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Study on Quality Decision-making and Coordination in Dual-channel When Considering Showrooming Effect

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Abstract

In the Dual-channel supply chain, consumers generally choose the consumption mode of first experiencing offline and then purchasing online. This consumption pattern leads to the increased demand for retailers with their offline services is divided by manufacturers' online direct sales channels, which reduces the retailer's service enthusiasm and intensifies the conflict between channels. To investigate this channel conflict problem, this paper adopt the differential game theory to study the optimal dynamic quality decisions of supply chain members under the showrooming effect. The optimal strategies for centralized Decision-making and decentralized Decision-making are respectively solved, and the manufacturer's service quality cost sharing contract for the retailer is designed. Through this contract, the Pareto improvement of the supply chain system in the case of decentralized Decision-making can be realized. The result shows that in the case of decentralized Decision-making, the manufacturer's product quality decision will not be affected by consumers' showrooming behavior. The retailer's service quality and corporate goodwill will decline with the increase of showrooming effect, which will reduce the overall profit of the supply chain. By establishing a contract for the sharing of service cost between the manufacturer and retailer, this paper also has some conclusion: the negative impact of the showrooming on retailer can be alleviated, the enthusiasm of retailer to provide service is increasing, corporate goodwill is improved, and Pareto improvement of supply chain profits is achieved under decentralized Decision-making.

Keywords

Showrooming; Dual-channel Supply Chain; Quality Decision; Differential Game; Cost Sharing Contract.

1. Introduction

With the rapid development of the Internet, many manufacturing companies have established online direct sales channels, forming a Dual-channel supply chain with the original offline sales channels, such as NIKE, Uniqlo, and Bonobos. In this Dual-channel model, consumers may transfer to the manufacturer's online channel to purchase after experiencing the product performance in the physical store. At this time, the retailer's service has a showrooming effect on the demand of online channel[1,2]. In the sales process of clothing, shoes, furniture, books, sporting goods and electronic products, it is very likely to induce consumers' showrooming behavior[3-5]. When the sales of offline channels are divided by online channels, it will inevitably affect retailers' service enthusiasm, bring resistance from downstream retailers, and exacerbate channel conflicts. For example, Levis finally closed its online store under the resistance of traditional retailers; Daphne announced on August 25, 2020 that it will completely withdraw from the physical retail business. In addition, with the expansion of sales channels, the consumer market continues to expand, leading to the emergence of many homogeneous

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products. Besides the price factor, consumers also consider the quality of the products. Quality includes the quality attributes of the product itself, as well as the service attributes that can only be measured by perception[6]. The quality decision in this article includes product quality decision and service quality decision. Product quality decision mainly refers to the manufacturer's improvement of product appearance and packaging, product quality inspection, establishment of product management mechanism. The service quality mainly refers to the service paid by retailers to provide consumers with relevant product information. Existing studies have shown that manufacturing companies have increased their profits through the operational strategy of quality improvement. In addition to advertising, quality is an important factor affecting consumer brand favorability. Improving product quality and service quality can help establish and improve corporate goodwill[7], and goodwill will have a certain impact on product sales. Manufacturers and retailers must consider this impact on goodwill when making quality decisions. Therefore, how to achieve a win-win situation by making quality decisions and coordinating strategy for supply chain participants are questions worth studying. Taking into account the common consumer's showrooming behavior in the Dual-channel supply chain, we intend to study the following questions

1.What's the influence of showrooming effect on manufacturer and retailer? Does the showrooming effect crack down retailer's activeness in service quality investment?

2.Does the cost-sharing contract reduce the negative effect of showrooming effect on retailer's activeness in service quality investment? Which condition would be more effective in motivating retailer to increase investment?

2. Literature Review

The research is mainly related to following topics: showrooming effect, Dual-channel supply chain coordination and quality research in Dual-channel.

2.1. Showrooming Effect

Research on the phenomenon of showrooming generally believes that consumers' showrooming behaviors will cause damage to physical stores and the supply chain. Basak et al. [5] used game theory to study the price decisions of a physical retailer and an online retailer under the phenomenon of showrooming. The result showed that the showrooming effect would lead to an overall decrease in retail prices, which is beneficial from a consumer's point of view. With the increase of the showrooming coefficient, the profits of the traditional retailer and the online retailer will decrease. The showrooming phenomenon is not only detrimental to traditional retailers, but also detrimental to online retailers. Jing et al. [8] found that the showrooming behavior would intensify channel competition and proposed five short-term strategies to counter the showrooming effect. But these strategies will reduce consumer demand to some extent. Some scholars also analyzed the advantages that showrooming may bring to supply chain members from a positive perspective. Kokho et al. [9] used a qualitative method to study the potential opportunities that the showrooming phenomenon may bring to retailers based on the perspective of consumer shopping experience. The research shows that retailers pay attention to consumers' shopping experience and make decisions, which can turn the threat posed by the showrooming phenomenon into an opportunity that benefits themselves. Kuksov et al. [2] believe that considering the manufacturer's decision, the ability of consumers to participate in the showrooming phenomenon may lead to an increase in the profitability of offline retailers rather than a decrease. Existing research on showrooming mostly focuses on short-term operation strategies, ignoring the long-term dynamics of enterprise operations. Most studies focus on price competition and ignore the impact of non-price factors such as product quality and service quality on the supply chain system. Gensler et al. [10]found that non-price factors play a key role in consumers' showrooming decisions.

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Therefore, it is necessary to pay attention to non-price factors when studying the Decision-making of supply chain members in the context of showrooming.

2.2. Dual-channel Supply Chain Coordination

There have been many studies on Dual-channel supply chain, including channel selection research, channel pricing research, channel coordination research, consumer channel selection research and other aspects. The research in this article mainly involves channel coordination. Regarding channel coordination, the main consideration is the competitive relationship between online and offline channels. Related scholars have designed and analyzed the influence of different incentive mechanisms on the Decision-making and profit function of supply chain members. The research of Yan et al. [11] showed that retailers were unwilling to cooperate with manufacturers to realize profit sharing, and proposed a combination mechanism of financial support and profit sharing, which proved that this mechanism can effectively solve the O2O competition problem and create higher profits for the supply chain participants. Pei et al. [12]propose an innovative and positive strategy can be utilized to solve the issue of O2O competition and conflict and help improve the channel member performance. The innovative strategy consists of the retailer’s sales effort and the manufacturer’s monetary support to the retailer’s local advertising.

2.3. Quality Research in Dual-channel

The research in this article also involves the relationship between the quality decisions of supply chain members and corporate goodwill. Giovanni[13] formulated an optimal control model, which considered the negative impact of product defects on goodwill. Relevant literature mostly considers a single participant, such as a monopoly company or different departments of the same company, but rarely considers the influence of members’ quality decisions on different participants in the context of a Dual-channel supply chain. More and more manufacturing companies have established dual channels for sales. Compared with a single sales channel, Dual-channel involves price games between different entities. At the same time, in the presence of the showrooming phenomenon, demand becomes more complicated than under a single channel. It is of practical significance to study the quality decisions of supply chain members under the background of a Dual-channel.

