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Effect of the manufacturer quality inspection policy on the supply chain decision-making and profits

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A B S T R A C T

Due to competitive pressure and information asymmetry, manufacturers will produce quality inspection avoidance behaviour to gain short-term economic benefits, but this behaviour affects the ultimate quality and safety of the product. This paper studies the two-echelon supply chain consisting of a manufacturer and a retailer, and analyses whether the manufacturer's quality inspection avoidance behaviour model is considered or not. This paper discusses the impact of quality inspection level, quality loss cost, product repair cost, product return rate on the profit and optimal decision-making behaviour of both actors of the supply chain. It is found that when the manufacturer's quality inspection avoidance level is high, the increase of retailer' quality inspection effort level, manufacturer's internal failure cost, consumer product return rate and retailer' external quality loss cost will lead to the decrease of manufacturer's quality effort level instead of increasing. Finally, the numerical study is given to verify the above conclusion, and analysed the influence of different parameters on the optimal decision and supply chain actors profits.

A R T I C L E I N F O

Keywords:
Supply chain;
Decision-making;
Quality inspection policy;
Quality inspection avoidance;
Incentive mechanism;
Product return;
Profit

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1. Introduction

Product quality is an important factor that affects consumers' purchase intention. Nowadays, more and more enterprises are outsourcing product design and manufacturing activities to manufacturers, and the price competition among enterprises is increasingly fierce. The huge competitive pressure requires manufacturers to further reduce production cost, which aggravates the incentive for manufacturers to conduct production with adulterated quality. The most commonly used measure of quality management and control in enterprises is quality inspection. But quality inspection has two major drawbacks: (a) they are costly, and (b) they are prone to lead to quality inspection evasion motivation. In recent years, there have been many safety accidents caused by product quality problems, such as the 2008 Sanlu milk powder illegal addition of melamine incident, the 2016 Samsung Note7 explosion, and Toyota recall. In this case, it is particularly important for companies to compensate for returned products in order to win back consumers [1]. A large number of facts show that some manufacturers conceal quality information and successfully avoid the inspection of buyers, industries and even countries. In order to control the quality of the products in the supply chain, it is necessary to coordinate the supply chain so that every participating enterprise in the supply chain is willing to strive to provide qualified products for customers. Jeong *et al*. [2] believes that the improvement of quality is conducive to the development of long-term cooperative relations among supply chain members. In contrast to information asymmetry, information symmetry can benefit upstream suppliers

[3]. In order to achieve supply chain coordination, various incentive strategies and supply chain contracts are generally considered to reduce the occurrence of such quality and safety incidents.

The remainder of the study is proceeds as follows. Section 2 discusses the relevant literature. Section 3 develops our model. We analysed whether the manufacturer's quality inspection avoidance behaviour model is considered or not. In Section 4, incentive mechanism is put forward to influence the quality decision of manufacturer. Section 5 verifies our basic model with results and numerical illustrations. Section 6 present conclusions and limitations.

2. Literature review

Three streams of literature are relevant with our research: (a) research on moral hazard caused by quality control strategies in the supply chain, (b) research on how to develop quality control contract and design quality incentive mechanism in supply chain, (c) research on how to implement quality risk control in the design of supply chain quality contract.

