < 0, \qquad \frac{\partial p_r^*}{\partial \alpha_2} = \frac{\lambda(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} < 0.$$

□

Proposition 4.3. *q_r and q_m are given, respectively, by:*

$$q_m = \frac{(\beta_1 + \lambda)\delta - \lambda\alpha_1 - \beta_1\alpha_2}{2\beta_1\beta_2 - 2\lambda^2}, \quad q_r = \frac{(\beta_2 + \lambda)\delta - \lambda\alpha_2 - \beta_2\alpha_1}{2\beta_1\beta_2 - 2\lambda^2}.$$

Proof. The results follow readily from taking partial derivatives of equations (4.1) and (4.2) with respect to q_m and q_r. Since $\delta > \alpha_1 > \alpha_2 > \beta_1 > \beta_2 > \lambda > 0$, $q_m > 0$, $q_r > 0$, it is clear that the optimal pricing of the dual-channel is an increasing function of quality. When considering the reference quality effect, the optimal pricing is higher. □

4.2. Pricing strategy of dual-channel supply chain under decentralized decision-making

In a dual-channel supply chain, the manufacturer and the retailer make decisions to maximize their respective profits. When supply is less than demand, for traditional manufacturing enterprises such as Huawei and Apple, the wholesale price of the product is determined by the manufacturer, and the retailer passively accepts it. The manufacturer has demand for any product it produces. In this kind of push supply chain, the manufacturer dominates and the retailer follows. Therefore, according to the decision-making process between them, they can be divided into Bertrand game and Stackelberg game.

4.2.1. Bertrand game under dual-channel decentralized decision-making

For the Bertrand game, it is applied to the case when the strength of the manufacturer and the retailer are roughly the same, neither party will make a decision based on the decision of the other party. The process of the game is: the manufacturer keeps the wholesale price unchanged, and sets the sales price of online direct sales channels to maximize its own profit. Without knowing the sales price of the online direct sales channel set by the manufacturer, the retailer sets the sales price of the traditional retail channel to maximize its own profit.

Proposition 4.4. *In the Bertrand game, the channel sales price strategies,* $\left(p_r^{B*}, p_m^{B*}\right)$*, of the retailer and the manufacturer are:*

$$p_r^{B*} = \frac{(1-a)\lambda k + 2ak\beta_2 + (\lambda + 2\beta_2)\delta q + w\left(2\beta_1\beta_2 + \lambda^2\right) + (\beta_2 - \lambda)c\lambda + 2\beta_2\alpha_1(q_{r0} - q) + \lambda\alpha_2(q_{m0} - q)}{4\beta_1\beta_2 - \lambda^2} \tag{4.3}$$

$$p_m^{B*} = \frac{(1-a)2\beta_1 k + ak\lambda + (\lambda + 2\beta_1)\delta q + 2c\beta_1(\beta_2 - \lambda) + 3w\beta_1\lambda + \lambda\alpha_1(q_{r0} - q) + 2\beta_1\alpha_2(q_{m0} - q)}{4\beta_1\beta_2 - \lambda^2}. \tag{4.4}$$

4.2.2. Stackelberg game under two-channel decentralized decision-making

The Stackelberg game is applicable to situations where the manufacturer plays a leading role, while the retailer plays a follow-up role. In this case, the retailer first determines the sales price of the retail channel based on the perceived sales price of the online direct sales channel that the manufacturer may set. The manufacturer then determines the sales price of the online direct sales channel based on the sales price of the retail channel to maximize its profit.

Proposition 4.5. *In the Stackelberg game, the manufacturer has a dominant position. The retailer and manufacturer's strategies* p_r^{S*}*,* p_m^{S*}*, for their respective sales prices are:*

$$\begin{aligned} p_r^{S*} = {} & \frac{(4\beta_1\beta_2 - 2\lambda^2)[ak + \delta q + \alpha_1(q_{r0} - q) + \beta_1 w]}{2\beta_1(4\beta_1\beta_2 - \lambda^2)} \\ & + \frac{\lambda\left[(1-a)2\beta_1 k + ak\lambda + (\lambda + 2\beta_1)\delta qc\left(2\beta_1\beta_2 - \lambda^2\right) + (2w - c)\beta_1\lambda + \lambda\alpha_1(q_{r0} - q) + 2\beta_1\alpha_2(q_{m0} - q)\right]}{2\beta_1(4\beta_1\beta_2 - \lambda^2)} \end{aligned} \tag{4.5}$$

$$p_m^{S*} = \frac{(1-a)2\beta_1 k + ak\lambda + (\lambda + 2\beta_1)\delta q + c\left(2\beta_1\beta_2 - \lambda^2\right) + (2w\beta_1 - c\beta_1)\lambda + \lambda\alpha_1(q_{r0} - q) + 2\beta_1\alpha_2(q_{m0} - q)}{4\beta_1\beta_2 - \lambda^2}. \tag{4.6}$$

4.3. The influence of the reference quality effects on the pricing strategy of dual-channel supply chain

From Propositions 4.1, 4.4, and 4.5, the following conclusions can be drawn: under different decision-making models, the reference quality effect has different influences on cross-channel sales prices, and the degree of impact varies greatly.

