Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 8313881, 7 pages
https://doi.org/10.1155/2022/8313881

Research Article

A Determining Method of the Project Quality Guarantee Deposit under the Condition of Asymmetric Information with the Contractor's Credit Level into Consideration

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Received 2 April 2022; Accepted 16 May 2022; Published 30 May 2022

Academic Editor: Wen-Tsao Pan

On the basis of analyzing the relationship between a contractor's credit, project quality assurance, owner's monitoring level, and the quality guarantee deposit, the quality expected benefit model of the owner and the contractor was constructed under the conditions of symmetric information and asymmetric information, in which the owner assumed the primary responsibility for the project quality, the project characteristics were incorporated, the credit level was taken as the contractor's decision variable, and the project quality monitoring level and detention of the quality guarantee deposit were taken as the owner's decision variables. In light of the maximum value principle, an optimal solution to the owner's quality monitoring decision and the quality deposit detention strategy was derived; through the simulation calculation, the decision-making results under different information conditions were analyzed.

1. Introduction

Project quality is one of the elementary objectives of a construction project. Under the market economy, a contractor, as the undertaker and the subject of liability of implementing the construction project, plays a fundamentally decisive role in the construction quality based on the quality assurance system under its credit level. As the guarantee mode of the project quality and a means of contract restraint of propelling contractors to improve their quality assurance credit levels, quality guarantee deposits have been widely adopted in the project contracting community over a long time. The amount of a quality guarantee deposit is usually determined in accordance with the relevant regulations or with reference to the experience in projects or market practices. This relatively onefold approach leads to an unreasonable quality guarantee deposit of varying degrees. Sometimes, the quality guarantee deposit for a contractor with a high credit level is high, which causes the contractor's capital efficiency loss and further increases the contract price at large if things continue this way; but sometimes, the quality guarantee deposit for a contractor with a low credit level is insufficient, which evidently increases the quality risk and the quality monitoring burden of the owner. There is still a lack of research on the mode to reasonably determine quality guarantee deposits [1].

Many scholars have begun to study the problem of quality control under asymmetric information [2–7]. The paper systematically studied the quality control in the supply chain of a water conservancy construction project [6, 7]. The owner and the contractor's quality benefit model in the supply chain was established, and an optimal solution to the owner's quality monitoring decision under the condition of asymmetric information was concluded. For the construction and implementation of the project, this paper helped the owner make an effective detention strategy for the quality guarantee deposit from the owner's standpoint with the impact of the contractor's credit level into consideration, which led to a more reasonable, more scientific, and more comprehensive detention of the quality guarantee deposit [8]. It was concluded that an optimal credit level would bring a win-win result for the owner and the contractor.

2. Expected Benefit of the Owner and the Contractor

This section is built on a two-level supply chain system of a construction project composed of an owner and a contractor who both had a neutral risk preference [8]. The owner was the dominant and the contractor was the follower, but they both pursued a maximized personal expected benefit. The owner was able to learn of the contractor's credit level based on which the detention proportion of project quality guarantee deposit and the monitoring level for the contractor were determined [9–12].

The expected benefit obtained by the owner in the construction project is

$$\begin{aligned} E(A) =& A_1[R_b + (1-R_b)I_a] + A_2(1-I_a)(1-R_b) \\ &- S(R_b)(1-I_a)(1-R_b) - B_a(I_a) - V. \end{aligned} \tag{1}$$

In the equation, $E(A)$ refers to the owner's expected benefit; A_1 refers to the benefit when there is a qualified project; A_2 refers to the benefit when there is an unqualified project; R_b refers to the contractor's credit level; I_a refers to the monitoring level of the owner for the contractor; $S(R_b)$ refers to the quality guarantee deposit; $B_a(I_a)$ refers to the owner's quality monitoring cost; and V refers to the total contract price paid by the owner to the contractor at the project settlement.

The expected benefit received by the contractor in the construction project is

$$E(B) = V + S(R_b)(1-I_a)(1-R_b) - B_r(R_b) - P(1-R_b)I_a. \tag{2}$$

In the equation, $E(B)$ refers to the contractor's expected benefit, B_r (R_b) refers to the contractor's credit level, and P refers to the cost of project reworking (or maintenance) when the owner finds quality problems by the contractor.

