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Coordination of dual-channel supply chain with perfect product considering sales effort

Hu, H.[a,*], **Wu, Q.**[a], **Han, S.**[a], **Zhang, Z.**[a]

[a]School of Economics and Management, Yanshan University, Qinhuangdao, P.R. China

ABSTRACT

As more and more people use e-commerce for shopping, manufacturers are willing to open online sales channels in order to obtain more profits. This paper discusses a dual-channel supply chain (DCSC) composed of a retailer with a traditional channel and a manufacturer with a direct channel. In the external environment of uncertain market demand and defective products produced by manufacturers, manufacturers make efforts to promote online products, and consumers have free rider behaviour. Therefore, three game models under the leadership of manufacturers are established: (a) non-cooperative game model; (b) coordination model under revenue-sharing contract; (c) coordination model under profit-sharing contract. The results indicate that the product defect rate has a certain influence on channel pricing and sale efforts. The competition between the actors of the dual-channel is beneficial to the consumers who pursue the price. Considering the overall profit of the DCSC, the cooperation between the manufacturer and retailer is more profitable than the channel competition, and they are more willing to make product sale efforts. The retailer's expected profit under revenue-sharing contract is less than that under profit-sharing contract, but the total profit of coordination model is more than the latter.

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**Corresponding author:*
huhaiju@ysu.edu.cn
(Hu, H.)

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1. Introduction

With the increasing willingness of consumers to shop online, more and more manufacturers are turning to online sales, and the DCSC with both offline and online sales channels will become a long-term market pattern. In 2018, there are about 1.8 billion customers electing shopping online, and the global e-retail sales reached $2.8 trillion, which is grown to $4.2 trillion by 2020 (https://www.statista.com/topics/871/online-shopping/). Some manufacturers use independent online retailers (e.g. amazon and taobao mall) to sell their products, while some brand-name manufacturers (e.g. Apple and Lenovo) build direct online channels to sell their products. The popularity of IT and market demand force manufacturers to choose dual-channel sales products. Compared with the centralized e-market platform, the agent-based platform is distributed and dynamic, which is closer to the natural state of the supply chain [1]. Online trading is more efficient than traditional trading, and products sell to market quickly [2]. Dual-channel supply chain not only brings convenient, comfortable and diversified experience to consumers, but also reduces market risk through profit sharing between the manufacturer and retailer. What's more, the indirect cost of online sales is low, and may make the product globally influential. The manufacturer establishes direct sales channel to improve the performance of the DCSC, and the ability of the DCSC actors to deal with risks can be enhanced [3].

It is impossible for manufacturers to produce high-quality products up to 100%. Therefore, in order to maintain market competitiveness, it is necessary for manufacturers to screen out defective quality products. The products are produced by the supplier. If there are defective products, they cannot be replaced by qualified products quickly [4]. Modak [5] believes that if the sold price of defective products is less than the production cost, the channel members' profit and manufacturer's wholesale price will decrease with the defect rate. When the uncertainty of product quality increases, the buyer will reduce the purchase intention [6]. Li [7] studied how the manufacturer and retailer sell products of different quality levels, among which the manufacturer sell products of low quality. When the retailer implements personalized pricing strategy, direct channel is beneficial to the manufacturer, but it often makes the retailer in trouble. Hu *et al*. [8] established a mathematical model for the detection, tracking and recall of defective products, and concluded that the avoidance of manufacturer's product quality inspection has seriously harmed the profits of retailer, and is not conducive to the long-term stable cooperation between the manufacturer and retailer.

In the actual production and operation, retailers and manufacturers actively carry out various promotional activities to attract consumers, and the continuous promotion has an important long-term impact on the image and market positioning of enterprises. Tsao [9] believes that the promotion cost sharing policy encourages the manufacturer to increase their promotion efforts, so that the retailer can order more products. Giovanni [10] believes that only when the contribution of advertising to goodwill is very large, advertising will be better than the strategy of improving product quality. Pu [11] compared the decentralized system with the centralized system, and found that the sales effort level of retailer and the profit of DCSC under the centralized system were both higher, and both increased with direct channel demand sales effort elasticity coefficient. Li *et al*. [12] studied the advertising cooperation strategies of the manufacturer and retailer in DCSC, and Chen [13] believed that appropriate product sales efforts can promote DCSC coordination and have win-win results. Ranjan [14] found that centralized supply chain management model can always bring the best supply chain profit, and the demand of different channels and the profit of SC can be improved through surplus value sharing mechanism. The incentive for promotion of retailer will reduce if the cost coefficient of sales efforts increases [15].

Supply chain management mainly emphasizes learning ability, and it is difficult to imitate and has creative value [16]. Considering the overall profit of DCSC, decentralized system is less than centralized system [17]. The contradiction among the actors of the DCSC can be adjusted by some contracts, and then the long-term cooperation among members can be promoted; for example, price discounts [18], two-part tariff [19], cost-sharing contract [20]. Liu [21] finds that the retailer almost always hates manufacturer to establish dual channels, and there is no motivation to share the information proved to be valuable to the manufacturer, and enterprises should carefully adopt quality differentiation as a strategy to alleviate channel conflict [22]. Jabarzare [23] thinks that the coordination effect of profits-sharing contract is better, and the competition among channel members is more favourable to consumers. Jafari [24] analyzed three game models: Bertrand, collusion, and Stackelberg, and concluded that the retail price is highest under cooperative game. Due to information asymmetry, the DCSC actors should set online and offline channel prices according to various factors such as demand uncertainty, market size and elasticity of demand to price [25].

