Game analysis on moral hazard of construction project managers in China

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Abstract

This paper aims to develop a quantitative game model for preventing construction project managers from moral hazard problem from the standpoint of construction enterprises in China. The authors analyze the sources of construction managers' moral hazard behaviors under China's specific situations on the basis of the principal-agent theory, establish a game theoretic model to analyze the moral hazard problem between construction enterprises and construction project managers, and calculate the equilibrium solution through building up the payoff matrix. The quantitative characterization of risk deposit system and performance appraisal system, which help to alleviate the moral hazard problem of construction project managers, are crucial contribution of this paper. The solutions results show that the probability of moral hazard problem of construction project managers can be reduced after implementing risk deposit system and performance appraisal system, which prove that the two systems could be taken as the effective measures by construction enterprises to address moral hazard problem of construction project managers.

Keywords: Building operations, Construction project manager, Moral hazard, Game model.

1. Introduction

Construction project managers play the key role in construction project, they work with project sponsors, lead the project team members and other involved people to work for realizing the goals and objectives of construction enterprises [1]. As a manager, he/she is responsible in initiating, planning, executing, monitoring and controlling of a project until it is finished properly [2]. Therefore, the actions of construction project managers are so important for project success that construction enterprises have to spend much time and energy supervising. A construction enterprise usually signs a contract with a construction project manager in order to ensure him/her get the expected results by constraining his/her behaviors before the implementation of project. Once after the contract is signed, a principal-agent relationship is set up, the construction enterprise is a principal while the construction project manager is an agent. Even though principals heavily rely on such managements strategies to elicit desired performance from their agents, there are situations where work contracts cannot fully control construction project managers' behavior, and thereby can give rise to

undesirable behavioral responses (from construction enterprises' standpoint). This unwanted behavior by construction project managers is well-known as the moral hazard problem (*hidden action*) in the economics and management literatures [3, 4, 5, 6].

In recent decades, Chinese scholars have done extensive researches on moral hazard problem in construction industry. Zhu [7] and Li [8] discuss the reasons of moral hazard problem of construction project managers (agents) and provide several precautions from the qualitative perspective. Yan [9], Gao et al [10], Chen et al [11], Zhu et al [12], Liu et al [13] and Qian [14] make a further study to explain the reasons of moral hazard problem of construction project managers by establishing a quantifiable model, and simultaneously proposed some suggestions to prevent agents from moral hazard problem. However, the studies mentioned above only present certain measures to resolve moral hazard problem without proving further the feasibility of the approaches by quantitative method. The basic summary of previous studies on moral hazard problem of managers is illustrated in Table 1.

To analyze moral hazard problem of construction project managers, a game theoretic model between construction enterprises and construction project managers is established by applying game and principal-agent theory. In this model, the classical assumption that construction enterprises are risk-neutral and construction project managers are risk-adverse is used as the theoretical basis [26]. Moreover, all the behaviors of construction enterprises and construction project managers are quantified so that the game equilibrium solution can be calculated in the payoff matrix. Finally, the optimal

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probability α^*, β^* can be obtained and their value range with the change of supervision success probability p can be also determined.

Table 1 The basic summary of previous studies on moral hazard problem of managers

Typical Scholars	Year	Main contribution
Qiang Zhu[7] Dahong Zhang[15] Baiji Li et al[8]	2003 2003 2008	Discussed the reasons of moral hazard problem of managers (agents), including asymmetric information, environmental uncertainty and the incompleteness of the contracts; provided several precautions from the qualitative perspective.
Wei Yan [9] Yang Gao et al[10] Tong Cheng et al[11] Bing Zhu et al[12] Ziwei Liu et al[13] Liangqun Qian[14]	1999 2001 2002 2005 2007 2009	Analyzed the reasons of moral hazard problem of managers by establishing a quantifiable model, and proposed some suggestions to prevent agents from moral hazard problem.
Heping Tang[16] Sunil Dutta[17] Antonio E. Bernardo et al[18]	2000 2003 2004	Proposed to use the optimal capital allocation, managerial compensation and bonus contract to give the managers incentives to control their moral hazard.
Guohua Zheng[19] Xiaofeng Zhang et al[20] Baomin Dong et al[21]	2002 2004 2013	Proposed to take stock options in the incentive contract to alleviate moral hazard problem of managers.
Lejiang Hu et al[22] Timothy M. Rose et al[23]	2009 2009	Provided the methods to determine the optimal compensation, potential level and optimal effort level of managers in order to promote the effectiveness of financial incentives.
Qinghua Zhang et al[24] Cong Xu[25]	2009 2012	Analyzed the incentive mechanism for project managers and its shortcomings and gave some suggestions to address the moral hazard problem from the point of project governance.