Based on the existing research, in the context of a Dual-channel supply chain composed of a single manufacturer and a single retailer, this paper aims at the quality Decision-making and coordination problems of the Dual-channel supply chain, and constructs a differential game model, taking the corporate goodwill as a state variable. We consider the impact of the manufacturer’s product quality decision and the retailer’s service quality decision on the manufacturer’s corporate goodwill, as well as on the revenue of the overall supply chain and its members. First, a differential game model considering the showrooming phenomenon is constructed as the basic model, which considers the impact of the quality of service paid by the retailer on the sales of the online channel. Through the solution from HJB equation, we obtain the optimal quality decisions of the manufacturer and the retailer respectively under centralized Decision-making and decentralized Decision-making scenarios. Then, considering the manufacturer’s incentive to the retailer’s service quality, the manufacturer’s service cost sharing contract with the retailer is designed. Finally, the numerical analysis is investigated, which verifies the effectiveness of the contract to coordinate the Dual-channel supply chain.

3. Problem Description and Basic Assumptions

This article considers a Dual-channel supply chain composed of a manufacturer and a retailer. The retailer sells in an offline channel, and the manufacturer sells the same product through its online direct sales channel. The manufacturer is the leader and the retailer is the follower. The two compete in Stackelberg. The manufacturer determines product quality, and the retailer pays a certain service quality effort to provide services to consumers. The improvement of product quality will have a positive impact on the goodwill of the company. Based on the N-A model[14], this paper considers the impact of product quality on goodwill, and obtains the change of goodwill over time as shown in the following formula

$$\acute{G}(t) = \alpha q(t) + \beta e(t) - \lambda G(t)\,, G(0) = G_0 \geq 0 \quad (1)$$

Among them, $q(t)$is the manufacturer's product quality decision. α is the product quality's influence coefficient on goodwill. $e(t)$is the retailer's service quality decision. β is the service quality's influence coefficient on goodwill. λ is the natural decline rate of goodwill, which represents the forgetting effect of consumers on the goodwill.

High quality can increase goodwill and sales. However, while improving quality, it also increases the cost of the manufacturer. Therefore, the manufacturer needs to choose the best quality decision to achieve the goal of maximizing profit. At the same time, the retailer also needs to determine its service quality level with the goal of maximizing the interests. Due to the showrooming phenomenon, some consumers are more inclined to purchase online channel with lower price after experiencing offline stores. Therefore, it is assumed that the retailer's sales effort can not only increase the sales of offline channel, but also increase the sales of online channel. We assume that the sale function of online channel is

$$D_1 = a - p_1 + bp_2 + de(t) + \theta_1 G(t) \quad (2)$$

the sale function of offline channel is

$$D_2 = 1 - a - p_2 + bp_1 + (1 - d)e(t) + \theta_2 G(t) \quad (3)$$

Among them, a is the market share of online channel, and $1 - a$ represents the market share of the offline channel. Respectively, p_1, p_2 are the selling prices of online and offline channels. We assuming that the cross-price impact on sales is less than the impact of channel prices on sales, $b < 1$. $e(t)$ is the service quality of the retailer. d represents the showrooming effect coefficient, which means that among the consumers attracted by the retailer through improving offline services, d ratio of people choose to buy online, and $1 - d$ ratio of people choose to buy offline and $0 < d < 1$ is satisfied. θ_1, θ_2 are the influence coefficients of goodwill on online and offline sales. Assuming that the wholesale price is w and the manufacturer's unit production cost is c.The revenue functions of the manufacturer and the retailer are respectively

$$\pi_M = (p_1 - c)D_1 + (w - c)D_2 - \frac{1}{2}q^2(t)$$

$$\pi_R = (p_2 - w)D_2 - \frac{1}{2}e^2(t)$$

In order to simplify the calculation, we suppose the manufacturer's unit production cost $c = 0$.[15-17] In addition to unit production cost, the manufacturer also bear the cost of product quality. Such cost functions are assumed to be quadratic functions. We assume that the cost of product quality is related to the manufacturer's quality decision, set as $\frac{1}{2}C_1 q^2(t)$.The model does not consider the sales cost of the online channel. The sales cost of the offline channel is related to the retailer's service quality, which is set as $\frac{1}{2}C_2 q^2(t)$ .Simplify cost parameters

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without loss of generality, suppose $C_1 = C_2 = 1$.[13] The time variable t will be omitted below. Then the profit functions of the manufacturer, retailer, and supply chain as a whole are respectively
Where $e^{-\rho t}$ is the discount factor and $\rho > 0$ is the discount rate.

$$\pi_M = \int_0^{\infty} e^{-\rho t}\,[\,p_1 D_1 + wD_2 - \tfrac{1}{2}q^2]dt \tag{4}$$

$$\pi_R = \int_0^{\infty} e^{-\rho t}\,[(p_2 - w)\,D_2 - \tfrac{1}{2}e^2]dt \tag{5}$$

$$\pi = \int_0^{\infty} e^{-\rho t}\,[\,p_1 D_1 +\ p_2 D_2 - \tfrac{1}{2}q^2 - \tfrac{1}{2}e^2]dt \tag{6}$$

4. Model Solution and Analysis

As consumers have more and more channels for obtaining price information, market price gradually become transparent, and corporate pricing is basically determined by the market. Therefore, this article assumes that the sales price p_1 of the online channel, the wholesale prices w, and retail price p_2 of the offline channel are all set to constants[18,19].The differential game model consists of a state variable $G(t)$ and two decision variables. The manufacturer determines the product quality q and the retailer determines the service quality e.

4.1. Centralized Decision Model

In the case of centralized Decision-making, the manufacturer and the retailer together make the decision. The profit maximization of the supply chain system is regarded as the decision goal. The differential game model of the supply chain can be expressed as

$$max\pi = \int_0^{\infty} e^{-\rho t}\,[p_1 D_1 + p_2 D_2 - \frac{1}{2}q^2 - \frac{1}{2}e^2]dt$$
$$\acute{G}(t) = \alpha q(t) + \beta e(t) - \lambda G(t)\,, G(0) = G_0 \geq 0 \tag{7}$$

Proposition 1. Under the centralized Decision-making situation, the manufacturer's optimal product quality strategy and the retailer's optimal service quality strategy are respectively

$$q^C = \frac{\alpha(p_1\theta_1 + p_2\theta_2)}{\rho + \lambda}$$
$$e^C = dp_1 + (1-d)p_2 + \frac{\beta(p_1\theta_1 + p_2\theta_2)}{\rho+\lambda} \tag{8}$$

Proof. Let $V^C(G)$ denote the optimal profit function of the overall supply chain under centralized Decision-making. According to the Bellman dynamic programming theory, construct the HJB equation under centralized Decision-making

$$\rho V^C(G) = max\left\{p_1(a - p_1 + bp_2 + de + \theta_1 G) + p_2(1 - a - p_2 + bp_1 + (1-d)e + \theta_2 G\right.$$
$$\left.) - \tfrac{1}{2}q^2 - \tfrac{1}{2}e^2 + \acute{V^C}(\alpha q + \beta e - \lambda G)\right\} \tag{9}$$

