

Pricing Decision of E-Commerce Supply Chains with Return and Online Review of Product Quality

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Abstract The online review function helps consumers grasp more real product information and reduce the possibility of returning, but it may also damage firms' reputations or profits. However, few studies considered the relationship between online reviews and consumer returns. Based on this, we develop an e-commerce supply chain (E-SC) game model consisting of a single manufacturer and a single e-platform, aiming to explore the relationship between consumer returns and online reviews and to analyze the impact on both the decision-making of E-SC members and their profits. We find that there is a negative relationship between consumer returns and online reviews of product quality, and consumer returns make the pricing decisions in the two scenarios of yes/no online reviews move toward two different directions. Only when the online review is positive and higher than a certain threshold will it have a positive impact on sales and E-SC members' profits. Finally, we design a new "commission joint returns and quality improvement costs sharing" contract to optimize the decentralized model with online reviews, and we find that the higher the accuracy of product information, the less conducive the contract applied to E-SC.

Keywords e-commerce supply chains; pricing decision; consumer returns; online review

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1 Introduction

In recent years, online shopping has been favored by more and more consumers due to its convenience and rich product variety, especially since the new crown epidemic in 2020. The epidemic prevention policy has caused many consumers to turn to online shopping, which has promoted the growth of online retail sales. China Bureau of Statistics shows that in 2021, China's online sales increased by 14.1% to 13.1 trillion CNY. Meanwhile, data from the US Department of Commerce shows that the total online sales increased to \$870 billion in 2021. The popularity of online sales has activated the consumer market and provided consumers with convenient services (Shulman, et al.^[1]).

However, despite the many advantages of online shopping, consumers are still unable to touch and try the products, which severely limits consumers' understanding of product information. Therefore, online shopping returns are more common than offline retail returns. As B-Stock statistics show, the average return rate of online sales is 30%, and the return rate will surge to 50% during holidays, while the average return rate of physical store sales is 8%~10%. Returns not only bring troubles to consumers and affect their shopping experience, but also can cause huge return processing costs for firms. For example, in 2017, fashion discounter Rue La La (www.ruelala.com) had a return processing cost of \$5 million. The higher return rate in online sales is due to consumers making incorrect purchasing decisions due to their low level of knowledge about the product^[2,3]. Therefore, e-platforms have developed online review service functions (online review service functions allow consumers to post comments on product quality, appearance, and platform services after purchasing products) to increase consumers' understanding of purchased products^[4]. According to a study conducted by Podium, nearly 60% of consumers browse online reviews at least once a week and 93% of consumers think online reviews influence their buying decisions. Therefore, when the online review function is provided, consumers can see more real and useful information, thereby increasing their understanding of the product and helping them make the right purchase decision^[5].

The consumer reviews of products are mixed. Positive reviews can improve consumer recognition of products and enhance their purchase intention, while negative reviews can damage the image of the product or firm and affect product sales. Therefore, in practice, some e-platforms offer an online review function, and some do not. According to Podium's research, only 13% of SMEs (small and medium-sized enterprises) have set up a feature that allows consumers to make online reviews.

Clarifying whether should provide online reviews, whether providing online reviews can effectively reduce product return rates, and how to reduce the impact of negative reviews on firms have become important issues that e-commerce companies need to face. For example, Amazon has updated the review display mechanism, and many merchants have been affected by negative product reviews, resulting in a sharp drop in product sales. Therefore, we aim to study the relationship between online reviews and return rates and analyze the impact of both on the decision-making and profits of E-SC members.

At present, most of the academic studies on online reviews analyze purchasing decisions and business operations from an empirical perspective^[6,7]. Few studies focus on online reviews from a supply chain perspective. Although Huang, et al.^[8] analyzed the operation of capacity-

constrained supply chains with online reviews and showed that the positive influence of online reviews on system operational efficiency depends on factors such as customer quality estimates and capacity constraints, the study did not take consumers' returns into account and analyze the relationship between returns and online reviews. Based on these studies, we study the return behavior of consumers when purchasing products online based on the influence of product information accuracy on consumer return, and explore the decision-making and profits of E-SC with online reviews. We mainly solve the following problems:

1) Under the influence of consumer return behavior, what are the optimal decisions and profits of E-SC members?

2) Considering the online review of product quality (OR-PQ), what is the relationship between OR-PQ and the return rate?

3) How do online reviews affect the decisions and profits of E-SC firms?

Our research has the following contributions:

1) Unlike Shen, et al.^[9], who directly explored the impact of product return rates on the decision-making of E-SC members, we incorporate the impact of product information accuracy on the return rate into the model and find that higher product information accuracy reduces the return rate, which is beneficial to E-SC firms' operation. And by comparing different models, we find that only when the accuracy of product information is higher than a certain threshold, providing online reviews is beneficial to E-SC operation. Additionally, we draw a different conclusion from Li, et al.^[10], finding that whether or not online reviews are provided, e-platforms do not change service level decisions due to changes in return rates.

2) Different from previous literature analyzing online reviews from the perspective of a single company or industry^[5,11], we take E-SC as the research object and construct an E-SC game model based on consumer returns and online reviews. Moreover, we draw different conclusions from Ögüt and Onur Taş^[12] that as consumers pay more attention to OR-PQ, the sales, E-SC members and system profits show a trend of first decreasing and then increasing.

3) We analyze the minimum review threshold for the profitability of E-SC members and systems under the provision of online reviews and explore the accuracy threshold of product information to maintain profitability under the provision of online reviews. This can help E-SC firms make decisions and operate better.

The work arrangement is as follows. We review the literature related to consumer returns and online reviews in Section 2 and describe models constructed in Section 3. Section 4 analyzes the optimal decisions and profits in two models, and compares the above two models. Then, we design a coordination mechanism in Section 5. Section 6 explores the influence of product information accuracy on decision-making and profit through numerical analysis. Finally, we summarize the research conclusions, make management recommendations, and suggest further research directions.

2 Related Literature

The research literature related to the paper mainly includes two aspects: Consumer return behavior and online reviews in E-SC.

2.1 Consumer Returns in Supply Chain

Research on returns in the supply chain has achieved a lot of results^[13]. Xu, et al.^[14] built models to analyze the economic influence of consumer return on retailers and supply chains under different return policies, and they found that the retailer's optimal refund is related to the valuation and residual value of returned products. Aiming at the return problem in the dual-channel supply chain, Li, et al. studied the optimal return/refund strategy of manufacturers in different channels, and found that when the return rate is low, it is more beneficial for the manufacturer to adopt a full refund strategy^[15]. Zhang, et al. studied the return problem based on product quality and proposed a revenue-sharing coordination contract to motivate retailers to recycle low-quality products^[16]. Based on this, Feng, et al. studied the relationship between quality disclosure strategies and consumer returns and found that when the return rate of new products is low, retailers should disclose more product quality information than manufacturers, otherwise, manufacturers will disclose more product quality information^[17]. Wan, et al. studied the return/refund strategies of monopoly retailers and derived product pricing strategies under different return strategies^[18].

We find that these works of literature analyze consumer returns from the perspective of the offline supply chain. With the popularity of online shopping recently, the impact of consumer return behavior on E-SC has attracted attention. Deng, et al. proposed a hybrid ant colony algorithm to decrease the cost of quality defect return and non-quality defect return in E-SC^[19]. Batarfi, et al. analyzed the pricing and profitability of the dual-channel supply chain with the return policy and found that a loose return policy is conducive to setting higher prices, and sales and system profit are higher^[20]. Cao, et al. analyzed OAO supply chain firms' decision-making with consumer returns and found that consumer return behavior in online sales has a strong impact on advertising decisions^[21]. Pi, et al. studied the channel strategy and return window strategy of the E-SC, and found that when choosing a single sales channel strategy under decentralized decision-making, the introduction of the return window can help suppliers cope with cost pressures^[22].

We find that the above literature assumes that the e-platform is an exogenous subject. However, the e-platform is often the leader of E-SC in reality, so it is necessary to incorporate the e-platform's service level decision into E-SC. Although Shen, et al.^[9] incorporated the e-platform into E-SC and discussed how consumer returns affect E-SC firms' decisions and profits under different power structures, which is related to this paper. However, they focused more on the comparison of optimal decisions and profits under different power structures and did not consider the relationship between consumer return behavior and online reviews.

2.2 Online Reviews

Online reviews have not only been widely used in practice, but also attracted the attention of a large number of researchers. Many scholars have analyzed the impact of online reviews on consumers from the perspective of empirical analysis. For example, Li, et al.^[11] and Gonçalves, et al.^[23] mainly focused on the motivation of consumers to post online reviews; Yu, et al. explored how online reviews affect consumers' purchasing decisions^[24]. Some scholars have also used game analysis to explore the impact of online reviews on firms' pricing decisions

and profitability. For example, Kwark, et al. constructed a game model consisting of two manufacturers and retailers, and found that the deviation of online reviews intensified the competition among manufacturers, which is not conducive to the manufacturer's profitability, but increases the retailer's profit^[25]; Cai, et al. established a game model consisting of a single online retailer and three competing manufacturers, and found that only when the standard deviation of product quality shown by online reviews is large enough, online reviews can increase the profitability of the online retailer's capabilities^[26]; Cao, et al. focused on the impact of online reviews on digital product companies' implementation of free version strategies^[27].

