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A determining method of the water consultancy project quality guarantee deposit considering the contractor's credit level under the incomplete information condition

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ABSTRACT

This paper studies the quality monitoring decision-making and quality guarantee deposit withholding strategy of the owner in the construction supply chain composed of the owner and the contractor in the engineering construction project under different information environments. Taking the quality monitoring level and quality guarantee deposit retention as the owner's decision variables and the credit level as the contractor's decision variables, when the owner's quality monitoring cost and the contractor's credit are non-concave and non-convex functions, the optimal solution of the owner's quality monitoring decision and quality guarantee deposit retention strategy under symmetric information, asymmetric information and incomplete information are deduced by using the maximum principle. Through simulation calculation, the decision results under different information conditions are analyzed. It helps to improve the effectiveness and reliability of the owner's quality monitoring and realize the expected quality control objectives and quality benefits.

Keywords: Quality guarantee deposit; Contractor's credit; Quality monitoring; Incomplete information

1. Introduction

The purpose of project quality control is to make all quality activities and results meet the quality requirements, and quality guarantee deposit is an effective quality control method. The quality deposit is mainly used for the reserved funds for the contractor to fulfill its own responsibilities, so as to provide financial guarantee for the owner to effectively supervise the contractor to successfully complete the defect repair work. At present, many scholars have carried out research on quality control under different information, such as Starbird [1] studied the problem of quality control in supply chain contracts, put forward incentive problems such as punishment, reward and monitoring in quality control, and studied the problem of adverse selection under principal-agent mode; Neil [2] established the supplier's and buyer's quality cost model in the supply chain, and put forward the punishment, reward and supervision strategies in quality control; Li and Chen [3] used the numerical analysis laboratory analysis method to study the probability boundary of default of various bonds in the case of asymmetry and the direct impact of the maturity date of bonds on the probability of default; Huang and Lu [4] established the supplier and buyer's quality cost model in the supply chain cooperation relationship, and used the maximum principle to solve the optimal quality control of supply chain management under the condition of asymmetric information; Zhang and Huang [5–7] established the suppliers and sellers' quality

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return function and deduced the optimal solution of supplier quality prevention when the seller's product evaluation information was hidden by using the maximum value theory, the buyers and suppliers' quality decision-making model is established, and the product quality evaluation decision-making problem of supply chain outsourcing under different information is studied; the quality evaluation and transfer payment of business outsourcing under asymmetric information are studied, considering the concealment of supplier quality prevention information; Fu and He [8] took the quality supervision and control level and project payment decision as the Party A's decision variables of BT project and take the quality prevention level as Party B's decision variables of BT project, the game model of quality control strategy of Party A and Party B is established, and the quality control decision of BT project under the condition of asymmetric information is discussed; Jin et al. [9] constructed the general contractor and subcontractor's quality return function, and obtained the optimal solution by using the principle of maximum value; Wang et al. [10] took the quality supervision level and project transfer payment as the decision variables for general contractors and project quality management level as the decision variables for subcontractors, quality benefit functions for general contractors and subcontractors is constructed, and applied the principle of great value to derive optimal solutions for quality supervision decision and quality deposit withholding of general contractors under asymmetric information. None of the above studies considered the impact of contractor credit on quality supervision decisions.

In addition, many scholars have carried out relevant research under the cost function, such as Li et al. [11] studied that the transaction cost is a V-shaped function of difference in general, and studied the optimal portfolio selection with transaction cost between the existing portfolio and the new portfolio; Wang [12] constructed the output game model of duopoly market with quadratic cost function, and the output is adjusted through long-term game to achieve the optimal profit by using quadratic cost function and Gd adjustment mechanism; Based on the original portfolio model with investor risk preference parameters, Wei et al. [13] applies different convex transaction cost functions to the portfolio model with investor risk preference parameters; by introducing the form of non-concave and non-convex cost function, Wang et al. [14] established a portfolio management model with typical transaction costs, and analyzed the impact of different transaction costs and different risk levels on the portfolio through numerical examples. At present, there are few research results on the owner's quality monitoring cost function and the contractor's credit cost function. Generally, in the actual water conservancy construction project, the transaction cost is a non-concave and non-convex function with two inflection points. Based on the existing research results, this paper studies the non-concave and non-convex function of the owner's quality monitoring cost and the contractor's credit cost.

From the owner's perspective, this paper studies the quality supervision decision and quality guarantee deposit withholding in the engineering supply chain composed of the owner and the contractor of the engineering construction projects under different information conditions considering the contractor's credit level. The effective detention strategy of the quality guarantee deposit is helped to formulate, which makes the quality guarantee deposit deduction more reasonable, scientific and complete, and finally determines the optimal credit level, so that the owner and the contractor can achieve a win–win situation for both sides.

