Decision on Quality Investment Level Under Moral Hazard Environment*

Zhang Cui-hua[1]† and Yu Hai-bin[2]

[1]School of Business Administration Northeastern University
Shenyang, 110004, P.R.China
E-mail: chzhang@mail.neu.edu.cn

[2]Shenyang Institute of Automation,Chinese Academy of Science
Shenyang, 110003, P.R.China
E-mail: yuhaibin@sia.cn

Abstract

Moral hazard and adverse selection often exist in asymmetric information environment. In this paper, quality investment decision problem is studied under moral hazard. A basic model for quality investment level decision is developed with the supplier as a principal and the buyer as an agent. And then we regard the supplier and the buyer's rational limitations to set up a model when the buyer's quality evaluation and processing activities are hidden. The model is optimized and the results under different backgrounds are discussed and compared. Results show that the buyer's quality evaluation level and processing level are mostly influenced by the supplier's quality assurance payment. Both the supplier and the buyer choose different quality investment levels under moral hazard because of the supplier's payment to the buyer in case of internal failure and external failure.

Key Words: Moral Hazard, Supply Chain, Quality, Decision, Optimization, Up-front Payment

1. Introduction

The supplier-buyer relationship of is often the basic form in supply chain. But it is faced with a great deal of challenge such as asymmetric information (Kashi *et al.*, 2005; Gorbet *et al.*, 2000; Barucci *et al.*, 2000 and Gauder *et al.*, 1998). The supplier possess private information of production and investment during contracting between the supplier and buyer, which results in adverse selection (Stanley *et al.*, 2000, 2001). On the other hand, the buyer

†Corresponding Author

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hides its action information after contracting, and this leads to moral hazard(Stanley *et al.*, 2000, 2001). How the supplier and the buyer deal with adverse selection and moral hazard is the key affecting the supply chain efficiency, which is becoming more and more important in supply chain research field(Stanley *et al.*, 2000).

Most papers have considered the moral hazard problem in supply chain quality control. To avoid the worse effect of moral hazard, incentive provisions are often provided in the delivery and control of quality in supplier-producer contracts (Reyniers *et al.*, 1995). The supplier and the buyer contracts on quality provisions including penalties for poor quality, rewards for better quality and rules for inspecting (Starbird 2001). In addition, the double-sided moral hazard problem between the supply chain partners is studied in franchising and the nature of share contracts is analyzed (Bhattacharyya and Lafontaine, 1995). Recent papers have focused on the relationship between contracting, product quality, quality cost and supply chain performance (Stanley *et al.*, 2000, 2001). The supplier and the buyer's quality cost functions are modeled, and their quality control level decisions are optimized regarding the information contracted upon. Furthermore, the interaction between contracting on incentive provisions and supply chain performance is examined in details, the incentive efficiency is testified (Stanley *et al.*, 2001). Stanley *et al.* (2001) model both an induced adverse selection problem on the supplier and a moral hazard problem on the buyer side. Kashi *et al.* (2005) studied quality warranty contracts in single moral hazard and double moral hazard cases. However, they didn't describe the quantitative relationship between decision variables and hidden information or hidden action. They didn't quantify the effect of the hidden information either.

We stress on the moral hazard problem caused by the buyer's quality investment action in supply chain. Based on the former studies of Stanley *et al.* (2000, 2001), our paper differs in that we add the supplier's individual rational limitation to develop a model. We consider the buyer's quality evaluation and product processing action hidden and set up a quantitative model between the decision variables and hidden information. We definitely describe the model's decision variables, solving the optimization problem and discussing the decision results. Furthermore, we try to quantify the effect of the hidden information and get a satisfied solution.

