Coordination and Risk Sharing with Considering Supply Chain External Quality Fault

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Abstract

Based on theory of Stackelberg non-cooperative game, this paper studies the coordination and risk-sharing problem in a supply chain under considering external quality fault. The Supply chain is consisted by one supplier and one retailer around a single product within one period. This paper presents the optimal profit, the optimal order quantity, coordination and the risk sharing problem in a supply chain by buyback contract under considering external quality fault. This mainly contributes of the paper are as follows. First, the supplier should avoid external quality fault and allow the retailer return his order quantity with wholesale price in a coordinated supply chain. Second, the optimal expected profit in a supply chain without quality fault is smaller than it when the external quality fault occurs, but the risk sharing in the case is larger. Third, the risk sharing of all parties in the coordinated supply chain are all positively correlated with the quality fault rate, the scrap rate, the wholesale price and the retail price but non-correlated with the buyback contract.

Keywords: Supply Chain Coordination; Risk Sharing; External Quality Fault; Buyback Contract; Stochastic Demand

1 Introduction

The product quality plays a significant role on maintaining the credibility, improving core competencies, increasing customer satisfaction and reducing the cost of the consequences of a risk of each party in supply chain. The requirements of customers about product quality and after-sale service are getting higher(Hansen, Jonasson and Neukirchen 2011; Li, Su, Zheng 2012; Balachandran and Radhakrishnan 2005; Balachandran Mohan and Seshadri 2008). It is almost impossible to evade the realistic issue on fulfilling the customers' needs for each party in supply chain relationship (Bernstein and Federgruen 2007). Providing with high-quality products with reasonable price, however, is not enough for a supply chain's objective (Xiao and Qi 2008; Yeung 2008). The success of supply chain nowadays depends significantly on collaborative operations among the internal supply chain and corresponding coordination and risk-sharing mechanism, which ongoing improve core competences, meet the customers' satisfaction, and bring about a win-win prospect of every party in supply chain (Esmaeili et al 2008; Kazhamiakin 2010). Therefore, risk sharing is an important part of the risk management in a supply chain.

Although the supplier and retailer give strict quality prevention measures, many supply chain still exist more or less external quality fault (Li, Su, Zheng 2012). The external quality fault means that the fault is discovered by the customer after the product has sold. Once product develops external quality fault, the whole supply chain will suffer great damages. Under this situation, it is desirable that a sound coordination and risk-sharing mechanism can be promptly built to tackle the crisis by putting forward corresponding buyback contract. (Chembers et al 2006; Sila et al 2006; Foster 2007; Kaynak and Hartley 2007). After occurring quality fault, not only buyback coordination strategy but also risk-sharing mechanism are very crucial in supply chain. For example, the recall case of Toyota due to the automobile quality fault confirms the importance that the supply chain should be equipped with a sound coordination and risk-sharing mechanism, especially after the external product quality fault occurs (Chen and Bell 2011; Wang and Ren 2012; Sodhi, Son and Tang 2012). Unfortunately, now there is no such coordination and risk-sharing mechanism both theory community and practice community.

Based on above reasons and Stackelberg model of non-cooperative game, by buyback contract, this paper is investigated the coordination and risk-sharing problem of each party in a supply chain which is consisted by one supplier and one retailer with a single product and one period when the external quality fault occurs (Chen and Bell 2011; Wang and Ren 2012; Xu and Zhai2010).