The purpose of this study is to examine some solutions to the moral hazard problem of construction project managers. In particular, two solutions including risk deposit system and performance appraisal system that can decrease moral hazard behaviors probability of construction project managers. With introducing these two solutions, there is a change of the game equilibrium solution and the results show that the construction project managers' moral hazard behaviors probability α^* becomes smaller, which indicates that it is effective to prevent construction project managers from moral hazard problem by introducing risk deposit system and performance appraisal system.

The rest of the paper is organized as follows. Section 2 presents related knowledge about the responsibilities and sources of moral hazard behaviors of construction project managers. Section 3 considers the basic model of game theory and presents our main assumptions. Section 4 introduces two solutions to resolve the moral hazard problem of construction project managers and analyzes their feasibilities. Section 5 concludes.

2. Related Knowledge

2.1. The responsibilities of construction project managers

The construction project management team works under construction project managers' leadership, construction project managers play a very important role on the operation of the project. The engineering practice has proved that a competent project manager who leads a

weak project management team is more likely to succeed in the project than a weak project manager who leads a strong project management team [27]. The main duties of the project managers are providing specialized services as agents of the construction enterprises by virtue of their own qualities, knowledge and abilities. Their main duties can be specifically summarized as follows [28, 29]:

(1) Establishing and maintaining an effective organizational structure and communication channels.

(2) Analyzing the project performance according to requirements of the project' time, cost and quality, detecting variances from the schedule/requirements, and dealing with their effects considering time and resource constraints.

(3) Optimizing resource allocation and utilization, organizing regular construction production meeting and solving the construction problems.

(4) Identifying or gathering information on defects, deficiencies, ambiguities, and conflicts in drawings and specifications and having them resolved.

(5) Monitoring the budget on all activities and taking corrective action and controlling project finances.

(6) Coordinating the relationship among all the parties and creating a good environment and construction conditions.

(7) Accumulating practical experiences and exercising the project management team to improve the level of enterprises' project management.

2.2. Manifestation of construction project managers' moral hazard behaviors

In various literatures, it is clear that moral hazard is defined as a negative concept that the agent pursues to maximize his/her own benefits and at the same time may infringe upon the interests of the principal or other agents in economic activities. The moral hazard behaviors of construction project managers generally include the following situations:

(1) Deliberately concealing the actual situation or providing less or false evidence and information to the construction enterprise, making a severe information asymmetry to defraud construction enterprise to give them higher returns.

(2) Cutting corners to control costs or accepting rebates from material suppliers, buying inferior quality-high price raw materials, and making conspiracy with supervisors to prevent project from strict inspection or even evade the inspection.

(3) Shirking and providing less than the agreed-upon level of effort in construction process, not strictly implementing the quality and safety programs so that lead to poor quality and frequent accidents.

(4) Trusting to luck and not take corresponding measures to prevent accidents and force majeure events, and finally resulted in significant losses on project.

2.3. The causes of moral hazard of construction project managers

Moral hazard is a hotly debated issue in related management and economics literatures. The causes of moral hazard of construction project manager can be mainly analyzed from two aspects:

2.3.1. Internal causes

The inherent root of moral hazard of construction project managers is profit-driven nature of human beings. According to the "rational economic man" hypothesis of modern economics, it is assumed that both the principal and the agent are rational decision makers who seek to maximize their own individual utility [30]. If the utility functions of these two self-serving parties coincide, no agency problem occurs. The agent (the construction project manager) is expected to reach decisions which maximize the principal's (the construction enterprise) utility because such decisions will also maximize the agent's utility. When the agent's interests diverge from those of the principal, however, the incentive element of an agency problem exists. That is, the agent is motivated to pursue his/her own interests at the expense of the principal. When this motivational problem exists, the agent is said to have an incentive to shirk [31].