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$$H = p_1(a - p_1 + bp_2 + de + \theta_1 G) + p_2(1 - a - p_2 + bp_1 + (1-d)e + \theta_2 G) - \frac{1}{2}q^2 - \frac{1}{2}e^2 + \acute{V^C}(\alpha q + \beta e - \lambda G)$$

$$\frac{\partial H}{\partial e} = dp_1 + (1-d)p_2 - e + \beta \acute{V^C} = 0$$

$$e^C = dp_1 + (1-d)p_2 + \beta \acute{V^C} \tag{10}$$

$$\frac{\partial H}{\partial q} = -q + \alpha \acute{V^C} = 0$$

$$q^C = \alpha \acute{V^C} \tag{11}$$

Substitute equations (10) and (11) into equation (9). According to the form of the HJB equation, assuming the form of the value function is

$$V^C(G) = B_1 G + B_2 \tag{12}$$

Where B_1, B_2 is the undetermined coefficient, then

$$\acute{V^C} = B_1 \tag{13}$$

Substituting equations (12) and (13) into the simplified HJB equation, the solution is

$$\begin{cases} B_1 = \frac{p_1\theta_1 + p_2\theta_2}{\rho + \lambda} \\ B_2 = \frac{1}{\rho}[p_1(a - p_1) + p_2(1 - a - p_2) + 2bp_1p_2] + \frac{1}{2\rho}(\alpha^2 + \beta^2){B_1}^2 \\ \quad + \frac{1}{2\rho}[dp_1 + (1-d)p_2]^2 + \frac{1}{\rho}\beta B_1[dp_1 + (1-d)p_2] \end{cases} \tag{14}$$

$$\acute{V^C} = B_1 = \frac{p_1\theta_1 + p_2\theta_2}{\rho + \lambda}$$

Substitute $\acute{V^C}$ into equations (10) and (11) to get

$$q^C = \frac{\alpha(p_1\theta_1 + p_2\theta_2)}{\rho + \lambda}$$

$$e^C = dp_1 + (1-d)p_2 + \frac{\beta(p_1\theta_1 + p_2\theta_2)}{\rho + \lambda}$$

Proposition 1 is proved.

Substituting the above optimal strategies into the expression (1) of goodwill and solving the univariate linear differential equation, we can obtain the change form of goodwill.

$$G^C(t) = \left(G_0 - {G_\infty}^C\right)e^{-\lambda t} + {G_\infty}^C \tag{15}$$

The stable state of goodwill $G^C(t)$ is

$$G_\infty{}^C = \frac{(\alpha^2+\beta^2)(p_1\theta_1+p_2\theta_2)}{\rho+\lambda} + \beta[dp_1+(1-d)p_2]$$

From Proposition 1, in the case of centralized Decision-making, from the expression of the manufacturer's optimal product quality decision q^C, it can be seen that the manufacturer's quality decision is related to the selling prices of the two channels. It is also related to the influence coefficients of goodwill on the sales of the two channels. The manufacturer needs to comprehensively consider price and the influence coefficients of goodwill on the two channels before deciding its optimal quality strategy. When online and offline market prices change, manufacturer must make corresponding adjustments. The quality decision of the manufacturer is positively correlated with the influence coefficient α of product quality on the goodwill, that is, the greater the influence of product quality on the goodwill, the more willing the manufacturer to increase quality investment. The reason is that the greater the influence coefficient of product quality on goodwill, the easier it is for the manufacturer to increase its quality investment to increase goodwill, and the increase in goodwill will increase the sales of online and offline channels and bring higher returns to manufacturer. Businesses are motivated to increase quality investment. Manufacturer's product quality decision affects corporate goodwill through the equation of state (1), which in turn affects the sales of online and offline channels.

From the expression of the retailer's optimal service strategy e^C, it can be seen that the retailer's service quality decision is related to the selling prices p_1, p_2 of the two channels, the influence coefficients θ_1, θ_2 of goodwill on the sales of the two channels, and the showrooming effect coefficient d.

The retailer's service quality decision is positively correlated with the influence coefficient β of service quality on goodwill, that is, the greater the influence of service quality on goodwill, the more willing the retailer to increase service quality investment. The same as the product quality of the manufacturer, the retailer's service can also indirectly increase demand by improving goodwill. Different from the product quality decision of the manufacturer, the improvement of the retailer's service quality can directly increase demand, not only increasing the sales of offline channel, but also increasing the sales of online channel due to the existence of the showrooming phenomenon. Therefore, the retailer should comprehensively consider the direct and indirect effects on the two channels when making its service quality decision.

Corollary 1. The partial derivatives of the manufacturer's product quality strategy q^C, the retailer's service quality strategy e^C, and the steady state goodwill $G_\infty{}^C$ with respect to the showrooming coefficient d are respectively

$$\frac{\partial q^C}{\partial d} = 0, \quad \frac{\partial e^C}{\partial d} = p_1 - p_2 < 0, \quad \frac{\partial G_\infty{}^C}{\partial d} = \beta(p_1 - p_2) < 0$$

Corollary 1 shows that under the centralized Decision-making situation, the influence of the showrooming coefficient d on the steady state of goodwill and the retailer's service quality strategy depends on the price difference between the two channels. Specifically, when $p_1 - p_2 < 0$, that is, when the online price is lower than the offline price, the larger the price difference, the smaller the retailer's service quality, and the lower the corporate goodwill level. The greater the online and offline price difference, the more sensitive the retailer's service quality and corporate goodwill will be to the showrooming coefficient. The manufacturer's product quality decision has nothing to do with the size of the showrooming coefficient. The reason is that the showroom effect will only allow the manufacturer to share part of the sales increased by the retailer's service, and will not affect the manufacturer's quality decision.

Corollary 2. The partial derivatives of the manufacturer's product quality strategy q^C, the retailer's service quality strategy e^C, and the steady state goodwill ${G_\infty}^C$ with respect to the influence factor α of product quality on goodwill are respectively

$$\frac{\partial q^C}{\partial \alpha}=\frac{p_1\theta_1+p_2\theta_2}{\rho+\lambda}>0,\quad \frac{\partial e^C}{\partial \alpha}=0,\quad \frac{\partial {G_\infty}^C}{\partial \alpha}=\frac{2\alpha(p_1\theta_1+p_2\theta_2)}{\rho+\lambda}>0$$

Corollary 2 shows that in the case of centralized Decision-making, the greater the influence factor α of product quality on goodwill, the higher the quality of product provided by the manufacturer, and the higher the goodwill of the company. This is because the improvement of the manufacturer's quality level will further increase the company's brand reputation, thereby increasing the online and offline sales of the product. The retailer's service quality level has nothing to do with this impact factor.

Corollary 3. The partial derivatives of the manufacturer's product quality strategy q^C, the retailer's service quality strategy e^C, and the steady state goodwill ${G_\infty}^C$ with respect to the influence factor β of service quality on goodwill are respectively

$$\frac{\partial q^C}{\partial \beta}=0,\quad \frac{\partial e^C}{\partial \beta}=\frac{p_1\theta_1+p_2\theta_2}{\rho+\lambda}>0,$$
$$\frac{\partial {G_\infty}^C}{\partial \beta}=\frac{2\beta(p_1\theta_1+p_2\theta_2)}{\rho+\lambda}+dp_1+(1-d)p_2>0$$

Corollary 3 shows that in the case of centralized Decision-making, the greater the influence factor β of service quality on goodwill, the higher the level of service quality provided by the retailer and the higher goodwill of the enterprise. This is because the improvement of the retailer's service quality will increase the goodwill, and the improvement of the goodwill will increase the retailer's offline channel sales. The larger the factor β, the more motivated the retailer to increase sales in offline channel by increasing the investment in service quality. The manufacturer's product quality decision has nothing to do with this impact factor.