Corollary 4.6. *In a dual-channel supply chain, the reference quality of retail channel consumers is positively correlated with the retail channel sales price. The reference quality of online direct sales channel customers is positively correlated with the online channel sales price.*

Proof.

$$\frac{\partial p_m^*}{\partial q_{m0}} = \frac{\beta_1\alpha_2}{2\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_r^*}{\partial q_{r0}} = \frac{\beta_2\alpha_1}{2\beta_1\beta_2 - 2\lambda^2} > 0,$$
$$\frac{\partial p_m^{B*}}{\partial q_{m0}} = \frac{2\beta_1\alpha_2}{4\beta_1\beta_2 - \lambda^2} > 0, \qquad \frac{\partial p_r^{B*}}{\partial q_{r0}} = \frac{2\beta_2\alpha_1}{4\beta_1\beta_2 - \lambda^2} > 0,$$
$$\frac{\partial p_m^{S*}}{\partial q_{m0}} = \frac{2\beta_1\alpha_2}{4\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_r^{S*}}{\partial q_{r0}} = \frac{\alpha_1\left(4\beta_1\beta_2 - 2\lambda^2\right) + \lambda^2\alpha_1}{2\beta_1(4\beta_1\beta_2 - 2\lambda^2)} > 0.$$

Corollary 4.6 shows that when the consumer reference quality of a certain channel is high, the sales channel can appropriately increase its sales price to obtain higher profits. Channel merchants can make rational decisions based on the different reference qualities of channel consumers. □

Corollary 4.7. *In a dual-channel supply chain, the reference quality of the corresponding channel will have a positive cross-effect on the value of the channel.*

Proof.

$$\frac{\partial p_m^*}{\partial q_{r0}} = \frac{\lambda\alpha_1}{2\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_r^*}{\partial q_{m0}} = \frac{\lambda\alpha_2}{2\beta_1\beta_2 - 2\lambda^2} > 0,$$
$$\frac{\partial p_m^{B*}}{\partial q_{r0}} = \frac{\lambda\alpha_1}{4\beta_1\beta_2 - \lambda^2} > 0, \qquad \frac{\partial p_r^{B*}}{\partial q_{m0}} = \frac{\lambda\alpha_2}{4\beta_1\beta_2 - \lambda^2} > 0,$$
$$\frac{\partial p_m^{S*}}{\partial q_{r0}} = \frac{\lambda\alpha_1}{4\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_r^{S*}}{\partial q_{m0}} = \frac{2\beta_1\lambda\alpha_2}{2\beta_1(4\beta_1\beta_2 - 2\lambda^2)} > 0.$$

Corollary 4.7 shows that when the reference quality of consumers in any channel improves, the other channel can appropriately increase the sales price, thereby realizing an increase in profits. □

Corollary 4.8. *The consumer reference quality q_{r0} of the retail channel has a greater impact on the sales prices of the retail channel than on the sales prices of the online direct sales channels. The consumer reference quality q_{m0} of the online direct sales channel has a greater impact on the selling price of the online direct sales channel than on the sales price of the retail channel.*

Proof.

$$\frac{\partial p_r^*}{\partial q_{r0}} - \frac{\partial p_m^*}{\partial q_{r0}} = \frac{\beta_2\alpha_1 - \lambda\alpha_1}{2\beta_1\beta_2 - 2\lambda^2} > 0, \qquad \frac{\partial p_m^*}{\partial q_{m0}} - \frac{\partial p_r^*}{\partial q_{m0}} = \frac{\beta_1\alpha_2 - \lambda\alpha_2}{2\beta_1\beta_2 - 2\lambda^2} > 0,$$
$$\frac{\partial p_r^{B*}}{\partial q_{r0}} - \frac{\partial p_m^{B*}}{\partial q_{r0}} = \frac{2\beta_2\alpha_1 - \lambda\alpha_1}{4\beta_1\beta_2 - \lambda^2} > 0, \qquad \frac{\partial p_m^{B*}}{\partial q_{m0}} - \frac{\partial p_r^{B*}}{\partial q_{m0}} = \frac{2\beta_1\alpha_2 - \lambda\alpha_2}{4\beta_1\beta_2 - \lambda^2} > 0,$$
$$\frac{\partial p_r^{S*}}{\partial q_{r0}} - \frac{\partial p_m^{S*}}{\partial q_{r0}} = \frac{\alpha_1\left(4\beta_1\beta_2 - 2\lambda^2\right) + \lambda^2\alpha_1 - 2\beta_1\lambda\alpha_1}{2\beta_1(4\beta_1\beta_2 - 2\lambda^2)} > 0, \qquad \frac{\partial p_m^{S*}}{\partial q_{m0}} - \frac{\partial p_r^{S*}}{\partial q_{m0}} = \frac{2\beta_1\alpha_2 - \lambda\alpha_2}{4\beta_1\beta_2 - 2\lambda^2} > 0.$$

It can be seen from Corollary 4.8 that the consumer reference quality of traditional retail channels not only affects the sales prices of traditional retail channels, but also affects the sales prices of online direct sales channels. However, it has a greater impact on retail channels. Therefore, when the customer reference quality of the retail channel is high, the retailer can increase its sales prices accordingly. When the consumer reference quality of the retail channel exceeds a certain level and the retail price also exceeds a certain level, the manufacturer can take the opportunity to increase the sales price of the online direct sales channel. However, the price increase should be less than the retail price increase. □

5. Analysis of the coordination mechanism of dual-channel supply chain

In traditional business management, the decision-making of supply chain members (*e.g.*, the increase in sales efforts of traditional retailers) will increase the double marginal utility. For the situation considered in this paper, the quality cost paid by the manufacturer under the decentralized decision model cannot be reasonably compensated. Thus, a rational manufacturer will lower the quality level or increase the wholesale price, which will lead to a decline in the overall operational efficiency of the supply chain. This paper proposes two mechanisms to deal with conflicts of interest between the manufacturer and the retailer involved in the supply chain: cost-sharing contracts and two-part tariff contracts.