This paper builds 3 kinds of game scenarios: non-cooperative game model, coordination model under revenue-sharing contract, and coordination model under profit-sharing contract, and derives the equilibrium result of the decision-making model by using Stackelberg game theory. The purposes of this research include: (a) to show the impact of defect rate on the optimal decision; (b) to analyze the relationship between manufacturer's sales efforts and consumers' free riding; (c) to verify whether the revenue-sharing contract and profits-sharing contract coordinate the DCSC.

2. Description of the problem

This paper studies a DCSC system, which consists of a retailer and a manufacturer which has a direct channel to sell product, and the DCSC structure is shown in Fig. 1. Considering the market environment of uncertain market demand and defective products produced by the manufacturer, it makes efforts to promote online products, and consumers have free riding behavior. This paper mainly considers the game model of DCSC led by the manufacturer, and then uses the method of backward induction method to solve the optimal action combination. The products produced by the manufacturer include the defective products with random ratio, but the defective products and the qualified products will be classified by inspection. The qualified products will flow to the market through online and offline channels, and the defective products will be sold to the secondary market in the form of low price. Market demand of different channel is termed as linear function in this paper, and it is respect to the manufacturer's sales effort and the price of each channel. The online sales price and sales effort level are determined by the manufacturer, while the retailer determines the retail price of the product. The notation and description used in this research is shown in Table 1.

Table1 Model parameters notation and description

notation	description
ρ	The tendency of customers to buy through offline channels
α	Basic market demand
t	Probability of defective product, random variable
$f(t)$	The probability density function of the random variable t
$E(t)$	The expected probability density of defective products
w	Wholesale prices offered by the manufacturer
g	Product sale efforts level (Manufacturer's decision)
p_m	Online selling price (Manufacturer's decision)
p_r	Offline selling price (Retailer's decision)
τ	Direct channel demand sales effort elasticity coefficient
b	Cross price elasticity coefficient between direct channel and traditional channel
p_l	Low selling price of unit defective products
c	Manufacturer's unit production cost
k	Cost coefficient of unit sales effort level
π_r	Retailer's profit function
π_m	Manufacturer's profit function

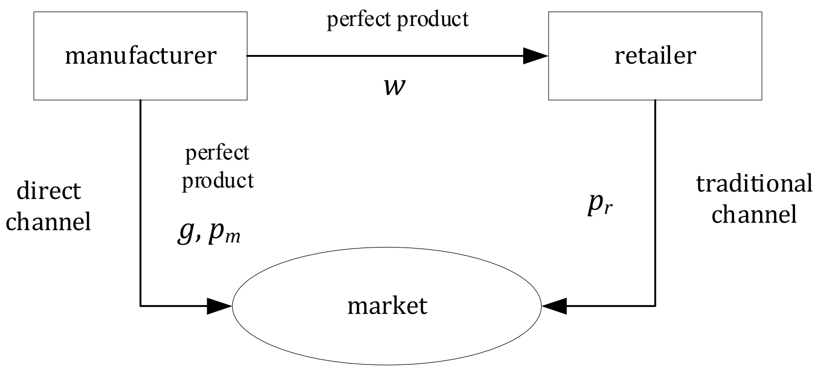


Fig. 1 DCSC structure

Research basic hypothesis:

- The DCSC actors are risk neutral, and both of them want to maximize their respective profits, similar to the RN model proposed by Jian [26].
- The wholesale price provided by the manufacturer is an exogenous variable, and the offline channel sales price is higher than that of the direct sales price. To make DCSC members profitable, we have $p_r > p_m > w > c$.
- $c > p_l$. Supposing that manufacturer's production cost is greater than that of the sale price of imperfect product.

- $c(g) = \frac{1}{2}kg^2$, $c(0) = 0$.The manufacturer's sales efforts cost function is convex, and when the manufacturer has no sales effort, its cost is 0.
- The cross-price elasticity of demand, b, is less than the self-price elasticity. In this paper, self-price elasticity is assumed to be 1, $0 \leq b \leq 1$.
- It is assumed that the product demand of the manufacturer and retailer is a linear function of price and sales effort. The manufacturer makes decision first to determine the price of direct channel and the level of product promotion effort. The retailer act as a follower and then decides the product price of the offline channel. Similar to Ranjan [14], their demand functions are: $D_m(p_r, p_m, g) = (1-\rho)\alpha - p_m + bp_r + \tau g$, $D_r(p_r, p_m, g) = \rho\alpha - p_r + bp_m + (1-\tau)g$.

3. Models for different game scenarios

This section mainly analyzes the profit function of DCSC members consisting a manufacturer and a retailer in three scenarios: (a) non-cooperative game model; (b) coordination model under revenue-sharing contract; (c) coordination model under profit-sharing contract. In order to gain some management insight, we analyze and discuss the optimal decision.