2. Principal-agent Model for Supply Chain Quality Investment Decision

We consider a supply chain consisting of one supplier and one buyer. The supplier produces parts for the buyer, and the buyer evaluates the products quality to decide whether to process further. The supplier's investment on manufacturing determines its product quality. Let P_S denote the supplier's manufacturing investment level, $P_S \in [0, 1]$. Accordingly, $C_S(P_S)$

denotes the supplier's manufacturing investment cost, which will be higher as the manufacturing investment level increases. So we assume the first derivation and the second derivation of $C_S(P_S)$ are both positive with respect to P_S. The buyer invests on the product quality evaluation and manufacturing. The investment levels are P_B and q, and the investment cost are $C_B(P_B)$ and $C(q)$ accordingly. The quality evaluation level and manufacture level will become higher as the costs of quality evaluation and manufacture increase. So we assume the first derivation and the second derivation of $C_B(P_B)$ with respect to P_B, $C(q)$ with respect to q are positive. P_B determines the probability of product defect detected by the buyer, $P_B \in [0, 1]$, q determines the quality level of the supplier's product, $q \in [0, 1]$. External failure means the opportunity cost from enterprise credit and sales reduction caused by the product's quality problem after sales, which is denoted by E. If there is not quality defect in the products supply, the quality evaluation system of the buyer will certificate it and then the probability of external loss is $1-q$. If the quality defect is detected by the buyer, it will cost him some resources to modify. That is to say, the buyer will bear internal failure, which is denoted by I. And the probability of external loss is $1-q$ If the quality defect is not certificated by the buyer's quality evaluation system, the buyer's product processing doesn't affect the product's quality, and then the probability of external failure is 1. Here, we assume E is far more than I, considering the supplier as principal and the buyer as agent. Then we develop the supplier's income function, i.e. the principal's object function is as follows:

$$\pi_1 = P - C_S - (1-P_S) P_B W^I - (1-P_S)(1-P_B) W^E \quad (1a)$$

$$P = P(P_B, q) \quad (1b)$$

$$C_S = C_S(P_S) \quad (1c)$$

$$P_S = P_S(P_B, q) \quad (1d)$$

Here π_1 denotes the supplier's income function, P denotes the buyer's up-front payment to the supplier to compensate for the supplier's investment on improving product quality and teaching employees, which is the supplier's decision variable and the function of the buyer's quality evaluation level P_B and manufacture level q. P_S denotes the supplier's manufacture investment level, P_B denotes the buyer's quality evaluation level. W^I is the buyer's quality assurance payment in case of internal failure. W^E is the supplier's quality assurance payment in case of external failure. Here we assume W^1 and W^E are constant determined by negotiation between the supplier and the buyer. The other parameters mean as described before. In the principal-agent problem, the buyer's quality evaluation level P_B and manufacture level q are information variables. In the condition of symmetric information, P_B and q are observable, so the supplier can observe the buyer's quality evaluation and manufacture action, and then decide his own manufacture investment level. P_S is the joint function of P_B and q. When P_B and q are hidden, the supplier can only estimate the buyer's quality evaluation and manufacture action, and then decide his investment level. P_S is the function of the estimated value of P_B and q. We consider supplier's individual rational limitation which is different from Stanley *et al.* (2001).

$$\pi_1 \geq R_1 \tag{2}$$

Here R_1 is the supplier's lowest income objective.

The buyer's income function, i.e. the agent's objective function is:

$$\pi_2 = V - P - C_B - C_q - (1-P_S)P_B(I - W^1 + (1-q)E) - (1-P_S)(1-P_B)(E - W^E) - P_S(1-q)E \tag{3a}$$

$$P = P(P_B, q) \tag{3b}$$

$$C_B = C_B(P_B) \tag{3c}$$

$$C_q = C(q) \tag{3d}$$

$$P_S = P_S(P_B, q) \tag{3e}$$

Here π_2 denotes the buyer's income, V is the product's market value, which is explicit to the supplier and the buyer. q denotes the buyer's manufacture level, which is an information variable relative to observation.

The buyer's individual sense restriction is

$$\pi_2 \geq R_2 \tag{4}$$

Here R_2 is the buyer's lowest income objective.