On this basis, scholars have studied the impact of online reviews on supply chain membership. For example, Li, et al. discussed the negative impact of online reviews in the O2O supply chain of intra-brand competition, arguing that the positive correlation between online reviews and sales caused intra-brand competition^[28]; Zhao and Zhang found that uncertain online reviews motivated two competing retailers to increase product prices under conditions suitable for dominant quality, and they could learn from online reviews^[29]. Further, some scholars have studied the impact of online reviews on the overall operational efficiency of the supply chain system. For example, Wang, et al. studied how consumers' deviations in product evaluation levels affect product quality and system profits at different stages^[5]; for capacity-constrained supply chains, Huang, et al. found that the positive impact of online reviews on system operating efficiency depends on factors such as customer quality estimates and capacity constraints^[8].

The above existing literature studies online reviews in the supply chain but ignores the impact of return factors on online reviews. Although Minnema, et al. studied how online reviews affect the return rate^[30], Sahoo, et al. also showed that online reviews can help reduce the probability of consumers returning products, but they did not consider the impact of different online review service strategies on the accuracy of product information^[3]. Therefore, we consider the accuracy of product information in online reviews, discuss the impact of online reviews on product returns, and then compare the changes in decision-making and profitability of e-commerce firms under different product information accuracy through numerical examples.

3 Model Description

3.1 Model Descriptions and Assumptions

This paper constructs an E-SC game model including a leader e-platform and a follower manufacturer. The manufacturer produces products and sets product sales prices, and consumers can place orders and purchase products on demand by browsing the product information through the e-platform, then the manufacturer posts products to consumers. When consumers think that the received product meets their expectations, the receipt will be confirmed, and the e-platform will hand over the payment after deducting the commission to the manufacturer; when consumers are not satisfied with the products they receive, they can return the products. During the purchase or return process, consumers can post their comments on the product on the e-platform. Figure 1 shows the model structure.

We construct two decision models of E-SC not providing online reviews and providing online reviews, which are common in reality. For example, H&M online mall (www.hm.com.cn), Louis Vuitton's official flagship store (www.louisvuitton.cn), and Sunrise Shopping Mall (www.sunrise-

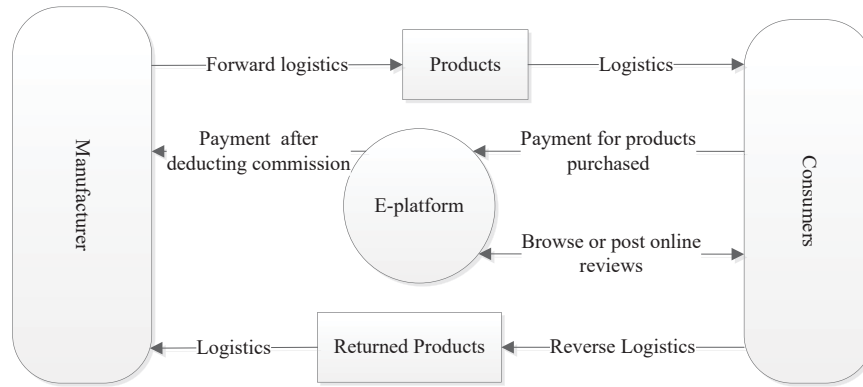


Figure 1 Operation mode of E-SC

dutyfree.com), etc., have not opened the online comment function, while eBay (www.ebay.com), Taobao (www.taobao.com), Amazon (www.amazon.cn), and so on, open online reviews to improve consumers' understanding for products, the opening of this service can also enable manufacturers to keep abreast of the consumer market and make improvements to their products.

We show the description of the model parameters in Table 1.

Table 1 Description of model parameters

Parameters	Description
i	As subscripts, m , e , z represent the manufacturer, e-platform, and E-SC respectively.
j	As superscripts, N , Y represent the cases of not providing online reviews and providing online reviews, respectively.
p^j	In Model- j , the price of a unit product (manufacturer's decision variable).
τ^Y	Product quality (manufacturer's decision variable in Model- Y).
s^j	In Model- j , service level (e-platform's decision variable).
α	The maximum market demand.
β	The elasticity coefficient of the price ($\beta > 0$).
γ	The elasticity coefficient of the service level ($\gamma > 0$).
μ	The elasticity coefficient of OR-PQ ($\mu > 0$).
c	The unit production cost.
ρ	The commission, charged for selling unit products on the e-platform.
ε	The product return rate ($0 < \varepsilon < 1$).
η	The impact of the product information accuracy on the return rate ($0 \leq \eta < 1$).
w	The residual value of a unit of returned product.
h	The processing cost per unit of returned product.
q^j	In Model- j , the product sale.
D^j	In Model- j , the actual sale.
$C(\tau)$	The effort cost paid by the manufacturer to improve product quality.
$C(s)$	The service level of the e-platform.
π_i^j	In Model- j , the profit of i .

To facilitate the analysis of the optimal decisions and profits under different decision models, we propose the following assumptions:

1) Following Wang, et al.^[31], the product sale is $q^N = \alpha - \beta p + \gamma s$. When the online review function is provided, consumers who have purchased products can post reviews about product quality, appearance, style, etc. These reviews are of reference value to consumers who have not purchased products and can influence their purchase decisions. In addition, when consumers do not post reviews, the e-platform will display “automatic default praise” (for example, www.taobao.com), this kind of review has little reference value for consumers, so we do not consider it. We assume that consumers will evaluate products from the dimension of product quality, and the higher the product quality, the higher the level of OR-PQ. Therefore, following Cai, et al.^[26] and Huang, et al.^[32], we assume that when the online review function is provided, the product sale is $q^Y = \alpha - \beta p + \gamma s + \mu \Delta r(\tau)$, where $\Delta r(\tau) = r(\tau) - r(\tau_0)$. $r(\tau)$ is the average level of OR-PQ, $r(\tau_0)$ is the threshold of the average level of OR-PQ determined by the product quality standard (τ_0). When $r(\tau) > r(\tau_0)$, OR-PQ is positive, which is conducive to the increase in product sale; when $r(\tau) < r(\tau_0)$, OR-PQ is negative, which is not conducive to an increase in product sale. In order not to lose the generality of the model, we do not set the specific function expression of $r(\tau)$, but according to Maiga, et al.^[33], we set $r'(\tau) > 0$ and $r''(\tau) < 0$ to represent the relationship between OR-PQ and product quality. This means that the higher product quality, the higher the level of OR-PQ, but high-quality products will not lead to an infinite increase in consumers' OR-PQ, which is consistent with reality. For example, Taobao, JD.com, Suning, and other e-platforms have a ten-point system and a five-point system for product review.

2) In the actual operation of E-SC, the complexity of online sales is far greater than offline sales, leading consumers to make wrong purchasing choices. Therefore, the accuracy of the product information provided by the manufacturer will have an impact on the return rate, and η ($0 \leq \eta < 1$) represents the impact of the product information accuracy on the return rate. The actual return rate of the products is $\eta\varepsilon$ ($0 < \eta\varepsilon < 1$), then following Radhi and Zhang^[34], the actual sale is $D^j = q^j / (1 - \eta\varepsilon)$.

3) Assuming that $C(\tau)$ is the effort cost paid by the manufacturer to improve product quality, and we do not set a specific function expression for $C(\tau)$ to maintain the generality of the model. But following Yoo and Cheong^[35], we assume that $C(\tau)$ is a monotonically increasing convex function of product quality τ , then $C'(\tau) > 0$, $C''(\tau) > 0$.

4) Since the returned products are all problems with the product itself, the return cost is borne by the manufacturer, so $h < w < c < p$ must be satisfied to ensure profitability.

5) Following Wang, et al.^[36], we assume that $C(s) = ks^2/2$.

6) In two different decision models, the manufacturer sells the same product.

7) We assume that the parameters should satisfy $2k\beta - \gamma^2 > 0$ to ensure that decisions are meaningful.

3.2 Model Building

3.2.1 Decision model without online reviews (Model-N)

When online reviews are not provided, the decision variables of E-SC members are price and service level. At this time, the manufacturer's decision variable is p , and the e-platform's decision variable is s . The manufacturer's profit is:

$$\pi_m = (p - \rho)q^N + (w - h)\eta\varepsilon D^N - cD^N. \quad (1)$$

The e-platform's profit is:

$$\pi_e = \rho q^N - \frac{ks^2}{2}. \quad (2)$$

The E-SC's profit is:

$$\pi_z = pq^N + (w - h)\eta\varepsilon D^N - cD^N - \frac{ks^2}{2}, \quad (3)$$

where $q^N = \alpha - \beta p + \gamma s$.

When making decisions, the dominant e-platform first determines s , and then the manufacturer decides p according to s . We use the backward induction method to get the price, service level, product sale, E-SC members' and E-SC's profits as shown in Table 2, and the specific solution process is shown in the Appendix.