3.1 Non-cooperative game model

A non-cooperative game is played between the DCSC actors, and the manufacturer is the leader in this case. The manufacturer will produce defective products with a random ratio of $t(0 \leq t \leq 1)$, but it will sell imperfect products at a lower price p_l to reduce product quality losses in the secondary market. Some qualified products are sold directly to consumers at the price of p_m, while others are sold to the retailer at the wholesale price of w, and finally flow to consumers at the retail price of p_r. This paper used reverse induction so as to achieve Stackelberg equilibrium. To do this, we must first solve the problem of the follower, and then solve the problem of the manufacturer. The manufacturer and retailer maximize their profits by determining channel prices and sales effort for their products, so the profit equation of DCSC actors is as follows:

$$\pi_r = (p_r - w)D_r \tag{1}$$

$$\pi_m = wD_r + p_m D_m + \left(p_l E(t) - c\big(1 + E(t)\big)\right)(D_r + D_m) - \frac{1}{2}kg^2 \tag{2}$$

Taking the second-order partial derivative about offline selling price p_r for retailer's profit π_r, we have $\frac{d^2\pi_r}{dp_r^2} = -2 < 0$. The Hessian matrix of π_m is obtained by calculation as shown below:

$$\begin{pmatrix} -k & b\left(-\frac{1}{2}\tau + \frac{1}{2}\right) + \tau \\ b\left(-\frac{1}{2}\tau + \frac{1}{2}\right) + \tau & b^2 - 2 \end{pmatrix}$$

If $0 < -k(b^2-2) - \left(b\left(-\frac{1}{2}\tau + \frac{1}{2}\right) + \tau\right)^2$, there is a maximum profit in the negative definite Hessian matrix, and π_m is concave with respect to p_m and g.

<u>Proposition 1:</u> In scenario 1, π_r is concave with respect to p_r, and π_m respect to p_m and g.

<u>Theorem 1:</u> Because the profit of each DCSC actor has a maximum value, the optimal channel pricing and sales efforts under non-cooperative game model are as follows:

$$g^{sg} = \frac{(-4 + (-4b + 4)\tau)w + B_1}{A_1} \tag{3}$$

$$p_m^{sg} = \frac{\big((-b+2)\tau^2 + (2b-2)\tau + (-4k-1)b\big)w + B_2}{A_1} \tag{4}$$

$$p_r^{sg} = \frac{(b\tau^2+(-b+4)\tau-4k-2)w+B_3}{A_1} \tag{5}$$

3.2 Coordination model under revenue-sharing contract

Similar to scenario 1, but the retailer seek to work with manufacturer to provide long-term customer demand and pay part of their revenue to manufacturer. By means of revenue-sharing contract to coordinate DCSC, the manufacturer receives a proportion of the retailer's revenues, ϕ. First, the offline selling price of optimal value is given by the retailer to maximize its expected profit. Then, considering the response of the retailer, the manufacturer, as the leader, determines the optimal direct selling price and the level of product sales effort to get its maximal profit. In model 2, we have the expected profit equation of DCSC actors as shown below:

$$\pi_r = \big((1-\phi)p_r - w\big)D_r \tag{6}$$

$$\pi_m = wD_r + p_m D_m + \Big(p_l E(t) - c\big(1+E(r)\big)\Big)(D_r + D_m) + \phi p_r D_r - \frac{1}{2}kg^2 \tag{7}$$

Taking the second-order partial derivative about offline selling price p_r for retailer's profit π_r, we have $\frac{d^2\pi_r}{dp_r^2} = -(1-\phi) < 0$. Through the above analysis, we get the Hessian matrix of π_m under scenario 2:

$$\begin{pmatrix} \frac{1}{2}(\tau-1)^2\phi - k & -\frac{1}{2}(\phi+1)(\tau-1)b+\tau \\ -\frac{1}{2}(\phi+1)(\tau-1)b+\tau & -2+\frac{1}{2}(\phi+2)b^2 \end{pmatrix}$$

If $\left(\frac{1}{2}(\tau-1)^2\phi - k\right)\left(-2+\frac{1}{2}(\phi+2)b^2\right) - \left(-\frac{1}{2}(\phi+1)(\tau-1)b+\tau\right)^2 > 0$, the second principal minor is greater than zero, but the first principal minor is less than zero, so π_m has a maximum value.

Proposition 2: The retailer's profit of under the revenue-sharing contract is concave with respect to p_r, and π_m respect to p_m and g.

Theorem 2: It can be found from Proposition 2 that the optimal values of g, p_m, and p_r under model 2 are obtained as follows:

$$g^r = \frac{\Big(\big((-2b^2-2b+4)\tau+2b^2-4\big)\phi+4+(4b-4)\tau\Big)w+B_4}{A_2} \tag{8}$$

$$p_m^{rs} = \frac{\left(\big((-2\phi+1)b+2\phi-2\big)\tau^2+\big((4\phi-2)b-2\varphi+2\big)\tau-2\left((k+1)\phi-2k-\frac{1}{2}\right)b\right)w+B_5}{A_2} \tag{9}$$

$$p_r^{rs} = \frac{\Big(\big((4b-4)\phi-b\big)\tau^2+\big((-4b+8)\phi+b-4\big)\tau-2b^2k\phi+4k-4\phi+2\Big)w+B_6}{A_2} \tag{10}$$