Fluke mind is another important internal cause that induce moral hazard problem of construction project managers. All people hope that they can succeed and get interests through accidental factors, or hope that accident not happen to avoid evil, punishment and loss. So the construction project managers are likely to take chances and muddle through to implement illegal behaviors, use unsafe scheme or carry out non-standard operation. Which

result in all kinds of project risk accidents, the loss of construction enterprises and even project failure.

2.3.2. External causes

Firstly, information is one important element of the agency problem. Under the principal-agent model, when the agent has private information not available to the principal (the asymmetric information case), the agent has greater potential to gain their own benefits, and hence a larger incentive to engage in self-interested actions at the principal's expense [32, 33]. That is, asymmetric information arises when the relevant information is only available to the agent and not shared with the principal. If this happens, it becomes difficult for the principal to monitor the agent's actions because of the lack of information. Asymmetric information, therefore, provides an opportunity for the agent to advance his/her self-interest without being detected by the principal. In a construction project, the construction project manager can grasp more information as an agent, he/she always knows more about the actual situation of the project than the construction enterprise. On the contrary, the construction enterprise acquires so less information that it is difficult for it to observe directly the level of effort of the construction project manager, only the results of the construction project manager's work can be observed. Therefore, the construction project manager may pursue his/her income as much as possible and simultaneously damage the interests of the principal when his/her behaviors cannot or be difficult to be observed by the principal. In addition, some external random factors being uncontrolled by people (such as weather, natural environment) can also affect the results of the construction project manager's work so that he/she may just send advantageous information to construction enterprise in order to reap high rewards and maximize his/her own utility. A new loss may be occurred if the construction enterprise cannot judge or verify the real level of effort of the construction project manager. Thus asymmetric information is the main external cause of moral hazard.

Secondly, the incomplete ownership is another external cause which can induce moral hazard problem of construction project managers because of institutional defects. It is the foundation of public morality construction to solve complicated social interests conflicts effectively by thorough institutional arrangement. However, because the absence of the owner of construction project interests caused by institutional defects during the socio-economic transition period in China, the real risk carrier (owners) does not have enough rights to know the facts, it is difficult for them to impose a substantial impact. In addition, the construction project manager is the phantom project risk carrier. It is not possible to avoid moral hazard if the construction project manager found that he/she can obtain over-interests by implementing non-ethical behavior without being punished. Finally, it is inevitable to stimulate construction project managers to take unethical behavior if there are no clear division in rights, obligations and risk sharing in the contract between construction

project managers and construction enterprises as well as the sub-contract between the general contractors and the subcontractors.

Thirdly, insufficient supervision and poor punishment are also external causes which can raise moral hazard problem of construction project managers. In modern society, inevitably mandatory power is relied on to guarantee people self moral discipline. Chairman Deng Xiaoping said, "There is a good system, bad guys can't do bad things, while there is no good system, good people do bad things." Here system refers to the rules and law which are upgraded from the certain social ethical principles and requirements. The objective conditions which can induce moral hazard behaviors come into being if the legal system on supervision and punishment is not perfect, and the insufficient supervision and poor punishment in the entire project process, which stimulate construction project managers to use information asymmetry and inappropriate rights to seek excess interests, encourage construction project managers to take chances, reduce construction project managers' psychological anticipated cost, and increase the probability of construction project managers' moral hazard behaviors.

3. The Model

As mentioned above, because of people's profit-driven nature and information asymmetry, it is possible for occurrence of construction project managers' moral hazard problem in the principal-agent relation between construction enterprises and construction project managers, avoiding moral hazard problem solving the incentive problem, i.e., how to motivate the agent to work hard. In the principal-agent relationship, people's risk attitude plays an important role in the contractual arrangement. People who hold different risk attitude are apt to take a different behavior, so the optimal incentives are also different. According to different attitudes to risk, the principal and the agent can be divided into three categories: risk-averse, risk-neutral and risk-appetite [34]. In this paper, the common assumptions that "the principal is risk-neutral, and the agent is risk-averse" is adopted to make quantitative analysis of moral hazard problem of construction project managers by establishing a game theoretic model in order to come up with effective countermeasures.