Table 2 The optimal solution

Optimal solution	
Model-N	$s^N = \frac{\gamma\rho}{2k};$ $p^N = \frac{\alpha}{2\beta} + \frac{\gamma^2\rho}{4k\beta} + \frac{c+\varepsilon\eta(h-w)+\rho(1-\varepsilon\eta)}{2(1-\varepsilon\eta)};$ $q^N = \frac{\alpha}{2} + \frac{\gamma^2\rho}{4k} - \frac{\beta[c+\varepsilon\eta(h-w)+\rho(1-\varepsilon\eta)]}{2(1-\varepsilon\eta)};$ $\pi_m^N = \frac{\{2k[\beta(c+h\varepsilon\eta-w\varepsilon\eta+\rho-\varepsilon\eta\rho)-\alpha(1-\varepsilon\eta)]-\gamma^2(1-\varepsilon\eta)\rho\}^2}{16k^2\beta(1-\varepsilon\eta)^2};$ $\pi_e^N = \frac{\alpha\rho}{2} + \frac{\gamma^2\rho^2}{8k} - \frac{\rho\beta[c+\varepsilon\eta(h-w)+\rho(1-\varepsilon\eta)]}{2(1-\varepsilon\eta)};$ $\pi_z^N = \pi_m^N + \pi_e^N.$
Model-Y	$s^Y = \frac{\gamma\rho}{2k};$ $p^Y = \frac{2k[(1-\varepsilon\eta)(\alpha+\beta C(\tau^Y)+\mu\Delta r(\tau^Y)+\beta\rho)+c\beta+\beta\eta\varepsilon(h-w)]+\gamma^2(1-\varepsilon\eta)\rho}{4k\beta(1-\varepsilon\eta)};$ $q^Y = \frac{\gamma^2\rho}{4k} + \frac{(1-\varepsilon\eta)(\alpha+\mu\Delta r(\tau^Y)-\beta\rho-\beta C(\tau^Y))-c\beta-\beta\eta\varepsilon(h-w)}{2(1-\varepsilon\eta)};$ $\pi_m^Y = \frac{\{2k[c\beta+\beta\eta\varepsilon(h-w)-(1-\varepsilon\eta)(\alpha+\mu\Delta r(\tau^Y)-\beta\rho-\beta C(\tau^Y))]-\gamma^2(1-\varepsilon\eta)\rho\}^2}{16k^2\beta(1-\varepsilon\eta)^2};$ $\pi_e^Y = \frac{\gamma^2\rho^2}{8k} + \frac{\rho[(1-\varepsilon\eta)(\alpha+\mu\Delta r(\tau^Y)-\beta\rho-\beta C(\tau^Y))-c\beta-\beta\eta\varepsilon(h-w)]}{2(1-\varepsilon\eta)};$ $\pi_z^Y = \pi_m^Y + \pi_e^Y.$

3.2.2 Decision model with online reviews (Model-Y)

When the online review service is provided, consumers browse past consumer reviews of product quality when purchasing a product and the manufacturer will strive to improve product quality. At this time, the manufacturer's decision variables are p and τ , and the e-platform's decision variable is s . Then, the manufacturer's profit is:

$$\pi_m = (p - \rho - C(\tau))q^Y + (w - h)\eta\varepsilon D^Y - cD^Y. \quad (4)$$

The e-platform's profit is:

$$\pi_e = \rho q^Y - \frac{ks^2}{2}. \quad (5)$$

The E-SC's profit is:

$$\pi_z = (p - C(\tau))q^Y + (w - h)\eta\varepsilon D^Y - cD^Y - \frac{ks^2}{2}, \quad (6)$$

where $q^Y = \alpha - \beta p + \gamma s + \mu\Delta r(\tau)$.

When making decisions, the dominant e-platform first determines s , and then the manufacturer decides p and τ according to s . Using the backward induction method to calculate the optimal decisions and find that only when $r'(\tau) = \frac{\beta C'(\tau)}{\mu(1-\eta\varepsilon)}$, there is an optimal product quality that allows the manufacturer to obtain the optimal profit. The price, service level, product sale, E-SC members', and E-SC's profits are obtained as shown in Table 2, and the solution process is shown in the Appendix.

4 Model Analysis

4.1 Analysis of Model- N

Proposition 1 p^N increases with the increase of ε ; q^N , π_m^N , π_e^N , π_z^N decrease with ε , s^N has nothing to do with ε . Similarly, p^N increases with the increase of η ; q^N , π_m^N , π_e^N , π_z^N decrease with η , s^N has nothing to do with η .

Proposition 2 1) p^N increases with the increase of h ; q^N , π_m^N , π_e^N , and π_z^N decreases with h ; s^N has nothing to do with h . 2) p^N decreases with the increase of w ; q^N , π_m^N , π_e^N , and π_z^N increases with w ; s^N has nothing to do with w .

Arrange Propositions 1 and 2 in Table 3.

Table 3 Correlation analysis of the optimal solution of Model- N

	p^N	q^N	π_m^N	π_e^N	π_z^N	s
$\varepsilon \uparrow$	\uparrow	\downarrow	\downarrow	\downarrow	\downarrow	\rightarrow
$\eta \uparrow$	\uparrow	\downarrow	\downarrow	\downarrow	\downarrow	\rightarrow
$h \uparrow$	\uparrow	\downarrow	\downarrow	\downarrow	\downarrow	\rightarrow
$w \uparrow$	\uparrow	\downarrow	\downarrow	\downarrow	\downarrow	\rightarrow

From Proposition 1, 2, and Table 3, we can draw the following conclusions:

1) A higher return rate leads to higher prices, lower sales and profits for E-SC members. This is because the manufacturer faces higher return processing costs and has to increase the price to alleviate the higher cost pressure. However, the higher price lost some price-sensitive consumers, and sales decreases. The increase in profit brought about by higher prices is less than the decrease in profit led by the decrease in sales, and the manufacturer's profit decreases. Additionally, different from Li, et al.^[10], we find that the service level is only related to the commission, elasticity coefficient of the service cost and elasticity coefficient of service level, but has nothing to do with the return rate. However, the increase in the return rate will lead to a decrease in its profit.

2) When the accuracy of product information is low (i.e., η is large), the product information disclosed by the manufacturer cannot accurately reflect the product performance, which leads to insufficient understanding of the product by consumers before purchasing the product online. Then the decline of product information on the return rate is small, making the product return rate at a high level. Accordingly, when the product information accuracy is higher (i.e., η is low), the manufacturer sets a lower product price, which is beneficial to the consumer surplus and E-SC.

3) We find that h is positively correlated with the price, negatively correlated with the sales and E-SC members' profits, but will not change the service level. This is because the return processing cost is an additional cost for the manufacturer, so the manufacturer transfers the cost to the consumer by raising the price. This cost transfer leads to a decrease in market demand and the manufacturer's profit. For the e-platform, the reduction in sales leads to a reduction in its commission income, but it does not reduce service level.

4) The higher the residual value, the more surplus the manufacturer has to decrease price to occupy the market, expanding the profitability of E-SC members. However, no matter how the residual value of returned products affects their profits, the e-platform will not change service level.

Proposition 3 *The loss of consumer returns to the manufacturer's profit is greater than the e-platform's.*

We see from Proposition 3 that under the influence of consumers' return behavior, the profits of the manufacturer and e-platform decrease (Proposition 1), but the manufacturer's profit is reduced more. Therefore, manufacturers should strictly supervise and control the process of product production, transportation, storage, etc., keep abreast of consumer preferences, and strive to lower the return rate. For e-platforms, the product information provided by manufacturers should be strictly supervised, to prevent manufacturers from producing fake and inferior products, avoid consumers' dissatisfaction, and jointly create a good e-commerce operating environment.

4.2 Analysis of Model-Y

Proposition 4 *$r(\tau^Y)$ decreases with the increase of ε .*

We see from Proposition 4 that there is a negative correlation between OR-PQ and the return rate. This is because a higher return rate means that the product quality does not meet consumer expectations. Although some consumers choose to return products to avoid losses, some consumers who do not choose to return products will issue lower OR-PQ. This means that under the influence of consumer returns, the average level of OR-PQ is lower than the threshold of OR-PQ (i.e. $r(\tau) < r(\tau_0)$), and then OR-PQ is not conducive to sales.

Proposition 5 *τ^Y increases with the increase of μ ; s^Y has nothing to do with μ ; only when $\Delta r(\tau^Y) > \Delta r_1(\tau^Y)$, p^Y increases with μ ; only when $\Delta r(\tau^Y) > \Delta r_2(\tau^Y)$, q^Y , π_m^Y , π_e^Y , and π_z^Y increase with μ .*

Note: $\Delta r_1(\tau^Y) = -(\frac{\beta C'(\tau)}{1-\varepsilon\eta} + \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}$, $\Delta r_2(\tau^Y) = -(\frac{\beta C'(\tau)}{1-\varepsilon\eta} - \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}$, where $\frac{\partial \tau^Y}{\partial \mu} = \frac{\beta C'(\tau^Y)}{\beta \mu C''(\tau^Y) - r''(\tau^Y) \mu^2 (1-\varepsilon\eta)}$ and $\Delta r_2(\tau^Y) > \Delta r_1(\tau^Y)$.

Proposition 6 When $\varepsilon < \varepsilon_1$, p^Y decreases with the increase of ε , otherwise, it increases; s^Y has nothing to do with ε ; τ^Y decreases with ε ; q^Y , π_m^Y , π_e^Y , and π_z^Y decrease with ε .

Note: $\varepsilon_1 = \frac{1}{\eta} - \frac{(c+h-w)\beta C''(\tau^Y) - \beta[C'(\tau^Y)]^2}{r''(\tau^Y)\mu\eta(c+h-w) + \beta\eta[C'(\tau^Y)]^2}$.

Arrange Propositions 5 and 6 in Table 4.

