Research on collaborative construction of multiple subjects inside and outside the engineering project team: Based on the perspective of principal-agent theory

Zenghai Wu¹, Beijie Yin*¹ and Jin Yang¹

¹International Business School, Shaanxi Normal University, Xi’an, Shaanxi, 710119, China

*Corresponding author’s e-mail: Belleybj@163.com

Abstract: During the construction of the project team, many problems are faced. Based on the game theory perspective of principal-agent, this paper constructs and analyses the game model inside and outside the engineering project team. The results show that: (1) in the internal knowledge contribution game of engineering project team, there is a game model of “Prisoner's Dilemma” among members. The final choice is often not to participate in the knowledge contribution, and this will damage its actual interests; (2) under the principal-agent game model of the contractor and the engineering project team, the engineering project team needs to continuously increase knowledge and improve technology to achieve the increase of marginal revenue; (3) in the three-party principal-agent game model of the owner, contractor and supervisor, the rent-seeking relationship between the supervisor and the contractor will affect the overall project efficiency, so it should be particularly vigilant. Finally, based on the above results, the countermeasures and suggestions for the collaborative construction management of multi-agents inside and outside the engineering project team are proposed.

1. Introduction

With the development of the “Belt and Road” and the pace of demolition and rebuilding of old buildings in China, the number of engineering projects has increased dramatically, and the number of engineering project teams has also increased rapidly. However, as the number of engineering projects increases, a series of risks also arise: In recent years, the incidence of serious accidents in China has remained high, resulting in numerous losses of personnel and property [1-2]. These risk issues all indicate the importance of efficient construction of engineering projects: What needs to be widely concerned in the current research is how to build an efficient project, and how the project team can improve its human capital stock and efficiency.

Previous researches only have certain one-sidedness from the perspective of engineering project management. Therefore, more and more scholars have introduced the game theory perspective in the research of engineering project team construction, trying to explore the method and necessity of engineering project team building through the model analysis of several parties [3]. In the game theory research of existing engineering projects, the game process and results are considered only from the overallity of several major subjects of project construction: Zhang Feiqi et al [4] passed the sampling inspection of the construction unit, established a punishment mechanism for unsafe construction units, and analysed the relationship between sampling inspection and punishment, and finally established a safety management game model for safety supervision organs and construction units; Han Chuanfeng
[5], Jiang Xin [6], An Hui[7], etc. established a multi-party game model for project payment and expense claims. It can be seen from the above research that, the previous research neglects the game within the engineering project team and the game generated by the principal-agent relationship among the three major subjects outside the engineering project team. Therefore, this paper uses the perspective of game theory again to analyse the problems that the predecessors have neglected, and based on the related issues, puts forward some suggestions on the construction of the project, which has certain innovation.

2. The game within the project team

Different from other types of teams, more practical construction experience and construction knowledge are needed in the construction of the project. These experiences are not available through education and training, but need to be spread by “learning by doing”, apprenticeship or experience sharing. Therefore, after the establishment of the engineering project team and the end of the entire project, it is necessary to continuously disseminate, share and contribute knowledge, experience, thereby increasing the overall human capital stock of the team, realizing the team's human capital appreciation and ultimately acting on performance. However, in the process of knowledge contribution, members will face a game.

Taking the game model of two members in the engineering project team as an example, we analyse the game results of the members' knowledge contribution within the team. For the team as a whole, the best result is clearly that both members are involved in the knowledge contribution, and the individual will give their knowledge and experience to each other. Members can improve their human capital in the knowledge sharing and correspondingly improve teamwork awareness and cohesiveness, thereby increasing the team's human capital stock. However, the individual members of the team are not an altruist. According to the hypothesis of rational man, individual members still follow the principle of maximizing individual interests and play the game according to this principle: If the individual's contribution is less than the non-contribution, he will choose knowledge hiding to maximize his own interests. In reality, when members contribute their own knowledge, they do not improve their own income, but instead provide the cost of contribution, so the contribution is unfavorable for the members themselves; When a member chooses not to contribute and receives knowledge contributed by other members, his or her own earnings will increase. Because new experiences and knowledge can be received without the need to spend extra costs, and through the “free rider”, the individual gains performance rewards from the increase in team human capital due to the knowledge contribution of other individuals.

Combining the benefit matrix of Table 1 below, we analyse the above viewpoint from the perspective of member 2: (1) When member 1 contributes: Member 2 will not choose to contribute to the contribution of member 1, because the benefit without contribution is 6, and the other is only 5; (2) When member 1 does not contribute: Member 2 still chooses not to contribute because his contribution benefit is 3 at this time, which is less than 4, the benefit that does not contribute. That is to say, regardless of any decision made by member 1, member 2's decision is not to participate in the contribution. Similarly, according to the principle of symmetry, regardless of the decision made by member 2, member 1 will choose not to participate in the contribution. Therefore, the final result of this game model is that members 1 and 2 do not contribute, and the team return at this time is 4+4=8, which is less than 10, the gain of knowledge contribution of both members.

| Table 1. Two members' knowledge contribution game within the project team |
|-------------------------------------------------|------|------|
| member 1 | contribute | doesn't contribute |
| member 2 | 5, 5 | 6, 3 |
| doesn’t contribute | 3, 6 | 4, 4 |