5.1. Cost-sharing contracts

For cost-sharing contracts, the retailer shares a certain proportion $\Phi(0 < \Phi < 1)$ of the cost of the manufacturer. However, in this coordination mechanism, the manufacturer still dominates the supply chain, and the retailer is the follower. Therefore, the optimization model under the cost-sharing contracts is:

$$\begin{aligned}\Pi_m^C &= (p_m - c)[(1-a)k - \beta_2 p_m + \lambda p_r + \delta q + \alpha_2(q_{m0} - q)] \\ &\quad + (w - c)[ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q)] - \Phi q^2 \qquad (5.1)\\ \Pi_r^C &= (p_r - w)[ak - \beta_1 p_r + \lambda p_m + \delta q + \alpha_1(q_{r0} - q)] - (1-\Phi)q^2. \qquad (5.2)\end{aligned}$$

Using the first-order necessary conditions, the optimal reaction function, p_r^C, for w^C and p_d^C with q being given is:

$$p_r^C = \frac{ak + \delta q + \alpha_1(q_{r0} - q) + \beta_1 w + \lambda p_m}{2\beta_1}. \qquad (5.3)$$

The optimal profit function of the physical store is:

$$\Pi_r^C = \frac{[ak + \delta q + \alpha_1(q_{r0} - q) - \beta_1 c + c\lambda}{16\beta_1} - (1-\Phi)q^2. \qquad (5.4)$$

Substituting p_r^C into Π_m^C gives

$$\begin{aligned}\Pi_m^C &= (p_m - c)\left[\frac{(1-a)2\beta_1 k + ak\lambda + \lambda\beta_1 w + (\lambda + 2\beta_1)\delta q + p_m\left(\lambda^2 - \beta_1\beta_2\right) + \alpha_1(q_{r0} - q) + 2\beta_1\alpha_2(q_{m0} - q)}{2\beta_1}\right] \\ &\quad + (w - c)\left[\frac{ak + \delta q + \alpha_1(q_{r0} - q) - \beta_1 w + \lambda p_m}{2}\right] - \Phi q^2. \qquad (5.5)\end{aligned}$$

With q being given, the manufacturer' s best wholesale price w^C, and the network direct sales price p_m^C are obtained as:

$$\begin{aligned}w^C &= \frac{\left[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2\right]\left[ak\beta_2 + \lambda k(1-a) + c\left(\beta_1\beta_2 - \lambda^2\right) + \beta_2\alpha_1 q_{r0} + \lambda\alpha_2 q_{m0}\right]}{2(\beta_1\beta_2 - \lambda^2)[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2]} \\ &\quad + \frac{[\beta_2(\delta - \alpha_1) + \lambda(\delta - \alpha_2)][(\delta - \alpha_1)(ak + \alpha_1 q_{r0} + c\lambda - \beta_1 c)]}{2(\beta_1\beta_2 - \lambda^2)[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2]} \qquad (5.6)\\ p_m^C &= \frac{\left[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2\right]\left[ak\lambda + \beta_1 k(1-a) + c\left(\beta_1\beta_2 - \lambda^2\right) + \lambda\alpha_1 q_{r0} + \beta_1\alpha_2 q_{m0}\right]}{2(\beta_1\beta_2 - \lambda^2)[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2]} \\ &\quad + \frac{[\lambda(\delta - \alpha_1) + \beta_1(\delta - \alpha_2)][(\delta - \alpha_1)(ak + \alpha_1 q_{r0} + c\lambda - \beta_1 c)]}{2(\beta_1\beta_2 - \lambda^2)[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2]}. \qquad (5.7)\end{aligned}$$

Substituting w^C and p_m^C into the expression of p_r^C gives

$$p_r^C = \frac{\left[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2\right]\left[(ak + \alpha_1 q_{r0})\left(3\beta_1\beta_2 - \lambda^2\right) + 2\beta_1 k\lambda(1-a) + c\left(\beta_1\beta_2 - \lambda^2\right)(\beta_1 + \lambda) + 2\lambda\beta_1\alpha_2 q_{m0}\right]}{4\beta_1(\beta_1\beta_2 - \lambda^2)[16\beta_1(1-\Phi) - (\delta - \alpha_1)^2]}$$

$$+\frac{\left[\left(3\beta_1\beta_2-\lambda^2\right)(\delta-\alpha_1)+2\lambda\beta_1(\delta-\alpha_2)\right]\left[(\delta-\alpha_1)(ak+\alpha_1 q_{r0}+c\lambda-\beta_1 c)\right]}{4\beta_1(\beta_1\beta_2-\lambda^2)[16\beta_1(1-\Phi)-(\delta-\alpha_1)^2]}. \tag{5.8}$$

Substitute w^C and p_m^C into the expression of Π_r^C. Take partial derivative of the resulting Π_r^C with respect to q and then setting it to equal to zero. Thus the product quality level q is:

$$q=\frac{[(\delta-\alpha_1)(ak+\alpha_1 q_{r0}+c\lambda-\beta_1 c)]}{[16\beta_1(1-\Phi)-(\delta-\alpha_1)^2]}. \tag{5.9}$$

Proposition 5.1. *It holds that $p_m^C > p_m^B$ and $p_m^C > p_m^S$, while $p_r^C > p_r^B$ and $p_r^C > p_r^S$.*

When other conditions remain unchanged, under the cost-sharing contracts, the profits of the manufacturer, the retailer and the supply chain systems are higher than those under the decentralized decision-making. It can be explained as follows. Compared with decentralized decision-making, cost-sharing contracts can increase the profits of the manufacturer and the retailer, thereby improving the efficiency of the supply chain system.