3. The Detention Strategy of the Quality Guarantee Deposit with Symmetric Information

With symmetric information, the owner is able to observe the contractor's credit level R_b by the credit rating system and results, so the owner's quality monitoring decision is an optimization problem [13–15]; i.e.,

$$\max E(A) = E(I_a). \tag{3}$$

At the same time, the contractor participation constraint is

$$\begin{aligned} E(B) =& V + S(R_b)(1-I_a)(1-R_b) \\ &- B_r(R_b) - P(1-R_b)I_a = M. \end{aligned} \tag{4}$$

In the equation, M is a normal number, and from (4),

$$S(R_b) = \frac{M - V - PR_bI_a + B_r(R_b) + PI_a}{(1-I_a)(1-R_b)}. \tag{5}$$

Substituting (5) into (3), we have

$$\begin{aligned} E(A) =& A_1[R_b + (1-R_b)I_a] + A_2(1-I_a)(1-R_b) \\ &- M - B_r(R_b) - P(1-R_b)I_a - B_a(I_a). \end{aligned} \tag{6}$$

The first-order partial derivative of the owner's quality monitoring level I_a is evaluated in (6) and made it 0.

$$B_a'(I_a) = (A_1 - A_2 - P)(1-R_b). \tag{7}$$

The owner's loss due to quality defects caused by the contractor is bigger than the contractor's reworking expenses, so (A1-A2-P) $(1 - \mathrm{Rb}) \geq 0$, and therefore, there is an extreme value in the above equation.

The owner's quality monitoring cost consists of two parts [16]: one is the direct monitoring cost of the owner C_1 and the other is the indirect monitoring cost. The indirect cost coefficient is k_a, so we can assume that the owner's control cost is as follows [17]: $B_a * (I_a) = k_a * I_a{}^2 + C_1{}^*$. The contractor's credit cost consists of two parts: one is the direct cost of safeguarding credit C_2 and the other is the indirect cost. The indirect cost coefficient is k_r, so we can assume that contractor's credit cost is $B_r * (R_b) = k_r * R_b{}^2 + C_2{}^*$. The second-order partial derivative in (3) with respect to I_a is $d^2E(A)/dI_a^2 = -B_a''(I_a) < 0$, so there is a maximum value for (3); at the same time, the owner's quality monitoring decision is $I_a I_a^*$ in (7).

After putting equation (7) and the owner's monitoring cost together, $I_a{}^*$ is obtained:

$$I_a^* = \frac{(A_1 - A_2 - P)(1-R_b)}{2k_a}. \tag{8}$$

The detention strategy of the quality guarantee deposit is

$$S(R_b) = \frac{M - V + B_r(R_b) + P(1-R_b)I_a^*}{(1-I_a^*)(1-R_b)}. \tag{9}$$

The detention of quality guarantee deposit S^{**} with symmetric information is

$$S^{**}(R_b) = \frac{M - V - PR_bI_a^* + PI_a^* + k_rR_b^2 + C_2}{(1-I_a^*)(1-R_b)},$$

$$S^{**} = \begin{cases} S^H, S^H \leq S(R_b), \\ S^{**}(R_b), S^L < S(R_b) < S^H, \\ S^L, S(R_b) \leq S^L. \end{cases} \tag{10}$$

4. The Owner's Quality Control and Detention Strategy of the Quality Guarantee Deposit with Asymmetric Information

Asymmetric information can be defined as information available about a risk category that cannot be observed by both parties to the transaction at the same time and for which neither party has complete information about the other. Asymmetric information as opposed to symmetric information means that under the condition of a given total amount of information that can be produced by the market economy, in the total amount of information market players do not have access to any information, do not have timely access to information, and have no knowledge of the accuracy of information [18, 19].

With asymmetric information, the contractor's credit level is completely unobservable to the owner, and the problem between the owner and the contractor is still an optimization problem [20–22]. The owner maximizes its own expected benefit by selecting its corresponding monitoring level I_a^{**} [6], namely,

$$\max_{I_a(R_b)} \int_{R_b^L}^{R_b^H} E(A) f(R_b) dR_b. \tag{11}$$

Suppose 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, the owner, as the leader of the game, has the advantage of being one step ahead, but when it is pursuing its own expected benefit maximization, given that the contractor is the follower, the owner will be subject to corresponding constraints from the contractor [23–26], namely,

$$\begin{aligned} R_b \in \operatorname{argmax} V &+ S(R_b)(1-I_a)(1-R_b) \\ &- B_r(R_b) - P(1-R_b)I_a - M. \end{aligned} \tag{12}$$

The first-order partial derivative of the equation is evaluated with respect to R_b:

$$\frac{dS(R_b)}{dR_b} = \frac{B_r(R_b)(1-R_b) + B_r'(R_b) - V + M}{(1-I_a)(1-R_b)^2}. \tag{13}$$