4.2. Decentralized Decision Model

In the case of decentralized Decision-making, both the manufacturer and the retailer aim at maximizing their own profits and each formulate their optimal strategies. The manufacturer makes product quality decisions, and the retailer makes service quality decisions. Use superscript D to indicate. Using differential game theory to solve the optimal decision of the manufacturer and retailer. We can get the following proposition.

Proposition 2. The optimal strategies under decentralized Decision-making are

$$q^D=\frac{\alpha(p_1\theta_1+w\theta_2)}{\rho+\lambda}$$
$$e^D=(1-d)(p_2-w)+\frac{(p_2-w)\beta\theta_2}{\rho+\lambda} \tag{16}$$

Proof. Let $V_M^D(G)$ and $V_R^D(G)$ denote the optimal profit functions of the manufacturer and the retailer under decentralized Decision-making. According to the Bellman dynamic programming theory, construct the HJB equations of the manufacturer and retailer under decentralized Decision-making as follows

$$\rho V_M^D(G) = max\left\{p_1(a - p_1 + bp_2 + de + \theta_1 G) + w(1 - a - p_2 + bp_1 + (1 - d)e + \theta_2 G\right.$$
$$\left.) - \frac{1}{2}q^2 + V_M^{\acute{D}}(\alpha q + \beta e - \lambda G)\right\} \quad (17)$$

$$\rho V_R^D(G) = max\left\{(p_2 - w)(1 - a - p_2 + bp_1 + (1 - d)e + \theta_2 G) - \frac{1}{2}e^2 + V_R^{\acute{D}}(\alpha q + \beta e - \lambda G)\right\} \quad (18)$$

Solving the optimization problem on the right side of the equation, the manufacturer's optimal product quality strategy and the retailer's optimal service strategy are

$$q^D = \alpha V_M^{\acute{D}}$$
$$e^D = (1 - d)(p_2 - w) + \beta V_R^{\acute{D}} \quad (19)$$

Substitute equation (19) into equations (17), (18) and simplify. According to the form of the HJB equation, it is assumed that the value functions of the manufacturer and retailer are respectively

$$V_M^D(G) = m_1 G + m_2$$
$$V_R^D(G) = n_1 G + n_2 \quad (20)$$

Where m_i and n_i $(i = 1,2)$ are undetermined coefficients, then there are

$$V_M^{\acute{D}} = m_1$$
$$V_R^{\acute{D}} = n_1 \quad (21)$$

Substituting equations (20) and (21) into the simplified HJB equations, the solutions are

$$\begin{cases} m_1 = \frac{p_1\theta_1 + w\theta_2}{\rho + \lambda} \\ m_2 = \frac{p_1}{\rho}(a - p_1 + bp_2) + \frac{w}{\rho}(1 - a - p_2 + bp_1) + \frac{1}{2\rho}\alpha^2 {m_1}^2 \\ \quad + \frac{1}{\rho}[p_1 d + w(1 - d) + \beta m_1][(p_2 - w)(1 - d) + \beta n_1] \end{cases} \quad (22)$$

$$\begin{cases} n_1 = \frac{(p_2 - w)\theta_2}{\rho + \lambda} \\ n_2 = \frac{1}{\rho}[(p_2 - w)(1 - a - p_2 + bp_1) + \alpha^2 m_1 n_1] \\ \quad + \frac{1}{2\rho}[(p_2 - w)(1 - d) + \beta n_1]^2 \end{cases} \quad (23)$$

Substituting $V_M^{\acute{D}}, V_R^{\acute{D}}$ into equation (19), we get

$$q^D = \frac{\alpha(p_1\theta_1 + w\theta_2)}{\rho + \lambda}$$

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$$e^D = (1-d)(p_2 - w) + \frac{(p_2 - w)\beta\theta_2}{\rho + \lambda}$$

Proposition 2 is proved.

Substituting the above optimal strategies into the expression of goodwill and solving the univariate linear differential equation, we can obtain the change form of goodwill.

$$G^D(t) = \left(G_0 - {G_\infty}^D\right)e^{-\lambda t} + {G_\infty}^D \tag{24}$$

The stable state of goodwill $G^D(t)$ is

$${G_\infty}^D = \frac{\alpha^2 p_1\theta_1 + \beta^2 p_2\theta_2 + (\alpha^2 - \beta^2)w\theta_2}{\rho + \lambda} + \beta(1-d)(p_2 - w)$$

It can be seen from Proposition 2 that the manufacturer's product quality decision is related to the price and wholesale price of the online channel, but has nothing to do with the price of the offline channel. The retailer's service quality decision is related to the offline channel price and the wholesale price, not to the online channel price. The manufacturer's quality decision is not only related to the influence coefficient θ_1 of goodwill on online channel sales, but also the influence coefficient θ_2 of goodwill on offline channel sales. This is because offline sales will also affect the manufacturer's revenue. The bigger θ_2 is, the more offline sales. That means the more wholesale revenue the manufacturer receives from the retailer, and the greater the manufacturer's total profit. The retailer's service quality decision has nothing to do with θ_1, but only with θ_2.Under the same conditions, the greater the influence coefficient θ_2 of goodwill on offline channel sales, the higher the retailer's service quality.

Corollary 4. The partial derivatives of the manufacturer's product quality strategy q^D, the retailer's service quality strategy e^D, and the steady state goodwill ${G_\infty}^D$ with respect to the showrooming coefficient d are respectively

$$\frac{\partial q^D}{\partial d} = 0,\quad \frac{\partial e^D}{\partial d} = -(p_2 - w) < 0,\quad \frac{\partial {G_\infty}^D}{\partial d} = -(p_2 - w) < 0$$

Corollary 4 shows that in the case of decentralized Decision-making, the steady state of goodwill and the retailer's service quality strategy are all negatively related to the showrooming coefficient. The manufacturer's product quality decision has nothing to do with the size of the showrooming coefficient. In the case of decentralized Decision-making, with the enhancement of showrooming, more consumers will choose the online channel to purchase among the consumers attracted by the retailer by improving offline services. This leads the retailer to reduce service level to reduce costs. It will also reduce the goodwill of the company.

Corollary 5. The partial derivatives of the manufacturer's product quality strategy q^D, the retailer's service quality strategy e^D, and the steady state goodwill ${G_\infty}^D$ with respect to the influence factor α of product quality on goodwill are respectively

$$\frac{\partial q^D}{\partial \alpha} = \frac{p_1\theta_1 + w\theta_2}{\rho + \lambda} > 0,\quad \frac{\partial e^D}{\partial \alpha} = 0,\quad \frac{\partial {G_\infty}^D}{\partial \alpha} = \frac{2\alpha(p_1\theta_1 + w\theta_2)}{\rho + \lambda} > 0$$

Corollary 5 shows that in the case of decentralized Decision-making, the greater the influence factor α of product quality on goodwill, the higher the quality provided by the manufacturer, and the higher the goodwill of the company. This is because the higher α, the higher the manufacturer's quality level will further improve the company's brand reputation, thereby increasing the online and offline sales of the product. The retailer's service quality level has nothing to do with this impact factor.