2 Literature Review

There are relatively few papers in the research literature which consider coordination and risk sharing in a supply chain under the situation of quality fault. Boyaci and Gallego (2004) studied the coordination problem on customer service competition between two supply chains with uncoordinated game theory, coordinated and hybrid scenarios respectively. They found coordination is the dominated strategy, but when the relationship of the supply chain was deteriorated, most of them would be mired into the prisoner's dilemma except for the only possible benefi-

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ciary, the customers. Besides, Chen and Chen (2006) studied the two-stage supply chain coordination with a long lead time and updating demand information. They built a risk-sharing contract to request one party to compensate the other party who suffered the loss due to overstocking or overproduction. Xu and Zhai (2010) investtigated a coordination of another two-stage supply chain with fuzzy demand information. They showed the total profit of the supply chain when coordinated outweighs the one when it wasn't. Wang and Xiao (2009) considered the coordination and risk-sharing of supply chain, particularly with proportional buy-back and discounted buy-back policy respectively. They explored buy-back policy can coordinate the supply chain by allow retailer return the redundant order at the wholesale price. However, all of them didn't take the quality fault into account to analyze the influence to the supply chain. He and Zhang (2008) studied a two level supply chain risk-sharing problem of a supplier and a retailer under considering stochastic demand and uncertain situation. They explored that, in some stochastic product cases, risk-sharing between supply chain parties could improve supply chain performance and reduced the double marginalization effect. But a little drawback of He and Zhang (2008) is that they do not consider how the quality fault impacts on the supply chain risk-sharing.

At the aspect of quality fault in supply chain, Balachandran and Radhakrishnan 2005 considered that internal fault was to find out the defective production during testing the materials coming from the supplier while external fault is the quality defect which the customers find out it by using. Reyniers and Tapiero (1995) considered the contract of the supply chain based on the internal fault. They show that the test was implemented at a certain possibility, but once found out the defective, the punishment would be placed on the supplier. By assuming to eliminate the situations of the erroneous or missed test, they tried to avoid the external fault when going on a test. Hwang and Radhakrishnan (2006) stated when internal fault was occurred, the buyer might simply return the defective to the supplier. However, when external fault occurred, both parties should assume the cost together according to an appropriate mechanism. In the case, they only considered the external cost which is determined by the fixed proportion associated with partial cost caused by the supplier and the possibility the external fault occurred.

According to the identified gap above, this paper studies the coordination and risk-sharing problem with external fault in a supply chain. This is a two-level supply chain which consists of one retailer and one supplier who allows the product returns. We focus on the single product with one period and assume that the product can't be sent to the customers. The supplier and the retailer who fail to maintain the no fault product and sell it to a customer may face penalties including cost loss and honour loss. The research questions of the paper as so far are as follows. First, how the external product quality fault affect the coordination problem especially risk sharing mechanism in a two-level supply chain? Second, which factors and how they affect the coordination and risk sharing of the each party if a product quality fault occurs in a supply chain?

The paper is organized as follows: In section 2, we briefly review some related literatures to identify the research gap in the field. Our basic model is introduced in section 3. In section 4, we solve coordination and risk-sharing problem under considering external product quality fault and buyback contract. Finally, section 5 summarizes the conclusions and gets some future research needs.

3 Model Description

The article is supposed a supplier and a retailer are both risk-neutral. Without considering the out-of-stock loss, the supplier's cost is $c_1 = c_1(q)$ without quality fault, where q denotes the quantity of products of the supplier. The consumers have a random demand θ, which satisfies the cumulated distribution function $F(x)(0 \le x < +\infty)$. Its probability density function is $f(x)$. Accordingly the mean of θ satisfies $u = E(x) = \int_0^\infty xf(x)dx$. Likewise, the retailer's cost is $c_2 = c_2(q)$ without external quality fault, where q denotes the order quantity of the retailer; the marginal costs are increasing. The supplier offers the retailer with the product uniformly at the wholesale price ω, and the retailer sells the product to the customers as possible as he can. At the end of the period, the products which fail to sell out can be bought back by the supplier at the price of $\alpha\omega(0 \le \alpha \le 1)$ per unit, where α is the discounted coefficient. Here the quantity of the products returned by retailer is β $(0 \le \beta \le 1)$ times of the order quantity. Besides, we assume δ $(0 \le \delta \le 1)$ as the degree coefficient of the quality fault. When δ satisfies $0 < \delta \le 0.5$, it means that products have normal quality fault. In this case, the retailer allows the customers to return at the price of $\alpha P(0 \le \alpha \le 1)$ and deals with these defective products with the repair fee η per unit. However, when δ belongs to $0.5 < \delta \le 1$, it means the products suffer serious quality fault. Normally, the possibility it happens is strictly constrained to $\gamma\left(0 \le \gamma \le 1\right)$. At this time, all these severely defective products are recalled at the market price and become scrapes with the loss ϑ per unit, the salvage value neglected. Furthermore, we suppose the product's market price is P; the coefficients η and ϑ are invariable in a single period and the relation of them maintains $\vartheta > \eta$; and coefficient $\omega, \alpha, \beta, \delta, \gamma$ are all determined by the supplier. If the product fault occur after selling out, namely an occurrence of external quality fault, the supplier and the retailer will bear the reputation compromise which equals to $\frac{\zeta}{2}(0 \le \zeta \le 1)$ times of the product market price.