R_b is used as the control variable, the classical control problem is solved by the maximum principle, and the Hamiltonian function of the problem is established, namely,

$$H = E(A) f(R_b) + \lambda \left[\frac{B_r(R_b)(1-R_b) + B_r'(R_b) + M - V}{(1-I_a)(1-R_b)^2} \right]. \tag{14}$$

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

$$\begin{aligned} \frac{\partial H}{\partial I_a} =& [(A_1 - A_2 - P)(1-R_b) - B_a'(I_a)] f(R_b) \\ &+ \lambda \left[\frac{B_r(R_b)(1-R_b) + B_r'(R_b) + M - V}{(1-I_a)(1-R_b)^2} \right]. \end{aligned} \tag{15}$$

The mimicry equation is

$$\frac{d\lambda}{dR_b} = -\frac{\partial H}{\partial S} = (1-I_a)(1-R_b) f(R_b). \tag{16}$$

From the above equation, we have

$$\lambda = (1-I_a)\left[F(R_b) - R_b F(R_b) + \int F(R_b) + C \right], \tag{17}$$

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

Since $\partial^2 H/\partial^2 I_a = -B_a''(I_a) f(R_b) < 0$, the second-order partial derivative is less than zero, so there is a maximum value on the optimal control issue. According to the equation (13) and the contractor's control cost,

$$\begin{aligned} I_a^* =& \frac{(A_1 - A_2 - P)(1-R_b)}{2k_a} + \frac{\lambda}{2k_a f(R_b)} \\ & \left[\frac{B_r(R_b)(1-R_b) + B_r'(R_b) + M - V}{(1-I_a)(1-R_b)^2} \right]. \end{aligned} \tag{18}$$

Detention strategy for quality guarantee deposit can be obtained as

$$S(R_b) = \frac{1}{(1-I_a)} \int \frac{B_r'(R_b)}{(1-R_b)} + \frac{B_r(R_b) + (M-V)}{(1-R_b)^2} d(R_b) + n. \tag{19}$$

Detention S^{**} of quality guarantee deposit with asymmetric information is

$$\begin{aligned} S^{**}(R_b) &= \frac{k_a \left[\ln(1-R_b) + 1/(1-R_b)^2 \right]}{(1-I_a)} \\ &\quad + \frac{(M-V)}{(1-I_a)(1-R_b)} + C, \\ S^{**} &= \begin{cases} S^H, S^H \le S(R_b), \\ S(R_b), S^L < S(R_b) < S^H, \\ S^L, S(R_b) \le S^L. \end{cases} \end{aligned} \tag{20}$$

5. Simulation Calculation

5.1. Simulation Calculation. Assume that $A_1 = 45000$, $A_2 = 38500$, $P = 6000$, $M = 30000$, $V = 31500$, ka = 500, kr = 500, $C_1 = 100$, $C_2 = 200$, and $S \in [2\%, 8\%] = [630, 2520]$, the contractor's credit level is controlled at $R_b \in [0.6, 0.9]$, the owner's monitoring level is maintained at $I_a \in [0.2, 0.8]$, and the results are as follows.

When the owner's monitoring cost function and the contractor's credit cost function are quadratic functions, the owner's monitoring level is related to the contractor's credit level. Different values of I_a are selected, and the square matrix results of the contractor's credit level and the