For convenience, we translate Equation (2), Equation (4) into the form of quadratic function as follows (Wu, 2000):

$$\pi_3 = \frac{1}{2} a_1 (\pi_1 - R_1)^2 \tag{5}$$

$$\pi_4 = \frac{1}{2} a_2 (\pi_2 - R_2)^2 \tag{6}$$

Here, a_1 and a_2 are the lowest income parameters for the supplier and the buyer, $a_1 > 0$, $a_2 > 0$.

Thus, the supplier's generalized income is:

$$\pi_5 = \pi_1 - \pi_3 \tag{7}$$

The buyer's generalized income is:

$$\pi_6 = \pi_2 - \pi_4 \tag{8}$$

When the supplier and the buyer possess symmetric information of each other's quality investment, the supplier can observe the buyer's quality evaluation action and manufacture action. So decision on the supplier's manufacture investment and the buyer's quality evaluation level and manufacture level is a joint income optimization problem. The supplier tends to choose a proper invest level P_S and up-front payment P to maximize his income function:

$$\underset{P,\, P_S}{Max} \quad \pi_5 = \pi_5(P,\, P_S) \tag{9}$$

According to principal-agent theory, the supplier as principal has the right to let the buyer's income be 0.It is as follows:

$$\pi_6 = 0 \tag{10}$$

From Equation (10), we get:

$$P = V - C_B - C_q - (1-P_S)P_B(I - W^I + (1-q)E) - (1-P_S)(-1P_B)(E - W^E)$$
$$- P_S(1-q)E - (a_2R_2 + 1 \pm \sqrt{2a_2R_2+1})/a_2 \tag{11}$$

Substituting Equation (11) into Equation (9), we get the first derivation with respect to P_S:

$$C_S' = P_B I + (1-P_B)qE \tag{12}$$

In addition, we can get the buyer's quality evaluation level and manufacture level under symmetric information through substituting Equation (11) into Equation (9) and then get the first derivation with respect to P_B and q accordingly as follows:

$$C_B' = (1-P_S)\,(qE-1) \tag{13}$$

$$C_q' = ((1-P_S)\,P_B + P_S)\,E \tag{14}$$

When

$$\frac{\partial^2\pi_5}{\partial P_S^2} = -C_S''\,(1-a_1(\pi_1-R_1)) - a_1\left(\frac{\partial\pi_1}{\partial P_S}\right)^2 \le 0,\quad \frac{\partial^2\pi_5}{\partial P_B^2} = -C_B''\,(1-a_1(\pi_1-R_1)) - a_1\left(\frac{\partial\pi_1}{\partial P_B}\right)^2 \le 0,$$

$$\frac{\partial^2\pi_5}{\partial q^2} = -C_q''\,(1-a_1(\pi_1-R_1)) - a_1\left(\frac{\partial\pi_1}{\partial q}\right)^2 \le 0$$

solution to the supplier's quality level, the buyer's quality evaluation level, up-front payment and manufacture level under symmetric information is as $\{P_S^*, P^*, P_B^*, q^*\}$.

We choose the buyer's evaluation cost function as $C_B(P_B)=\frac{1}{2}K_B P_B^2$, the manufacture cost function as $C(q)=\frac{1}{2}K_q q^2$, and the supplier's manufacture investment cost function as $C_s(P_s)=\frac{1}{2}K_S P_S^2$. K_S, K_B, K_q are coefficient to be determined. Then, integrating Equation (12), Equation (13) and Equation (14), we can get as follows:

$$\begin{aligned} K_S P_S = & \left[(1-P_S)(E^2 P_S - K_q I)I\right]/\left[K_B K_q - (1-P_S)^2 E^2\right] + \\ & \left\{1-\left[(1-P_S)(E^2 P_S - K_q I)\right]/\left[K_B K_q - (1-P_S)^2 E^2\right]\right\} * \\ & \left\{\left[(1-P_S)^2 E^2 (E^2 P_S - K_q I)\right]/\left[K_B K_q^2 - (1-P_S)^2 E^2 K_{q)}\right] + P_S E^2/K_q\right\} \end{aligned} \quad (15)$$

$$P_S^* = f(E, I, K_B, K_S K_q) \quad (16)$$

$$P_B^* = \left[(1-P_S)(E^2 P_S - K_q I)\right]/\left[K_B K_q - (1-P_S)^2 E^2\right] \quad (17)$$

$$q^* = \left[(1-P_S)^2 E(E^2 P_S - K_q I)\right]/\left[K_B K_q^2 - (1-P_S)^2 E^2 K_q\right] + P_S E/K_q \quad (18)$$

$$P^* = f(P_S, P_B, q, a_2, R_2) \quad (19)$$

Here P_S^* satisfies Equation (15) and P^*satisfies Equation (11).