Of course, the retailer only sells the products at least when the predicted profit is above the break-even point. And the products which fail to sell out worth nothing to the supplier and the retailer.

4 Model Construction

The external product quality fault in the supply chain is a quality fault when is occurs after the product has been sold to the customers by the end of the selling period. Under this situation, customers feedback the quality fault to the retailer and then return them. The retailer receives the defective products and then returns them to the supplier at the wholesale price. Then, the expected profit of the supplier $\pi_s^{'}$ is:

$$E(\pi_s^{'}) = \omega q - c_1(q) - \delta q(1-\gamma)\eta - \delta q\gamma\vartheta - \frac{\zeta}{2}\delta q - \alpha\omega\int_{(1-\beta)q}^{q} F(x)dx + (\delta\eta - \delta\eta\gamma + \delta\gamma\vartheta + \frac{\zeta}{2}\delta)\int_0^q F(x)dx . \quad (1)$$

The expectation profit of the retailer $E(\pi_r^{'})$ is:

$$E(\pi_r^{'}) = (p-\omega)q - c_2(q) - \frac{\zeta}{2}\delta q + \alpha\omega\int_{(1-\beta)q}^{q} F(x)dx + (\frac{\zeta}{2}\delta - p)\int_0^q F(x)dx \ . \quad (2)$$

The total expectation profit of supply chain $E(\pi^{'})$ is:

$$E(\pi^{'}) = pq - c_1(q) - c_2(q) - \delta q(1-\gamma)\eta - \delta q\gamma\vartheta - \zeta\delta q + (\delta\eta - \delta\eta\gamma + \delta\gamma\vartheta + \zeta\delta - p)\int_0^q F(x)dx . \quad (3)$$

From those equations, this paper can easily be found the expectation of the profit of the supplier and retailer both is consisted of 4 parts, namely the selling income with the order quantity q, the producing, selling and ordering cost, the expectation risk caused by the return with the customer's random demand and the loss of production quality fault. We know the total loss of the supply chain depends on the order quantity q, the degree coefficient of quality fault δ, the scrap coefficient γ, the coefficient of reputation compromise when occurrence of the external quality fault ζ and the market price p, but irrelevant to the buyback contract and the coefficient α, β.

4.1 THE SUPPLY CHAIN COORDINATION

PROPOSITION 1:
$E(\pi_r^{'})$ is a convex function of the order quantity q.

PROOF OF PROPOSITION 1:
Because the retailer will sell his product if his profit is at least above the breaking-even point, under the situation of the external product quality fault, there must be:

$p - \omega - \frac{\delta\zeta}{2} \geq 0$, due to $p - \alpha\omega - \frac{\delta\zeta}{2} \geq 0$.

Due to $\frac{d^2E(\pi_r^{'})}{dq^2} \leq 0$, then $E(\pi_r^{'})$ is a convex function of q.