5.2. Two-part tariff contracts

This is an effective mechanism to solve the profit distribution between the manufacturer and the retailer. With this mechanism, the manufacturer gives the retailer a certain wholesale price, and the retailer gives the manufacturer a fixed fee. The goal is to maximize the profit of the retailer, while also increasing the profit of the manufacturer. To achieve dual-channel supply chain coordination, two-part tariff contracts (w, f) are adopted, where the manufacturer sets the wholesale price of w to the retailer, and f is the fixed income that the manufacturer receives from the retailer. Here, $f \geq 0$. Then, under the two-part tariff contracts, the manufacturer's profit function is:

$$\begin{aligned}\Pi_m^{\wedge} &= (p_m-c)[(1-a)k-\beta_2 p_m+\lambda p_r+\delta q+\alpha_2(q_{m0}-q)]\\ &\quad+(w-c)[ak-\beta_1 p_r+\lambda p_m+\delta q+\alpha_1(q_{r0}-q)]-q^2+f.\end{aligned} \tag{5.10}$$

The retailer' s profit function is:

$$\Pi_r^{\wedge}=(p_r-w)[ak-\beta_1 p_r+\lambda p_m+\delta q+\alpha_1(q_{r0}-q)]-f. \tag{5.11}$$

Let the fixed income $f^{\wedge}$ received by the manufacturer from the retailer be greater than μ, where $\mu \geq 0$ is a certain fixed value. μ does not affect the optimal sales price of the retailer. The expression of $f^{\wedge}$ is:

$$f^{\wedge}=(p_r-w)[ak-\beta_1 p_r+\lambda p_m+\delta q+\alpha_1(q_{r0}-q)]-\mu. \tag{5.12}$$

The profit function of the manufacturer is:

$$\begin{aligned}\Pi_m^{\wedge} &= (p_m-c)[(1-a)k-\beta_2 p_m+\lambda p_r+\delta q+\alpha_2(q_{m0}-q)]\\ &\quad+(p_r-c)[ak-\beta_1 p_r+\lambda p_m+\delta q+\alpha_1(q_{r0}-q)]-q^2-\mu.\end{aligned} \tag{5.13}$$

Under the $(w, f^{\wedge})$ contract, the optimization problem for the manufacturer to maximize its profit is:

$$\begin{aligned}\max_{p_r,w}\Pi_m^{\wedge} &= (p_m-c)[(1-a)k-\beta_2 p_m+\lambda p_r+\delta q+\alpha_2(q_{m0}-q)]\\ &\quad+(p_r-c)[ak-\beta_1 p_r+\lambda p_m+\delta q+\alpha_1(q_{r0}-q)]-q^2-\mu\\ \frac{\partial\Pi_m^{\wedge}}{\partial p_r} &= ak-2(\beta_1+\alpha_1)p_r+\lambda p_m+\delta q+\alpha_1 q_{r0}+w(\beta_1+\alpha_1)=0.\end{aligned} \tag{5.14}$$

Proposition 5.2. *Under the two-part tariff contracts $(w^{\wedge}, f^{\wedge})$, the conformity of the dual-channel supply chain is achieved.*

Proof. Take the partial derivative of $\Pi_r^\wedge$ with respect to p_r and set it equal to zero. Then,

$$p_r^\wedge = \frac{ak + \delta q + \alpha_1(q_{r0} - q) + \beta_1 w + \lambda p_m}{2\beta_1}. \tag{5.15}$$

Substitute $p_r^\wedge$ into the manufacturer' s profit function $\Pi_m^\wedge$. Then, takes the partial derivatives of the resulting $\Pi_m^\wedge$ with respect to w and p_m, and then setting them equal to 0. This gives

$$\frac{\partial \Pi_m^\wedge}{\partial w} = \frac{\beta_1 c + \lambda p_m - \lambda c}{\beta_1} = 0 \tag{5.16}$$

$$\frac{\partial \Pi_m^\wedge}{\partial p_m} = \frac{(1-a)2\beta_1 k + 2ak\lambda + 2(\lambda+\beta_1)\delta q + c\left(2\beta_1\beta_2 - \lambda^2\right) + (w-c)\beta_1\lambda + 2\lambda\alpha_1(q_{r0} - q) + 2\beta_1\alpha_2(q_{m0} - q)}{4\beta_1\beta_2 - 3\lambda^2}. \tag{5.17}$$