Table 4 Proposition of Model-Y

	τ^Y	p^Y	q^Y	π_m^Y	π_e^Y	π_z^Y	s^Y
$\mu \uparrow$	\uparrow	$\Delta r(\tau^Y) > \Delta r_1(\tau^Y)$		$\Delta r(\tau^Y) > \Delta r_2(\tau^Y)$			\rightarrow
		\uparrow	\uparrow	\uparrow	\uparrow	\uparrow	
$\varepsilon \uparrow$	\downarrow	$\varepsilon < \varepsilon_1$	$\varepsilon > \varepsilon_1$	\downarrow	\downarrow	\downarrow	\rightarrow
		\downarrow	\uparrow				

From Propositions 5, 6, and Table 4, we can draw the following conclusions:

1) We see that the increase of μ means that consumers are more sensitive to OR-PQ, so the manufacturer chooses to improve product quality to attract more consumers. However, higher OR-PQ requires the manufacturer to pay a higher cost for improving quality, increasing cost pressures on the manufacturer. Therefore, when $\Delta r(\tau^Y) > \Delta r_1(\tau^Y)$, the manufacturer will increase the price to relieve the cost pressure. When $\Delta r(\tau^Y) \in (\Delta r_1(\tau^Y), \Delta r_2(\tau^Y))$, consumers' attention to product quality leads to higher prices and quality, but the product quality at this time is not enough to attract more consumers, so sales and E-SC members' profits are lower. When $\Delta r(\tau^Y) > \Delta r_2(\tau^Y)$, higher product quality attracts consumers, and the sales and profits of E-SC members increase. However, even if consumers' focus on product quality increases the e-platform's profit, it will not improve the service level.

2) Since the return rate is inversely proportional to OR-PQ (Proposition 4), when ε is lower than a certain threshold ($\varepsilon \in (0, \varepsilon_1)$), OR-PQ is higher. Within this range, as ε increases, manufacturers will lower prices to attract price-sensitive consumers to maintain consumer traffic. However, consistent with Proposition 1, the return rate is always not conducive to sales, resulting in a decrease in the profits of E-SC and its members, but it does not affect the service level.

4.3 Model Comparison

Next, we will compare and analyze the decisions and profits of two different decision-making models to analyze the impact of online reviews on E-SC.

Proposition 7 $s^Y = s^N$; when $\Delta r(\tau^Y) > -\Delta r_3(\tau^Y)$, $p^Y > p^N$; when $\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$, $q^Y > q^N$.

Note: $\Delta r_3(\tau^Y) = \frac{\beta C(\tau^Y)}{\mu}$.

We see from Proposition 7 that providing online reviews is not always conducive to an increase in price. Specifically, when $\Delta r(\tau^Y) > -\Delta r_3(\tau^Y)$, providing online reviews can help the manufacturer to increase the price to compensate for the cost of improving quality. Compared with the model without online reviews, only when $\Delta r(\tau^Y) \in (-\Delta r_3(\tau^Y), \Delta r_3(\tau^Y))$, the product quality and price increase, but the sales always decrease. Only when the positive OR-PQ is higher than a certain threshold ($\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$), providing online reviews increase

consumers' understanding of the product, leading the sales is higher. However, whether or not online reviews are provided does not change the e-platform's service level.

Proposition 8 *Only when $\Delta r(\tau^Y) < \Delta r_3(\tau^Y)$, $\pi_m^Y < \pi_m^N$, $\pi_e^Y < \pi_e^N$, and $\pi_z^Y < \pi_z^N$; otherwise, $\pi_m^Y > \pi_m^N$, $\pi_e^Y > \pi_e^N$, and $\pi_z^Y > \pi_z^N$.*

We see from Proposition 8 that how providing online reviews affect the profitability of E-SC members is related to the level of OR-PQ, and it is not always beneficial to the profitability of E-SC members and system efficiency. Specifically, only when the positive OR-PQ is higher than a certain threshold ($\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$), the product quality, price, sales, and E-SC members' profits are higher than those of the model without online reviews. However, when OR-PQ is low or even negative ($\Delta r(\tau^Y) < \Delta r_3(\tau^Y)$), consumers are dissatisfied with the product quality and the sales are lower, not providing online reviews is beneficial to E-SC operation.

5 Supply Chain Coordination

We follow Maiga, et al.^[33] and Wang, et al.^[36] to explore the coordinated operation of the decentralized model with online reviews.

5.1 Centralized Model with Online Reviews

In the centralized model with online reviews, E-SC firms cooperate to optimize system efficiency. The decision function of E-SC firms is:

$$\max_{p, \tau, s} \pi(p, s) = (p - C(\tau))q^{YC} + (w - h)\eta\varepsilon D^{YC} - cD^{YC} - \frac{ks^2}{2}, \quad (7)$$

where $q^{YC} = \alpha - \beta p + \gamma s + \mu\Delta r(\tau)$, $D^{YC} = q^{YC}/(1 - \varepsilon\eta)$.

We use optimization theory to find that when $r'(\tau) = \beta C'(\tau^{YC})/(\mu(1 - \varepsilon\eta))$, and there are optimal decisions and profits as follows:

$$\begin{aligned} p^{YC} &= \frac{k[(\alpha + \beta C(\tau^{YC}) + \mu\Delta r(\tau^{YC}))(1 - \varepsilon\eta) + c\beta + \beta\eta\varepsilon(h - w)] - \gamma^2[c + C(\tau^{YC})(1 - \varepsilon\eta) + (h - w)\eta\varepsilon]}{(2k\beta - \gamma^2)(1 - \varepsilon\eta)}; \\ s^{YC} &= \frac{\gamma[(\alpha - \beta C(\tau^{YC}) + \mu\Delta r(\tau^{YC}))(1 - \varepsilon\eta) - c\beta - \beta\eta\varepsilon(h - w)]}{(2k\beta - \gamma^2)(1 - \varepsilon\eta)}; \\ q^{YC} &= \frac{k\beta[(\alpha - \beta C(\tau^{YC}) + \mu\Delta r(\tau^{YC}))(1 - \varepsilon\eta) - c\beta - \beta\eta\varepsilon(h - w)]}{(2k\beta - \gamma^2)(1 - \varepsilon\eta)}; \\ \pi^{YC} &= \frac{k[c\beta + \beta\eta\varepsilon(h - w) + (\alpha - \beta C(\tau^{YC}) + \mu\Delta r(\tau^{YC}))(1 - \varepsilon\eta)]}{(2k\beta - \gamma^2)(1 - \varepsilon\eta)}. \end{aligned}$$

Proposition 9 $p^{YC} < p^Y$, $s^{YC} > s^Y$, $q^{YC} > q^Y$, $\pi_z^{YC} > \pi_z^Y$.

The lower price and higher service level, sales, and E-SC profit show that the centralized model is a better operation mode. However, this mode requires close E-SC firms' operation, which is uneasy in reality. Therefore, we next design a new mechanism to optimize the decentralized model with online reviews to realize the efficiency of centralized models.

5.2 Coordination Mechanism

Considering that consumer returns and product quality improvement bring cost pressure to manufacturers, we design a new "commission joint returns and quality improvement costs

sharing” contract to optimize the decentralized model with online reviews. Among them, to maintain the enthusiasm of manufacturers’ cooperation, the e-platforms take the initiative to bear returns and quality improvement costs at the ratio of v , and also adjust commission to \bar{p} . So the manufacturer’s profit is:

$$\max_{p,\tau} \bar{\pi}_m^Y = (p - \bar{p})q^{YC} + w\eta\varepsilon D^{YC} - cD^{YC} - (1 - v)(h\eta\varepsilon D^{YC} + C(\tau)q^{YC}). \quad (8)$$

The e-platform’s profit is:

$$\max_s \bar{\pi}_e^Y = \bar{p}q^{YC} - \frac{ks^2}{2} - v(h\eta\varepsilon D^{YC} + C(\tau)q^{YC}), \quad (9)$$

where $q^{YC} = \alpha - \beta p + \gamma s + \mu\Delta r(\tau)$, $D^{YC} = \frac{q^{YC}}{1 - \varepsilon\eta}$.

Proposition 10 ϕ ($0 < \phi < 1$) is the proportion of the manufacturer’s profit in the system after coordination, so when

$$\begin{cases} \bar{p} = (1 - \phi)p + \frac{(1 - \phi)(w\eta\varepsilon - c)D + \frac{\phi ks^2}{2}}{q}, \\ v = 1 - \phi, \end{cases}$$

“commission joint returns and quality improvement costs sharing” contract can coordinate the decentralized model with online reviews.

Proof Put

$$\begin{cases} \bar{p} = (1 - \phi)p + \frac{(1 - \phi)(w\eta\varepsilon - c)D + \frac{\phi ks^2}{2}}{q}, \\ v = 1 - \phi, \end{cases}$$

into the E-SC firms’ profits after coordination, we get:

$$\begin{aligned} \max_{p,\tau} \bar{\pi}_m^Y &= (p - \bar{p})q + w\eta\varepsilon D - cD - (1 - v)(h\eta\varepsilon D + C(\tau)q) \\ &= \phi \left[pq + (w - h)\eta\varepsilon D - cD - \frac{ks^2}{2} \right] \\ &= \phi \bar{\pi}^{YC}, \\ \max_s \bar{\pi}_e^Y &= \bar{p}q - \frac{ks^2}{2} + v(h\eta\varepsilon D + C(\tau)q) \\ &= (1 - \phi) \left[(p - C(\tau))q + (w - h)\eta\varepsilon D - cD - \frac{ks^2}{2} \right] \\ &= (1 - \phi) \bar{\pi}^{YC}. \end{aligned}$$

We find that E-SC firms’ profits after coordination are linear functions of system profit, which indicates that E-SC firms make decisions to maximize system profit, and this contract can optimize the E-SC system.