Gao *at al*. [4] established the decision-making control model of moral hazard when they studied the cost sharing of internal and external quality losses. Fan *at al*. [5] considered the issue of corporate social responsibility, and believed that social responsibility is conducive to improving product quality and product demand, while making supply chain enterprises more profitable. Liu *at al*. [6] believes that CSR cost-sharing can maximize the profits of the whole supply chain and improve the competitiveness of supply chain members. Starbird [7], in the process of studying the design of supply chain quality contract, proposed how to design supply chain punishment, reward and inspection strategies, and put forward the quality incentive mechanism accordingly. Based on the incentive function of punishment and reward, Zhang *at al*. [8] proposed a cooperative mechanism combining order quantity, penalty cost and bonus. Chao *at al*. [9] considered the problem of information asymmetry under the cost-sharing contract of recall, and proposed how to conduct quality improvement incentive and contract design in product recall. Lee *at al*. [10] studied that buyback and revenue-sharing contracts could not achieve supply chain coordination under the uncertain quality of manufacturers and imperfect detection mechanism of retailers, and put forward quality compensation contracts. Hu *at al*. [11] think that the initiative recall of unqualified products and compensation can positively affect customers' purchase intention in the perspective of service recovery. Huang *at al*. [12] believes that offering money-back guarantee will help improve quality, demand, consumer surplus and retailers' profits, while reducing the return rate of defective products. McWilliams [13] pointed out that both high-quality products and low-quality products have the power to provide refund guarantee, and the refund guarantee can improve the profit level of low-quality enterprises. Zhang [14] believes that consumer characteristics (naive or sophisticated) exert subtle influence on the seller’s strategy choice between partial returns and full returns. Giannoccaro and Pontrandolfo [15] proposed that revenue sharing contracts had a coordinating effect on supply chain members, but Xiao *at al*. [16] found that revenue sharing contracts were more beneficial to the upstream of the supply chain. Yan *at al*. [17] take the quality level of products provided by suppliers as reference standard. It is found that suppliers and retailers will voluntarily cooperate in accordance with contracts to achieve balanced results when retailers pay same attention to their own earnings and fairness. Zhu *at al*. [18] studied the buyer's determination of the inspection level based on the investment level of the manufacturer's production process, and the results showed that when the manufacturer's investment level increased, the buyer's quality inspection level decreased significantly. Babich and Tang [19] dealt with the adulteration of product quality through the delayed payment mechanism and the detection mechanism, and found that the detection mechanism could not completely prevent the adulteration of suppliers' products, while the delayed payment method could. Cao *at al*. [20] analysed the influence of product quality level on supply chain actors from the perspective of pricing and guarantee time, and found that manufacturers should set high wholesale price and long guarantee time for producing high-quality products. When consumers' sensitivity to warranty periods falls below the threshold, manufacturers of low-quality products can make more profit than their competitors. Cao *at al*. [21] compared the influence of deferred payment mechanism, inspection mechanism and traceability mechanism on supplier adulteration. It was found that increasing the buyer's product liability cost could effectively reduce supplier's willingness to adulterate. By reducing inspection cost and traceability cost, the buyer could better restrain supplier adulteration behaviour. On the basis of the existing research, this paper considers the manufacturer's quality inspection evasive behaviour, discusses the quality decision and profit change of the upstream and downstream members of the supply chain in this case, and further expands the research on the relationship between manufacturer's quality management behaviour and supply chain performance.

3. Model formulation and notation

A manufacturer M and a retailer R form the traditional two-echelon supply chain system. The retailer purchases a certain number of products from the manufacturer, and then sells them to consumers in the market for economic profit. In order to ensure the delivery quality of final products, retailer conducts quality inspection and incentive on manufacturer to avoid the cost of quality loss caused by potential quality risks. In the case of limited retailer' quality inspection level and information asymmetry, manufacturer will invest a certain cost to avoid retailer' quality inspection, so as to obtain greater profits in short term. The notation used in this paper is given in Table 1.

Supposing the manufacturer's quality effort level is x, the manufacturer's evasive inspection effort level h, and the retailer's quality test effort level y, where x, h and $y \in (0,1)$ correspond to the product quality qualification rate, the success rate of evasive inspection, and the success rate of quality inspection, respectively. Hypothesis the inspection of retailer can correctly identify the products without defects, but there is a certain probability of accepting the defective products. If the quality inspection is passed, the retailer will purchase a certain number of products from the manufacturer at the wholesale price w and sell them to the customer at the market price p. If not, the product will be repaired or reprocessed by the manufacturer and then delivered to the retailer. The reprocessed product will pass the quality inspection with probability 1 [4], and the resulting internal failure cost is m. The manufacturer's unit production cost is c. In addition, the retailer's quality inspection level is limited. When customers find low-quality products and return them to the retailer, the retailer will face external quality loss cost s and product return rate t. Let $\frac{1}{2}ax^2$, $\frac{1}{2}by^2$, and $\frac{1}{2}eh^2$ respectively be the manufacturer's quality effort cost function, the retailer's quality inspection cost function, and the manufacturer's quality inspection avoidance cost function. The three cost functions are strictly convex. The higher the level of product quality, detection and evading detection, the higher the cost it will pay.

Table 1 Model parameters and decision variables

Notation	Description
x	Manufacturer's quality effort level
y	Retailer's quality inspection effort level
h	The evading level of manufacturer's quality inspection
m	Internal failure cost per unit product
t	The possibility of return when the customer receives a nonconforming product
p	The retail price offered by the retailer to the customer
w	The wholesale price charged by a manufacturer to a retailer
c	Manufacturer's unit production cost
a	Manufacturer of quality coefficient
b	Retailer coefficient of quality testing effort
e	Manufacturer detection avoidance effort coefficient
s	Cost of quality penalty faced by retailer

Research basic hypothesis are:

(1) Both the manufacturer and the retailer are rational decision-makers, risk-neutral, and each pursues the maximization of expected profits.
(2) When the products produced by the manufacturer are qualified, there is no "rejection" phenomenon in the retailer' quality inspection.
(3) $s > p > w > c$. When the product is returned, the retailer will not only return p to the consumers, but also need some extra expenses, such as logistics cost and economic compensation.
(4) $a > e$. If the evading effort coefficient of the manufacturer is less than the quality effort coefficient of the manufacturer, the manufacturer will have the motive of evading the quality inspection.
(5) $m < w - c$. The potential quality risk causes internal failure cost to the manufacturer to be smaller than the expected income, so manufacturer has the motivation to avoid quality inspection.
(6) $a > m$. When the cost coefficient of manufacturer's quality effort is larger than the cost of manufacturer's quality loss, the manufacturer will have the motive of avoiding quality inspection.