In view of the main manifestation of moral hazard problem of construction project managers is not working hard, we use the degree of effort of construction project managers to show whether their moral hazard problem occurs or not. Suppose construction project managers have two kinds of action selections H and L, a=H means the project managers take a high level of effort and moral hazard problem does not occur, a=L means the project managers take a lower level of effort and moral hazard problem occurs. Meanwhile, construction enterprises as the principal also have two kinds of choices, i.e., to

supervise or not. Construction enterprises' supervision is not likely to get the desired results due to regulatory defects or other objective factors, so assume p is the probability of construction enterprises' supervision success. and W is the salary which construction enterprises pay for construction project managers, when a = L, it means construction project managers raise moral hazard problem, if construction enterprises have unsuccessfully or not supervised construction project managers, construction enterprises will have a loss D and construction project managers get additional income R. According to practical experience, assume D≥R. The cost of supervision (C) need to be expended when construction enterprises supervise the behaviors of construction project managers, If construction enterprises supervise successfully, construction project managers will be punished by construction enterprises because of their moral hazard behavior, the fine is F. In this case, construction project managers not only cannot get additional revenue, but also pay a fine.

Based on the above analysis, a game theoretic model is established between construction enterprises and construction project managers.

(1) Construction project managers' moral hazard problem occurs and construction enterprises supervise successfully, construction project managers not only cannot get an extra income R, but also need to pay a fine F, so construction project managers' income is W-F and construction enterprises' income is F-C; if construction enterprises supervise unsuccessfully, construction project managers' income is W+R and construction enterprises' income is -C-D.

(2) Construction project managers' moral hazard problem occurs and construction enterprises do not supervise, construction project managers' income is W+R and construction enterprises' income is -D.

(3) Construction project managers' moral hazard problem does not occur, they work with high level of effort and construction enterprises choose supervision, construction project managers' income is W and construction enterprises' income is -C.

(4) Construction project managers' moral hazard problem does not occur, they work with high level of effort and construction enterprises do not choose supervision, construction project managers' income is W and construction enterprises' income is 0.

Assume the probability of construction project managers' moral hazard problem to occur is α, so the probability of construction project managers' moral hazard problem not to occur is $(1-\alpha)$; and assume the probability of construction enterprises to supervise is β, the probability of no supervision is $(1-\beta)$. Then the payoff matrix of the game theoretic model between construction enterprises and construction project managers can be obtained as is shown in Table 2 [35].

Table 2 The payoff matrix of the game theoretic model between construction enterprises and construction project managers

Enterprises' income / Project Managers' income	Supervision(β)		No supervision $(1-\beta)$
	Success(p)	Unsuccess$(1-p)$	
Moral hazard(α)	$(W-F, F-C)$	$(W+R, -C-D)$	$(W+R, -D)$
No moral hazard$(1-\alpha)$	$(W, -C)$	$(W, -C)$	$(W, 0)$

Calculate the game equilibrium solution between construction enterprises and construction project managers, we can get:

A. The income of construction enterprises

The income of construction enterprises with supervision:

$$\pi_{C1} = \alpha[P(F-C)+(1-p)(-C-D)]+(1-\alpha)(-C)$$
$$= \alpha(PF - D + PD) - C$$

The income of construction enterprises with no supervision:

$$\pi_{C2} = \alpha(-D)+(1-\alpha)0 = -\alpha D$$

B. The income of construction project managers

The income of construction project managers with moral hazard behaviors:

$$\pi_{M1} = \beta[p(W-F)+(1-p)(W+R)]$$
$$+(1-\beta)(W+R) = \beta(-pF-pR)+W+R$$

The income of construction project managers with high level of effort:

$$\pi_{M2} = \beta[pW+(1-p)W]+(1-\beta)W = W$$

And then, calculate the expected income of construction enterprises and construction project managers.

A. The expected income of construction enterprises:

$$E(\pi_C) = \beta\pi_{C1}+(1-\beta)\pi_{C2}$$
$$= \alpha\beta(pF-D+pD)-\beta C+(1-\beta)(-\alpha D)$$
$$= \alpha\beta pF + \alpha\beta pD - \beta C - \alpha D$$
$$\Rightarrow \frac{\partial E(\pi_C)}{\partial\beta} = \alpha pF + \alpha pD - C = 0$$
$$\Rightarrow \alpha^* = \frac{C}{p(F+D)}$$