Then the retailer has the optimal order quantity, which satisfies

$$\begin{aligned} c_2^{'}(q^{**}) &= (p-\omega) - \frac{\zeta\delta}{2} - \alpha\omega(1-\beta)F[(1-\beta)q^{**}] + \\ &+ (\alpha\omega + \frac{\zeta}{2}\delta - p)F(q^{**}) \end{aligned} . \quad (4)$$

So there will be

$\frac{\partial q^{**}}{\partial\omega} < 0$, $\frac{\partial q^{**}}{\partial\delta} \leq 0$, $\frac{\partial q^{**}}{\partial\zeta} \leq 0$, $\frac{\partial q^{**}}{\partial\alpha} > 0$, $\frac{\partial q^{**}}{\partial\beta} > 0$.

As to the supplier, he can get:

$\omega^{**}_{(\alpha,\beta,\delta,\gamma,\zeta)}$ and $q^{**}_{(\alpha,\omega,\beta,\delta,\gamma,\zeta)}$, when let $\frac{dE(\pi_s^{'})}{d\omega} = 0$.

Because $E(\pi_r^{'})$ is a convex function of q, let $\frac{dE(\pi^{''})}{dq} = 0$, $\bar{\bar{q}}$ which is the optimal order quantity satisfies

$$\begin{aligned} & p[1-F(\bar{\bar{q}})] = c_1^{'}(\bar{\bar{q}}) + c_2^{'}(\bar{\bar{q}}) + \delta(1-\gamma)\eta + \\ & +\delta\gamma\vartheta + \zeta\delta - (\delta\eta - \delta\eta\gamma + \delta\gamma\vartheta + \delta\zeta)F(\bar{\bar{q}}) \end{aligned} . \quad (5)$$

From the equation (4) and (5), the contract can be gotten when the supply chain is coordinated. The equation (4) considers conditions to maximize the profit of the retailer as well as the supplier. When the supply chain is coordinated, both they should maximize their profits. Therefore the profit of the supplier should meet the following planning optimal solution.

$$\begin{cases} \max\limits_{\omega,\alpha,\beta,\delta,\gamma,\zeta} E(\pi_s^{'}) = \omega\bar{\bar{q}} - c_1(\bar{\bar{q}}) - \delta\bar{\bar{q}}(1-\gamma)\eta - \delta\bar{\bar{q}}\gamma\vartheta - \frac{\zeta}{2}\delta\bar{\bar{q}} \\ -\alpha\omega\int_{(1-\beta)\bar{\bar{q}}}^{\bar{\bar{q}}} F(x)dx + (\delta\eta - \delta\eta\gamma + \delta\gamma\vartheta + \frac{\zeta}{2}\delta)\int_0^{\bar{\bar{q}}} F(x)dx \\ s.t. 0 \leq \alpha \leq 1, 0 \leq \beta \leq 1, 0 \leq \delta \leq 1, 0 \leq \gamma \leq 1, 0 \leq \zeta \leq 1 \end{cases} . \quad (6)$$

Due to $\omega > 0$, $\vartheta > \eta$,

$1 - \alpha F(\bar{\bar{q}}) + (1-\beta)\alpha F[(1-\beta)\bar{\bar{q}}] > 0$,

it can be learned that $E(\pi_s^{'})$ will decrease with the decrease of the α and the increase of δ, ζ. In theory, the profit of the supplier will be maximized when $\delta = \gamma = \zeta = 0$ and $\alpha = \beta = 1$.

4.1.1 No External Quality Fault Situation

At this time, the optimal coefficient of the supplier is

$$\alpha = 1, \beta = 1, \delta = 0, \gamma = 0, \zeta = 0, \omega = \frac{c_1^{'}(\bar{\bar{q}})}{1 - F(\bar{\bar{q}})} . \quad (7)$$

It can be seen, when the coordination in the supply chain, the supplier should avoid the external quality fault, especially the serious one, and further reputation compromise. Besides, the supplier should also allow the retailer to return all the unsold products at the wholesale price to share the risk together.