3. Supply Chain Quality Investment Level Decision under Moral Hazard

Here we consider the buyer hides his quality evaluation and manufacture action, which leads to moral hazard(Ann,1993; Barucci *et al.*, 2000; Starbird *et al.*, 1994).

3.1 The Supplier's Quality Evaluation Investment and Processing Investment

When the supplier can't observe the buyer's quality evaluation action and manufacture action, the buyer will not choose to invest as Equation (17) and Equation (18), but to maximize his own income (Starbird *et al.*, 1994; Yu, 2002). So the quality level and manufacture level are determined by solving the first derivation problem of Equation (3a) with respect to P_B and q:

$$\frac{\partial \pi_2}{\partial P_B} = -C_B' + (1-P_S)(qE - I + W^I - W^E) = 0 \quad (20)$$

$$\frac{\partial \pi_2}{\partial q} = -C_q' + ((1-P_S)P_B + P_S)E = 0 \quad (21)$$

From Equation (20), Equation (21), we get as follows:

$$C_B{}' = (1-P_S)(qE-I+W^I-W^E) \tag{22}$$

$$C_q{}' = ((1-P_S)P_B+P_S)E \tag{23}$$

Here we choose $C_B(P_B)$, $C(q)$ and $C_S(P_S)$ as before, we can get from Equation (22) and Equation (23) as follows:

$$\begin{aligned} P_B = &\left[(1-P_S)/(E^2P_S-K_qI)\right]/\left[K_BK_q-(1-P_S)^2E^2\right] \\ &+(1-P_S)K_q(W^I-W^E)/\left[K_BK_q-(1-P_S)^2E^2\right] \end{aligned} \tag{24}$$

$$\begin{aligned} q= &\left[(1-P_S)^2E(E^2P_S-K_qI)\right]/\left[K_BK_q^2-(1-P_X)^2E^2K_q\right] \\ &+\left[(1-P_S)^2EK_q((W^I-W^E))\right]/\left[K_BK_q^2-(1-P_S)^2E^2K_q\right]+P_sE/K_q \end{aligned} \tag{25}$$

Equation (17) is the buyer's supposed quality evaluation level, but he actually chooses the quality evaluation level as Equation (24) under moral hazard, the difference is as follows:

$$\Delta P_B = (1-P_S)K_q(W^I-W^E)/[(K_BK_q-(1-P_S)^2E^2 \tag{26}$$

It can be defined as the measurement of moral hazard concerning the buyer's quality evaluation action. The buyer's supposed manufacture level is as Equation (18), but he actually chooses as Equation (25), the difference is as follows:

$$\Delta q = [(1-P_S)^2EK_q((W^I-W^E))]/[K_BK_q^2E^2K_q] \tag{27}$$

It can be defined as the measurement of moral hazard concerning the buyer's manufacture action. Under certain manufacture level of the supplier, the moral hazard is decided by the difference of internal quality assurance and external quality assurance payment the supplier gives to the buyer.