B. The expected income of construction project managers:

$$E(\pi_M) = \alpha\beta(-pF-pR)+\alpha W+\alpha R+(1-\alpha)W$$
$$= -\alpha\beta pF - \alpha\beta pR + \alpha R + W$$
$$\Rightarrow \frac{\partial E(\pi_M)}{\partial\alpha} = -\beta pF - \beta pR + R = 0$$
$$\Rightarrow \beta^* = \frac{R}{p(F+R)}$$

From the above results we can see that $\alpha^* = \frac{C}{p(F+D)}$ is the optimal probability for construction project managers to choose moral hazard behaviors. That is, when $\alpha > \alpha^*$, construction project managers' moral hazard problem will occur, the optimal strategy for construction enterprises is to supervise; when $\alpha < \alpha^*$, construction project managers' moral hazard problem will not occur, the optimal strategy for construction enterprises is not to supervise. Meanwhile, $\beta^* = \frac{R}{p(F+R)}$ is the optimal probability for construction enterprises to choose to supervise the moral hazard behaviors of construction project managers. When $\beta > \beta^*$, construction enterprises will choose to supervise, the optimal strategy for construction project managers is to work hard without moral hazard behaviors; when $\beta < \beta^*$, construction enterprises will not supervise, the optimal strategy for construction project managers is to raise moral hazard problem.

So under the equilibrium condition, the expected revenue of construction enterprises and construction project managers is respectively:

$$E(\pi_C^*) = \alpha^*\beta^* pF + \alpha^*\beta^* pD - \beta^* C - \alpha^* D = \frac{-CD}{p(F+D)}$$
$$E(\pi_M^*) = -\alpha^*\beta^* pF - \alpha^*\beta^* pR + \alpha^* R + W = W$$

From the equilibrium solution we can get whether construction enterprises supervise the moral hazard problem of construction project managers or not relates to the probability of supervision success. When p approaches to 1, the lowest probability of construction project managers' moral hazard problem to occur is $\frac{C}{F+D}$, and the lowest probability of construction enterprises to supervise is $\frac{R}{F+R}$. Taking into account the status of insufficient supervision and less corresponding supervision cost in many Chinese construction enterprises, we assume the extra revenue R which construction project managers can obtain is greater than the supervision costs C of construction enterprises, along with $D \geq R$ mentioned above, we can get $\frac{R}{F+R} > \frac{C}{F+D}$. And $\alpha \in [0, 1]$, $\beta \in [0, 1]$, the value ranges of p can be obtained by analyzing the game equilibrium.

$$\begin{cases} \alpha^* = \frac{C}{p(F+D)}, \quad \beta^* = \frac{R}{p(F+R)} & \left(\frac{R}{F+R} \leq p \leq 1\right) \\ \alpha^* = 1, \quad \beta^* = 1 & \left(\frac{C}{F+D} \leq p < \frac{R}{F+R}\right) \\ \alpha^* = 1, \quad \beta^* = 0 & \left(0 \leq p < \frac{C}{F+D}\right) \end{cases}$$

From the above formulas we can obtain the result, that is, when $p < \frac{R}{F+R}$, it is inevitable for construction project managers to raise moral hazard problem; when $p < \frac{C}{F+D}$, construction enterprises will give up supervision due to the small probability of supervision success.

4. Solutions

Pim [36] suggested that standardization improves productivity. It is true that the opportunist behavior of moral hazard can be prevented due to an incentive system of payment, or an implementation of a system of control and penalties [37]. Based on this understanding, risk deposit system and performance appraisal system could be the feasible solutions. China government has started to introduce the corresponding measures including the two systems, but up to now, few construction enterprises have adopted them. The construction enterprises pay less attention to the two systems is because of the failure in awareness of the long-term economic benefits brought by the two systems from the theoretical high level. Hence in this paper, risk deposit system and performance appraisal system are quantitatively analyzed to enable construction enterprises to intuitively understand why and how the two systems can help to alleviate the moral hazard problem of construction project managers, and go deeper to improve the managerial system of construction enterprises.

4.1. Risk deposit system

Based on the above analysis, construction project managers are very possible to raise moral hazard problem because of the profit-driven nature of people, information asymmetry and incomplete contract between construction enterprises and construction project managers. Thus, it is necessary to implement risk deposit system to prevent moral hazard. Once the contract is signed, construction project managers should pay the risk deposit. The risk deposit would be deducted partly or confiscated if the quality, safety, duration and cost of the project are unable to meet the requirements of construction enterprises. In this case, construction project managers will work hard with the high level of effort in order to avoid loss of income. In this paper, we set G to indicate the risk deposit and make the detailed analysis by the game theoretic model. The payoff matrix is presented in Table 3.