By rearrangement, it follows that

$$p_m^\wedge = \frac{(1-a)\beta_1 k + ak\lambda + (\lambda+\beta_1)\delta q + c\left(\beta_1\beta_2 - \lambda^2\right) + \lambda\alpha_1(q_{r0} - q) + \beta_1\alpha_2(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2} \tag{5.18}$$

$$w^\wedge = \frac{(1-a)\lambda\beta_1 k + ak\lambda^2 + (\lambda+\beta_1)\lambda\delta q + \lambda c\left(\lambda^2 - 2\beta_1\beta_2\right) + 2c\left(\beta_1^2\beta_2 - \lambda^2\beta_1\right) + \lambda^2\alpha_1(q_{r0} - q) + \lambda\beta_1\alpha_2(q_{m0} - q)}{\beta_1(2\beta_1\beta_2 - 2\lambda^2)}. \tag{5.19}$$

Substituting $p_m^\wedge$ and $w^\wedge$ into $p_r^\wedge$ gives

$$p_r^* = \frac{(1-a)\lambda k + ak\beta_2 + (\lambda+\beta_2)\delta q + c\left(\beta_1\beta_2 - \lambda^2\right) + \beta_2\alpha_1(q_{r0} - q) + \lambda\alpha_2(q_{m0} - q)}{2\beta_1\beta_2 - 2\lambda^2}. \tag{5.20}$$

The optimal selling prices for the manufacturer and the retailer under centralized decision-making should be equal to the optimal sales prices for the manufacturer and the retailer under decentralized decision-making. This shows that the dual-channel supply chain has achieved coordination. Combining the results obtained above, this paper concludes that the use of a two-part tariff contract can achieve the coordination of the dual-channel supply chain. □

Proposition 5.3. $\Pi_m = \Pi_m^\wedge > \Pi_m^C$ *and* $\Pi_r = \Pi_r^\wedge > \Pi_r^C$.

The two-part tariff contracts realize the coordination of the dual-channel supply chain and solve the problem of double marginal effect in the supply chain. Although the cost-sharing contracts do not completely settle the matter of dual-channel supply chain coordination, it increases the profits of the manufacturer and the retailer to a certain extent, and improves the efficiency of the dual-channel supply chain.

6. Illustrative example

6.1. The impact of centralized and decentralized system on equilibrium results

To illustrate the influence of consumers' reference quality effect on various equilibrium policies, the following comparative analysis is made through numerical examples. The parameter setting in this paper is as that reported in [16]. The total market size $k = 400$, the market demand distribution ratio $a = 0.6$, the retail channel reference quality $q_{r0} = 35$, the reference quality of the online direct sales channel $q_{m0} = 30$, product quality $q = 28$, production cost $c = 20$, wholesale price $w = 30$, the elasticity coefficient $\lambda = 3$ that affects the sales price between the two channels, the price elasticity coefficient of the traditional retail channel $\beta_1 = 6$, the price elasticity coefficient of the online direct sales channel $\beta_2 = 5$, mass elastic coefficient $\delta = 10$, the elasticity coefficient $\alpha_1 = 8$ being considered by the retail channel as the reference quality effect, and the elasticity coefficient $\alpha_2 = 7$ being considered by the online direct sales channel as the reference quality effect.

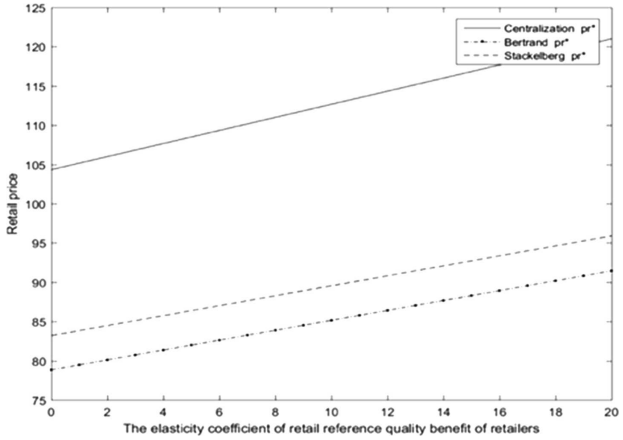

FIGURE 2. The trends of retailer prices with α_1.

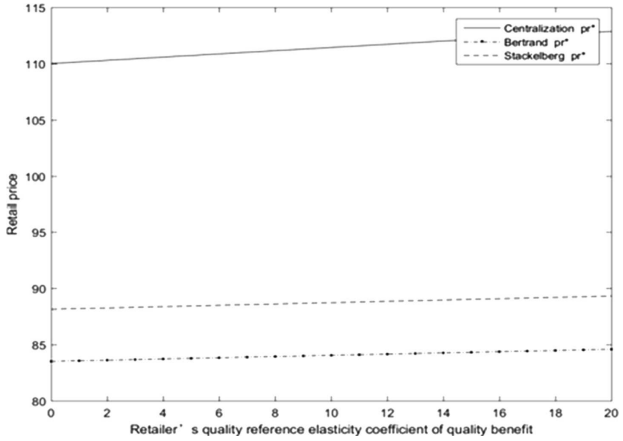

FIGURE 3. The trends of retailer prices with α_2.