2. Expected income model for owner and contractor

Build a two-level supply chain system of engineering construction project composed of one owner and one contractor, and their risk preference is neutral [4–10]. The owner is the dominant player and the contractor is the follower. Both parties pursue to maximize their own expected returns. The owner can obtain the credit level of the contractor and determine the monitoring level of the contractor based on the credit level of the contractor to determine the percentage of the project quality bond with holding [15–17].

The expected income obtained by the owner in the project is:

$$E(A) = A_1\left[R_b + (1 - R_b)I_a\right] + A_2(1 - I_a)(1 - R_b) - S(R_b)(1 - I_a)(1 - R_b) - B_a(I_a) - V \quad (1)$$

where $E(A)$ represents the owner's expected income; A_1 represents the income when the project quality is qualified; A_2 represents the income from unqualified project quality; R_b represents the contractor's credit level; I_a represents the owner's monitoring level on the contractor; $S(R_b)$ represents the quality guarantee deposit; $B_a(I_a)$ represents the owner's quality monitoring cost; V represents the total contract price paid by the owner to the contractor at the time of project settlement.

The expected income obtained by the contractor in the construction project is:

$$E(B) = V + S(R_b)(1 - I_a)(1 - R_b) - B_r(R_b) - P(1 - R_b)I_a \quad (2)$$

where $E(B)$ represents the contractor's expected income; $B_r(R_b)$ represents the contractor's credit level; P represents the cost of project reworking (or maintenance) when the contractor is found to have quality problems by the owner.

3. Non-concave non-convex function model of owner monitoring cost and contractor credit cost

According to the actual situation of the project, it is assumed that with the improvement of the owner's monitoring level I_a, that is, $0 \le I_a \le I_A$, the rising trend of the owner's monitoring cost gradually decreases, before reaching point A, the owner's monitoring cost function $B_a(I_a)$ is a convex function; when $I_A \le I_a \le I$, the owner's monitoring cost function $B_a(I_a)$ increases linearly with the increase of I_A; when $I_B \le I_a \le I_a^H$, the owner's monitoring cost function $B_a(I_a)$ increases with the increase of I_A, the influencing factors of market price changes in each stage of the project cause the cost to rise, after reaching point B, the owner's monitoring cost function $B(I_a)$ is a concave function. The function image of the owner's monitoring cost with the monitoring level I_a is shown in Fig. 1.

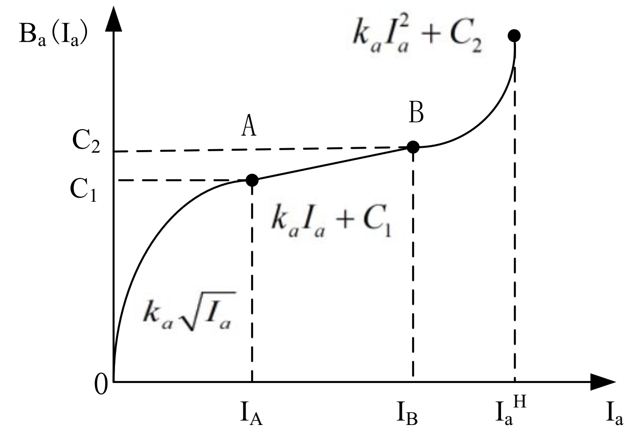

Fig. 1. Owner's monitoring cost function (non-concave and non-convex functions).

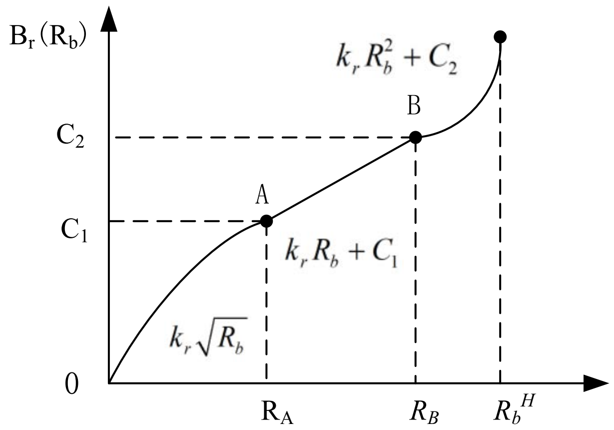

Fig. 2. Contractor's credit cost function (non-concave and non-convex functions).