Table 3 The payoff matrix of the game theoretic model between construction enterprises and construction project managers

Project managers' income \ Enterprises' income	Supervision(β)		No supervision
	Success(p)	Unsuccess($1-p$)	$(1-\beta)$
Moral hazard(α)	$(W-F-G, F+G-C)$	$(W+R, -C-D)$	$(W+R, -D)$
No moral hazard($1-\alpha$)	$(W, -C)$	$(W, -C)$	$(W, 0)$

After calculated, the equilibrium solution between construction enterprises and construction project managers turned into the following formulas:

$$\begin{cases} \alpha^{**} = \frac{C}{p(F+G+D)}, & \beta^{**} = \frac{R}{p(F+G+R)} & \left(\frac{R}{F+G+R} \le p \le 1\right) \\ \alpha^{**} = 1, & \beta^{**} = 1 & \left(\frac{C}{F+G+D} \le p < \frac{R}{F+G+R}\right) \\ \alpha^{**} = 1, & \beta^{**} = 0 & \left(0 \le p < \frac{C}{F+G+D}\right) \end{cases}$$

From the above formulas, we can see that the equilibrium solution between construction enterprises and construction project managers changed after introduced the risk deposit system (details are shown in Fig. 1).

Fig. 1 shows that the construction project managers' moral hazard behaviors probability became smaller, which means that the risk deposit system can well prevent construction project managers from raising moral hazard problem, so the feasibility of risk deposit system is proved. However, we also see that the supervision probability of construction enterprises reduced, which can be interpreted this way:

(1) The necessity of supervision for construction enterprises will become smaller when the probability of moral hazard problem reduces, thus the supervision probability of construction enterprises reduces.

(2) According to the principal-agent theory, the behavior of the agent is difficult to observe, it is easy for construction enterprises to get the results of construction project managers' behaviors. Construction enterprises may not obtain the desired effect in spite of spending to supervise construction project managers' work from contract signing to the completion of the project, so construction enterprises still judge construction project managers' work according to the results of the work. We investigated China Construction Seventh Engineering Division Corporation Ltd. to examine our points. The research results show that: construction project managers' work is overall judged by the standards, such as whether cost overspent, time limit for a project lagged behind and security accident occurred, when monitoring of acceptance check of the project by this company. If construction project managers' work does not meet the expected requirement, their risk deposit will be deducted partly or confiscated. Therefore, even if the supervision probability of construction enterprises has become smaller, construction enterprises can also achieve the prospective target as long as they grasp major process node.

(3) As the other team members of the project management department also pay the risk deposit, they will supervise the construction project manager's behavior in order to avoid their own loss of risk deposit. The risk

deposit system will not only play a complementary role in the supervision of construction enterprises, but also reduce the supervision fee. In short, the overall goal is to prevent construction project managers from the moral hazard problem.
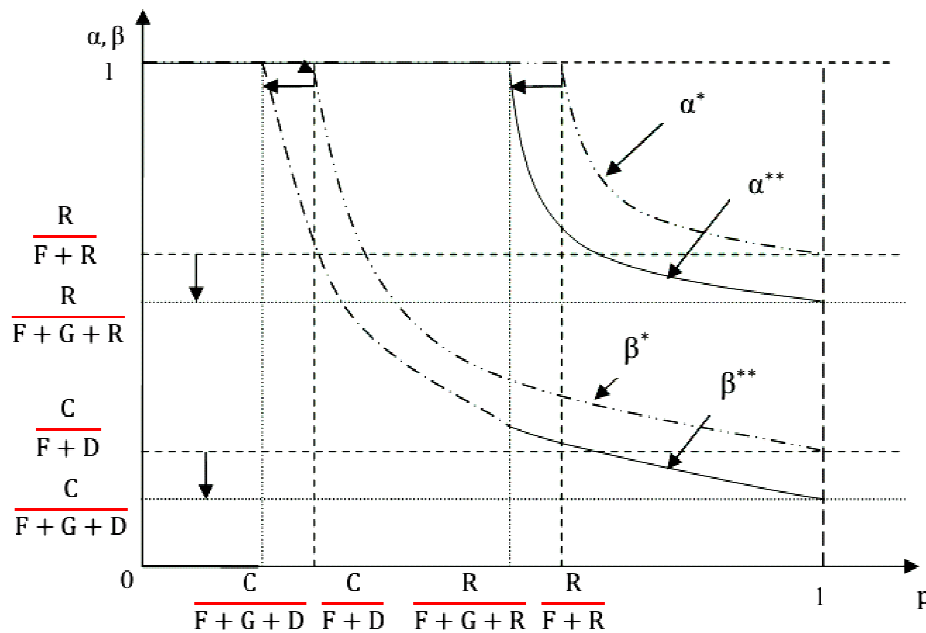