(1) The results obtained in Corollaries 4.6 and 4.7 show that the equilibrium values of the retailer and the manufacturer are positively related to the reference quality effect, which are increasing functions of the reference quality effect elasticity coefficients α_1 and α_2. The improvement of the consumer reference quality effect is beneficial to the retailer as well as the manufacturer. The cross-effects between the two channels are also beneficial to all parties. The retailer' s equilibrium price is influenced more by the reference quality effect coefficient α_1 of the retailer than the reference quality effect coefficient α_2 of the manufacturer. It is seen from the slopes of the curves depicted in Figures 2 and 3 that the manufacturer' s equilibrium price is affected more by the reference quality effect coefficient α_2 of the manufacturer than the reference quality effect coefficient α_1 of the retailer. From the slopes of the curves depicted in Figures 4 and 5, it can be seen that the larger the α_1, α_2, the more obvious the reference quality effect. Therefore, the manufacturer will pay more attention to improve product quality so as to better respond to consumers' increased sensitivity to quality. Buyers are willing to pay higher prices for products with improved quality. Due to the increase in costs, the manufacturer will increase the wholesale prices of products accordingly, as such retailer will also increase their sales prices.

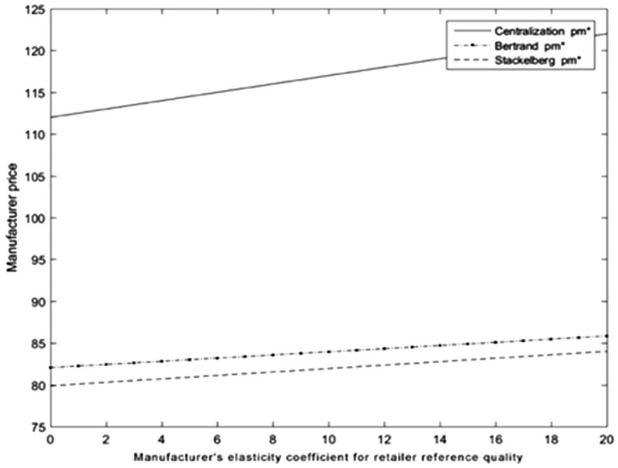

FIGURE 4. The manufacturer's price trends related to α_1.

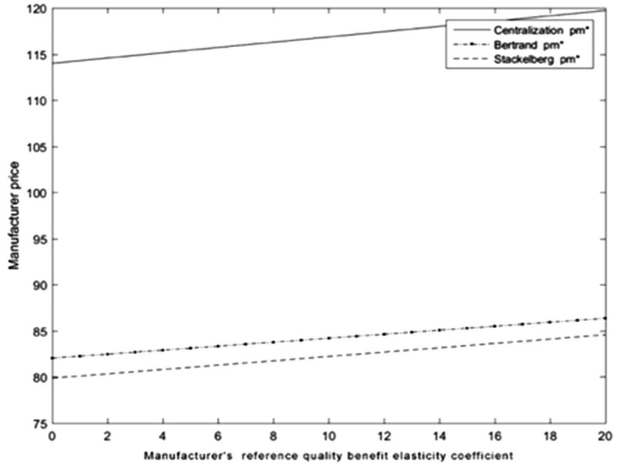

FIGURE 5. The manufacturer's price trends related to α_2.

(2) Figures 2–5 show that the equilibrium price under centralized decision-making is higher than the equilibrium price under decentralized decision-making. The centralized consideration maximizes the profit of the supply chain system, while for the decentralized decision-making, the manufacturer and the retailer pay attention to their own profits. For different decentralized decisions, under the Stackelberg game, the traditional retail channel price is higher than the retail price under the Bertrand game. The manufacturer's online direct sales price under the Bertrand game is higher than the direct sales price under the Stackelberg game. This is because Bertrand's oligopoly game chooses prices to compete, and the lower price will win the entire market. The manufacturer's wholesale price is fixed, and the retailer formulates the retail price without the knowledge of the sales price of the direct sales channel. In the Stackelberg game, the manufacturer dominates, and the retailer follows. The manufacturer is more concerned about how to achieve optimal output to maximize profits.

(3) From Figures 6 to 9, it can be seen that with the reference quality effects being taken into account, the sales prices of the traditional retail channel and the online direct sales channel have increased when compared

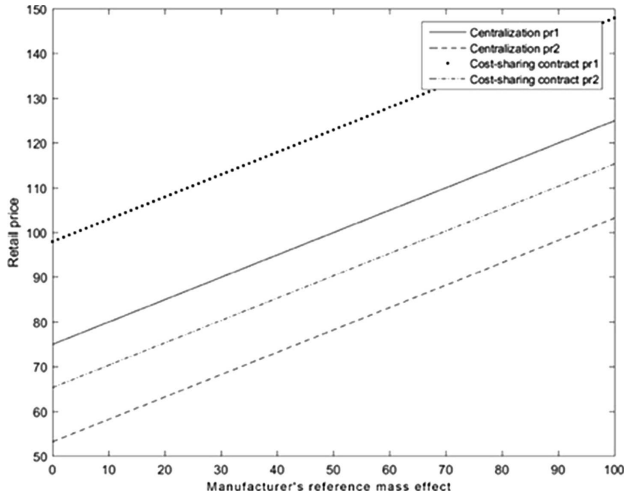

FIGURE 6. The retailer's price trends related q_{m0}, with or without q_{r0}.