The owner's monitoring cost $B_a(I_a)$ function is:

$$B_a(I_a)=\begin{cases} k_a\sqrt{I_a}, & 0 \le I_a \le I_A \\ k_a I_a + C_1, & I_A \le I_a \le I_B \\ k_a I_a^2 + C_2, & I_B \le I_a \le 1 \end{cases} \quad (3)$$

Evaluate the first-order partial derivative of the owner's quality monitoring level I_a in Eq. (3):

$$B'_a(I_a)=\begin{cases} \dfrac{k_a}{2\sqrt{I_a}}, & 0 \le I_a \le I_A \\ k_a, & I_A \le I_a \le I_B \\ 2k_a I_a, & I_B \le I_a \le 1 \end{cases} \quad (4)$$

With the improvement of the contractor's credit level R_b, that is, $0 \le R_b \le R_A$, the rising trend of contractor's credit cost gradually decreases, before reaching point A, the contractor's credit cost function $B_r(R_b)$ is a convex function; when $R_A \le R_b \le R_B$, the contractor's credit cost function $B_r(R_b)$increases linearly with the increase of R_b; when $R_B \le R_b \le R_b^H$, the contractor's credit cost function $B_r(R_b)$increases with R_b. and the cost increases due to the influencing factors of the change of market price in each stage of the project. After reaching point B, the contractor's credit cost function $B(R_b)$ is a concave function [9]. The function image of the contractor's credit cost with the credit level R_b is shown in Fig. 2.

The function of the contractor's credit cost $B_r(R_b)$ is:

$$B_r(R_b)=\begin{cases} k_r\sqrt{R_b}, & 0 \le R_b \le R_A \\ k_r R_b + C_1, & R_A \le R_b \le R_B \\ k_r R_b^2 + C_2, & R_B \le R_b \le 1 \end{cases} \quad (5)$$

Evaluate the first-order partial derivative of the contractor's credit level R_b in Eq. (5):

$$B'_r(R_b)=\begin{cases} \dfrac{k_r}{2\sqrt{R_b}}, & 0 \le R_b \le R_A \\ k_r, & R_A \le R_b \le R_B \\ 2k_r R_b, & R_B \le R_b \le 1 \end{cases} \quad (6)$$

4. Detention strategy of the quality guarantee deposit with symmetric information

Under symmetrical information, the owner can observe the contractor's credit level R_b through the credit evaluation system and performance, so the owner's quality monitoring decision-making problem is an optimization problem [18–21], namely:

$$\max E(A) = E(I_a) \quad (7)$$

At this time, the contractor's participation constraints is:

$$E(B) = V + S(R_b)(1-I_a)(1-R_b) - B_r(R_b) - P(1-R_b)I_a = M \quad (8)$$

where M is a normal number, which can be obtained from Eq. (8):

$$S(R_b) = \frac{M - V - PR_b I_a + B_r(R_b) + PI_a}{(1-I_a)(1-R_b)} \quad (9)$$

Substituting Eq. (9) into Eq. (7), we have:

$$E(A) = A_1\left[R_b + (1-R_b)I_a\right] + A_2(1-I_a)(1-R_b) - M - B_r(R_b) - P(1-R_b)I_a - B_a(I_a) \quad (10)$$

Evaluate the first-order partial derivative of the owner's quality monitoring level I_a in Eq. (10) and make it 0:

$$B'_a\left(I_a\right)=\left(A_1-A_2-P\right)\left(1-R_b\right) \quad (11)$$

The loss caused by the contractor's quality defect to the owner is greater than the contractor's rework cost, so (A_1–A_2–P) (1–R_b) ≥ 0, so there is an extreme value in the above formula.

The second-order partial derivative $\frac{d^2E(A)}{dI_a^2}=-B''_a\left(I_a\right)<0$ of Eq. (7) to I_a, so Eq. (7) has a maximum value. At this time, the owner's quality monitoring decision meets Eq. (11).

Put Eq. (4) and Eq. (11) together, and I_a* is obtained:

$$I_a^*=\begin{cases}\dfrac{k_a^2}{4\left(A_1-A_2-P\right)^2\left(1-R_b\right)^2},0\le R_b\le R_A\\ I_a^H \qquad ,R_A\le R_b\le R_B\\ \dfrac{\left(A_1-A_2-P\right)\left(1-R_b\right)}{2k_a},R_B\le R_b\le 1\end{cases} \quad (12)$$

Assuming $I_A = R_A$, $I_B = R_B$, it is concluded that under the condition of symmetrical information, when the contractor's credit cost function is non-concave and non-convex function, the retention S of quality deposit is:

$$S\left(R_b\right)=\begin{cases}\dfrac{M-V+k_r\sqrt{R_b}+P\left(1-R_b\right)I_a}{\left(1-I_a\right)\left(1-R_b\right)},0\le R_b\le R_A\\ \dfrac{M-V+k_rR_b+C_1+P\left(1-R_b\right)I_a}{\left(1-I_a\right)\left(1-R_b\right)},R_A\le R_b\le R_B\\ \dfrac{M-V+k_rR_b^2+C_2+P\left(1-R_b\right)I_a}{\left(1-I_a\right)\left(1-R_b\right)},R_B\le R_b\le 1\end{cases} \quad (13)$$

$$S=\begin{cases}S^H,S^H\le S\left(R_b\right)\\ S\left(R_b\right),S^L<S\left(R_b\right)<S^H\\ S^L,S\left(R_b\right)\le S^L\end{cases} \quad (14)$$