On the other hand, from $\delta=0,\gamma=0,\zeta=0$, the market price can be gotten as follows.

$$p=\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}+\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}, \tag{8}$$

where $\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$ is the wholesale price ω. $\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$ is gotten by the supplier and $\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$ is determined by the retailer.

Hence, $\max E(\pi_s')$ and $\max E(\pi_r')$ are respectively:

$$\max E(\pi_s')=\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}(\bar{\bar{q}}-\int_0^{\bar{\bar{q}}}F(x)dx)-c_1(\bar{\bar{q}}), \tag{9}$$

$$\max E(\pi_r')=\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}(\bar{\bar{q}}-\int_0^{\bar{\bar{q}}}F(x)dx)-c_2(\bar{\bar{q}}), \tag{10}$$

And the total supply chain profit is

$$\max E(\pi')=\frac{c_1'(\bar{\bar{q}})+c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}(\bar{\bar{q}}-\int_0^{\bar{\bar{q}}}F(x)dx)-c_1(\bar{\bar{q}})-c_2(\bar{\bar{q}}). \tag{11}$$

4.1.2 Occurring External Quality Fault Situation

Theoretically, if $\delta=\gamma=\zeta=0$ and $\alpha=\beta=1$, then the maximum profit of the supply chain will be obtained. If $\delta\neq 0,\gamma\neq 0,\zeta\neq 0$, the optimal profit of the coordinating supply chain will be obtained when $\alpha=\beta=1$. In this situation, the optimal coefficient values of the supply chain become:

$$\alpha=1,\beta=1,\omega=\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}+\delta(1-\gamma)\eta+\delta\gamma\vartheta+\frac{\zeta\delta}{2}, \tag{12}$$

where the $\delta\neq 0,\gamma\neq 0,\zeta\neq 0$. Those coefficient values show that the supplier should also allow the retailer to return all the unsold products at the wholesale price to share the risk together. So we can learn

$$\underset{(\delta\neq 0,\gamma\neq 0)}{p}=\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}+\delta(1-\gamma)\eta+\delta\gamma\vartheta+\zeta\delta+\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}, \tag{13}$$

Where $\frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}+\delta(1-\gamma)\eta+\delta\gamma\vartheta+\frac{\zeta\delta}{2}$,

which is the wholesale price ω and $\frac{\zeta\delta}{2}+\frac{c_2'(\bar{q})}{1-F(\bar{q})}$ are determined by the supplier and the retailer respectively.

Hence, the optimal profits of the supplier and the retailer are respectively:

$$\max_{(\delta\neq 0,\gamma\neq 0)} E(\pi_s')=-\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\bar{\bar{q}}-c_1(\bar{\bar{q}})-\delta\bar{\bar{q}}(1-\gamma)\eta-\delta\bar{\bar{q}}\gamma\vartheta-\zeta\delta\bar{\bar{q}}+p\bar{\bar{q}}+(\delta\eta-\delta\eta\gamma+\delta\gamma\vartheta-p+\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})})\int_0^{\bar{\bar{q}}}F(x)dx, \tag{14}$$

$$\max_{(\delta\neq 0,\gamma\neq 0)} E(\pi_r')=\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}[\bar{\bar{q}}-\int_0^{\bar{\bar{q}}}F(x)dx]-c_2(\bar{\bar{q}}). \tag{15}$$

And the total profit of the supply chain is

$$\max_{(\delta\neq 0,\gamma\neq 0)} E(\pi')=[p-\delta(1-\gamma)\eta-\delta\gamma\vartheta-\zeta\delta]\bar{\bar{q}}-c_1(\bar{\bar{q}})-c_2(\bar{\bar{q}})+(\delta\eta-\delta\eta\gamma+\delta\gamma\vartheta+\zeta\delta-p)\int_0^{\bar{\bar{q}}}F(x)dx, \tag{16}$$

where $p=\frac{c_1'(\bar{\bar{q}})+\delta(1-\gamma)\eta+\delta\gamma\vartheta-(\delta\eta-\delta\eta\gamma+\delta\gamma\vartheta)F(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}+\zeta\delta+\frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$.