Corollary 6. The partial derivatives of the manufacturer's product quality strategy q^D, the retailer's service quality strategy e^D, and the steady state goodwill $G_\infty{}^D$ with respect to the influence factor β of service quality on goodwill are respectively

$$\frac{\partial q^D}{\partial \beta} = 0, \frac{\partial e^D}{\partial \beta} = \frac{(p_2 - w)\theta_2}{\rho + \lambda} > 0,$$
$$\frac{\partial G_\infty{}^D}{\partial \beta} = \frac{2\beta(p_2 - w)\theta_2}{\rho + \lambda} + (1 - d)(p_2 - w) > 0$$

Corollary 6 shows that in the case of decentralized Decision-making, the level of service quality provided by the retailer and the goodwill of the enterprise are positively related to the impact factor β of the retailer's service quality on goodwill. The manufacturer's product quality decision has nothing to do with β.This is because after retailer's service quality level is improved, the offline physical store can bring consumers more information about products and better shopping experience. The larger β, the easier it is to increase the goodwill of the company and promote the sales of online and offline.

Corollary 7. Comparing the manufacturer's optimal product quality decision, the retailer's optimal service quality decision, corporate goodwill and the respective sales of the two channels in the two situations of centralized and decentralized Decision-making, we can obtain

$$q^C > q^D, e^C > e^D, G_\infty{}^C > G_\infty{}^D, D_1{}^C > D_1{}^D, D_2{}^C > D_2{}^D$$

Corollary 7 shows that in the case of centralized Decision-making, the corporate goodwill, the quality effort of the manufacturer and the retailer are greater than that of decentralized Decision-making. The demand for online and offline channels under centralized Decision-making is greater than that under decentralized Decision-making. In the case of decentralized Decision-making, the strategies of the manufacturer and the retailer are to maximize their own interests. The retailer will be affected by consumers' showrooming behavior and will correspondingly reduce service costs, which will lead to a decline in goodwill. The decline in goodwill will lead to a decline in sales in both channels. This is not conducive to the improvement of the overall profit of the supply chain, so it is necessary to introduce a cooperation contract to realize the coordination and improvement of the supply chain in the case of decentralized Decision-making.

4.3. Service Quality Cost Sharing Model

From the above analysis, it can be seen that the quality decision of the supply chain members, the goodwill of the company, and the sales of two channels under the decentralized Decision-making situation are lower than those under the centralized Decision-making situation, and the supply chain system cannot achieve the optimal state. Retailer's improvement in service quality can directly increase the sales of offline channel. At the same time, due to the existence of the showrooming phenomenon, it can also indirectly increase the sales of online channel. While increasing Dual-channel revenue, it also intensifies competition between online and offline channels. In order to alleviate channel competition and achieve Pareto improvement, this paper designs an incentive mechanism for the manufacturer to provide the retailer with certain transfer payments. That is, the manufacturer shares part of retailer's service quality investment under decentralized Decision-making. Assuming the sharing ratio is γ, the transfer payment provided by the manufacturer is $T=\frac{1}{2}\gamma e^2$.The manufacturer is in a leader position, and first make product quality and sharing ratio decisions. The retailer determines service quality strategy based on the manufacturer's strategy. Using the reverse induction method, we first solved the retailer's strategy, and then bring it into the manufacturer's HJB equation to obtain the optimal service quality cost sharing ratio. The model is

$$\begin{gathered} max\pi_M=\int_0^\infty e^{-\rho t}\,[p_1D_1+wD_2-\frac{1}{2}q^2-\frac{1}{2}\gamma e^2]dt \\ max\pi_R=\int_0^\infty e^{-\rho t}\,[(p_2-w)D_2-\frac{1}{2}(1-\gamma)e^2]dt \\ \acute{G}(t)=\alpha q(t)+\beta e(t)-\lambda G(t)\,,G(0)=G_0\geq 0 \end{gathered} \tag{25}$$

Proposition 3. Under the incentive mechanism that the manufacturer shares part of the service quality cost, the manufacturer's optimal product quality strategy, the retailer's optimal service quality strategy and the cost sharing ratio are respectively

$$\begin{gathered} q^B=\frac{\alpha(p_1\theta_1+w\theta_2)}{\rho+\lambda} \\ e^B=p_1d+\frac{1}{2}(p_2+w)(1-d)+\frac{\beta[2p_1\theta_1+(p_2+w)\theta_2]}{2(\rho+\lambda)} \\ \gamma^B=\frac{(\rho+\lambda)[2p_1d+(3w-p_2)(1-d)]+\beta[2p_1\theta_1+(3w-p_2)\theta_2]}{(\rho+\lambda)[2p_1d+(w+p_2)(1-d)]+\beta[2p_1\theta_1+(w+p_2)\theta_2]} \end{gathered} \tag{26}$$

Proof. Let $V_M^B(G)$ and $V_R^B(G)$ respectively denote the optimal profit functions of the manufacturer and the retailer under the service quality cost sharing mode. In this case, the value function of the retailer satisfies the HJB equation is

$$\rho V_R^B(G)=max\left\{(p_2-w)(1-a-p_2+bp_1+(1-d)e+\theta_2G)-\frac{1}{2}(1-\gamma)e^2+\acute{V}_R^B(\alpha q+\beta e-\lambda G)\right\} \tag{27}$$

Solving the optimization problem on the right side of the equation, the retailer's optimal service quality strategy can be obtained as

$$e^B=\frac{(p_2-w)(1-d)+\beta\acute{V}_R^B}{1-\gamma} \tag{28}$$

The HJB equation satisfied by the manufacturer's value function in the case of service quality cost sharing is

$$\begin{gathered} \rho V_M^B(G)=max\left\{p_1(a-p_1+bp_2+de+\theta_1G)+w(1-a-p_2+bp_1+(1-d)e+\theta_2G\right. \\ \left.)-\frac{1}{2}q^2-\frac{1}{2}\gamma e^2+\acute{V}_M^B(\alpha q+\beta e-\lambda G)\right\} \end{gathered} \tag{29}$$

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Substitute equation (28) into equation (29) to simplify and solve the optimization problem. The manufacturer's optimal product quality decision and optimal service quality cost sharing ratio are obtained respectively

$$q^B = \alpha \acute{V}_M^B \tag{30}$$

$$\gamma^B = \frac{2[dp_1 + w(1-d) + \beta \acute{V}_M^B] - [(p_2 - w)(1-d) + \beta \acute{V}_R^B]}{2[dp_1 + w(1-d) + \beta \acute{V}_M^B] + [(p_2 - w)(1-d) + \beta \acute{V}_R^B]} \tag{31}$$

Assume that the value function of the manufacturer and retailer are as follows

$$\begin{gathered} V_M^B(G) = l_1 G + l_2 \\ V_R^B(G) = g_1 G + g_2 \end{gathered} \tag{32}$$

Among them, l_i and g_i $(i = 1,2)$ are undetermined coefficients, then there are $\acute{V}_M^B = l_1$,$\acute{V}_R^B = g_1$.Let

$$\begin{gathered} A = p_1 d + w(1-d) + \beta l_1 \\ B = (p_2 - w)(1-d) + \beta g_1 \end{gathered}$$

Then

$$\gamma^B = \frac{2A - B}{2A + B}$$

$$e^B = \frac{2A + B}{2} \tag{33}$$

Substituting equations (30), (32), (33) into the HJB equations of the manufacturer and retailer, we can get

$$\begin{cases} l_1 = \dfrac{p_1\theta_1 + w\theta_2}{\rho + \lambda} \\ l_2 = \dfrac{1}{\rho}[p_1(a - p_1 + bp_2) + w(1 - a - p_2 + bp_1) + \dfrac{\alpha^2 {l_1}^2}{2} + \dfrac{(2A+B)^2}{8}] \end{cases} \tag{34}$$

$$\begin{cases} g_1 = \dfrac{(p_2 - w)\theta_2}{\rho + \lambda} \\ g_2 = \dfrac{1}{\rho}[(p_2 - w)(1 - a - p_2 + bp_1) + \alpha^2 l_1 g_1 + \dfrac{B(2A+B)}{4}] \end{cases} \tag{35}$$

where

$$\begin{gathered} A = p_1 d + w(1-d) + \frac{\beta(p_1\theta_1 + w\theta_2)}{\rho + \lambda} \\ B = (p_2 - w)(1-d) + \frac{(p_2 - w)\beta\theta_2}{\rho + \lambda} \end{gathered}$$

Substituting l_1, A, B into (30) and (33) to get proposition 3.