We next calculate the feasible scope of this contract. To make E-SC firms accept this contract, we need to ensure that their profits after coordination are higher than before coordination, that is, $\begin{cases} \bar{\pi}_m^Y \geq \pi_m^Y \\ \bar{\pi}_e^Y \geq \pi_e^Y \end{cases}$. So the feasible scope is $[\frac{\pi_m^Y}{\pi_z^{YC}}, 1 - \frac{\pi_e^Y}{\pi_z^{YC}}]$, after simplification:

$$\frac{(2k\beta - \gamma^2) \left\{ \gamma^2 \rho(1 - \varepsilon\eta) + 2k[(\alpha - \beta C(\tau^{YC}) + \mu \Delta r(\tau^{YC}) - \beta \rho)(1 - \varepsilon\eta) - c\beta - \beta \varepsilon \eta(h - w)] \right\}^2}{8k^3 \beta [(\alpha - \beta C(\tau^{YC}) + \mu \Delta r(\tau^{YC}))(1 - \varepsilon\eta) - c\beta - \beta \varepsilon \eta(h - w)]^2} \leq \phi \leq$$

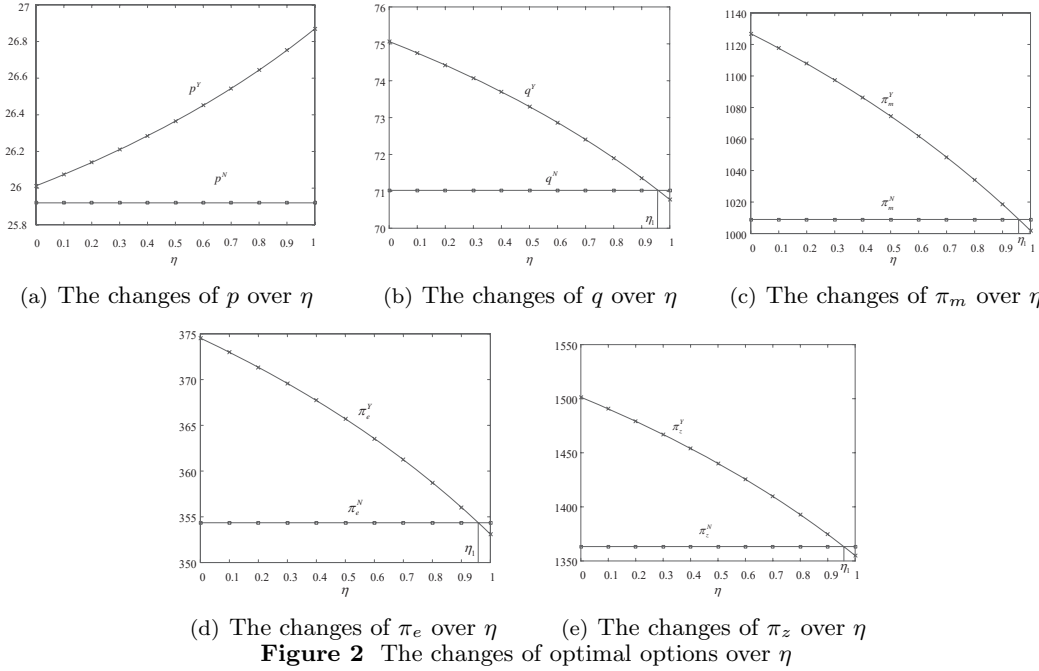
$$1 - \frac{(2k\beta - \gamma^2)(1 - \varepsilon\eta) \rho \left\{ \gamma^2 \rho(1 - \varepsilon\eta) + 4k[(\alpha - \beta C(\tau^{YC}) + \mu \Delta r(\tau^{YC}) - \beta \rho)(1 - \varepsilon\eta) - c\beta - \beta \varepsilon \eta(h - w)] \right\}}{4k^2 \beta [(\alpha - \beta C(\tau^{YC}) + \mu \Delta r(\tau^{YC}))(1 - \varepsilon\eta) - c\beta - \beta \varepsilon \eta(h - w)]^2}.$$

Proposition 11 *The proportion of e-platforms sharing the manufacturers' return and quality improvement costs is equal to the proportion of e-platform's profit in E-SC.*

In coordination, the more e-platforms share manufacturers' costs, the more profits they will obtain. This contract can reduce the cost pressure faced by manufacturers, and the stronger the willingness of e-platforms to bear manufacturers' costs, the more beneficial to both E-SC members. This indicates that the contract can promote E-SC firms to reach a cooperation game relationship and achieve the maximum profit of the E-SC system.

6 Numerical Analysis

The above analysis of returns and online reviews assumes that product information accuracy is the same in both decision models with or without online reviews. However, compared with the model without online reviews, online reviews have the characteristics of interactivity, authenticity, and effectiveness, so the accuracy of product information when providing online reviews is higher, which can effectively reduce the return rate. Therefore, we assume that the accuracy of product information is lower in the model without online reviews, that is, $\eta = 1$. Then we set the accuracy of product information in the model with online reviews as the independent variable, that is, η ($\eta \in (0, 1)$). Following Bandi, et al.^[37], we assume that $\alpha = 200$, $\beta = 5$, $\gamma = 1$, $\mu = 3$, $k = 4$, $c = 5$, $w = 3$, $h = 2$, and $\rho = 5$; following Shen, et al.^[9], we set $\varepsilon = 0.3$; following Jiang and Yang^[38], we assume that $C(\tau^Y) = 1$. According to the current mainstream e-platforms adopting a five-point evaluation grade, we assume that the average OR-PQ is $r(\tau) = 4.5$, and the threshold of OR-PQ is $r(\tau_0) = 3$, so $\Delta r(\tau) = 1.5$. We plot the effect of η on price, sales, and E-SC members' profits as shown in Figures 2.



We see from Figure 2(a) that the higher the accuracy of product information, the higher the price, that is, $p^Y > p^N$, which shows that providing online review services is conducive to the manufacturer setting a higher price. As the accuracy of product information decreases (that is, η tends to 1), the price gap between the two models becomes larger and larger. This is because when the product information fails to show the true performance of the product, it increases the probability of consumers making wrong purchasing decisions, which brings additional return processing costs to the manufacturer, thus increasing the price.

We see from Figure 2(b)~(e), compared with the model without online review, when the product information is more accurate, the sales and E-SC members' profits are higher in the model with online reviews. However, when the product information is less accurate ($\eta_1, 1$), the sales and E-SC members' profits are lower. This shows that E-SC firms should pay attention to the accuracy of product information, and only when it maintains a high level can they ensure that the provision of online review services will not hurt E-SC operations. Therefore, for the manufacturer, e-platform, and E-SC system, if and only when the accuracy of product information is higher than a certain threshold, that is, $\eta < \eta_1$, providing online reviews is conducive to improving profits. Accordingly, in the interval $(\eta_1, 1)$, manufacturers and e-platforms should not provide online reviews, and only in the interval $(0, \eta_1)$, it is a wise choice to provide online reviews. In addition, we find from Figure 2(c) and 2(d) that $|\frac{\partial \Delta \pi_m}{\partial \eta}| > |\frac{\partial \Delta \pi_e}{\partial \eta}|$, showing that the accuracy of product information has a greater impact on manufacturers' profits, which indicates that the manufacturer should disclose more accurate product information as much as possible, which is beneficial to themselves and the system.

$$\text{Note: } \eta_1 = \frac{\beta \varepsilon (c+h-w) - (\beta C(\tau^Y) - \mu \Delta r(\tau^Y))(1-\varepsilon)}{\varepsilon [\beta (c+h-w) - (\beta C(\tau^Y) - \mu \Delta r(\tau^Y))(1-\varepsilon)]}.$$

Then, we verify the validity of the “commission joint returns and quality improvement costs sharing” contract. Based on the above values, we set $\eta = 0.5$. The feasible range of commission, profits, and coordination mechanism before and after coordination is shown in Table 5.

Table 5 The operation of the decision model with online reviews before and after coordination

	Before coordination	After coordination
ρ	5	$\overline{\rho^Y} \in (5.1009, 6.7901)$
The manufacturer's profit	$\pi_m^Y = 1074.5$	$\overline{\pi_m^Y} \in (1074.5132, 1201.4492)$
The e-platform's profit	$\pi_e^Y = 365.7077$	$\overline{\pi_e^Y} \in (385.2507, 512.1867)$
Coordination mechanism	—	$\phi \in (0.6772, 0.7695)$

Before and after coordination, E-SC firms' profits follow the feasible scope of the coordination mechanism $\phi \in (0.6772, 0.7695)$ as shown in Figure 3. Next, take η ($\eta \in (0, 1)$) is the independent variable, and the feasible range of the coordination mechanism is plotted as shown in Figure 4.