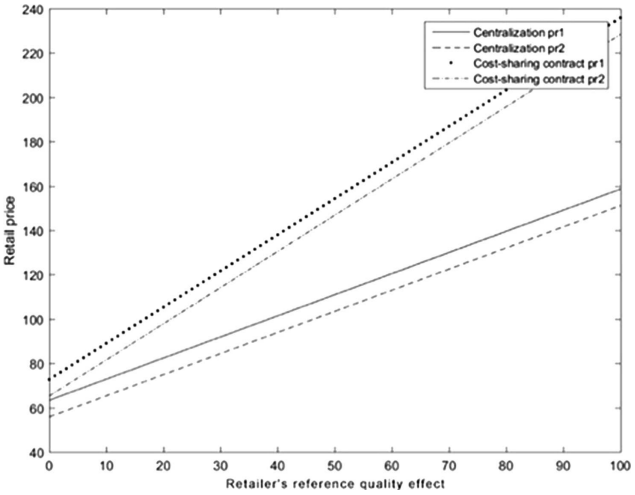

FIGURE 7. The retailer's price trends related q_{r0}, with or without q_{m0}.

with the case where the reference quality effect is not taken into consideration, regardless of whether it is under centralized decision-making or contract coordination. Since consumers have higher expectation for product quality, in order to retain customers, the manufacturer needs to improve product quality, so as to meet consumer needs. This will, however, lead to an increase in production cost. The increase in production cost will, in turn, lead to an increase in wholesale price and online direct sales price. An increase in the wholesale price of product will cause the sales price of the traditional retail channel to go up. When the reference quality effect is not taken into account, the price curve of the retailer has a greater decline than that of the manufacturer, as shown in Figures 6 and 8. When the reference quality effect of the manufacturer is not being considered, the manufacturer's price curve has a greater decline than that of the retailer, as shown in Figures 7 and 9. The results show that the retailer's reference quality effect has a greater impact

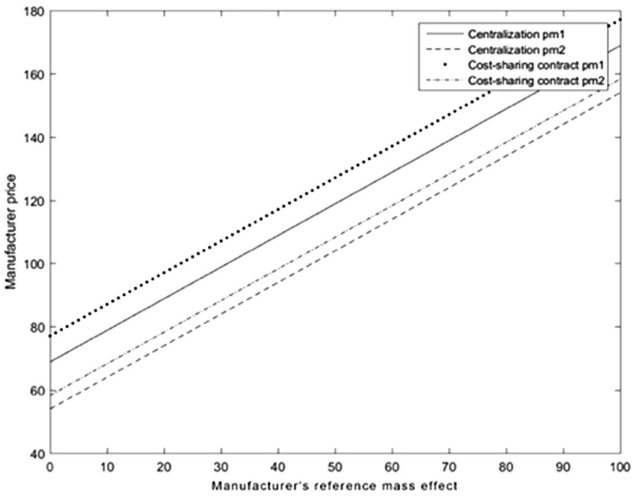

FIGURE 8. The manufacturer's price trends related to q_{m0}, with or without q_{r0}.

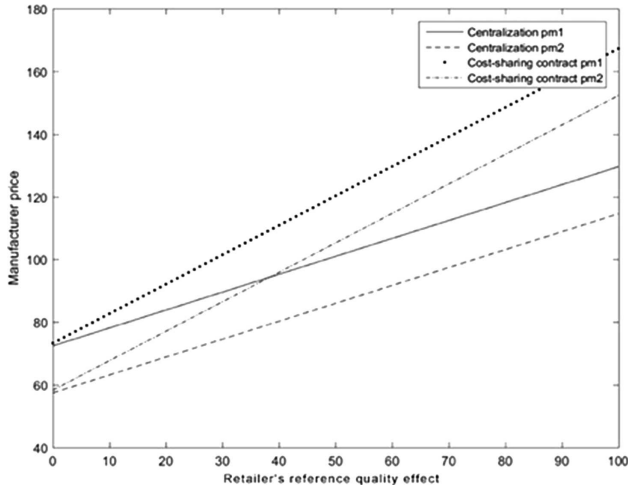

FIGURE 9. The manufacturer's price trends related to q_{r0}, with or without q_{m0}.

on the traditional retail channel than on the online direct sales channel. Manufacturer's reference quality effect has a greater impact on the direct sales channel than on the traditional retail channel.

(4) By virtue of the analysis of the slopes of the curves, it is noted that the profit of the supply chain system is an increasing function in relation to the reference quality effect. Furthermore, the influence of the retail channel reference quality effect on the supply chain system is greater than that of the direct sales channel. As the reference quality effect increases, the manufacturer will increase its investment to improve product quality to gain more favor from consumers. This will lead to an increase in the production cost and as such will increase the wholesale price. However, the increased sales can make up for the increased production cost. Therefore, the manufacturer's profit will not decrease. The retailer does not need to share the cost of improving product quality. Despite rising retail price, most customers are willing to pay more for high-

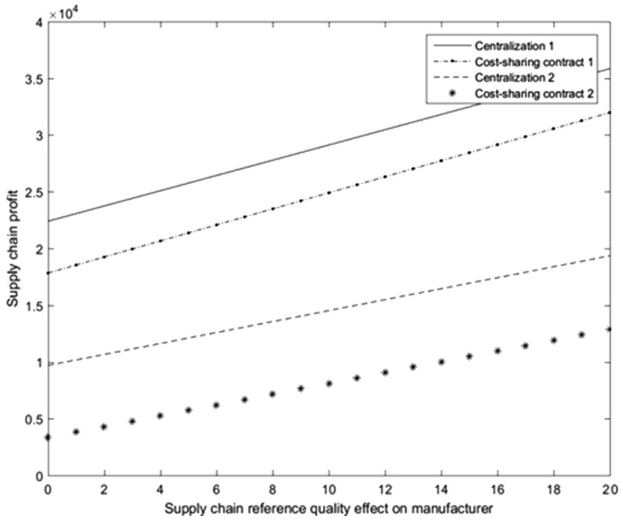

FIGURE 10. Supply chain profit trends related to q_{m0}, with or without q_{r0}.

quality products, resulting in an increase of profit for the retailer. Therefore, with the improvement of the reference quality effect, the profit of the supply chain system will go up.