Substituting the above optimal strategy into the expression of goodwill and solving the differential equation, we can obtain the changing form of goodwill

$$G^B(t) = \left(G_0 - G_\infty{}^B\right)e^{-\lambda t} + G_\infty{}^B \tag{36}$$

The stable state of goodwill $G^B(t)$ is

$$G_\infty{}^B = \frac{2(\alpha^2+\beta^2)p_1\theta_1 + (2\alpha^2+\beta^2)w\theta_2 + \beta^2 p_2\theta_2}{2(\rho+\lambda)} + \frac{\beta}{2}[2p_1 d + (p_2+w)(1-d)]$$

Corollary 8. Comparing the manufacturer's optimal product quality decision under the cost sharing situation and the decentralized Decision-making situation, there are $q^B = q^D$.That is, compared with the decentralized Decision-making situation, the introduction of the cost sharing contract does not affect the manufacturer's optimal product quality decision. Comparing the retailer's service quality decisions and the steady-state value of goodwill in the two Decision-making situations, when the showrooming coefficient satisfies $d > \frac{(\rho+\lambda+\beta\theta_2)(p_2-3w)-2\beta p_1\theta_1}{(\rho+\lambda)(2p_1+p_2-3w)}$, introducing the cost sharing contract in the case of decentralized Decision-making can improve the service quality of the retailer and the corporate goodwill.

Corollary 9. The partial derivative of the service quality cost sharing ratio γ with respect to the showrooming coefficient d is $\frac{\partial\gamma^B}{\partial d} > 0$.

Corollary 9 shows that the manufacturer's share ratio of the retailer's service quality cost is positively related to the showrooming coefficient. The larger the coefficient, the higher the proportion of consumers attracted by the improvement of the retailer's service quality who choose the online channel to purchase, and the more the manufacturer is willing to increase the share ratio in order to obtain higher sales.

5. Numerical Analysis

We analyzed the influence of different strategies made by supply chain members on corporate goodwill and supply chain profits in the case of decentralized and centralized Decision-making. The service quality cost sharing contract is established to achieve supply chain coordination. In this section, numerical analysis is used to visually demonstrate the impact of relevant parameters on the supply chain system. The parameters are set as$a = 0.4, d = 0.5, p_1 = 3, p_2 = 4, w = 2, \alpha = 1, \beta = 1.2, \rho = 0.1, \lambda = 0.5, \theta_1 = 1, \theta_2 = 1.2, G_0 = 0$.

The effect of the showrooming coefficient on the overall supply chain and the profit of members is shown in Fig.1, Fig.2, and Fig.3.The Pareto effect of the cost sharing contract on the profit of members is shown in Fig.4.

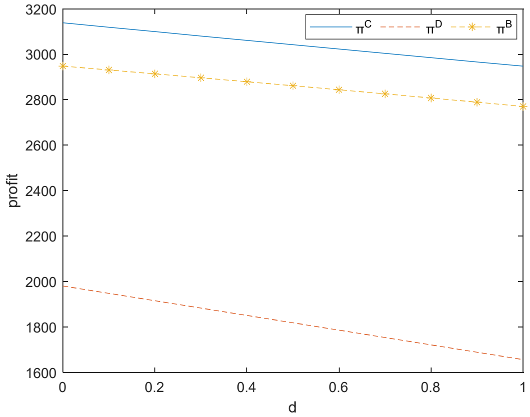

Fig 1. The influence of the coefficient d on the overall profit of the supply chain

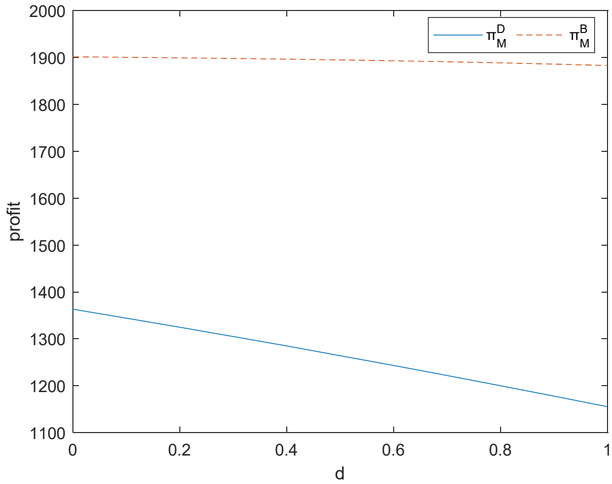

Fig 2. The influence of the coefficient d on the manufacturer's profit

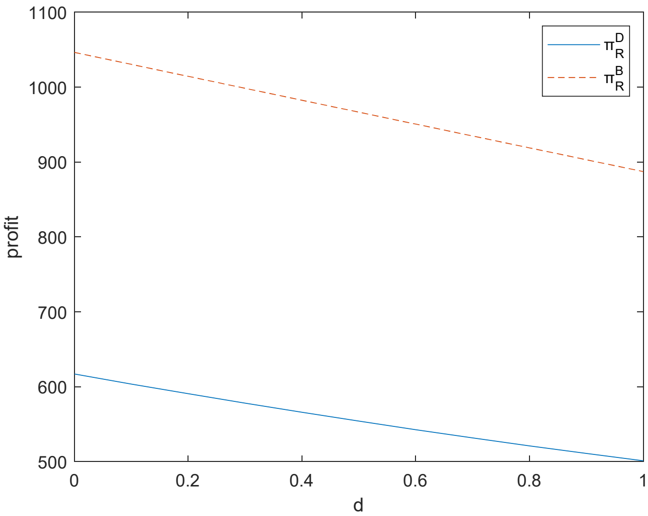

Fig 3. The influence of the coefficient d on the retailer's profit

It can be seen from Figs.1, 2 and 3 that with the increase of the showrooming coefficient in the three cases, the overall profit of the supply chain gradually decreases. The respective profits of the manufacturer and retailer decrease as the showrooming coefficient increases. Under the cost sharing contract, the overall profit of the supply chain is higher than the profit in the case of decentralized Decision-making, and the respective profits of the manufacturer and the retailer are higher than the profit in the case of decentralized Decision-making. This indicates that the contract can help manufacturer and retailer achieve the Pareto improvement of the total profit of the supply chain and the Decision-making parties' profit level. But the total profit is still lower than the profit under the centralized Decision-making situation, which indicates that the contract to share the retailer's service quality cost is not helpful for the maximum Pareto improvement.