3.3 Coordination model under profit sharing contract

In this scenario, the manufacturer and retailer realize the coordination of DCSC through profit-sharing contract, so as to alleviate the cost of the manufacturer's product sales efforts and the loss of product quality. The retailer pay manufacturer a percentage of their profits θ for long-term cooperation. As in the previous two cases, Stackelberg game is played between DCSC participants, with the retailer being the follower and the manufacturer its leader. First, the retailer gives the optimal offline selling price p_r, and then the manufacturer combines the decision-making actions of the retail to get the sales effort g and the online selling price p_m. Different channel expected profit under the profit-sharing contract is respectively:

$$\pi_r = (1-\theta)(p_r - w)D_r \tag{11}$$

$$\pi_m = wD_r + p_m D_m + \left(p_l E(t) - c\left(1+E(t)\right)\right)(D_r + D_m) + \theta(p_r - w)D_r - \frac{1}{2}kg^2 \tag{12}$$

Similar to Proposition 1 and 2, both the π_r and π_m are concave function of its decision variables. If $0 < \left(\frac{1}{2}\theta\tau^2 - \theta\tau + \frac{1}{2}\theta - k\right)\left(-\frac{1}{2}\theta b^2 + (b\theta + b)b - 2\right) - \left((b\theta + b)\left(-\frac{1}{2}\tau + \frac{1}{2}\right) + \tau\right)^2$, according to the Hessian matrix, the maximum value of the manufacturer can be obtained.

Theorem 3: In view of the above discussion, the optimal values of g, p_m, and p_r under the scenario 3 are obtained as follows:

$$g^{ps} = \frac{\left(\left((2b^2+2b-4)\tau - 2b^2+4\right)\theta - 4 + (-4b+4)\tau\right)w + B_7}{A_3} \tag{13}$$

$$p_m^{ps} = \frac{\left(((2\theta-1)b - 2\theta+2)\tau^2 + ((-4\theta+2)b + 2\theta - 2)\tau + 2b\left((k+1)\theta - 2k - 1/2\right)\right)w + B_8}{A_3} \tag{14}$$

$$p_r^{ps} = \frac{\left((-b^2+5b-4)\tau^2 + (2b^2-5b+4)\tau + (-4k-1)b^2 + 4k + A_3 - 2\right)w + B_9}{A_3} \tag{15}$$

The values of A_i and B_i are shown in the Appendix.

4. Parameter analysis

4.1 Imperfect product probability

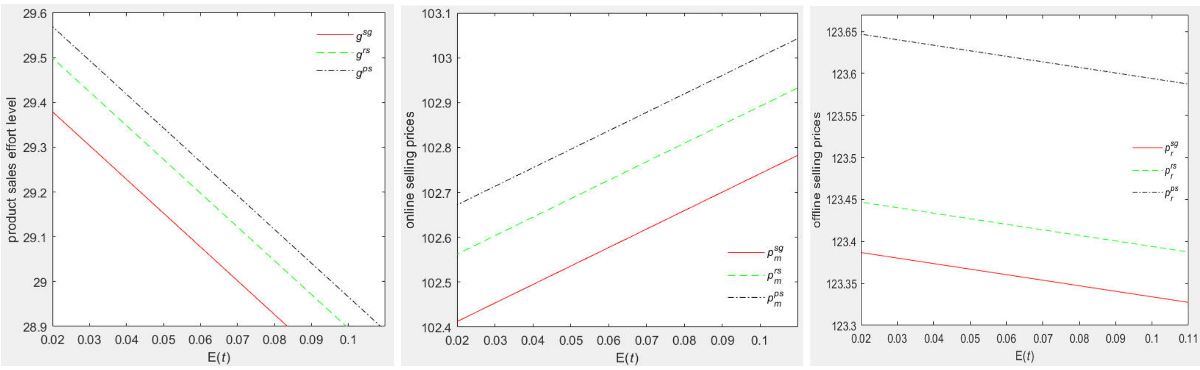
In general, it is common for defective quality products to sell for less than their cost of production in marketing, so we assume $c > p_l$. In this paper, it is assumed that the distribution of defect rate of products t is uniformed, that is, $t \sim \cup\,(0.02, 0.2)$. Next, we analyze the effect of the expected probability density of defective products on the optimal decision in three game situations.

$$\frac{dp_m^{ps}}{dE(t)} = \frac{2\left(\frac{1}{2}(b-1)(b-2\theta-2)\tau^2 + (-b^2+(\theta+1)b - 2\theta+1)\tau + \left(k+\frac{1}{2}\right)b - 2k + \theta\right)(c-p_l)}{A_3} \tag{16}$$

Proposition 3: If $\frac{-(b-1)(b-2\theta-2)\tau^2 + (2b^2+(-2\theta-2)b+4\theta-2)\tau - b^2 - b - 2\theta}{2b^2+2b-4} < k$, then $\frac{dp_m^{ps}}{dE(t)} > 0$, so the probability of defective products has a positive effect on the direct selling price.

$$\frac{dp_r^{sg}}{dE(t)} = \frac{(c-p_l)((b^3+b^2-2b)k + (-\tau^2+\tau)b^2 + (\tau^2+1)b - 2\tau + 2)}{A_1} \tag{17}$$

Proposition 4: If $k < \frac{b^2\tau^2 - b^2\tau - b\tau^2 - b + 2\tau - 2}{b(b^2+b-2)}$, then $\frac{dp_r^{sg}}{dE(t)} < 0$, so imperfect product probability has a negative effect on retail price.