We see from Figure 3 that after the “commission joint returns and quality improvement costs sharing” contract coordinates the decentralized model with online reviews, E-SC firms' profits are improved, showing it's profitable for E-SC firms to accept this contract. Figure 4(a) shows that with the improvement of the accuracy of product information (i.e., η approaches 0), the upper and lower limits of the coordination mechanism are increased, that is, the manufacturer's

voice in the channel is increased. However, Figure 4(b) shows that the lower limit increases more rapidly, which reduces the feasible range of the coordination mechanism.

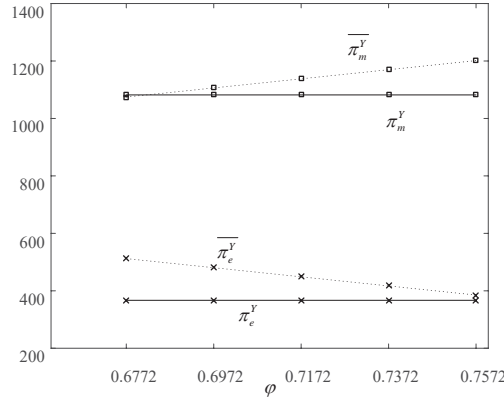
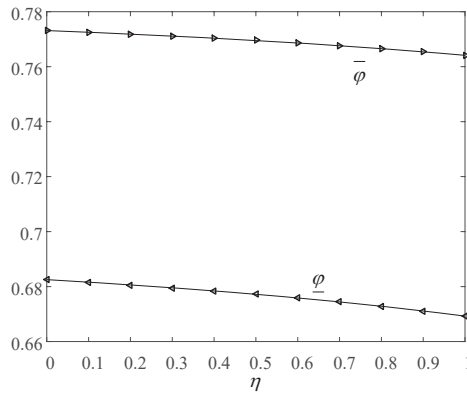
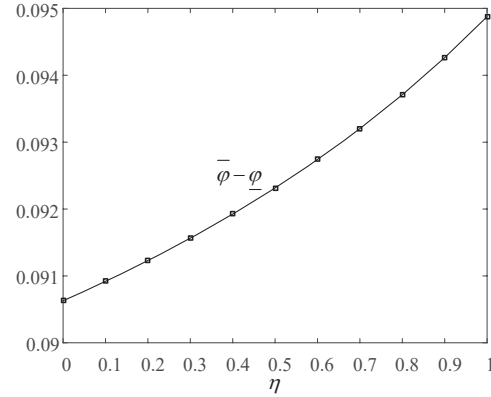


Figure 3 The changes of profits before and after coordination over ϕ



(a) The changes of feasible range over η



(b) The changes of upper and lower limits of coordination mechanism over η

Figure 4 The feasible range of the coordination mechanism

7 Conclusions and Recommendations

7.1 Conclusions

We consider the impact of consumer returns to construct E-SC game models with or without online reviews, and then compare and analyze the two models. The results show that:

1) In the model without online reviews, return rate and return processing cost are positively related to price and negatively related to the sales, profits of E-SC firms, and system. When the product information is accurate and the return residual value is high, the manufacturer sets a lower price, expanding the sales and profits of E-SC members. However, return rate, return processing cost, return residual value, and product information accuracy are not affecting the e-platform's service level. Additionally, returns have a more negative impact on the manufacturer's profit than e-platforms.

2) In the model with online reviews, the higher return rate leads to a lower OR-PQ level, making the price decrease first and then increase, but it is always unconducive to sales and E-SC

operation. Although consumers' attention to OR-PQ will promote manufacturers to improve product quality, only when OR-PQ is higher than a certain threshold will consumers' attention has a positive impact on sales, the E-SC.

3) By comparing and analyzing the optimal decision and profit of the two models, we find that only when OR-PQ is positive and higher than a certain threshold, online review increases E-SC members' profits. This also shows that providing online reviews is not always conducive to the actual operation of E-SC. We analyze the impact of product information accuracy on optimal decisions and profits of E-SC members, and we find that when and only when the product information accuracy is higher than a certain threshold (i.e., $\eta < \frac{\beta\varepsilon(c+h-w)-(\beta C(\tau^Y)-\mu\Delta r(\tau^Y))(1-\varepsilon)}{\varepsilon[\beta(c+h-w)-(\beta C(\tau^Y)-\mu\Delta r(\tau^Y))(1-\varepsilon)]}$), E-SC members shall provide online reviews.

4) In the "commission joint returns and quality improvement costs sharing" contract, the proportion of e-platforms sharing the manufacturers' return and quality improvement costs is equal to the proportion of e-platform's profit in E-SC. The contract can effectively optimize the decentralized model with online reviews, and improve the E-SC firms and system profits, but the feasible scope of the contract decreases with the improvement of the accuracy of product information.

7.2 Managerial Implications

Our research provides the following management enlightenment for E-SC node firms:

On the one hand, under the background of rampant false information and publicity in online sales, manufacturers can provide more accurate product information to help consumers understand the products, reduce the probability of consumers making wrong purchase decisions, and then reduce the return rate in online sales, which is conducive to E-SC firms (Proposition 1). Therefore, manufacturers should strictly supervise and disclose product information to reduce the return rate, which will increase their profits more than that of e-platforms (Proposition 3). Additionally, product quality is also an important reason for affecting the return rate (Proposition 6). Therefore, manufacturers providing higher quality products will not only help them expand their profit margins but also help build their brand image.

On the other hand, manufacturers and e-platforms should pay attention to OR-PQ and make timely improvements based on consumers' reviews. Because only when OR-PQ is higher than a certain threshold, it's conducive for E-SC members to provide online reviews (Proposition 8). It's the joint responsibility of manufacturers and platforms to reduce the return rate and focus on product reviews. The e-platform should provide a more complete data integration function to help manufacturers understand consumer preferences, strive to cooperate with manufacturers in production, and raise OR-PQ above the threshold to maintain profitability, which is mutually beneficial for manufacturers and e-platforms.

7.3 Future Research Directions

The next step of our research is as follows:

- 1) We assume that the returned products have the same product residual value, and do not include the residual value difference of returned products into the model for research.
- 2) The manufacturer only cooperates with a single e-platform in our paper, but in reality, the manufacturer not only enters multiple platforms for sales, but also sells products in offline

stores. The “online and offline combination” and “one to many” supply chain operation mode will be our next research.

3) We only consider how online reviews affect a single manufacturer’s decision-making and profitability, and do not ponder on the interaction of online reviews on multiple competitive manufacturers. The next step is to study how online review affects competitive E-SC firms’ operations.

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APPENDIX

A1 Derivation of the Optimal Decisions and Profit of Decision Model without Online Reviews

Since $\frac{\partial^2 \pi_m}{\partial p^2} = -2\beta(1 - \varepsilon\eta) < 0$, there is a price that maximizes the manufacturer's profit. From $\frac{\partial \pi_m}{\partial p} = 0$, the reaction function of price can be obtained as:

$$p = \frac{(1 - \varepsilon\eta)(\alpha + s\gamma + \beta\rho) + c\beta + \beta\varepsilon\eta(h - w)}{2\beta(1 - \varepsilon\eta)}. \quad (\text{A1})$$

Substituting (A1) into the profit of the e-platform, we can get $\frac{\partial^2 \pi_e}{\partial s^2} = -k < 0$. Accordingly, from

$\frac{\partial \pi_e}{\partial s} = 0$, we get the optimal service level is:

$$s^N = \frac{\gamma \rho}{2k}. \quad (A2)$$

Substituting (A2) into the reaction function of price, the optimal price can be obtained as:

$$p^N = \frac{\alpha}{2\beta} + \frac{\gamma^2 \rho}{4k\beta} + \frac{c + \varepsilon \eta(h - w) + \rho(1 - \varepsilon \eta)}{2(1 - \varepsilon \eta)}. \quad (A3)$$

Accordingly, the optimal sale is:

$$q^N = \frac{\alpha}{2} + \frac{\gamma^2 \rho}{4k} - \frac{\beta[c + \varepsilon \eta(h - w) + \rho(1 - \varepsilon \eta)]}{2(1 - \varepsilon \eta)}. \quad (A4)$$

Substituting the above decisions into profit functions, we can get the optimal profits are:

$$\pi_m^N = \frac{\{2k[\beta(c + h\varepsilon\eta - w\varepsilon\eta + \rho - \varepsilon\eta\rho) - \alpha(1 - \varepsilon\eta)] - \gamma^2(1 - \varepsilon\eta)\rho\}^2}{16k^2\beta(1 - \varepsilon\eta)^2}, \quad (A5)$$

$$\pi_e^N = \frac{\alpha\rho}{2} + \frac{\gamma^2\rho^2}{8k} - \frac{\rho\beta[c + \eta\varepsilon(h - w) + \rho(1 - \varepsilon\eta)]}{2(1 - \varepsilon\eta)}. \quad (A6)$$