3.1 Without considering manufacturer's quality inspection avoidance behaviour (model 1)

In terms of the above model notations and assumption, the profits of the manufacturer and the retailer, Π_M and Π_R are defined as follows:

$$\Pi_M(x) = w - c - (1-x)ym - \frac{1}{2}ax^2 \tag{1}$$

$$\Pi_R(y) = p - w - (1-y)(1-x)ts - \frac{1}{2}by^2 \tag{2}$$

$(1-x)ym$ is that the product has not passed the retailer's quality inspection and returned to the manufacturer for repair, so that the qualified rate is 1, resulting in internal failure cost per unit product;$(1-y)(1-x)ts$ is external penalty imposed by a retailer who fails to detect a defective product and then flows to the market and is returned by the consumer.

We could have the optimal quality strategy of the manufacturer as $\hat{x} = R(y) = \frac{ym}{a}$, and the retailer as $\hat{y} = R(x) = \frac{ts(1-x)}{b}$. By solving $\frac{\partial \Pi_M(x)}{\partial x} = 0$, $\frac{\partial \Pi_R(y)}{\partial y} = 0$, we have manufacturer and retailer optimal strategy

$$x^* = \frac{stm}{mst+ab} \tag{3}$$

$$y^* = \frac{ast}{mst+ab} \tag{4}$$

Proposition 1: Without considering the manufacturer's quality inspection avoidance behaviour: The manufacturer's optimal quality effort level x increases with the retailer's inspection effort level y. With the increase of internal failure cost, external penalty and return rate, the manufacturer's optimal quality level will be improved.

3.2 Considering the manufacturer's quality inspection avoidance behaviour (model 2)

The model assumes that the manufacturer has the motivation to evade quality inspection, and may cheat, forge or bribe the retailer in the process of quality inspection, expecting to invest with low quality cost and obtain excess economic profit. In this model, the manufacturer determines its quality effort level and quality inspection avoidance level, and the retailer determines the quality inspection level of the manufacturer. The behaviour choices of both actors are not understood by the other actor, and they make independent decisions with the goal of maximizing their own economic profits. Then, the expected profits of manufacturer and retailer are $\Pi'_M(x,h)$ and $\Pi'_R(y)$.

$$\Pi'_M(x,h) = w - c - (1-x)y(1-h)m - \frac{1}{2}eh^2 - \frac{1}{2}ax^2 \tag{5}$$

$$\Pi'_R(y) = p - w - (1-y+yh)(1-x)ts - \frac{1}{2}by^2 \tag{6}$$

Because of $\frac{\partial^2 \Pi'_R(y)}{\partial y^2} = -b < 0$, $\Pi'_R(x)$ has the optimal solution. From Eq. 5 to find the Hessian matrix about x and h for the manufacturer's profit function Π'_M, we can get $\mathrm{H}[\Pi'_M(x,h)] = \begin{bmatrix} -a & -ym \\ -ym & -e \end{bmatrix}$. When $ae - y^2m^2$>0, there are the optimal solutions of Eq. 5.

By solving $\frac{\partial \Pi'_M(x,h)}{\partial x} = 0$, $\frac{\partial \Pi'_M(x,h)}{\partial h} = 0$, $\frac{\partial \Pi'_R(y)}{\partial y} = 0$, we have manufacturer and retailer optimal strategy.

$$\tilde{x} = \frac{y(1-h)m}{a} \tag{7}$$

$$\tilde{h} = \frac{(1-x)ym}{e} \tag{8}$$

$$\tilde{y} = \frac{(1-x)(1-h)ts}{b} \tag{9}$$

The combination of the optimal strategy for（$\tilde{x}$，$\tilde{h}$，$\tilde{y}$）, can achieve their maximum benefit.

4. Retailer's quality incentives to manufacturer

This chapter mainly considers the problem of quality incentive in the case of quality evading. Based on the consideration of manufacturer's quality inspection evading behaviour, it analyses several common measures in actual quality management, and whether there is the possibility of failure when the manufacturer has the motive of quality inspection evading.

4.1 incentive effect of quality inspection the level y

Generally speaking, quality inspection can effectively improve the quality of the manufacturer's products.