5. Owner's quality control and detention strategy of the quality guarantee deposit with the incomplete information condition

Under the condition of asymmetric information, the contractor's credit level is completely unobservable to the owner [10], and the problem between the owner and the contractor is still an optimization problem. The owner maximizes its expected income by selecting its own corresponding monitoring level, namely:

$$\max_{I_a\left(R_b\right)}\int_{R_b^L}^{R_b^H}E\left(A\right)f\left(R_b\right)dR_b \quad (15)$$

Assuming the contractor's credit level $R_b \in [R_b^L, R_b^H]$, and R_b follows the probability distribution of probability density $f(R_b)$, Under the condition of asymmetric information, although the owner has the advantage of taking the first step as a leader, while pursuing the maximization of its expected income, considering the contractor as a follower, the owner will be subject to corresponding constraints from the contractor [21–24], namely:

$$R_b\in\arg\max V+S\left(R_b\right)\left(1-I_a\right)\left(1-R_b\right) -B_r\left(R_b\right)-P\left(1-R_b\right)I_a-M \quad (16)$$

Evaluate the first-order partial derivative of the Eq. (15) with respect to R_b:

$$\frac{dS\left(R_b\right)}{dR_b}=\frac{B'_r\left(R_b\right)\left(1-R_b\right)+B_r\left(R_b\right)-V+M}{\left(1-I_a\right)\left(1-R_b\right)^2} \quad (17)$$

R_b is used as the control variable, and the Hamiltonian function of the problem is established through the maximum principle, namely:

$$H=E\left(A\right)f\left(R_b\right)+\lambda\left[\frac{B'_r\left(R_b\right)\left(1-R_b\right)+B_r\left(R_b\right)+M-V}{\left(1-I_a\right)\left(1-R_b\right)^2}\right] \quad (18)$$

Among them, λ is a covariate. The governing equation is:

$$\frac{\partial H}{\partial I_a}=\left[\left(A_1-A_2-P\right)\left(1-R_b\right)-B'_a\left(I_a\right)\right]f\left(R_b\right) +\lambda\left[\frac{B_r\left(R_b\right)\left(1-R_b\right)+B'_r\left(R_b\right)+M-V}{\left(1-I_a\right)\left(1-R_b\right)^2}\right] \quad (19)$$

The mimicry equation is:

$$\frac{d\lambda}{dR_b}=-\frac{\partial H}{\partial S}=\left(1-I_a\right)\left(1-R_b\right)f\left(R_b\right) \quad (20)$$

From the above equation, we have:

$$\lambda=\left(1-I_a\right)\left[F\left(R_b\right)-R_bF\left(R_b\right)+\int F\left(R_b\right)+C\right] \quad (21)$$

where $F(R_b)$ is the probability distribution function of the contractor's credit level $F(R_b) = (R_b - R_b^L)/(R_b^H - R_b^L)$, $f(R_b) = 1/(R_b^H - R_b^L)$; C is a constant.

Since $\frac{\partial^2 H}{\partial^2 I_a}=-B''_a\left(I_a\right)f\left(R_b\right)<0$, the second-order partial derivative is less than zero, so there is a maximum value on the optimal control issue. Put Eq. (4) and Eq. (11) together, and I_a* is obtained:

$$I_a^* = \begin{cases} \dfrac{k_a^2}{\left\{2\left(A_1 - A_2 - P\right)\left(1 - R_b\right) + \dfrac{2\lambda}{f\left(R_b\right)}\left[\dfrac{B_r'\left(R_b\right)\left(1 - R_b\right) + B_r\left(R_b\right) + M - V}{\left(1 - I_a\right)\left(1 - R_b\right)^2}\right]\right\}^2}, & 0 \le R_b \le R_A \\ I_a^H, & R_A \le R_b \le R_B \\ \left(A_1 - A_2 - P\right)\left(1 - R_b\right)/2k_a + \dfrac{\lambda}{2k_a f\left(R_b\right)}\left[\dfrac{B_r'\left(R_b\right)\left(1 - R_b\right) + B_r\left(R_b\right) + M - V}{\left(1 - I_a\right)\left(1 - R_b\right)^2}\right], & R_B \le R_b \le 1 \end{cases} \tag{22}$$