(5) The dual-channel supply chain can achieve coordination between the two-part tariff contracts, and the profit curves completely overlap. The profit of the supply chain system under centralized decision-making or the two-part tariff contracts is greater than the profit of the supply chain system under the cost sharing contract. Therefore, the two-part tariff contracts are optimal for the supply chain system. The profit of the supply chain system under the cost-sharing contract is affected more than the profit of the supply chain under centralized or two-part tariff contracts. The cost-sharing contracts reduce profits more significantly. But in a cost sharing contract, when the value of Φ is within a certain range, the retailer has a certain bargaining power. According to the example analysis, when the value of Φ is 0.7–0.85, the retailer has a certain bargaining power; when the value of Φ is not within this range, the contract cannot improve the overall profit of the supply chain under the premise of maximizing the retailer's profit, so the retailer has no bargaining power. In a word, for decision makers, the reference quality effect should be taken into consideration so as to meet the customer's continuous quality improvement requirements. The improvement of product quality leads to an increase in production costs, which will lead to an increase in selling prices. Most consumers will accept the increase in price because of the improved product quality. For enterprises, price competition is no longer the most important business competition. Facing the diversification of consumer demand, improving product quality plays an increasingly important role (Figs. 10 and 11).

6.2. Managerial implications

Based on comparative analysis and numerical simulation, the results obtained in this paper have three main management implications. First, in supply chain management, manufacturers will not take the initiative to improve product quality, because such behavior will reduce their profits. Therefore, retailers should actively encourage manufacturers to improve product quality and share the costs involved in quality improvement. Second, dual-channel supply chain companies must coordinate channel sales. In the dual-channel supply chain, the issue of bilateral effects may affect the start-up of the dual-channel supply chain. At the same time, with the increase in the number of direct sales channels in the corporate network, the need to increase investment in quality improvement will become too frequent. Third, due to the increase in the number of direct sales channels,

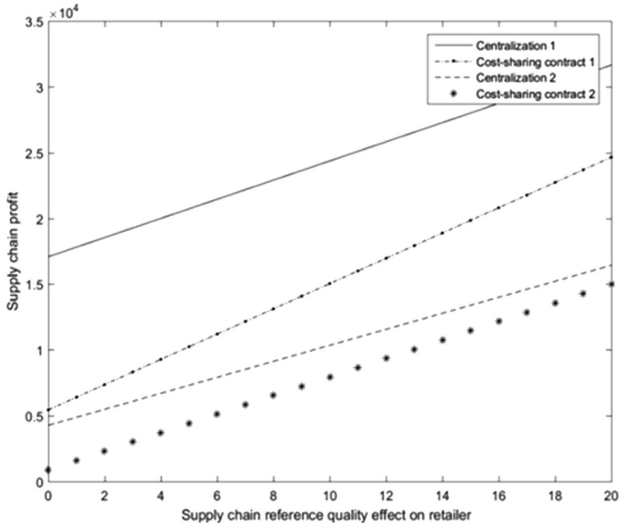

FIGURE 11. Supply chain profit trends related to q_{r0}, with or without q_{m0}.

manufacturers will gain higher market share and profits in the dual-channel supply chain. This is not conducive to market development and mutual benefit. Therefore, the dual-channel supply chain should actively develop a reasonable and effective compliance mechanism and adopt reasonable quality improvement measures. The company must also ensure product quality and coordinate channel conflicts.

7. Conclusions

This paper studies the dual-channel supply chain pricing strategy under the background of considering customer reference quality effect. It has made contributions to the business decision-making management. First, with reference to the quality effect, we used the game method to obtain the optimal equilibrium price of the dual-channel supply chain. Second, we compared the price and profit changes of dual-channel supply chain participants with and without reference quality effect being taken into consideration. Third, we realized the coordination of the dual-channel supply chain through different coordination mechanisms. Specifically, the following conclusions can be drawn from the theoretical results obtained: (1) The equilibrium pricing of each channel of the dual-channel supply chain and the profit of the supply chain system are increasing functions of the quality reference effect. (2) Compared with the case of considering the reference quality effect, ignoring the reference quality effect will lead to a decrease in the equilibrium price and profit of each channel of the dual-channel supply chain. (3) With reference to quality effect, centralized decision-making is better than decentralized decision-making. (4) The cost-sharing contract can improve the efficiency of the dual-channel supply chain to a certain extent, thereby increasing the profit of the dual-channel supply chain system; two pricing contracts can coordinate the dual-channel supply chain.

There are many aspects related to this paper that need to be studied in depth. For example, there is only one manufacturer in the supply chain considered in this paper. What happens when there are multiple manufacturers in the supply chain and there is brand competition? What will happen to the price and how the quality cost should be allocated? When retailers dominate, the results will change. Therefore, there will be of great interest and significance in future research around these aspects. In addition, another interesting future research topic is on the supply chain coordination when retailers dominate and manufacturers follow.

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