Proof of Proposition 1

$$\begin{aligned} \frac{\partial p^N}{\partial \varepsilon} &= \frac{(c+h-w)\eta}{2(1-\varepsilon\eta)^2} > 0; \quad \frac{\partial s^N}{\partial \varepsilon} = 0; \quad \frac{\partial q^N}{\partial \varepsilon} = -\frac{(c+h-w)\beta\eta}{2(1-\varepsilon\eta)^2} < 0; \quad \frac{\partial \pi_e^N}{\partial \varepsilon} = -\frac{(c+h-w)\beta\eta\rho}{2(1-\varepsilon\eta)^2} < 0; \quad \frac{\partial \pi_m^N}{\partial \varepsilon} = \\ &= -\frac{(c+h-w)\eta\{\gamma^2(1-\varepsilon\eta)\rho + 2k[\alpha(1-\varepsilon\eta) - \beta(c+h\varepsilon\eta - w\varepsilon\eta + \rho - \varepsilon\eta\rho)]\}}{4k(1-\varepsilon\eta)^3} < 0; \quad \frac{\partial \pi_e^N}{\partial \varepsilon} = \frac{\partial \pi_m^N}{\partial \varepsilon} + \frac{\partial \pi_e^N}{\partial \varepsilon} < 0; \quad \text{Similarly, } \frac{\partial p^N}{\partial \eta} > 0; \\ \frac{\partial s^N}{\partial \eta} &= 0; \quad \frac{\partial q^N}{\partial \eta} < 0; \quad \frac{\partial \pi_m^N}{\partial \eta} < 0; \quad \frac{\partial \pi_e^N}{\partial \eta} < 0; \quad \frac{\partial \pi_e^N}{\partial \eta} < 0. \end{aligned}$$

Proof of Proposition 2

$$\begin{aligned} \text{According to } 2k\beta - \gamma^2 > 0 \text{ and } c + h - w > 0, \text{ we can get: } \frac{\partial p^N}{\partial h} &= \frac{\varepsilon\eta}{2(1-\varepsilon\eta)} > 0; \quad \frac{\partial s^N}{\partial h} = 0; \\ \frac{\partial q^N}{\partial h} &= -\frac{\beta\varepsilon\eta}{2(1-\varepsilon\eta)} < 0; \quad \frac{\partial \pi_m^N}{\partial h} = -\frac{\varepsilon\eta\{\gamma^2(1-\varepsilon\eta)\rho + 2k[\alpha(1-\varepsilon\eta) - \beta(c+h\varepsilon\eta - w\varepsilon\eta + \rho - \varepsilon\eta\rho)]\}}{4k(1-\varepsilon\eta)^2} < 0; \quad \frac{\partial \pi_e^N}{\partial h} = -\frac{\beta\varepsilon\eta\rho}{2(1-\varepsilon\eta)} < 0; \\ \frac{\partial \pi_m^N}{\partial h} &= \frac{\partial \pi_m^N}{\partial h} + \frac{\partial \pi_e^N}{\partial h} < 0. \end{aligned}$$

Proof of Proposition 3

$$\left| \frac{\partial \pi_m^N}{\partial \varepsilon} \right| - \left| \frac{\partial \pi_e^N}{\partial \varepsilon} \right| = \frac{(c+h-w)\eta\{\gamma^2(1-\varepsilon\eta)\rho + 2k[\alpha(1-\varepsilon\eta) - \beta(c+h\varepsilon\eta - w\varepsilon\eta + 2\rho - 2\varepsilon\eta\rho)]\}}{4k(1-\varepsilon\eta)^3} > 0, \text{ that is, } \left| \frac{\partial \pi_m^N}{\partial \varepsilon} \right| > \left| \frac{\partial \pi_e^N}{\partial \varepsilon} \right|.$$

B1 Derivation of the Optimal Decisions and Profit of Decision Model with Online Reviews

Since $\frac{\partial^2 \pi_m}{\partial p^2} = -2\beta(1 - \varepsilon\eta) < 0$, there is a price that maximizes the manufacturer's profit. From $\frac{\partial \pi_m}{\partial p} = 0$, the reaction function of price can be obtained as:

$$p = \frac{(1 - \varepsilon\eta)(\alpha + \beta C(\tau) + s\gamma + \mu\Delta r(\tau) + \beta\rho) + c\beta + \beta\eta\varepsilon(h - w)}{2\beta(1 - \varepsilon\eta)}. \quad (B1)$$

Substituting (B1) into the profit of the manufacturer, we can get:

$$\begin{aligned} \frac{\partial \pi_m}{\partial \tau} &= \frac{\{c\beta + (1-\varepsilon\eta)[\beta\rho + \beta C(\tau) - s\gamma - \alpha - \mu\Delta r(\tau)] + \beta\eta\varepsilon(h-w)\}[\beta C'(\tau) - (1-\varepsilon\eta)\mu r'(\tau)]}{2\beta(1-\varepsilon\eta)}; \\ \frac{\partial^2 \pi_m}{\partial \tau^2} &= \frac{\{[\beta C'(\tau) - (1-\varepsilon\eta)\mu r'(\tau)]^2 - [(1-\varepsilon\eta)(s\gamma + \alpha + \mu\Delta r(\tau) - \beta\rho - \beta C(\tau)) - c\beta - \beta\eta\varepsilon(h-w)][(1-\varepsilon\eta)(\beta C''(\tau) - \mu r''(\tau))]\}}{2\beta(1-\varepsilon\eta)}. \end{aligned}$$

Since $r'(\tau) > 0$ and $r''(\tau) < 0$, only when $r'(\tau) = \frac{\beta C'(\tau)}{\mu(1-\varepsilon\eta)}$, $\frac{\partial \pi_m}{\partial \tau} = 0$ and $\frac{\partial^2 \pi_m}{\partial \tau^2} < 0$, there is optimal product quality.

Substituting (B1) and τ into the e-platform's profit function, we can get $\frac{\partial^2 \pi_e}{\partial s^2} = -k < 0$, so from $\frac{\partial \pi_e}{\partial s} = 0$, we get the optimal service level is:

$$s^Y = \frac{\gamma \rho}{2k}. \quad (B2)$$

Substituting (B2) into (B1), the optimal price can be obtained as:

$$p^Y = \frac{2k[(1 - \varepsilon\eta)(\alpha + \beta C(\tau^Y) + \mu\Delta r(\tau^Y) + \beta\rho) + c\beta + \beta\eta\varepsilon(h - w)] + \gamma^2(1 - \varepsilon\eta)\rho}{4k\beta(1 - \varepsilon\eta)}. \quad (B3)$$

Accordingly, the optimal sale is:

$$q^Y = \frac{\gamma^2 \rho}{4k} + \frac{(1 - \varepsilon\eta)(\alpha + \mu\Delta r(\tau^Y) - \beta\rho - \beta C(\tau^Y)) - c\beta - \beta\varepsilon\eta(h - w)}{2(1 - \varepsilon\eta)}. \quad (B4)$$

Substituting the above decisions into profit functions, we can get the optimal profits are:

$$\pi_m^Y = \frac{\{2k[c\beta + \beta\eta\varepsilon(h - w) - (1 - \varepsilon\eta)(\alpha + \mu\Delta r(\tau^Y) - \beta\rho - \beta C(\tau^Y))] - \gamma^2(1 - \varepsilon\eta)\rho\}^2}{16k^2\beta(1 - \varepsilon\eta)^2}, \quad (B5)$$

$$\pi_e^Y = \frac{\gamma^2 \rho^2}{8k} + \frac{\rho[(1 - \varepsilon\eta)(\alpha + \mu\Delta r(\tau^Y) - \beta\rho - \beta C(\tau^Y)) - c\beta - \beta\eta\varepsilon(h - w)]}{2(1 - \varepsilon\eta)}. \quad (B6)$$

Proof of Proposition 4

Assuming that T is the maximum product quality that the manufacturer can provide, according to $r'(\tau) = \frac{\beta C'(\tau)}{\mu(1 - \varepsilon\eta)}$, we can get the level of OR-PQ is $r(\tau) = \int_0^T \frac{\beta C'(x)}{\mu(1 - \varepsilon\eta)} dx = \frac{\beta C(\tau)}{\mu(1 - \varepsilon\eta)}$. Therefore, the relationship between OR-PQ and return rate is $\frac{\partial r(\tau^Y)}{\partial \varepsilon} = -\frac{\beta\eta C(\tau)}{\mu(1 - \varepsilon\eta)^2} < 0$.

Proof of Proposition 5

The first order of $r'(\tau) = \frac{\beta C'(\tau)}{\mu(1 - \varepsilon\eta)}$ about μ is $r''(\tau^Y) \frac{\partial \tau^Y}{\partial \mu} = \frac{\beta(\mu C''(\tau^Y) \frac{\partial \tau^Y}{\partial \mu} - C'(\tau^Y))}{\mu^2(1 - \varepsilon\eta)}$. Since $C''(\tau^Y) > 0$ and $r''(\tau^Y) < 0$, we can get the first order of OR-PQ about μ is $\frac{\partial \tau^Y}{\partial \mu} = \frac{\beta C'(\tau^Y)}{\beta\mu C''(\tau^Y) - r''(\tau^Y)\mu^2(1 - \varepsilon\eta)} > 0$. According to the optimal decision, we can get first orders of service level and price about μ are $\frac{\partial s^Y}{\partial \mu} = 0$, $\frac{\partial p^Y}{\partial \mu} = \frac{\Delta r(\tau^Y) + \beta C'(\tau^Y) \frac{\partial \tau^Y}{\partial \mu} + \mu r'(\tau^Y) \frac{\partial \tau^Y}{\partial \mu}}{2\beta}$.

We find that only when $\Delta r(\tau^Y) > \Delta r_1(\tau^Y) = -(\frac{\beta C'(\tau^Y)}{1 - \varepsilon\eta} + \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}$, $\frac{\partial p^Y}{\partial \mu} > 0$.