Denote $\frac{\partial \Pi'_M(x,h)}{\partial x} = 0$, $\frac{\partial \Pi'_M(x,h)}{\partial h} = 0$, $\frac{\partial \Pi'_R(y)}{\partial y} = 0$. We have

$$x'(y) = \frac{eym - y^2m^2}{ae - y^2m^2} \tag{10}$$

Denote $\frac{\partial x'(y)}{\partial y} = 0$. We have

$$\overline{x'} = \frac{me(y^2m^2 - 2amy + ae)}{(ae - y^2m^2)^2} \tag{11}$$

Theorem 1: When $y \in \left(0, \frac{a - \sqrt{a^2 - ae}}{m}\right)$, manufacturer’s quality effort level increases with the retailer's inspection level. When $y \in \left(\frac{a - \sqrt{a^2 - ae}}{m}, 1\right)$, manufacturer’s quality effort level decreases with the retailer's inspection level.

Quality inspection will always improve the quality of the manufacturer's products in model 1, but in model 2, if the quality inspection exceeds a threshold, the manufacturer is more willing to use evasive methods.

Denote $\frac{\partial \Pi'^2_M(x,h)}{\partial x \partial y} = 0$, $\frac{\partial \Pi'^2_M(x,h)}{\partial h \partial y} = 0$. We have

$$\frac{\partial \tilde{x}}{\partial y} = \frac{em(1 - 2\tilde{h})}{ae - y^2m^2} \tag{12}$$

$$\frac{\partial \tilde{h}}{\partial y} = \frac{am - 2m^2y(1 - \tilde{h})}{ae - y^2m^2} \tag{13}$$

Proposition 2: If $\tilde{h} > 0.5$, then $\frac{\partial \tilde{x}}{\partial y} < 0, \frac{\partial \tilde{h}}{\partial y} > 0$.

Because of $a > e$, manufacturer' quality evasion motivation will always be greater than its quality effort level. When the manufacturer has high quality avoidance motivation, the retailer will force the manufacturer to reduce the level of quality efforts and invest more in quality avoidance. Manufacturer can ease the pressure on quality inspection and repair by avoiding methods, but retailer will face more returns of unqualified products, seriously reducing its expected profits.

4.2 Incentive effect of internal failure quality cost m

The internal failure quality cost is the repair of nonconforming products, less than the external penalty cost flowing to the market, and effectively improves the retailer's expected revenue.

Denote $\frac{\partial \Pi_M'^2(x,h)}{\partial x \partial m}=0$, $\frac{\partial \Pi_M'^2(x,h)}{\partial h \partial m}=0$, $\frac{\partial \Pi_R'^2(y)}{\partial y \partial m}=0$. We have

$$\begin{cases} a\frac{\partial \tilde{x}}{\partial m}=\frac{\partial \tilde{y}}{\partial m}(1-\tilde{h})m-\tilde{y}\frac{\partial \tilde{h}}{\partial m}m+\tilde{y}(1-\tilde{h}) \\ e\frac{\partial \tilde{h}}{\partial m}=-\frac{\partial \tilde{x}}{\partial m}\tilde{y}m+(1-\tilde{x})\frac{\partial \tilde{y}}{\partial m}m+(1-\tilde{x})\tilde{y} \\ b\frac{\partial \tilde{y}}{\partial m}=-\frac{\partial \tilde{x}}{\partial m}(1-\tilde{h})ts-(1-\tilde{x})\frac{\partial \tilde{h}}{\partial m}ts-b\frac{\partial \tilde{y}}{\partial m} \end{cases} \tag{14}$$

Denote $-amst\tilde{x}-5bm^2\tilde{y}^2-e\tilde{h}mst+amst+emst+abe=U, U>0$, we have:

$$\begin{cases} \frac{\partial \tilde{h}}{\partial m}=\frac{ab\tilde{y}(1-2\tilde{x})}{U} \\ \frac{\partial \tilde{x}}{\partial m}=\frac{be\tilde{y}(1-2\tilde{h})}{U} \\ \frac{\partial \tilde{y}}{\partial m}=\frac{ast\tilde{y}(\tilde{x}-1)+est\tilde{y}(\tilde{h}-1)+4bm\tilde{y}^3}{U} \end{cases} \tag{15}$$

Proposition 3: If $\tilde{x}>1/2$, then $\frac{\partial \tilde{h}}{\partial m}<0$; If $\tilde{x}<1/2$, $\frac{\partial \tilde{h}}{\partial m}>0$. If $\tilde{h}>1/2$, then $\frac{\partial \tilde{x}}{\partial m}<0$. If $\tilde{h}<1/2$, then $\frac{\partial \tilde{x}}{\partial m}>0$.

If the quality level of the product is high, the increase in internal failure cost will weaken the manufacturer's motivation to avoid detection, and manufacturer is more willing to increase the investment in product quality. Otherwise, the greater the loss of internal quality, the stronger the motivation to avoid quality inspection. When manufacturer has strong quality avoidance motivation, internal failure cost will force manufacturer to reduce the level of quality efforts and invest more in quality inspection avoidance. Owing to $\tilde{x}<\tilde{h}$ and $a>e$, the increase of quality avoidance is larger than that of quality effort at the beginning. If $\tilde{h}<1/2$, the increase of internal failure quality cost will reduce the manufacturer's profits, but the repair cost is greater than the investment of quality avoidance cost.