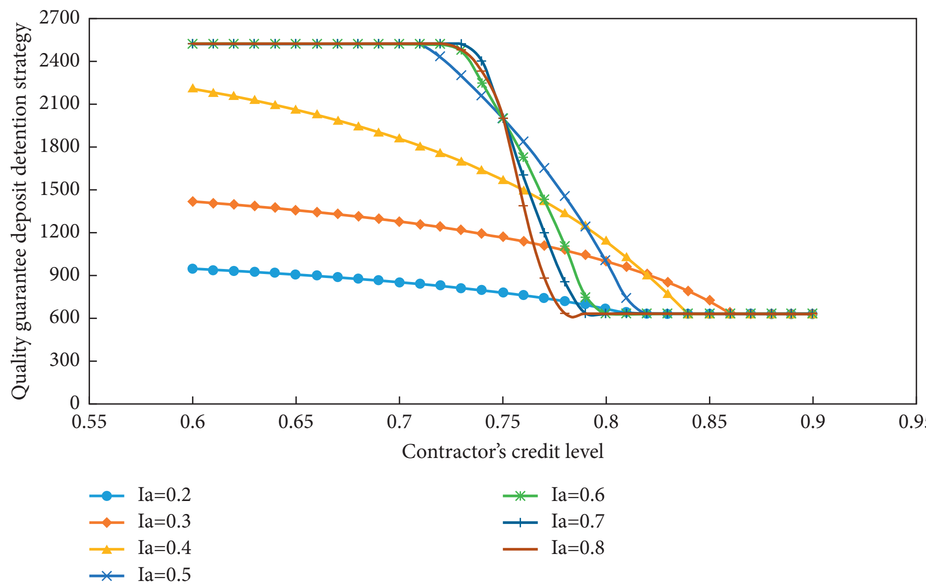

Figure 1: The detention of quality guarantee deposit at different monitoring levels under the condition of symmetric information.

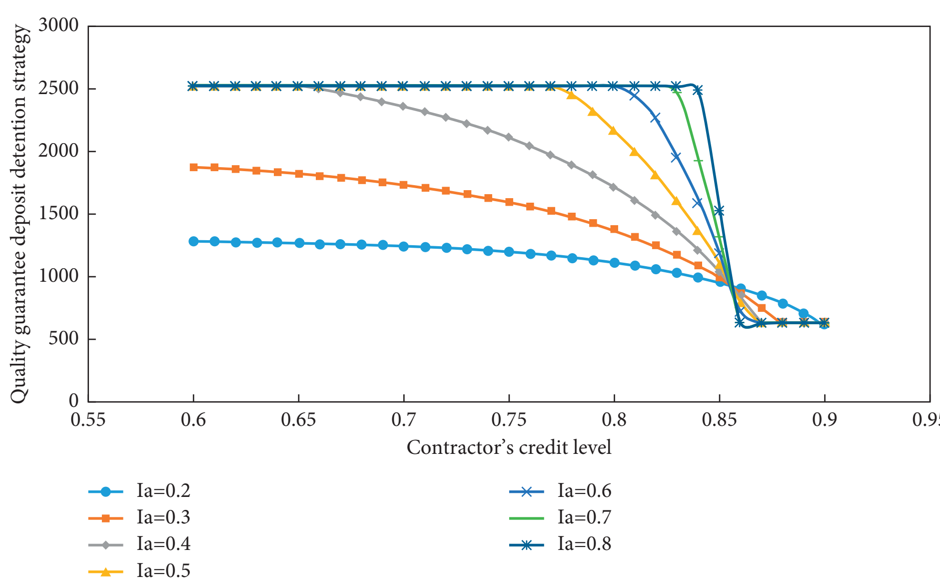

Figure 2: The detention of quality guarantee deposit at different monitoring levels under the condition of asymmetric information.

detention strategy of quality guarantee deposit under different information conditions when I_a takes different monitoring levels are shown in Figures 1–6.

5.2. Results

(1) Under the conditions of symmetric information and asymmetric information, for the owner's certain monitoring level I_a, detention of the owner's quality guarantee deposit decreased with the increase of the contractor's credit level R_b; for the contractor's certain credit level R_b, detention of the owner's quality guarantee deposit increased with the increase of the contractor's credit level $S(R_b)$; but under the condition of asymmetric information, for the owner's same monitoring level I_a, detention of the quality guarantee deposit was relatively high.

(2) At the same monitoring level with asymmetric information, for the contractor's certain credit level R_b, the owner's expected benefit E(A) and the contractor's expected benefit E(B) were both smaller than those under the condition of symmetric information. With asymmetric information, the owner's expected benefit E(A) increased with the increase of the contractor's credit level Rb; the contractor's expected benefit E(B) decreased with the increase of the contractor's credit level R_b. For the contractor's certain credit level R_b, the owner's expected benefit E(A) increased with the increase of the owner's monitoring level I_a, and the contractor's