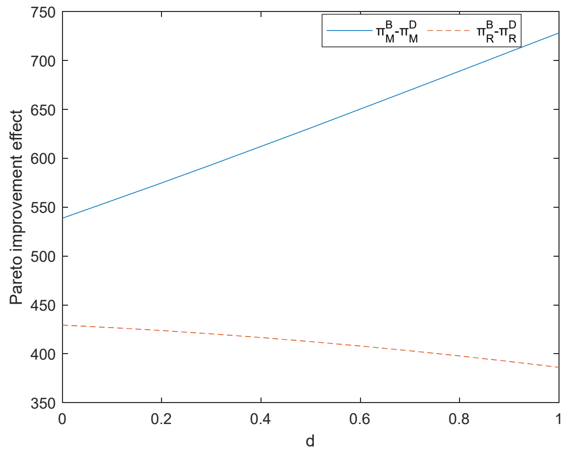

Fig 4. The influence of the coefficient d on the Pareto improvement effect of the cost sharing contract

Fig.4 shows that regardless of the showrooming coefficient, the cost sharing contract achieves the Pareto improvement in the profits of the manufacturer and retailer in the case of decentralized Decision-making, and the effect of improving the profit of the manufacturer is more obvious than that of the retailer. With the increasing of the showrooming coefficient, the Pareto improvement effect of the contract on the profit of the manufacturer is increasing, while the improvement effect of the retailer's profit is decreasing. This indicates that the showrooming phenomenon has a certain impact on the implementation effect of the contract. The decision makers need to consider the size of the coefficient in the market when formulating the service quality cost sharing contract and determining the cost sharing ratio.

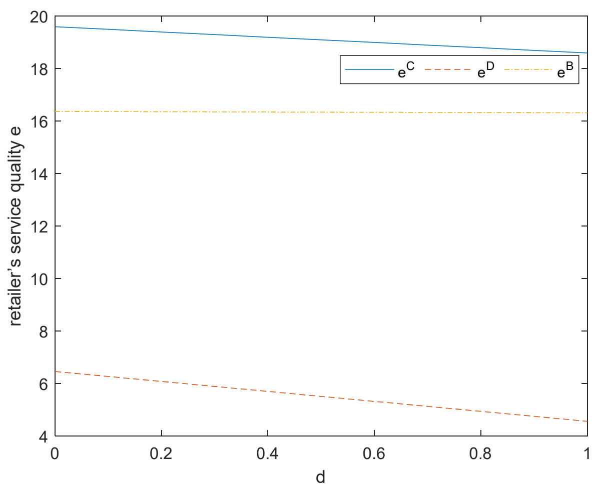

Fig 5. The influence of the coefficient d on the retailer's service quality.

It can be seen from Fig.5 that the quality of service provided by the retailer in the case of decentralized Decision-making is lower than that in the case of centralized Decision-making. In both Decision-making situations, as the showrooming coefficient increases, the quality of service provided by the retailer is both gradually decline, and in the case of decentralized Decision-making, the quality of service declines faster. This is because centralized Decision-making is aimed at maximizing the overall profit of the supply chain, while in the case of decentralized Decision-making, the members of the supply chain each aim at maximizing their respective profits. When the retailer dealing with the negative impact of the showrooming phenomenon, it will choose to reduce the service quality cost to obtain a higher level of profit. After introducing the service quality cost sharing contract, the retailer's service quality is higher

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than the service quality in the case of decentralized Decision-making. Because the manufacturer shares the service quality cost of the retailer. It boosts retailer's motivation to provide good service and makes the less impact of showrooming phenomenon on the retailer. It also makes the retailer's service quality less sensitive to the coefficient, that is, as the showrooming coefficient increases, the retailer's service quality level basically remains unchanged.

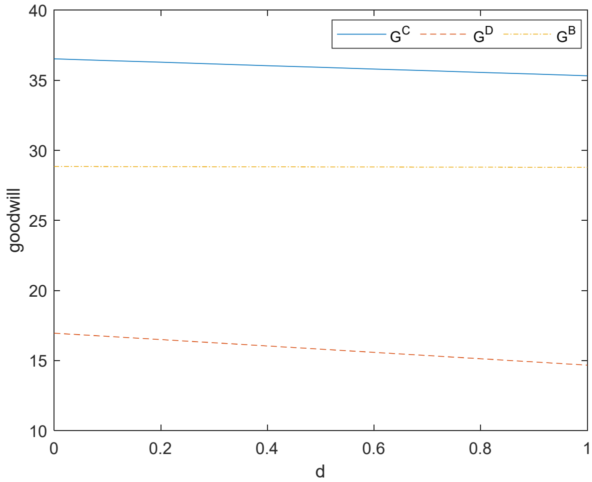

Fig 6. The influence of the coefficient d on the goodwill

Fig.6 shows that the goodwill under the three Decision-making situations are different. Among them, the goodwill under the centralized Decision-making is the highest, and under the decentralized Decision-making is the lowest. In the case of decentralized Decision-making, the introduction of cost sharing contract for the retailer has improved goodwill to a certain extent. In the case of decentralized Decision-making, goodwill is most sensitive to the showrooming coefficient. After the introduction of the contract, the sensitivity of goodwill to the coefficient is reduced, and the showrooming coefficient has almost no effect on the goodwill. It shows that increasing the contract can increase goodwill and reduce the negative impact of the showrooming phenomenon on goodwill.

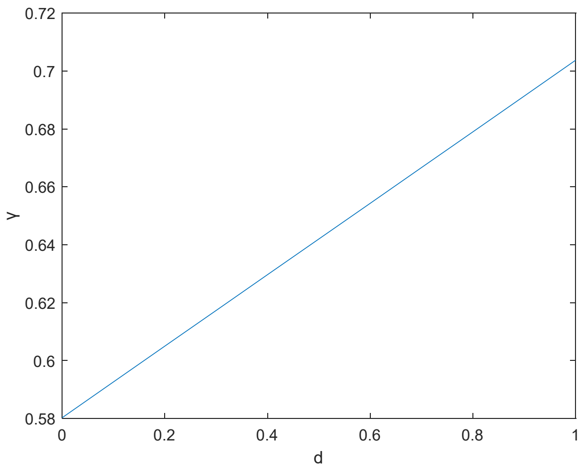

Fig 7. The influence of the coefficient d on the cost sharing factor

It can be seen from Fig.7 that with the enhancement of consumers' showrooming behavior, the proportion of the manufacturer sharing the retailer's service cost gradually increases. This is because when the showrooming coefficient increases, consumers attracted by the retailer's services are more likely to choose online purchases. It makes the retailer pay the service cost but not receive the corresponding profit return. The retailer must reduce the service quality to deal with the negative impact of the showrooming phenomenon. The retailer's service quality affects the goodwill and product sales. In order to enhance the retailer's service enthusiasm, the manufacturer will choose a larger share ratio to encourage the retailer to provide higher service quality.

Considering that both the manufacturer's product quality decision and the retailer's service quality decision will affect the company's goodwill, and over time will affect the sales of the Dual-channel and the profit level of members, the following first analyzes the changes in goodwill over time. The trajectory is shown in Fig.8. Next, the time trajectory of the overall supply chain and the profits of different participants in the three Decision-making scenarios is analyzed, as shown in Figs.9,10, and 11.