4.3 Incentive effect of unqualified product return rate t

The parameter t is the percentage of unqualified products accepted by the retailer but returned by the consumers. As the defective products return rate increase, expected benefit of the seller is being lost in the form of compensation [22].

Denote $\frac{\partial \Pi_M'^2(x,h)}{\partial x \partial t}=0$, $\frac{\partial \Pi_M'^2(x,h)}{\partial h \partial t}=0$, $\frac{\partial \Pi_R'^2(y)}{\partial y \partial t}=0$. We have:

$$\frac{\partial \tilde{y}}{\partial t}=\frac{aes(1-\tilde{x}-\tilde{h})}{U} \tag{16}$$

$$\frac{\partial \tilde{x}}{\partial t}=\frac{ems(1-\tilde{x})(\tilde{h}-1)(2\tilde{h}-1)}{U} \tag{17}$$

Proposition 4: If $\tilde{x}+\tilde{h}>1$, then $\frac{\partial \tilde{y}}{\partial t}<0$. If $\tilde{x}+\tilde{h}<1$, then $\frac{\partial \tilde{y}}{\partial t}>0$. If $h<1/2$, then $\frac{\partial \tilde{x}}{\partial t}>0$. If $h>1/2$, $\frac{\partial \tilde{x}}{\partial t}<0$.

At the beginning, the return rate of unqualified products has a positive effect on the quality efforts of manufacturer if $h<1/2$. When the manufacturer has strong quality avoidance motivation, the increase of unqualified product return rate will force the manufacturer to reduce the level of quality efforts and invest more in quality inspection avoidance. If $\tilde{h}<1-\tilde{x}$, retailer's quality inspection effort level increases with unqualified product return rate.

4.4 Incentive effect of external quality penalty cost s

The increase of external quality penalty will make retailer strengthen the quality inspection level and improve manufacturer’s product quality to a certain extent.

Denote $\frac{\partial \Pi_M'^2(x,h)}{\partial x \partial s} = 0$， $\frac{\partial \Pi_M'^2(x,h)}{\partial h \partial s} = 0$， $\frac{\partial \Pi_R'^2(y)}{\partial y \partial s} = 0$. We have:

$$\frac{\partial \tilde{y}}{\partial s} = \frac{aet\left(1-\tilde{x}-\tilde{h}\right)}{U} \tag{18}$$

$$\frac{\partial \tilde{x}}{\partial s} = \frac{emt(1-x)(h-1)(2h-1)}{U} \tag{19}$$

Proposition 5: If $\tilde{x} + \tilde{h} > 1$, then $\frac{\partial \tilde{y}}{\partial s} < 0$. If $\tilde{x} + \tilde{h} < 1$, then $\frac{\partial \tilde{y}}{\partial s} > 0$. If $h < 1/2$, then $\frac{\partial \tilde{x}}{\partial s} > 0$. If $h > 1/2$, then $\frac{\partial \tilde{x}}{\partial s} < 0$.

When the manufacturer has strong quality avoidance motivation, the increase of external quality penalty cost will force the manufacturer to reduce the level of quality efforts and invest more in quality inspection avoidance. Quality inspection avoidance will replace the manufacturer's quality efforts. If $\tilde{h} < 1 - \tilde{x}$, retailer’s quality inspection effort level increases with external quality penalty cost.

5. Results and discussion of numerical simulation

In this section, numerical simulation will be used to compare the two situations between not considering manufacturer's quality evading behaviour and considering manufacturer's quality evading behaviour, and to analyse the influence of quality inspection level, internal failure cost, external quality penalty cost and product return rate on the quality decision-making of supply chain actors. x1, y1, M1 and R1 are respectively the manufacturer's product quality effort level, the retailer's quality inspection level, the manufacturer's expected profit and the retailer's expected profit without considering the manufacturer's quality inspection avoidance iour. x2, y2, M2 and R2 are respectively the manufacturer's product quality effort level, the retailer's quality inspection level, the manufacturer's expected benefits and the retailer's expected benefits considering manufacturer's quality inspection avoidance behaviour. We use the following parameters to illustrate this model, $p = 35$, c $= 8$, $w = 18$, $a = 9$, $e = 8$, $b = 8$, and its results are presented in Figs. 1 to 8.