Detention strategy for quality guarantee deposit can be obtained:

$$S\left(R_b\right) = \frac{1}{\left(1 - I_a^*\right)} \int \frac{B_r'\left(R_b\right)}{\left(1 - R_b\right)} + \frac{B_r\left(R_b\right) + \left(M - V\right)}{\left(1 - R_b\right)^2} d\left(R_b\right) + n \tag{23}$$

Put Eq. (23) and Eq. (6) together, and, the retention S of quality guarantee deposit under the condition of asymmetric information is obtained:

$$S\left(R_b\right) = \begin{cases} k_r\left[\left(1 - R_b\right)\ln\left(\dfrac{1 - \sqrt{R_b}}{1 + \sqrt{R_b}}\right) - 2\ln\left(\dfrac{2 - \sqrt{R_b}}{2 + \sqrt{R_b}}\right) + 2\sqrt{R_b}\right]\dfrac{1}{\left(1 - I_a\right)} + \dfrac{\left(M - V\right)}{\left(1 - R_b\right)\left(1 - I_a\right)} + C, & 0 \le R_b \le R_A \\ \dfrac{\left(M - V\right) - k_r + C_1}{\left(1 - I_a\right)\left(1 - R_b\right)} + C, & R_A \le R_b \le R_B \\ \dfrac{k_r\left[-R_b + \dfrac{1}{\left(1 - R_b\right)}\right]}{\left(1 - I_a\right)} + \dfrac{\left(M - V + C_2\right)}{\left(1 - I_a\right)\left(1 - R_b\right)} + C, & R_B \le R_b \le 1 \end{cases} \tag{24}$$

$$S = \begin{cases} S^H, S^H \le S\left(R_b\right) \\ S\left(R_b\right), S^L < S\left(R_b\right) < S^H \\ S^L, S\left(R_b\right) \le S^L \end{cases} \tag{25}$$

6. Owner's quality control and detention strategy of the quality guarantee deposit with the incomplete information condition

Under the condition of incomplete information, the contractor's credit level is partially observable to the owner. Assuming that the owner's monitoring level is the median level, the symmetry coefficient $\beta \in [0,1]$ is introduced, β represents the quality guarantee deposit that should be withheld when the information is symmetrical.

The expected benefit obtained by the owner under the condition of incomplete information is:

$$\begin{aligned} E_i\left(A\right) &= A_1\left[R_b + \left(1 - R_b\right)I_a\right] + A_2\left(1 - I_a\right)\left(1 - R_b\right) \\ &- \left[\beta S_1\left(R_b\right) + \left(1 - \beta\right)S_2\left(R_b\right)\right]\left(1 - I_a\right)\left(1 - R_b\right) - B_a\left(I_a\right) - V \end{aligned} \tag{26}$$

where $E_i(A)$ represents the owner's expected benefit under incomplete information; $S_1(R_b)$ represents quality guarantee deposit under symmetric information; $S_2(R_b)$ represents quality guarantee deposit under asymmetric information; β represents symmetry coefficient.

The expected benefit received by the contractor under the condition of incomplete information is:

$$\begin{aligned} E_i\left(B\right) &= V + \left[\beta S_1\left(R_b\right) + \left(1 - \beta\right)S_2\left(R_b\right)\right]\left(1 - I_a\right)\left(1 - R_b\right) \\ &+ B_r\left(R_b\right) - P\left(1 - R_b\right)I_a \end{aligned} \tag{27}$$

where $E_i(B)$ represents the contractor's expected benefit under incomplete information.

At this time, the contractor's participation constraints is:

$$\begin{aligned} E_i\left(B\right) &= V + \left[\beta S_1\left(R_b\right) + \left(1 - \beta\right)S_2\left(R_b\right)\right]\left(1 - I_a\right)\left(1 - R_b\right) \\ &+ B_r\left(R_b\right) - P\left(1 - R_b\right)I_a = M \end{aligned} \tag{28}$$

where M is a normal number, which can be obtained from Eq. (28):

$$\beta S_1\left(R_b\right) + \left(1 - \beta\right)S_2\left(R_b\right) = \frac{M - V - PR_bI_a + B_r\left(R_b\right) + PI_a}{\left(1 - I_a\right)\left(1 - R_b\right)} \tag{29}$$

Substitute Eq. (28) into Eq. (26), we have:

$$E_i(A) = A_1\left[R_b + (1-R_b)I_a\right] + A_2(1-I_a)(1-R_b) - M - B_r(R_b) - P(1-R_b)I_a - B_a(I_a) \tag{30}$$

Eq. (30) is the same as Eq. (10), and the owner's expected benefit in the project under symmetrical information and incomplete information is the same. At this time, the owner's quality monitoring decision meets Eq. (12).