Comparing Equation (17) with Equation (24), Equation (18) with Equation (25), we can get: if $W^I=W^E$, then $P_B=P_B^*$, $q=q^*$; if $W^I>W^E$, then $P_B>P_B^*$, $q>q^*$; if $W^I<W^E$, then$P_B<P_B^*$, $q<q^*$. That is to say, the buyer's quality evaluation level and processing level are mostly influenced by the supplier's quality assurance payment. If the supplier's quality assurance payment for internal quality failure is equal to that for external quality failure, the buyer tends to select the expected quality evaluation level and processing level. If the supplier's quality assurance payment for internal quality failure exceeds that for external quality failure, tends to make an effort to gain more income from internal failure payment from the

supplier. Accordingly, the buyer will strengthen his investment on quality evaluation, which results in that the buyer's quality evaluation investment level under moral hazard is higher than the expected level under symmetric information. When the buyer increases his quality evaluation investment, he is more capable of inspecting the supplier's product defect. And then it is more valuable to process the supplier's good quality products. Therefore, the buyer selects higher processing level. If the supplier's quality assurance payment for internal quality failure is less than that for external quality failure, the buyer will consider this reduces his marginal investment effect of quality evaluation and processing. And then the buyer is inspired to gain more external quality assurance income to reduce his investment on quality evaluation and product processing. As a result, the buyer's quality evaluation level is lower than the expected level under moral hazard, and his processing level is so too. Moreover, the buyer's lower investment on quality evaluation reduces his ability to inspect the supplier's product defect, which makes it of less sense to further process the products. This also leads the buyer to lower his processing level than that under symmetric information.

From the above analysis, we know that the presence of moral hazard twists the buyer's selection of quality evaluation investment and processing investment. As a result, buyer selects his level of quality evaluation and processing deviating from the expected values. However, the supplier could design a definite incentive scheme to inspire the buyer to choose his quality level to satisfy his objective, and at the same time the supplier can reach its own goal (Barucci *et al.*, 2000; Zhang, 2000).

3.2 The Supplier's Quality Investment and Up-front Payment Decision

Now we analyze the supplier's quality investment level decision and up-front payment required from the buyer under moral hazard. The model is as follows:

$$\underset{P,\, P_S}{Max} \quad \pi_1 \tag{28}$$

$$\text{s.t} \quad \pi_1 \geq R_1 \tag{2}$$

$$\pi_2 \geq R_2 \tag{4}$$

$$(P_B, q) = \underset{(P_B,\, q)}{Arg\max} \;\; \pi_2 \; (P_B, q) \tag{29}$$

Here, Equation (29) is the supplier's incentive compatible constraint to the buyer, which is the application of reveals principle theory and guarantees the buyer choose his quality evaluation level and processing level satisfying his optimal objective.

In order to solve this optimization problem, we translate the individual rational constraint conditions into the form of quadratic function and translate Equation (29) into the first derivation. In this way, the model can be as follows:

$$\max_{P, P_S} \ \pi_1 - \frac{1}{2}a_1(\pi_1 - R_1)^2 - \frac{1}{2}a_2(\pi_2 - R_2)^2 \tag{30}$$

$$s.t \ C_B' = (1-P_S)(qE - 1 + W^I - W^E) \tag{22}$$

$$C_q' = ((1-P_S)P_B + P_S)E \tag{23}$$

And then, we have

$$\frac{\partial \pi_1}{\partial P}[1 - a_1(\pi_1 - R_1)] - \frac{\partial \pi_2}{\partial P}a_2(\pi_2 - R_2) = 0 \tag{31}$$

$$\frac{\partial \pi_1}{\partial P_S}[1 - a_1(\pi_1 - R_1)] - \frac{\partial \pi_2}{\partial P_S}a_2(\pi_2 - R_2) = 0 \tag{32}$$

From Equation (31), we can get:

$$1 - a_1(\pi_1 - R_1) = -a_2(\pi_2 - R_2) \tag{33}$$

Substituting Equation (1a) and Equation (3a) into Equation (33), we can get:

$$P = \frac{1}{a_1 + a_2}[1 + a_1 R_1 - a_2 R_2 - a_1(C_S + (1-P_S)P_B W^I + (1-P_S)(1-P_B)W^E) + a_2(V - C_B - C_q - (1-P_S)P_B(I - W^I + (1-q)E) - (1-P_S)(1-P_B)(E - W^E) - P_S(1-q)E)] \tag{34}$$