(a) (b) (c)

Fig. 2 The influence of defect rate on the optimal decision of (a) product sales effort level, (b) online selling prices and (c) offline selling prices

Obviously, as the expected probability density of defective products $E(t)$ increases, in order to offset the cost of quality loss and maximize their own profits, the manufacturer will reduce their sales efforts to products, Fig. 2(a), and increase the direct selling price of qualified products Fig. 2(b). However, in order to expand offline demand, the retailer will reduce retail prices, Fig. 2(c).

4.2 Consumer preference coefficient

The higher of the consumer's channel preference coefficient ρ, the more consumers are willing to experience or purchase products offline, so the demand of retail channel is more. Eq. (18) shows the first order derivative of the market demand of the offline channel in scenario 2, D_r^{rs}, with respect to consumer's preference coefficient, ρ.

$$\frac{dD_r^{rs}}{d\rho} = \frac{(\phi-1)(b^2k+(2k-\tau+1)b-4k+2\tau)\alpha}{A_2} \tag{18}$$

Proposition 5: If $\tau < \frac{kb^2+2kb-4k+b}{b-2}$, then $\frac{dD_r^{rs}}{d\rho} > 0$, so consumers' preference of offline channel has a positive effect on retailers' demand.

It can be concluded that the retailer increasing offline attraction to consumers, such as product experience, can increase the market demand for offline products and thus improve their expected profits.

4.3 The wholesale price

This sub-section analyzes the impact of manufacturer's wholesale prices on retailer's offline sales prices. Eq. (19) gives the first order derivative of offline selling prices under model 2, p_r^{rs}, with respect to the wholesale price, w.

$$\frac{dp_r^{rs}}{dw} = \frac{\big((4\phi-1)b-4\phi\big)\tau^2+\big((-4\phi+1)b+8\phi-4\big)\tau-2kb^2\phi+4k-4\phi+2}{A_2} \tag{19}$$

Proposition 6: If $\frac{4\tau^2b\phi-\tau^2b-4\tau^2\phi-4\tau b\phi+\tau b+8\tau\phi-4\tau-4\phi+2}{2(b^2\varphi-2)} < k$, then $\frac{dp_r^{rs}}{dw} > 0$, so the increase in wholesale prices has a positive impact on offline retail prices.

The increase of wholesale price proposed by the manufacturer will promote an increase in the offline selling price, and consumers will ultimately bear this part of the cost because of the retailer maximizing its profit.

5. Numerical simulation – Result and discussion

In this section, we will study the proposed 3 game model through numerical simulation and discuss the impact of key parameters. The parameter data is below in Table 2.

The sensitivity is mainly used to analyze the influence of direct channel demand sale efforts elasticity coefficient τ and sharing ratio (ϕ, θ) on the optimal values. At the same time, the paper analyzes the influence of sale efforts cost coefficient k on the profit of DCSC.

Table 2 Data of parameters

Parameter	ρ	α	$E(t)$	τ	b	p_l	c	k	ϕ	θ	w
Value	0.6	200	0.11	0.54	0.52	5	25	2	0.25	0.25	60

5.1 Direct channel demand sale efforts elasticity coefficient τ

To study the effects of sale efforts elasticity coefficient (τ), we donate $\phi = 0.25$, $\theta = 0.25$. For the given value of parameters, set the interval of τ to [0,1].