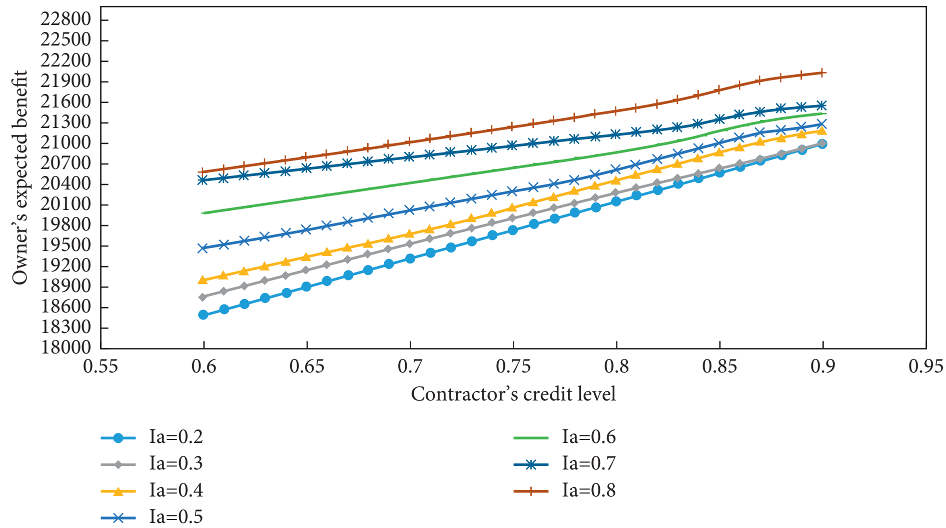

FIGURE 3: Comparison of the owner's expected benefit at different monitoring levels under the condition of symmetric information.

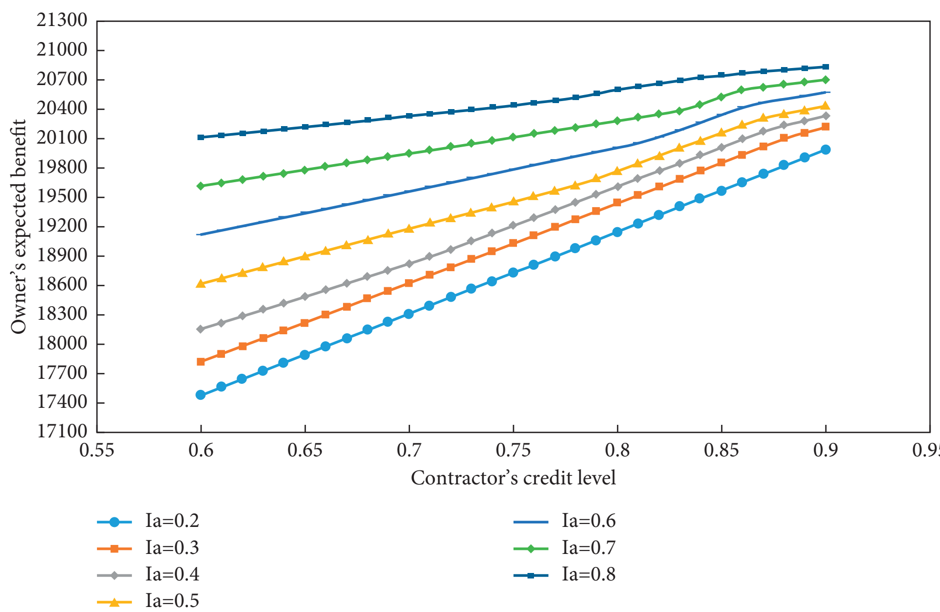

FIGURE 4: Comparison of the owner's expected benefit at different monitoring levels under the condition of asymmetric information.

expected benefit E(B) decreased with the increase of the owner's monitoring level I_a.

(3) Under the condition of asymmetric information, the information of both parties was unobservable, and the contractor's detained quality guarantee deposit was relatively small when the owner's monitoring level was at a low level. With the improvement of the contractor's credit level, the amount of the detained quality guarantee deposit had a continuous decline until it reached a minimum amount. Therefore, the amount of the detained quality guarantee deposit under the condition of asymmetric information was higher than that of symmetric information, indicating that the owner should keep a relatively high monitoring level to ensure the project quality.

(4) The balance point between the owner's expected benefit and the contractor's expected benefit corresponded to the fact that the contractor's credit level R_b decreased with the increase of the owner's monitoring level I_a. With the increase of the contractor's credit level, the owner's expected benefit increased, while the contractor's expected benefit decreased; at the same time, at different quality monitoring levels from the owner, the contractor's credit levels at which both sides reached the desired benefit equilibrium point were also different.