Similarly, first orders of sales and the profits of E-SC members about μ are:

$$\begin{aligned} \frac{\partial q^Y}{\partial \mu} &= \frac{1}{2}[\Delta r(\tau^Y) + (\frac{\beta C'(\tau^Y)}{1 - \varepsilon\eta} - \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}], \\ \frac{\partial \pi_m^Y}{\partial \mu} &= \frac{[\Delta r(\tau^Y) + \mu r'(\tau^Y) \frac{\partial \tau^Y}{\partial \mu} - \beta C'(\tau^Y) \frac{\partial \tau^Y}{\partial \mu}]\{\gamma^2(1 - \varepsilon\eta)\rho + 2k[(\alpha + \mu\Delta r(\tau^Y) - \beta\rho - \beta C(\tau^Y))(1 - \varepsilon\eta) - c\beta - \beta\varepsilon\eta(h - w)]\}}{4k\beta(1 - \varepsilon\eta)}, \\ \frac{\partial \pi_e^Y}{\partial \mu} &= \frac{\rho}{2}[\Delta r(\tau^Y) + (\frac{\beta C'(\tau^Y)}{1 - \varepsilon\eta} - \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}]. \end{aligned}$$

Since $0 < 1 - \varepsilon\eta < 1$, $\frac{\beta C'(\tau^Y)}{1 - \varepsilon\eta} - \beta C'(\tau^Y) > 0$, we find that only when $\Delta r(\tau^Y) > \Delta r_2(\tau^Y) = -(\frac{\beta C'(\tau^Y)}{1 - \varepsilon\eta} - \beta C'(\tau^Y)) \frac{\partial \tau^Y}{\partial \mu}$, $\frac{\partial q^Y}{\partial \mu} > 0$, $\frac{\partial \pi_m^Y}{\partial \mu} > 0$, and $\frac{\partial \pi_e^Y}{\partial \mu} > 0$, where $\Delta r_2(\tau^Y) > \Delta r_1(\tau^Y)$.

Proof of Proposition 6

The first order of $r'(\tau) = \frac{\beta C'(\tau)}{\mu(1 - \varepsilon\eta)}$ about ε is $r''(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon} = \frac{\beta C''(\tau^Y)(1 - \varepsilon\eta) \frac{\partial \tau^Y}{\partial \varepsilon} + \beta\eta C'(\tau^Y)}{\mu(1 - \varepsilon\eta)^2}$.

Therefore, the first order of product quality about return rate is $\frac{\partial \tau^Y}{\partial \varepsilon} = \frac{\beta\eta C'(\tau^Y)}{(1 - \varepsilon\eta)[r''(\tau^Y)\mu(1 - \varepsilon\eta) - \beta C''(\tau^Y)]} < 0$.

According to the optimal decision, we can get first orders of service level and price about ε are $\frac{\partial s^Y}{\partial \varepsilon} = 0$, $\frac{\partial p^Y}{\partial \varepsilon} = \frac{1}{2}[\frac{\eta(c + h - w)}{(1 - \varepsilon\eta)^2} + C'(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon} + \mu r'(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon}]$.

Bringing $\frac{\partial \tau^Y}{\partial \varepsilon} = \frac{\beta\eta C'(\tau^Y)}{(1 - \varepsilon\eta)[r''(\tau^Y)\mu(1 - \varepsilon\eta) - \beta C''(\tau^Y)]}$ into the above equations, we can get:

$$\frac{\partial p^Y}{\partial \varepsilon} = \frac{\eta(c + h - w)[r''(\tau^Y)\mu(1 - \varepsilon\eta) - \beta C''(\tau^Y)] + (2 - \varepsilon\eta)\beta\eta[C'(\tau^Y)]^2}{(1 - \varepsilon\eta)^2[r''(\tau^Y)\mu(1 - \varepsilon\eta) - \beta C''(\tau^Y)]}.$$

Accordingly, only when $\varepsilon \in (0, \varepsilon_1)$, $\frac{\partial p^Y}{\partial \varepsilon} < 0$; only when $\varepsilon \in (\varepsilon_1, 1)$, $\frac{\partial p^Y}{\partial \varepsilon} > 0$, where $\varepsilon_1 = \frac{1}{\eta} - \frac{(c + h - w)\beta C''(\tau^Y) - \beta\eta[C'(\tau^Y)]^2}{r''(\tau^Y)\mu\eta(c + h - w) + \beta\eta[C'(\tau^Y)]^2}$.

Similarly, first orders of sales and the profits of E-SC members about ε are:

$$\begin{aligned} \frac{\partial q^Y}{\partial \varepsilon} &= -\frac{\beta}{2} \left[\frac{\eta(c + h - w)}{(1 - \varepsilon\eta)^2} + \left(C'(\tau^Y) - \frac{C'(\tau^Y)}{1 - \varepsilon\eta} \right) \frac{\partial \tau^Y}{\partial \varepsilon} \right]; \\ \frac{\partial \pi_m^Y}{\partial \varepsilon} &= -\frac{1}{4k\beta(1 - \varepsilon\eta)^3} \left\{ \gamma^2(1 - \varepsilon\eta)\rho + 2k[(\alpha + \mu r(\tau^Y) - \beta\rho - \beta C(\tau^Y))(1 - \varepsilon\eta) - c\beta - \beta\varepsilon\eta(h - w)] \right\}. \end{aligned}$$

$$\left[(c+h-w)\beta\eta + \beta(1-\varepsilon\eta)^2 C'(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon} - (1-\varepsilon\eta)^2 \mu r'(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon} \right];$$

$$\frac{\partial \pi_e^Y}{\partial \varepsilon} = -\frac{\beta\rho}{2} \left[\frac{\eta(c+h-w)}{(1-\varepsilon\eta)^2} + \left(C'(\tau^Y) \frac{\partial \tau^Y}{\partial \varepsilon} - \frac{\mu r'(\tau^Y)}{\beta} \right) \frac{\partial \tau^Y}{\partial \varepsilon} \right].$$

Since $0 < 1 - \varepsilon\eta < 1$, $C'(\tau^Y) - \frac{C'(\tau^Y)}{1-\varepsilon\eta} < 0$, and then we find that $\frac{\partial q^Y}{\partial \varepsilon} < 0$, $\frac{\partial \pi_m^Y}{\partial \varepsilon} < 0$, and $\frac{\partial \pi_e^Y}{\partial \varepsilon} > 0$.

Proof of Proposition 7

$p^Y - p^N = \frac{\beta C(\tau^Y) + \mu \Delta r(\tau^Y)}{2\beta}$; $s^Y - s^N = 0$; $q^Y - q^N = \frac{1}{2}(\mu \Delta r(\tau^Y) - \beta C(\tau^Y))$. Only when $\Delta r(\tau^Y) > -\Delta r_3(\tau^Y) = -\frac{\beta C(\tau^Y)}{\mu}$, $p^Y > p^N$. Only when $\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$, $q^Y > q^N$.

Proof of Proposition 8

$\pi_m^Y - \pi_m^N = \frac{(\mu \Delta r(\tau^Y) - \beta C(\tau^Y)) \{ \gamma^2(1-\varepsilon\eta)\rho + k[(2\alpha + \beta C(\tau^Y) - 2\beta + \mu \Delta r(\tau^Y))(1-\varepsilon\eta) - 2c\beta - 2\beta\varepsilon\eta(h-w)] \}}{4k\beta(1-\varepsilon\eta)}$; $\pi_e^Y - \pi_e^N = \frac{\rho}{2}(\mu \Delta r(\tau^Y) - \beta C(\tau^Y))$. Accordingly, only when $\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$, $\pi_m^Y > \pi_m^N$, $\pi_e^Y > \pi_e^N$. Similarly, only when $\Delta r(\tau^Y) > \Delta r_3(\tau^Y)$, $\pi_z^Y > \pi_z^N$.

Proof of Proposition 9

$$p^{YC} - p^Y = -\frac{\rho(4k^2\beta^2 - \gamma^4)(1-\varepsilon\eta) - 2k\gamma^2[(\alpha + \mu \Delta r(\tau^{YC}) - \beta C(\tau^{YC}))(1-\varepsilon\eta) - c\beta - \beta\varepsilon\eta(h-w)]}{4k\beta(2k\beta - \gamma^2)(1-\varepsilon\eta)} < 0;$$

$$s^{YC} - s^Y = \frac{\gamma[(\alpha + \mu \Delta r(\tau^{YC}) - \beta C(\tau^{YC}))(1-\varepsilon\eta) - c\beta - \beta\varepsilon\eta(h-w)]}{(2k\beta - \gamma^2)(1-\varepsilon\eta)} - \frac{\gamma\rho}{2k} > 0;$$

$$q^{YC} - q^Y = \frac{(4k^2\beta^2 + \gamma^4)(1-\varepsilon\eta)\rho + 2k\gamma^2[(\alpha + \mu \Delta r(\tau^{YC}) - \beta C(\tau^{YC}) - 2\beta\rho)(1-\varepsilon\eta) - c\beta - \beta\varepsilon\eta(h-w)]}{4k\beta(2k\beta - \gamma^2)(1-\varepsilon\eta)} > 0;$$

Similarly, $\pi_z^Y - \pi_z^N > 0$.