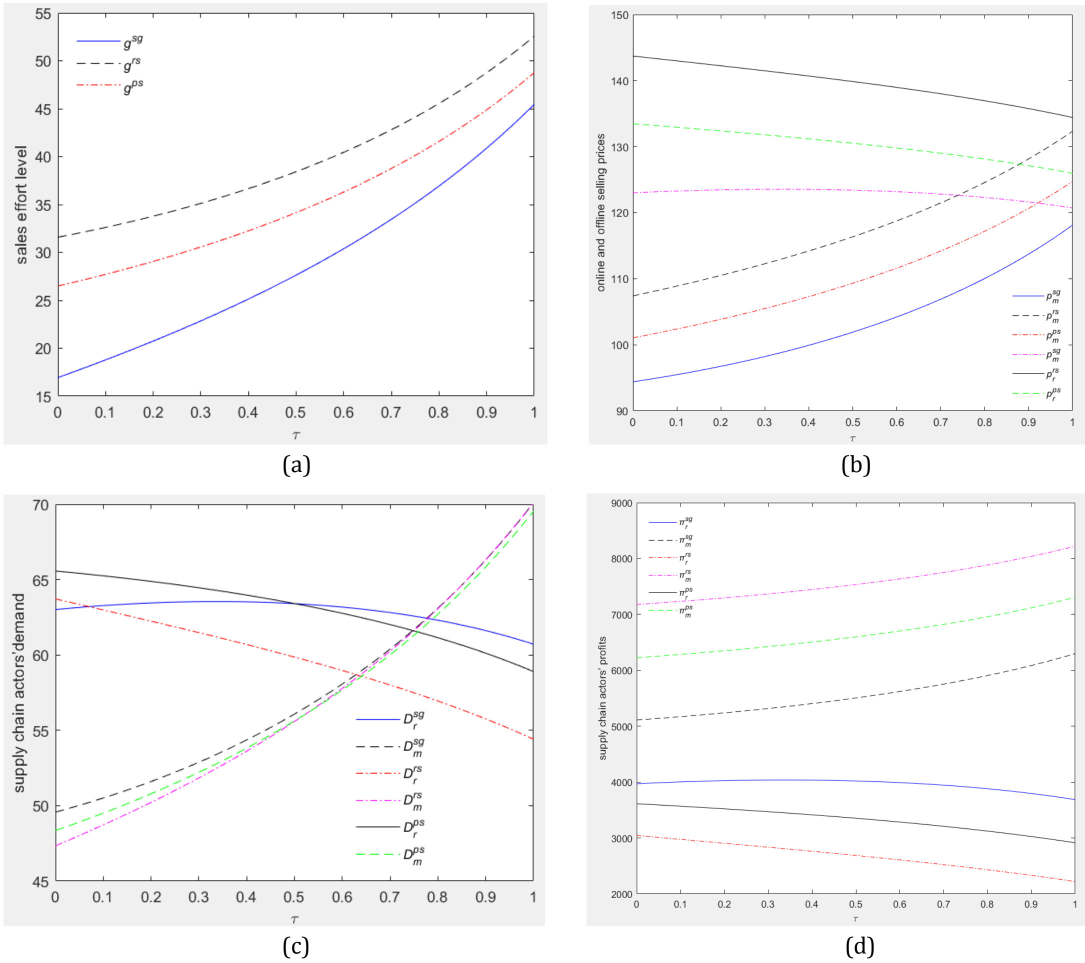


Fig. 3 The influence of sale efforts elasticity coefficient on the optimal decision of (a) sales effort level, (b) online and offline selling prices, (c) supply chain actors' demand, and (d) supply chain actors' profits

In Fig. 3(a), from the demand function of each channel, the sales effort level g increased with the sale efforts elasticity coefficient τ, but the cooperation model under scenario 2 had the highest level of sales effort. Because the larger τ value means the less possibility of free rider behavior, the more demand for direct sales channels, and the demand for traditional retail channels is decreasing, as shown in Fig. 3(c). As shown in Fig. 3(d), the retailer's profit is the lowest under scenario 2, but the overall profit of the DCSC can significantly improve. In Fig. 3(b), the online selling price increases with τ, but the offline selling price decreases with τ, and the traditional channel price is greater than the direct selling price.

5.2 Impact of the sharing ratio $(\boldsymbol{\phi}, \boldsymbol{\theta})$

The sharing ratio (ϕ, θ) is also an important parameter influencing the optimal decision and demand in this study. Therefore, the manufacturer's sales effort elasticity coefficient (τ) is fixed at 0.54. In order to make the online sales price less than the offline sales price and the profit of DCSC members is positive, we set (ϕ, θ) belong to interval $[0.05, 0.45]$.

In Fig. 4(a), the sales effort level g increases with the sharing ratio (ϕ, θ), but the sales effort under the model 2 is greater than the other two scenarios. The manufacturer gets the most profit under the revenue-sharing contract, but the corresponding retailer's profit is the lowest, as shown in Fig. 4(d). Understandably, an increase in the sharing ratio (ϕ, θ) forces the retailer to increase offline selling prices, which in turn increases direct-sales prices, as shown in Fig. 4 (b). In Fig. 4(c), the increase in the proportion of manufacturer's revenue sharing will reduce the demand for retail channels and the demand for direct sales channels; However, the increase in the proportion of manufacturer's profit-sharing will increase the demand for retail channels and the demand for direct sales channels. Relatively speaking, the manufacturer is willing to use revenue sharing contracts, while the retailer prefers profit-sharing contracts.