Fig. 1 The influence on the equilibrium solution by the risk deposit system

4.2. Performance appraisal system

As mentioned earlier, construction project managers have two kinds of action selections H and L. Construction project managers should get high salary if they work hard from the point of justice, while the managers who do not work hard with moral hazard problem can only get the reservation wage, and possibly to be dismissed. Here, we use W_0 represent the reservation wage. According to the principal-agent theory, the higher wage is beneficial to reduce the moral hazard problem of construction project managers when construction enterprises cannot fully supervise the behaviors of construction project managers. So, in the modern enterprise system, construction project managers' remuneration can be divided into two parts which contain regular salary and floating wage. Regular salary is relatively changeless and we usually call the reservation wages. At the same time, floating wage which fluctuates in accordance with the results of construction project managers' work is changable, so we can call it the merit pay. If construction project managers' work passes the performance appraisal, they get the merit pay; otherwise, they can only get the reservation wage. In this paper, we assume that the reservation wage demonstrates the local lowest market price, construction project managers would not choose to enter the enterprise whose salary standard is below this limit. Because all construction enterprises spend human resources management cost whatever the size, there is no necessity to consider any additional cost generated by performance appraisal system. From the above analysis, we can get the payoff matrix between construction enterprises and construction project managers as is shown in Table 4.

Table 4 The payoff matrix of the game theoretic model between construction enterprises and construction project managers

Project managers' income \ Enterprises' income	Supervision(β)		No supervision $(1-\beta)$
	Success (p)	Unsuccess $(1-p)$	
Moral hazard(α)	$(W_0 - F - G, F + G - C + W - W_0)$	$(W + R, -C - D)$	$(W + R, -D)$
No hazard$(1-\alpha)$	$(W, -C)$	$(W, -C)$	$(W, 0)$

After calculated, the equilibrium solution between construction enterprises and construction project managers turned into the following formulas:

$$\begin{cases} \alpha^{***} = \dfrac{C}{p(F+G+D+W-W_0)}, \quad \beta^{***} = \dfrac{R}{p(F+G+R+W-W_0)} \\ \qquad \left(\dfrac{R}{F+G+R+W-W_0} \le p \le 1 \right) \\ \alpha^{***} = 1, \quad \beta^{***} = 1 \qquad \left(\dfrac{C}{F+G+D+W-W_0} \le p < \right. \\ \left. \dfrac{R}{F+G+R+W-W_0} \right) \\ \alpha^{***} = 1, \quad \beta^{***} = 0 \qquad \left(0 \le p < \dfrac{C}{F+G+D+W-W_0} \right) \end{cases}$$

From the above formulas, we can also see that the equilibrium solution between construction enterprises and construction project managers changed after introduced the performance appraisal system (details are shown in Fig. 2).

From Fig. 2 we can see that the construction project managers' moral hazard behaviors probability will further reduce along with the improvement of the probability of supervision success of construction enterprises after take the performance evaluation on construction project managers' work, which shows that it is feasible to prevent construction project managers from moral hazard problem by introducing the performance appraisal system.