Under the condition of incomplete information, the owner's monitoring level I_a^* is:

$$I_a^* = \begin{cases} \dfrac{k_a^2}{4(A_1 - A_2 - P)^2(1-R_b)^2}, 0 \le R_b \le R_A \\ I_a^H \qquad , R_A \le R_b \le R_B \\ \dfrac{(A_1 - A_2 - P)(1-R_b)}{2k_a}, R_B \le R_b \le 1 \end{cases} \tag{31}$$

The retention S of quality guarantee deposit under the condition of incomplete information is:

$$S(R_b) = \beta S_1(R_b) + (1-\beta)S_2(R_b) \tag{32}$$

Namely:

$$S(R_b) = \begin{cases} \beta\left[\dfrac{M - V + k_r\sqrt{R_b} + P(1-R_b)I_a}{(1-I_a)(1-R_b)}\right] \\ \quad + (1-\beta)\left\{k_r\left[(1-R_b)\ln\left(\dfrac{1-\sqrt{R_b}}{1+\sqrt{R_b}}\right) - 2\ln\left(\dfrac{2-\sqrt{R_b}}{2+\sqrt{R_b}}\right) + 2\sqrt{R_b}\right]\dfrac{1}{(1-I_a)} + \dfrac{(M-V)}{(1-R_b)(1-I_a)}\right\}, & 0 \le R_b \le R_A \\ \beta\left[\dfrac{M - V + k_r R_b + C_1 + P(1-R_b)I_a}{(1-I_a)(1-R_b)}\right] + (1-\beta)\left[\dfrac{(M-V) - k_r + C_1}{(1-I_a)(1-R_b)} + C\right], & R_A \le R_b \le R_B \\ \beta\left[\dfrac{M - V + k_r R_b^2 + C_2 + P(1-R_b)I_a}{(1-I_a)(1-R_b)}\right] + (1-\beta)\left\{k_r\left[-R_b + \dfrac{1}{(1-R_b)}\right]\dfrac{1}{(1-I_a)} + \dfrac{(M - V + C_2)}{(1-I_a)(1-R_b)} + C\right\}, & R_B \le R_b \le 1 \end{cases} \tag{33}$$

$$S = \begin{cases} S^H, S^H \le S(R_b) \\ S(R_b), S^L < S(R_b) < S^H \\ S^L, S(R_b) \le S^L \end{cases} \tag{34}$$

7. Simulation calculation

7.1. Simulation calculation under symmetric and asymmetric information conditions

Assuming that A_1 = 45,000, A_2 = 38,500, P = 6,000, M = 30,000, V = 31,500, k_a = 500, k_r = 500, C_1 = 100, C_2 = 200, $S \in$ [2%, 8%] = [630, 2,520], the contractor's credit level is controlled at $R_b \in$ [0.6, 0.9], and the owner's monitoring level is maintained at $I_a \in$ [0.2, 0.8],the results are as follows.

When the owner's monitoring cost function and the contractor's credit cost function are non-concave and non-convex functions, the owner's monitoring level is related to the contractor's credit level. Select different values of I_a, and the simulation results of the contractor's credit level and quality guarantee deposit retention strategy when I_a takes different monitoring levels are shown in Figs. 3 and 4.

The owner's and the contractor's expected benefit results are shown in Figs. 5–8.

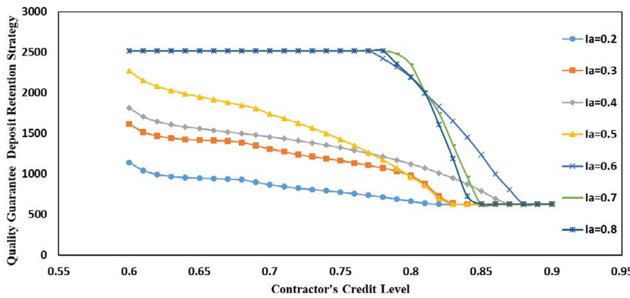

Fig. 3. Quality guarantee deposit withholding strategy under different monitoring levels under symmetric information.

7.2. Simulation calculation under the incomplete information conditions

Assuming that A_1 = 45,000, A_2 = 38,500, P = 6,000, M = 30,000, V = 31,500, k_a = 500, k_r = 500, C_1 = 100, C_2 = 200, $S \in$ [2%, 8%] = [630, 2,520], the owner's monitoring level is I_a = 0.5, and the contractor's credit level is maintained at $R_b \in$ [0.6, 0.9], the results are as follows.