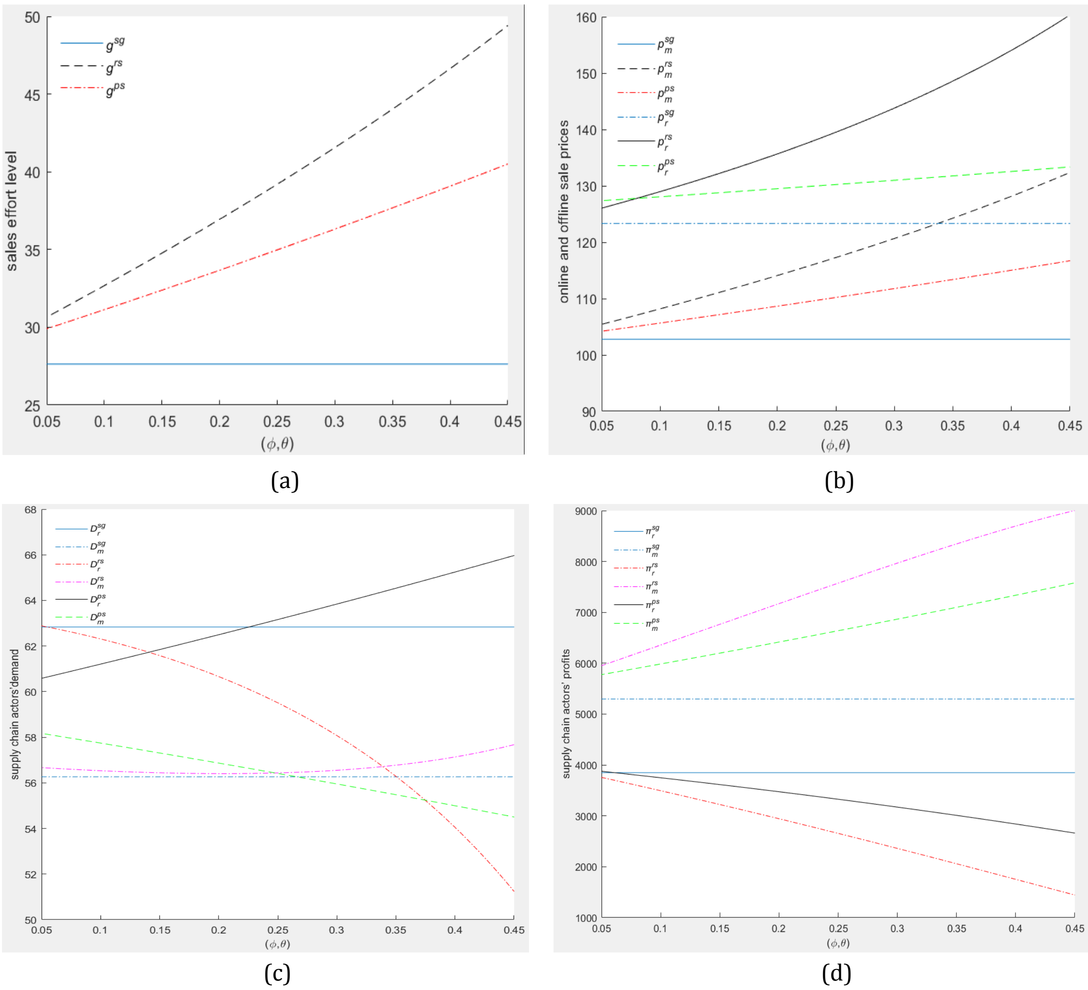


Fig. 4 The influence of sharing ratio on the optimal decision of (a)sales effort level, (b) online and offline sale prices, (c) supply chain actors' demand, and (d) supply chain actors' profits

5.3 Influence of k on the DCSC profit

Generally speaking, as the cost coefficient of sales effort k increases, manufacturer's motivation for promotion will be weakened.

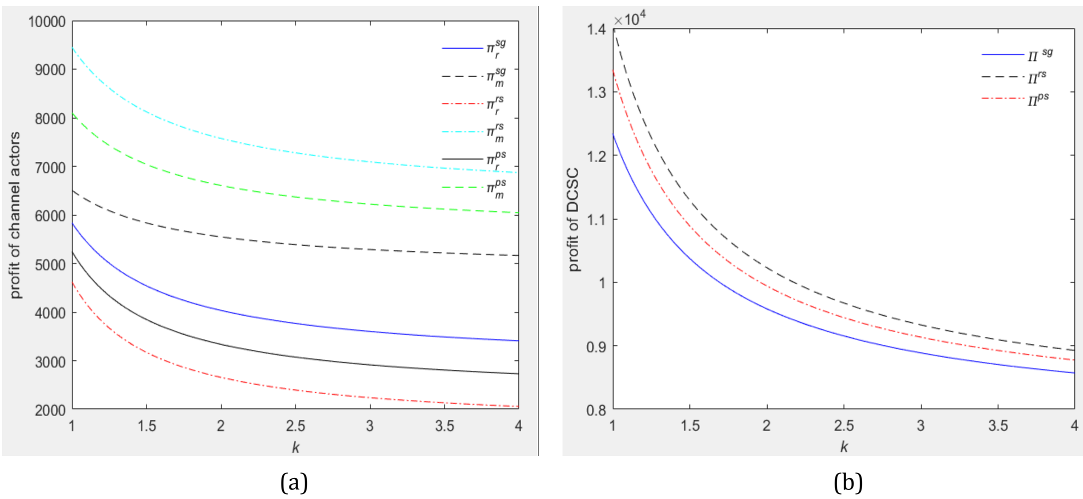


Fig. 5 The influence of cost coefficient of sales effort on profit of (a) channel actors, and (b) DCSC

As shown in Fig. 5, in the three game models, the profit of channel members will decrease with k, but the total profit of DCSC under scenario 2 is higher than other two models. If k increases, the level of manufacturer's sales effort will decrease, which brings about reducing the demand of direct sales channels. In order to mitigate the adverse impact of sales effort level on direct channel demand, the manufacturer reduces the online selling price(p_m). In addition, the demand in the offline channel will decline, prompting the retailer to reduce offline selling prices for expanding demand.

6. Conclusion

This paper discusses the pricing strategies and sales efforts with qualified product in a DCSC, which consists of a manufacturer and a retailer, and compared 3 game model. In addition, it considers that defective products are flow to the secondary market at a low price. The level of sale efforts and online selling price are the decision variables of the manufacturer, while the decision variable of retailer is offline selling price. We studied a competition and two coordination situations between DCSC members, determined their optimal strategies, and analyzed the model through numerical examples. The results showed that the product defect rate has considerable impact on pricing and sales efforts. For consumers who are pursuing price, competition between the DCSC actors is advantageous. In the light of DCSC profits, cooperation between the manufacturer and retailer is more profitable than channel competition, and they are more willing to make product sales efforts. In order to maximize profits, the manufacturer is more inclined to choose revenue-sharing contracts.

Although the model proposed in this paper is more in line with enterprise production management practices, there are still some shortcomings. This article only assumes that the product defect rate follows a uniform distribution, and does not consider more complicated situations, such as following the positive distribution. In addition, the flow of defective products to the secondary market may also have a certain impact on the demand for qualified products, which we have not taken into account. This paper only considers that the manufacturer set up online channels, which is just a form of DCSC, and does not study retailer building online channels.