In addition, a wider investigation in China's construction enterprises regarding to solutions to project managers' moral hazard problem is being undertaken by our research team so as to get actual data from representative projects, and then we can make an empirical research to compare with the results obtained by game theory aiming at verifying and improving the previous method.
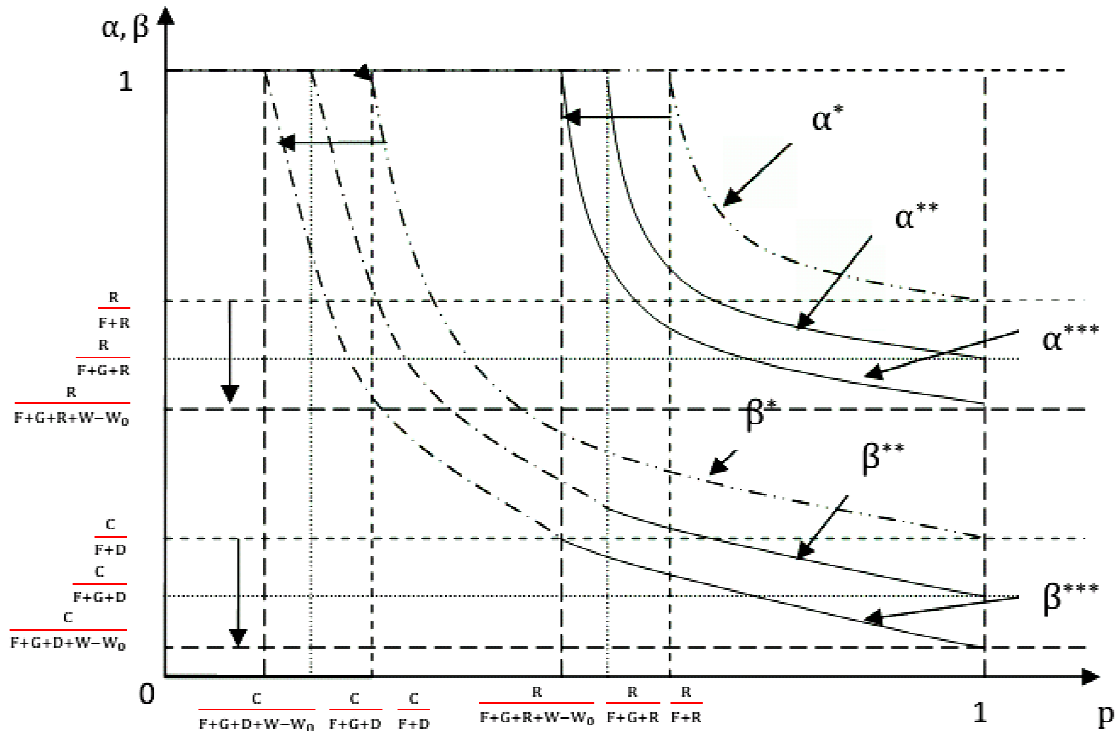

Fig. 2 The influence on the equilibrium solution by the performance appraisal system

5. Conclusions

This paper defined the responsibilities and roles of construction project managers in construction project, analyzed the manifestation and sources of the moral hazard problem of construction project managers, established the game theoretic model between construction enterprises and construction project managers by applying theory of game and information economics, and finally calculated the game equilibrium solution: $\alpha^* = \dfrac{C}{p(F+D)}$, $\beta^* = \dfrac{R}{p(F+R)}$, that is, the optimal probability for construction project managers to choose moral hazard behaviors is $\dfrac{C}{p(F+D)}$ and the optimal probability of construction enterprises to supervise is $\dfrac{R}{p(F+R)}$. From the result of calculation $\alpha^* = \dfrac{C}{p(F+D)}$, we can get that the higher it costs for the construction enterprises to supervise, the bigger probability of the construction project managers' moral hazard behaviors to occur. Meanwhile, from the result of calculation $\beta^* = \dfrac{R}{p(F+R)}$, we can get that the greater additional income the construction project managers get by taking moral hazard behaviors, the more

probability the construction enterprises will supervise. However, it is not easy to operate because of the large uncertainty of the corporate supervision cost C and additional revenue R; in addition, although the larger the amount of punishment F is, the smaller the construction project managers' moral hazard behaviors' probability is, the amount of punishment has a meaningful limit which construction enterprises cannot exceed. In this case, this paper proposes two measures to prevent construction project managers from moral hazard by introducing the risk deposit system and the performance appraisal system.

This paper provides certain work basis for future research. We suggest the directions for future research as follows: Firstly, the specific moral hazard behaviors of construction project managers should be further identified to determine the key factors for construction enterprises to focus on. Secondly, further empirical research is required to analyze the relationship between moral hazard problem of construction project managers and project success. Thirdly, coping with moral hazard problem of construction project managers by common agent theory is also a brand-new front direction of this field deserves to research on.

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