When the owner's monitoring cost function and the contractor's credit cost function are non-concave and non-convex functions, the owner's monitoring level is related to

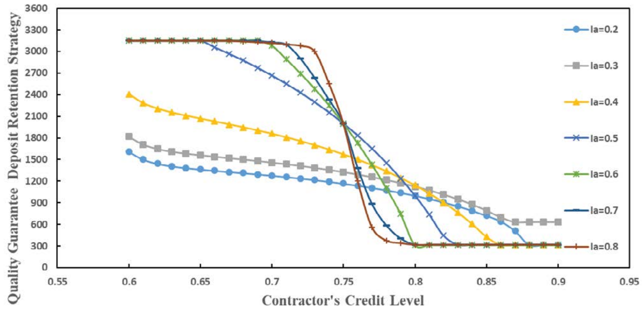

Fig. 4. Quality guarantee deposit withholding strategy under different monitoring levels under asymmetric information.

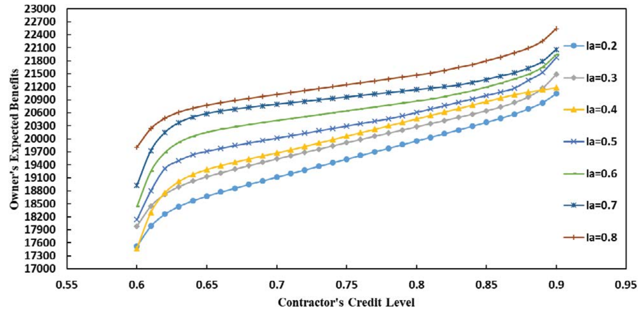

Fig. 5. Comparison of owners' expected benefits under different monitoring levels under the condition of symmetric information.

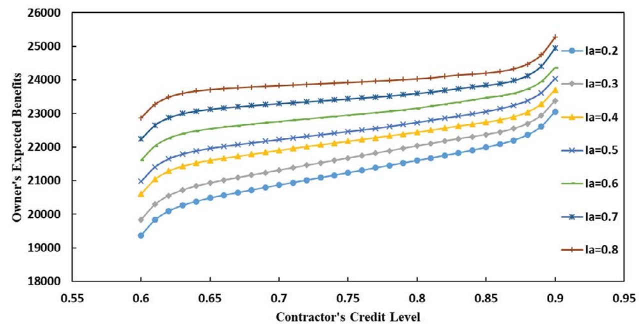

Fig. 6. Comparison of owners' expected benefits under different monitoring levels under the condition of asymmetric information.

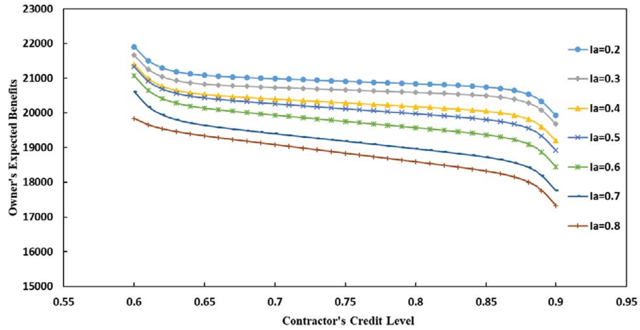

Fig. 7. Comparison of contractor's expected benefits under different monitoring levels under the condition of symmetric information.

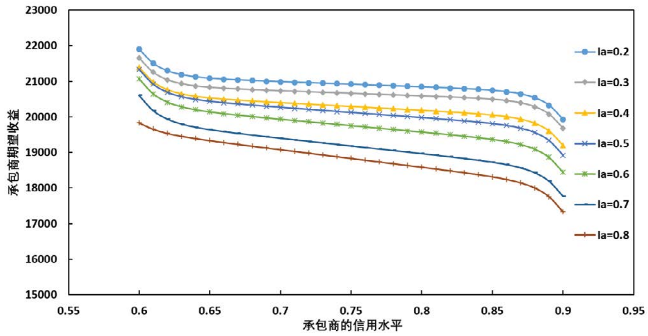

Fig. 8. Comparison of contractor's expected benefits under different monitoring levels under the condition of asymmetric information.

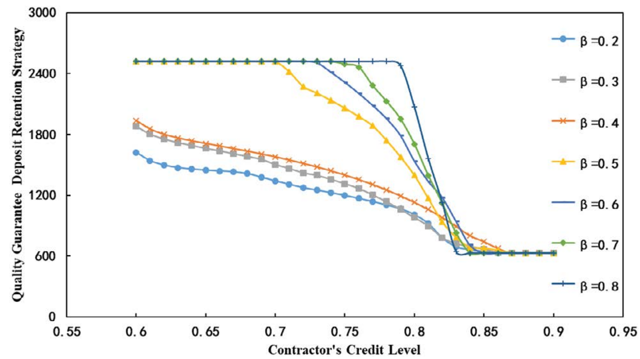

Fig. 9. Quality guarantee deposit withholding strategy under different symmetry coefficients under incomplete information.

the contractor's credit level. Because the owner can observe the credit level of some contractors, the simulation results of the contractor's credit level and quality guarantee deposit retention strategy when β takes different symmetry coefficients are shown in Fig. 9.