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Appendix

For the convenience of calculation, we let $X = \mathrm{E}(r)p_l - \big(1 + E(r)\big)c$. Since the price of the defective product is usually lower than the production cost, we have $X < 0$. Similarly, A_i represents the denominator of the optimal decision in the three scenarios, and B_i is obtained by numerator merging of similar items.

$$X = \mathrm{E}(r)p_l - \big(1 + E(r)\big)c \tag{A1}$$

$$A_1 = (\tau^2 + 4k - 2\tau + 1)b^2 + (-4\tau^2 + 4\tau)b + 4\tau^2 - 8k \tag{A2}$$

$$B_1 = \big((b-2)\tau - b\big)(b\rho - 2\rho + 2)\alpha - 4w(1 + (b-1)\tau) \tag{A3}$$

$$B_2 = \big((-\tau^2 - 2k + 2\tau - 1)b^2 + (3\tau^2 - 2k - 2\tau - 1)b - 2\tau^2 + 4k - 2\tau\big)X - 2k\alpha(b\rho - 2\rho + 2) \tag{A4}$$

$$B_3 = -kXb^3 + \left(\alpha k\rho - X(-\tau^2 + k + \tau)\right)b^2 + \left((-\tau^2 + (-\rho + 2)\tau + (2\rho - 2)k + \rho - 1)\alpha - X\tau^2 + X(2k - 1)\right)b + (2\tau^2 + (2\rho - 2)\tau - 4\rho k)\alpha + 2X(\tau - 1) \quad \text{(A5)}$$

$$A_2 = 2\left(\left(\frac{1}{2}b^2 + (-2\phi - 2)b + 2\phi + 2\right)\tau^2 - (b - 2)(b - 2\phi)\tau + \left(k\phi + 2k + \frac{1}{2}\right)b^2 - 4k + 2\phi\right)(\phi - 1) \quad \text{(A6)}$$

$$B_4 = -(\phi - 1)\left(X(\tau - 1)b^3 + (-\rho(\tau - 1)\alpha + (-2X\phi - X)\tau - X)b^2 + \left(4(\tau + 1)\left(\left(\rho - \frac{1}{2}\right)\tau - \frac{1}{2}\rho + \frac{1}{2}\right)\alpha + 2X(\tau\phi - \phi + 1)\right)b + ((-4\rho\phi - 4\rho + 4)\tau + 4\rho\phi)\alpha + 4X\right) \quad \text{(A7)}$$

$$B_5 = -2\left(\left(\frac{1}{2}(b - 1)(b - 2\varphi - 2)\tau^2 + ((b - 2)\phi - b^2 + b + 1)\tau + \phi + \left(\frac{1}{2} + k\right)b^2 + \left(\frac{1}{2} + k\right)b - 2k\right)X + \left(-\tau^2\phi - \phi(\rho - 2)\tau + (bk\rho + \rho - 1)\phi + k(b\rho - 2\rho + 2)\right)\alpha\right)(\phi - 1) \quad \text{(A8)}$$

$$B_6 = -(\phi - 1)\left(kXb^3 + \left(-\alpha k\rho + X(-\tau^2 + k + \tau)\right)b^2 + \left((\tau^2 + (\rho - 2)\tau + (-2\rho + 2)k - \rho + 1)\alpha + X\tau^2 + (-2k + 1)X\right)b + (-2\tau^2 + (-2\rho + 2)\tau + 4\rho k)\alpha - 2X(\tau - 1)\right) \quad \text{(A9)}$$

$$A_3 = (b^2 + (-4\theta - 4)b + 4\theta + 4)\tau^2 - 2(b - 2)(b - 2\theta)\tau + (2k\theta + 4k + 1)b^2 - 8k + 4\theta \quad \text{(A10)}$$

$$B_7 = -X(\tau - 1)b^3 + (\rho(\tau - 1)\alpha + (2X\theta + X)\tau + X)b^2 + \left(-4(\theta + 1)\left(\left(\rho - \frac{1}{2}\right)\tau - \frac{1}{2}\rho + \frac{1}{2}\right)\alpha - 2X(\tau\theta - \theta + 1)\right)b + \left((4\rho\theta + 4\rho - 4)\tau - 4\rho\theta\right)\alpha - 4X \quad \text{(A11)}$$

$$B_8 = (-(b - 1)(b - 2\theta - 2)\tau^2 + (2b^2 + (-2\theta - 2)b + 4\theta - 2)\tau + (-2k - 1)b^2 + (-2k - 1)b + 4k - 2\theta)X - 2\left(-\tau^2\theta - \theta(\rho - 2)\tau + k\rho(\theta + 1)b - 2\left(k - \frac{1}{2}\theta\right)(\rho - 1)\right)\alpha \quad \text{(A12)}$$

$$B_9 = -kXb^3 + \left(\alpha k\rho - X(-\tau^2 + k + \tau)\right)b^2 + \left((-\tau^2 + (-\rho + 2)\tau + (2\rho - 2)k + \rho - 1)\alpha - X\tau^2 + X(2k - 1)\right)b + (2\tau^2 + (2\rho - 2)\tau - 4\rho k)\alpha + 2X(\tau - 1) \quad \text{(A13)}$$