4.2 THE RISK SHARING

The cost of risks of the supplier and retailer based on considering external product quality fault and buyback contract are respectively as follows.

$$r_s'=\delta q(1-\gamma)\eta+\delta q\gamma\vartheta+\alpha\omega\int_{(1-\beta)q}^{q}F(x)dx+\frac{\zeta}{2}\delta q-(\delta\eta-\delta\eta\gamma+\delta\gamma\vartheta+\frac{\zeta}{2}\delta)\int_0^q F(x)dx\ , \tag{17}$$

$$r_r'=\frac{\zeta}{2}\delta q-\alpha\omega\int_{(1-\beta)q}^{q}F(x)dx-(\frac{\zeta}{2}\delta-p)\int_0^q F(x)dx. \tag{18}$$

Eq. (17) and Eq. (18) show that if the total risk is determined, the risk-sharing of the each parties in the supply chain depends on the wholesale ω, buyback contract adjustment coefficient α,β, quality fault adjustment coefficient δ,γ and the reputation compromise adjustment coefficient ζ. When ω,α and β increase, the risks which burdened by the supplier will increase as well, but the risks which burdened by the retailer will decrease. When δ, γ

and ζ increase, the risk shared by both supplier and retailer will increase. While the fault adjustment coefficient δ and the scrap rate γ are determined, the market price p has positive correlation to the risk shared by the retailer too.

Then, the total risk of the supply chain r' is:

$$r' = \delta q(1-\gamma)\eta + \delta q\gamma\vartheta + \zeta\delta q - \\ -(\delta\eta - \delta\eta\gamma + \delta\gamma\vartheta + \zeta\delta - p)\int_0^q F(x)dx \quad . \tag{19}$$

Eq.(19) shows that under considering external quality fault in a supply chain, the total risk has positive correlation to the quality fault adjustment coefficient δ, the scrap rate γ, reputation compromise adjustment coefficient ζ, the market price p and the wholesale ω. The total risk is however non-correlated to the buyback contract adjustment coefficients α, β.

4.2.1 No External Quality Fault Situation

Under this condition, when the supply chain is coordinated, risks which the supplier and retailer share become

$$r_s' = \frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\int_0^{\bar{\bar{q}}} F(x)dx , \tag{20}$$

$$r_r' = \frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\int_0^{\bar{\bar{q}}} F(x)dx . \tag{21}$$

From the Eq.(20) and Eq.(21) , when the total risk is determined, the risk sharing of the each party in the supply chain is independent of buyback contract adjustment coefficients α, β. The risk which the supplier takes is determined only by the wholesale $\omega = \frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$, and the risk of the retailer is determined by $p-\omega = \frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$. In a coordinated situation, although the retailer can return all the unsold order to the supplier, but the risk thereof can't be zero and it is: $p-\omega = \frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}$.

Then, the ratio of risk sharing of both parties is:

$$\frac{r_s'}{r_r'} = \frac{c_1'(\bar{\bar{q}})}{c_2'(\bar{\bar{q}})} \quad . \tag{22}$$

From this equation, it can be concluded that the ratio of the risk shared by both parties equal to the ratio of supplier's marginal cost to the retailer's at the $\bar{\bar{q}}$, which is independent of the coordination coefficient between the parties in the coordinated supply chain.

In this situation, the total risk in the supply chain is

$$r' = p\int_0^{\bar{\bar{q}}} F(x)dx . \tag{23}$$

Therefore, in the condition of buyback contract and no product quality fault, the total cost of the supply chain is positive correlated to the market retail price p and the wholesale price ω, but it has no correlation to the buyback contract adjustment coefficients α, β.