The owner's and the contractor's expected benefit results are shown in Figs. 10 and 11.

7.3. Results

- Under the condition of symmetric information and asymmetric information, for a certain monitoring level I_a of the owner, the retention of the owner's quality guarantee deposit decreases with the increase of the contractor's credit level R_b; For a certain credit level R_b of the contractor, the retention of the owner's quality assurance $S(R_b)$ fund increases with the increase of the owner's monitoring level I_a; However, under the condition of asymmetric information, for a certain monitoring level I_a of the owner, the quality deposit withheld is higher.
- Under the condition of incomplete information, for a certain monitoring level I_a of the owner, the retention of the owner's quality guarantee deposit decreases with the increase of the contractor's credit level R_b; For a certain credit level R_b of the contractor, the retention of

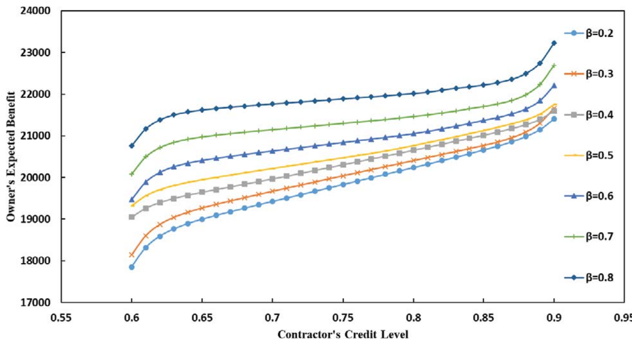

Fig. 10. Comparison of owners' expected benefit under different symmetry coefficients under the condition of incomplete information.

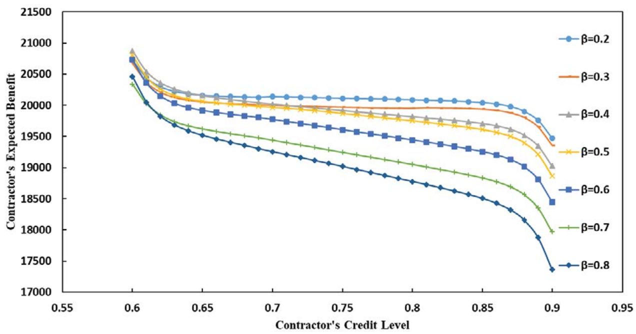

Fig. 11. Comparison of contractor's expected benefit under different symmetry coefficients under the condition of incomplete information.

the owner's quality assurance $S(R_b)$ will increase with the increase of the owner's monitoring level I_a. Under the same quality monitoring level I_a of incomplete information, the retention of quality deposit corresponding to the three cost functions is not concentrated in a small range of the contractor's credit level, and the change range of quality deposit is large.

- Under the same monitoring level of the owner with incomplete information, the contractor's credit level R_b increases and the retention amount of quality deposit decreases, but the contractor's expected income $E(B)$ does not increase, which shows that the expected income brought by the contractor's improvement of credit level is less than that brought by the owner's reduction of monitoring level, and the owner can increase its expected income through the contractor's improvement of credit level. In order to solve this contradiction, both sides can seek a balance point in the game, so that both sides can achieve the maximum expected return and achieve the purpose of win–win.
- Comparing the final expected income of both parties under the three information conditions, with the increase of the owner's quality monitoring level, the balance point of the contractor's credit level that both parties seek the maximum income decreases, indicating that the owner's strong supervision will reduce the requirements for the contractor's credit to a certain extent, so the owner should choose the appropriate quality monitoring level.
- When considering the factors of monitoring cost and credit cost of both parties under three different information conditions, the owner and the contractor's expected benefits have changed. The expected benefits of the three cost functions are very different for the owner and the contractor. Therefore, both parties should control their own monitoring cost and credit cost respectively to obtain greater expected benefits.

8. Conclusion

This paper studies the determination method of project quality guarantee deposit considering the contractor's credit level under different information conditions, improves the possible moral hazard of the contractor in the project supply chain by introducing the variable of the contractor's credit level, establishes the corresponding quality expected income model, and analyzes the examples under different information conditions and different credit levels of the contractor. The quality deposit withholding strategy and quality income of the owner and the contractor provide a basis for the owner to formulate an effective monitoring strategy.

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