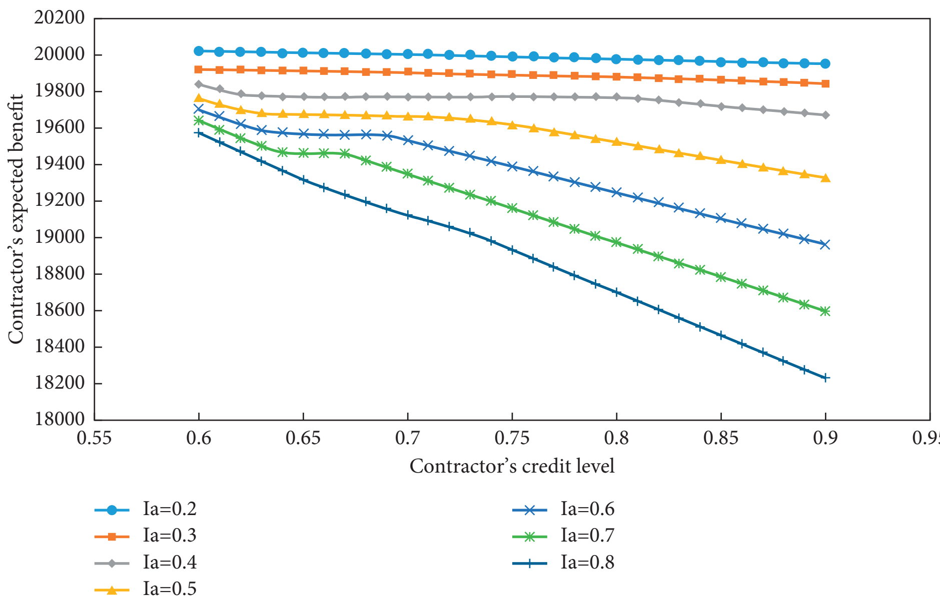

Figure 5: Comparison of the contractor's expected benefit at different monitoring levels under the condition of symmetric information.

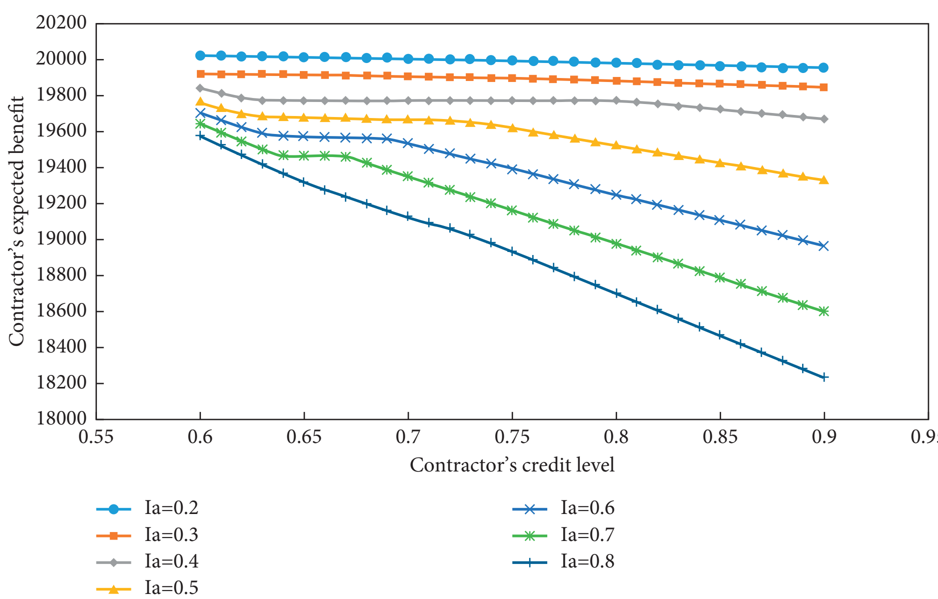

Figure 6: Comparison of the contractor's expected benefit at different monitoring levels under the condition of asymmetric information.

Therefore, both the owner and the contractor should have an appropriate monitoring level and a proper credit level so that both sides can realize their own maximum expected benefit.

6. Conclusion

This paper studied the determination method of the quality guarantee deposit of construction under different information conditions with the contractor's credit level taken into account. By introducing the variable of the contractor's credit level, potential moral hazards for a contractor in a construction supply chain was improved, and the corresponding quality benefit model was established. With living cases, the owner's and the contractor's quality guarantee deposit detention strategies and quality benefits under different information conditions and at different credit levels of the contractor were analyzed, providing owners with the basis to make effective monitoring strategies. From the perspective of the final expected benefits of both parties, as the owner's quality monitoring level increases, the smaller the equilibrium point of the contractor's credit level where both parties seek maximum benefits, which indicates that the owner's strong supervision will reduce the requirement of the contractor's credit to a certain extent, so the owner should choose the appropriate quality monitoring level.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors are grateful to the support of the National Natural Science Foundation of China (Nos. 51979116 and 51979109).

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