5.1 Optimal decision and expected benefits with respect to y

Here, let $m = 7.5$， $t = 0.5$， $s = 36$. The calculation result is shown in the following Figs. 1 and 2. Without considering manufacturer quality inspection avoidance behaviour, the quality effort level of the manufacturer increases with y. The manufacturer's expected benefits decrease with y. The retailer's expected benefits increase at first and then decreases with y. When considering manufacturer's quality avoidance behaviour, the level of manufacturer's quality inspection avoidance increases with y. When the evading level of manufacturer's quality inspection is greater than 0.5, the manufacturer's quality effort decreases with y, so manufacturer's quality inspection evading input will take the place of manufacturer's quality effort input. The expected benefits of the manufacturer decrease with y. The retailer's expected revenue is convex. In equilibrium, no matter how y changes, the level of manufacturer's quality effort in model 1 is greater than that in model 2. Under model 2, the manufacturer's profit is improved, but the retailer's profit is far less than model 1.

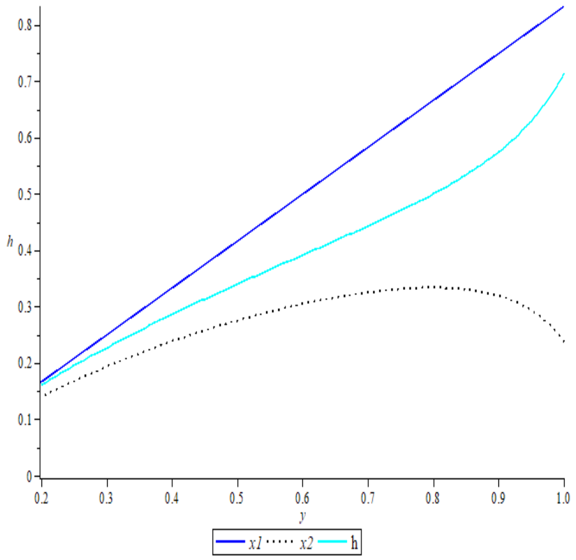

Fig. 1 Optimal decision with respect to y

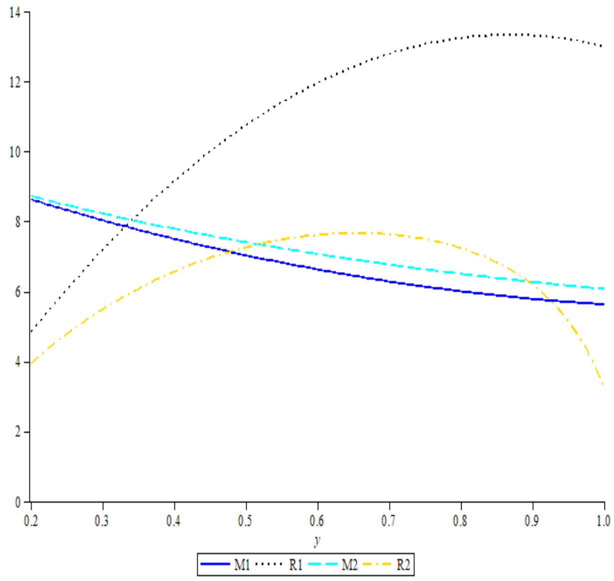

Fig. 2 Expected benefits with respect to y

5.2 Optimal decision and expected benefits with respect to m

Here, let $t = 0.5$, $s = 36$, $m \in [5,10]$, and the calculation result is shown in the Figs. 3 and 4. Without considering manufacturer' quality inspection avoidance behaviour, the manufacturer quality effort level increases with m. The retailer quality inspection level decreases with m. At the same time, the manufacturer's expected benefits decrease with m, and the retailer expected benefits increase with m, but the impact is not significant. When considering manufacturer's quality inspection behaviour, the retailer's quality inspection level decreases with m. Owing to $x < 0.5$, the evasion level of quality inspection of manufacturer increases with m. Manufacturer' quality effort level is convex function. When $h > 0.5$, the manufacturer's quality effort level decreases with m. The manufacturer and retailer's expected revenue decreases with m. In equilibrium, no matter how y changes, the level of manufacturer's quality effort in model 1 is greater than that in model 2. Although the level of retailer' quality inspection decreased with m, model 1 was more than model 2 at the beginning, and later less than model 2. Internal failure quality cost is negative with manufacturer's profit, and positive with retailer's profit. Under model 2, the manufacturer's profit is slightly improved, but the retailer's profit is far less than model 1.