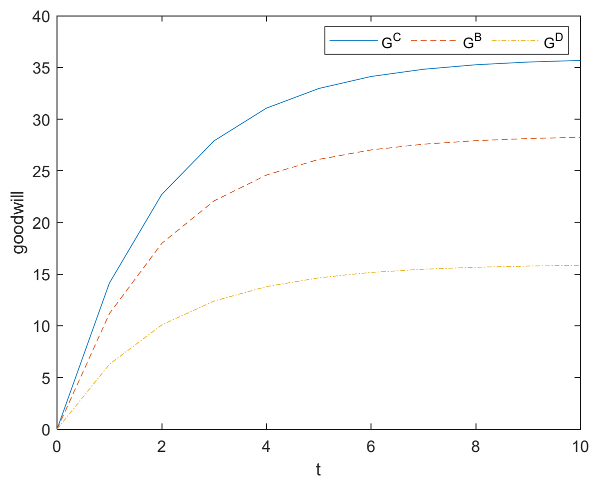

Fig 8. Time trajectory diagram of goodwill

It can be seen from Fig.8 that in the three Decision-making situations, the levels of goodwill continue to increase over time and eventually stabilizes. The level of goodwill in the case of centralized Decision-making is the highest, and in the case of decentralized Decision-making is the lowest. After the introduction of the manufacturer's service cost sharing contract with the retailer, the goodwill in the case of decentralized Decision-making is improved. It indicates that the manufacturer's sharing of part of the service quality cost can encourage the retailer to improve the service level, thereby increasing the company's goodwill.

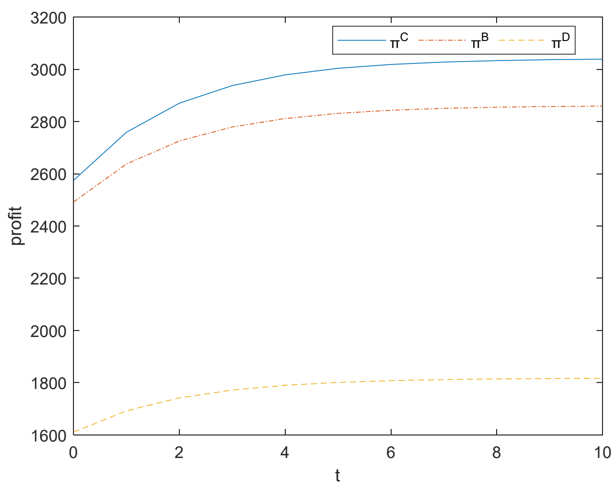

Fig 9. Time trajectory diagram of the overall profit of the supply chain

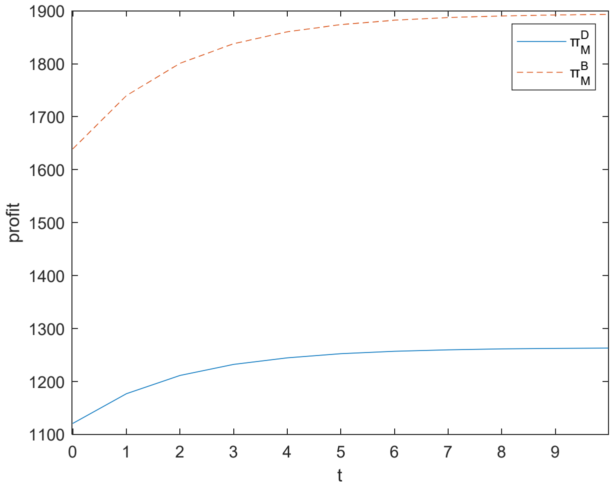

Fig 10. Time trajectory diagram of the manufacturer's profit

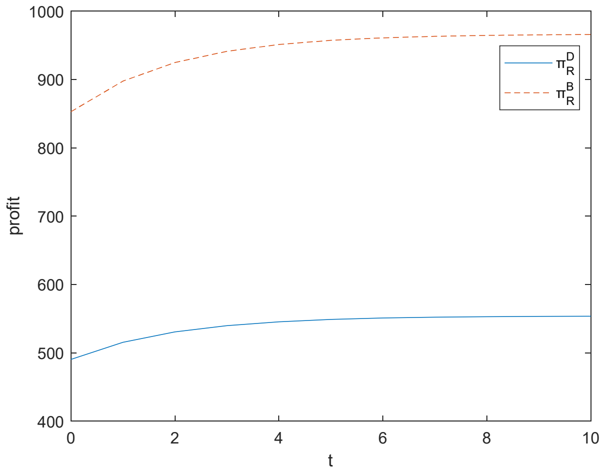

Fig 11. Time trajectory diagram of the retailer's profit

From Figs.9, 10 and 11, we can see that under the three models, the overall profit of the supply chain, the profits of the manufacturer and the retailer, respectively, gradually increase over time and eventually stabilize. The profit of the members under the cost-sharing contract is higher than that in the case of decentralized Decision-making. It indicates that the manufacturer shares part of the retailer's service quality cost, which not only increases the retailer's profit, the manufacturer's own profit has not been lost, but also been improved. The reason is that the manufacturer sharing part of the retailer's service quality cost can increase the retailer's enthusiasm for service, improve their goodwill, and increase sales in online and offline channels. This contract can effectively increase the profits of both parties in the supply chain, and achieve Pareto improvement. It can be seen from Fig.9 that the profit level is the highest in the case of centralized Decision-making. After the introduction of the contract, the overall profit level of the supply chain is significantly higher than that of decentralized Decision-making. Figs.10 and 11 illustrate that after the introduction of the contract, compared to the case of decentralized Decision-making, the profit levels of supply chain members have been greatly improved.

6. Conclusion

This paper uses the dynamic differential game theory to construct the centralized and decentralized Decision-making models. We consider the influence of showrooming coefficient on the quality decisions of supply chain members under different Decision-making situations,

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and get the following conclusions. Firstly, the manufacturer's optimal product quality decision is independent of the size of the showrooming coefficient. The optimal service quality decision is negatively correlated with the showrooming coefficient. That means the showrooming phenomenon will not affect manufacturers' quality decisions, but will dampen the enthusiasm of the physical retailer to provide services and crack down retailer's activeness in service quality investment. Secondly, through the comparison of the optimal decisions under different Decision-making situations, the manufacturer's service quality cost sharing contract with the retailer is designed and we get the optimal share ratio for the manufacturer that will be more effective in motivating retailer to increase investment. The Pareto improvement of the profits of the supply chain members under the decentralized Decision-making situation is realized. Finally, the improvement effect of the cost sharing contract is verified by numerical analysis. In the case of decentralized Decision-making, the manufacturer and retailer have reduced their respective quality costs in order to maximize their profits. The optimal product quality decision and the optimal service quality decision are smaller than that under the centralized decision. Under the cost sharing contract, the profits of the manufacturer and the retailer are both higher than that in the case of decentralized Decision-making, indicating that the introduction of this contract can increase the profits of both parties in the supply chain and reduce the negative effect of showrooming effect on retailer's activeness in service quality investment.

7. Limitations and Future Directions

This paper studies the optimal dynamic quality decisions of supply chain members under the showrooming effect, and gets some valuable conclusions. We have introduced the service quality cost sharing contract between the manufacturer and the retailer to achieve the optimization of the supply chain. However, there are still some shortcomings in the research of this article. After introducing the cost-sharing contract, the total profit is still lower than the profit in the case of centralized Decision-making, indicating that only the contract for the retailer's service quality cost-sharing is not enough to achieve the Pareto optimal improvement effect. In the future, we can consider introducing other contracts, such as joining a profit-sharing mechanism, to further realize the Pareto improvement of the supply chain.

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