Substituting Equation (33) into Equation (32), we can get:

$$C_S' = P_B I + (1-P_B)qE \tag{35}$$

We make a contrast between Equation (35) and Equation (12). It is noticed that they seems the same. However, the supplier's investment on quality under moral hazard is different from that under symmetric information owing to the buyer's different investment on quality evaluation and processing from that under symmetric information. Substituting Equation (24) and Equation (25) into Equation (35), we can get:

$$K_S P_S = [(1-P_S)(E^2 P_S - K_q(I - W^I + W^E))(I - W^I + W^E)]/[K_B K_q - (1-P_S)^2 E^2 + \{1 - [(1-P_S)(E^2 P_S - K_q(I - W^I + W^E))]/[K_B K_q - (1-P_S)^2 E^2]\} * \{[(1-P_S)^2 E^2(E^2 P_S - K_q(I - W^I + W^E))]/[K_B K_q^2 - (1-P_S)^2 E^2 K_q] + P_S E^2/K_q\} \tag{36}$$

The supplier's investment level on quality under moral hazard satisfies Equation (36).

For convenience to deal with, we assume that the buyer's quality evaluation level and processing level is bigger than 0.5.

When $0.5 \leq P_B < P_B^*$, $q < q^*$,

$$C_S'(P_S) - C_S'(P_S^*) = (P_B - P_B^*)I + (q - q^*)E - (P_B q - P_B^* q^*)E < (q - q^*)E - (P_B q - P_B^* q^*)E < 0$$

$$C_S''(P_S) > 0, \text{ so } C_S'(P_S) < C_S'(P_S^*), \ P_S < P_S^*.$$

When $P_B > P_B^* \geq 0.5$, $q > q^*$,

$$C_S'(P_S) - C_S'(P_S^*) = (P_B - P_B^*)I + (q - q^*)E - (P_B q - P_B^* q^*)E > (q - q^*)E - (P_B q - P_B^* q^*)E > 0,$$

$$C_S''(P_S) > 0, \text{ so } C_S'(P_S) > C_S'(P_S^*), \ P_S > P_S^*.$$

That is to say, when the buyer's quality evaluation level and processing level moral hazard are higher than the supposed values, the supplier tend to select higher quality prevention level, which guarantees good quality products so as to decrease the internal and external failure occurrence. Thereby, the supplier can decrease his quality assurance payment. From the viewpoint of the whole supply chain, this can promote the supply chain's effective operation to provide high quality products. When the buyer's quality evaluation level and processing level moral hazard are lower than the supposed values, the supplier tends to select lower quality prevention level. This is because the buyer loosens his evaluation activities under moral hazard, which reduces the possibility of punishing the supplier for internal failure. On the other hand, this enhances the possibility of external failure occurrence, increasing the feasibility of punishing the supplier for external failure. Therefore, from the supplier's viewpoint, he won't increase his investment on quality to guarantee his own profit. On the contrary, he chooses lower quality level so as to reduce his own production cost. For the whole supply chain, this is a danger challenging the long-run supply chain relationship.

From the above analyses, we know that both the supplier and the buyer choose different quality investment levels under moral hazard because of the supplier's payment to the buyer in case of internal failure and external failure. Therefore, how to negotiate on quality assurance level between the supplier and the buyer is the key to decrease the effect of moral hazard.

4. Conclusions

This paper studies the problem of a supply chain's quality investment decision under moral hazard that the buyer's behavior is hidden. Results show that the buyer's quality evaluation level and processing level are mostly influenced by the supplier's quality assurance payment. If the supplier's quality assurance payment for internal quality failure exceeds that for external quality failure, the buyer will strengthen his investment on qualitative evaluation, which results in that the buyer's quality evaluation investment level under moral hazard is higher than the expected level under symmetric information. Both the supplier and the buyer choose different quality investment levels under moral hazard because of the supplier's payment to the buyer in case of internal failure and external failure. Therefore, how to negotiate on quality assurance level between the supplier and the buyer is the key to reduce the effect of moral hazard, which is the major research emphasis in future.

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