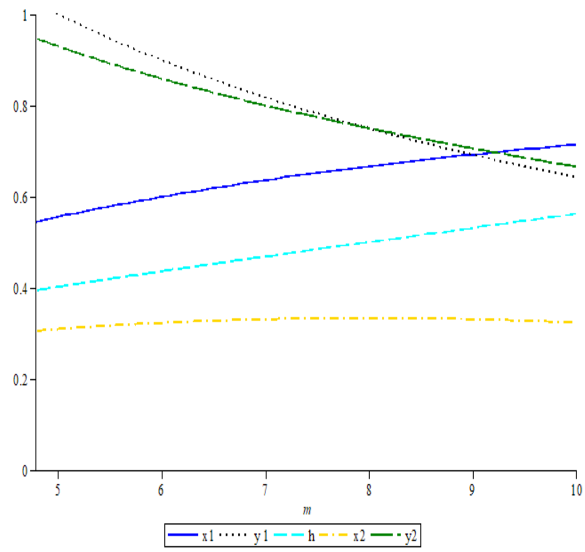

Fig. 3 Optimal decision with respect to m

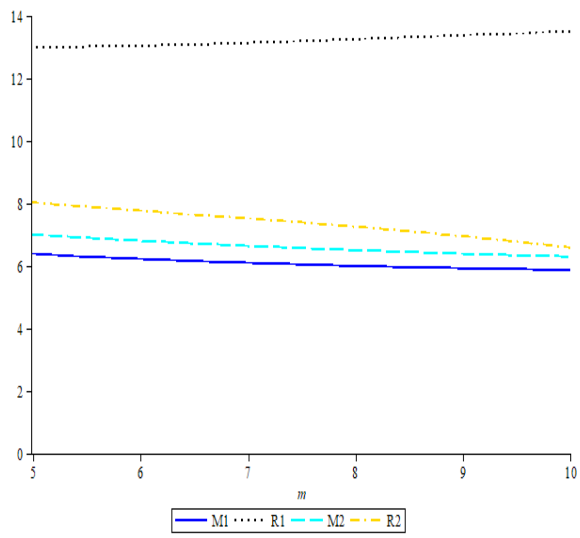

Fig. 4 Expected benefits with respect to m

5.3 Optimal decision and expected benefits with respect to t

Here, let $m = 7.5$, $s = 36$, $t \in [0.1,0.8]$, and the calculation result is shown in the Figs. 5 and 6. Without considering manufacturer quality inspection avoidance behaviour, manufacturer quality effort level increases with t. Retailer's quality inspection level increases with t. Manufacturer and retailer's expected profits decrease with t, but when $t > 0.3$, the downward trend is gentle. When considering manufacturer quality inspection avoidance behaviour, the manufacturers' quality inspection avoidance level increases with t. Manufacturer' quality effort level is convex function. When $h > 0.5$, the manufacturer's quality effort level decreases with t. Owing to $h + x < 1$, retailer quality inspection efforts increase with t. At the same time, the manufacturer and the retailer expected the profit to decrease with t. In equilibrium, no matter how t changes, the level of manufacturer's quality effort in model 1 is greater than that in model 2. Although the level of retailer' quality inspection increased with t, model 1 was more than model 2 at the beginning, and later less than model 2. Unqualified product return rate is negative with manufacturer and retailer's profit. If the return rate is large enough, the retailer will face losses.