4.2.2 Occurring External Quality Fault Situation

The problem of the risk-sharing of the coordinative supply chain under considering external product quality fault is

$$\alpha = 1, \beta = 1, \omega = \frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})} + \delta(1-\gamma)\eta + \delta\gamma\vartheta + \frac{\zeta\delta}{2}$$

and $\delta \neq 0, \gamma \neq 0, \zeta \neq 0$.

Then, when the supply chain is coordinated, risks which the supplier and retailer share become

$$r_s' = \delta\bar{\bar{q}}(1-\gamma)\eta + \delta\bar{\bar{q}}\gamma\vartheta + \frac{\zeta}{2}\delta\bar{\bar{q}} + \frac{c_1'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\int_0^{\bar{\bar{q}}} F(x)dx , \tag{24}$$

$$r_r' = \frac{\zeta}{2}\delta\bar{\bar{q}} + \frac{c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\int_0^{\bar{\bar{q}}} F(x)dx \ . \tag{25}$$

From the Eq.(24), (25), with only considering external product quality fault and buyback contract, the risk shared by each party is non-correlated to the buyback contract adjustment coefficients α, β. However, the risk of the supplier depends positively on the wholesale price ω, the quality fault rate δ , the scrap rate γ and honour loss rate ζ while the risk of the retailer has positive correlation only to the quality fault rate δ and the honour loss rate ζ. If in a coordinated situation, although the retailer can return all the unsold order to the supplier, but the risk thereof can't be zero but r_r'. Then, the total risk of the supply chain is

$$r' = \delta\bar{\bar{q}}(1-\gamma)\eta + \delta\bar{\bar{q}}\gamma\vartheta + \zeta\delta\bar{\bar{q}} + \\ + \frac{c_1'(\bar{\bar{q}}) + c_2'(\bar{\bar{q}})}{1-F(\bar{\bar{q}})}\int_0^{\bar{\bar{q}}} F(x)dx \quad . \tag{26}$$

Therefore, under a coordinated situation and considering external product quality fault and buyback contract, the total cost of the supply chain has positive correlation to the market price p, the wholesale price ω, the quality fault rate δ, the scrap rate γ and the honour loss rate ζ, but no correlation to the buyback contract adjustment coefficients α, β. And the risks of the supplier, the retailer and whole supply chain when the external quality fault exists in the supply chain are all lager than the ones when the external quality fault doesn't exist in the supply chain.

5 Conclusions

This study investigates the coordination and risk sharing problem in a supply chain under considering external quality fault. The paper analyzes the optimal profit of the whole supply chain, the optimal order quantity of the retailer, the coordination and risk sharing problems under external quality fault coordinative situation.

Under considering external quality fault in a coordinative supply chain, the supplier should allow the retailer to return all the unsold orders at the wholesale price and try to avoid the product quality fault simultaneously. The each party's profits by occurring product quality fault are all lower than those without product quality fault, but this is opposite to the risk sharing in a coordinated supply chain. The risk sharing in supply chain has positive correlation to quality fault rate but no correlation to the buyback contract. The entire risks of supply chain are positively correlated to the retail price and wholesale price. Furthermore, the study explores that even though the retailer may return all the unsold order at the wholesale price, the risk it bears is still above zero.

This study is limited. One of limitations is that the out-of-stock situation and the related coordination and risk sharing problem don't be taken into account. However, there are often out-of-stock situation in a real supply chain. This gap could be investigated in the future research.

Secondly, the paper do not consider the condition that raw material may be exist quality defect or both raw material may be exist quality defect and the supplier (manufacturer) occur product quality fault. Therefore, future research can be also considered the supply chain coordination and risk sharing problem with the condition that both raw material may be exist quality defect and the supplier (manufacturer) occur product quality fault.

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