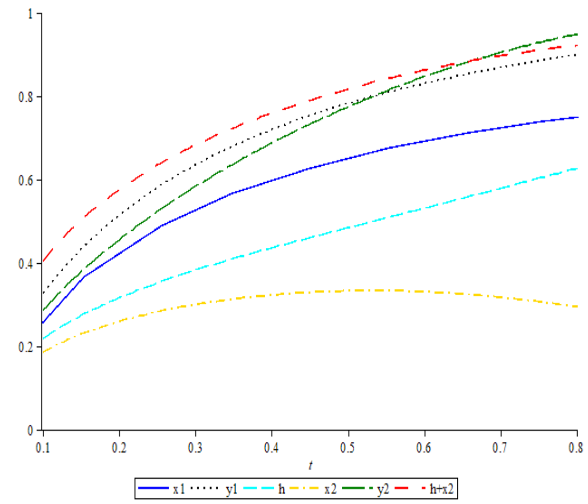

Fig. 5 Optimal decision with respect to t

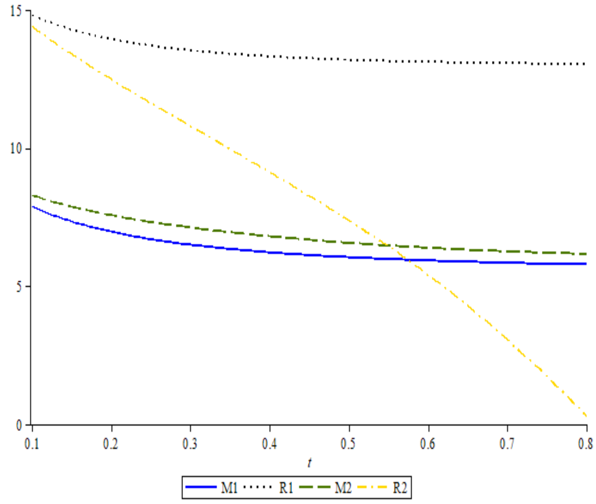

Fig. 6 Expected benefits with respect to t

5.4 Optimal decision and expected benefits with respect to s

Here, let $m = 7.5$, $t = 0.5$, $s \in [30,40]$, and the calculation result is shown in the Figs. 7 and 8 show that without considering manufacturer quality inspection avoidance behaviour, manufacturer quality effort level increases with s, retailer quality inspection level increases with s. Manufacturer and retailer expected profits decrease with s, but the downward trend is gentle. When considering manufacturer's quality inspection avoidance behaviour, the evasive level of manufacturer's quality inspection increases with s. Manufacturer' quality effort level is convex function. When $h > 0.5$, the manufacturer's quality effort level decreases with s. Since $h + x < 1$, retailer' quality inspection efforts increase with s. At the same time, the manufacturer and retailer's expected profit decrease with t. In equilibrium, no matter how s changes, the level of manufacturer's quality effort in model 1 is greater than that in model 2. In the two models, the optimal quality inspection level of the retailer is very similar. External quality penalty cost is negative with manufacturer and retailer's profit. In model 1, increasing external quality loss cost will improve the manufacturer's quality level, and the retailer can offset some negative impact through the improvement of quality assurance ability.

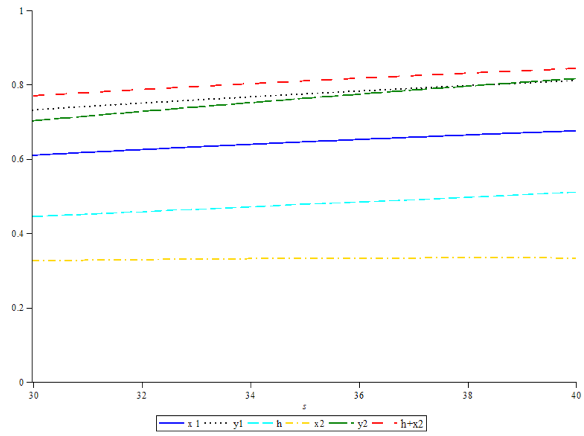

Fig. 7 Optimal decision with respect to *s*

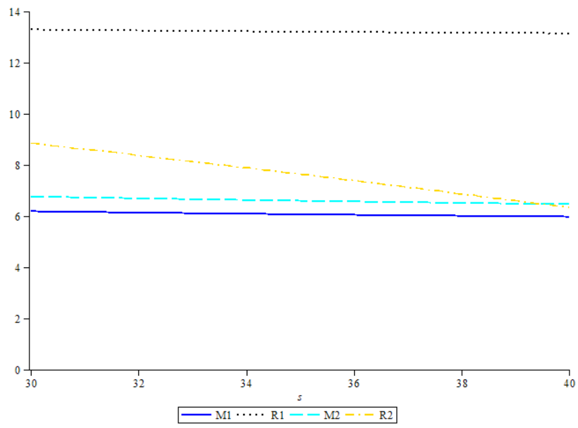

Fig. 8 Expected benefits with respect to *s*

6. Conclusion

This paper studies the two-echelon supply chain system composed of manufacturer and retailer. In this system, the information asymmetry between manufacturer and retailer cannot eliminate the opportunistic behaviour of manufacturer due to the pursuit of short-term economic benefits. Comparative analysis of the level of quality inspection, internal quality loss, external quality loss, defective product return rate to actors of the supply chain optimal decision and expected benefits, it is concluded that the manufacturer' evading of quality inspection will weaken their motivation of quality effort and have a significant negative impact on retailer' revenue, which is not beneficial to coordination and cooperation of the supply chain from the long run. If the evading level of manufacturer's quality inspection is more than 0.5, manufacturer's product quality effort level will decrease with external quality penalty, product return rate, internal failure cost. The increase of retailer' investment in quality inspection will lead to the reduction of manufacturer' efforts in product quality and the further enhancement of inspection avoidance incentives. If the product quality level provided by the manufacturer is high, the level of quality inspection avoidance of the manufacturer will decrease with the increase of internal quality loss. If $h + x < 1$, retailer' investment in quality inspection will increase with product return rate and external quality penalty.

Information sharing is a leading capability [23]. The retailer can invest in this capability to design a contract to achieve sustainable performance, rather than in quality inspection that would incur more costs. The development of supply chain actors should be based on the harmonious and win-win business circle. For the convenience of calculation and research, this paper only considers the traditional two-echelon supply chain model. In actual management of the enterprise, a complete supply chain is usually made up of multiple enterprise node, and affected by external environment. The quality decision-making of supply chain is relatively complex, and it is necessary to further study. In addition, although the model construction has drawn valuable conclusions, it is not very clear about the path and mechanism of manufacturer's evasive behaviour on quality and performance.

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