Through the benefit matrix of the two members’ knowledge contribution game, it can be seen that, for the entire engineering project team, the shared contribution of knowledge and experience by the members is actually the most beneficial to the team's human capital improvement and team
performance increase. However, the results of the game indicate that individuals will choose not to participate in knowledge contributions and hide their knowledge. There are three reasons for this: (1) During the game, the individual observes that, instead of making knowledge contribution, he can obtain the proceeds from the contribution of others through “free-riding”, so he chooses not to contribute because of social inertia; (2) Individual members need to pay a certain contribution cost when making contributions, In addition, his sharing of knowledge and experience information within the team will make his information lose its uniqueness, so individuals will choose to stop contributing and hide their unique information; (3) The individual's contribution to knowledge within the team leads to “free rider” behavior of other members, which will damage the individual's interests, so the individual will have a resentment, thereby reducing or stopping the knowledge contribution. These three reasons have combined to cause the team members to choose the game results without knowledge contribution.

This game result seems to be favorable in the short term. However, in practice, the performance appraisal method of the engineering project team is mostly based on the team, that is, the individual performance reward is determined by the overall output of the team. That is to say, the maximization of the team benefits can maximize the team reward and realize the maximization of individual interests. Therefore, from this perspective, members should choose to share the knowledge, experience, and information sharing within the team to improve the team's human capital stock, thereby improving the overall revenue of the team.

3. The multi-agent game outside the project team

Among the engineering projects undertaken by the engineering project team, there are three main participants: the owner, the contractor and the supervisor (the engineering team is subordinate to the contractor). The relationship between these four is shown in figure 1. The owner and the contractor establish a contractual relationship based on the principal and agent through bidding, The owner delegates the project to the contractor for design, construction and construction, and the contractor is the agent of the project; The contractor and the engineering project team form a principal-agent relationship based on employment, The project team is a sub-project department of the contractor company, which is entrusted by the contractor and is fully authorized to represent the project; The owner, through the contractor, establishes a factual agency relationship with the engineering project team. On the other hand, the construction of engineering projects requires the supervision of a third party. Therefore, the owner and the supervising party sign an agreement, the owner delegates the supervision right of the project to the supervising party, and the supervising party acts as the agent of the owner in the supervision power in the project; Therefore, the supervisory party is the assistant supervision relationship for the engineering project team, and the latter is subject to the supervision and supervision of the former. The two are interdependent and interrelated. Based on the above relationship, it can be seen that as the main body of the engineering project team, it will be supervised and managed by the three parties from the owners, contractors and supervisors. Therefore, the human capital and efficiency of the team will be affected by these three parties.
3.1. The principal-agent game between the contractor and the engineering project team

As the direct commissioning of the project team, the contractor has a direct impact on the human capital improvement of the project team. For the contractor, there are two options: consign or not consign; after the contractor consigned the project team to carry out the project construction, the project team had two options, work hard or load on the job, which produced negative effects E and S respectively. After the project is over, the contractor will give the project team different rewards according to the performance of the project. The output of the project team's efforts is R(E), and the corresponding reward is w(E); The output after laziness is R(S), and the corresponding reward is w(S).

As can be seen from the above, R(E) > R(S), w(E) > w(S). The basic game model is shown in figure 2.

Set the input and output function of the engineering project team to 5e-e^2, make the effort level 2, lazy to work level 1, and the negative effect of effort E=2, lazy negative effect S=1. Let w(E) be 6, and w(S) be 3, then we can calculate that R(E)=6, R(S)=4, and strive for the final return is w(E)-2=4, lazy final income is w(S)-1=2. The specific game path is shown in figure 3. As can be seen from figure 3, the final game result of the contractor and the engineering project team is that the contractor entrusted the project team to carry out the project construction. The engineering team will choose the former when it comes to hard work and laziness, because the output after hard work makes the contractor pay more.

This game result can illustrate a simple economic principle: Within a certain limit, the more inputs, the more outputs, the more rewards are obtained, which is the law of increasing marginal returns; When the factor is invested higher but other elements are not changed, its output may decline, and the reward thus obtained will also decrease. This is the law of diminishing marginal returns. Different from the classic law of diminishing marginal returns, the law of increasing marginal returns is due to the value-added of knowledge in the knowledge-based economy. Therefore, in order to maintain the marginal return, it is necessary to continuously increase the knowledge stock to improve the technical level. In the context of the construction of the project team, in order to maintain the incrementality of the project team and the incremental returns, it is necessary to increase the human capital of the project.
team, so that the team’s knowledge, skills and capabilities of the project team can be increased. It will continue to produce new knowledge and new technologies, so as to continue to increase marginal returns. It can be seen that the prerequisite for improving the performance output of engineering project teams is to improve the human capital of the team.

3.2. Three-party game among owners, contractors and supervisors

The three parties in the construction of the project are faced with a game. The outcome of this game will directly affect the progress of the project and the performance of the project team. In the game of the three subjects, the addition of the supervisor made it possible to have a complicity relationship with the contractor [8-9]. This relationship means that the performance results of the project construction are not only affected by the contractor's efforts, but also with the complicity between the supervisor and the contractor. Suppose the contractor's effort to produce \( R(E) \), at which point the owner's remuneration to the contractor is \( w(E)c \), and the compensation to the supervisor is \( w(E)s \). The contractor's lazy output is \( R(S) \), and two things will happen: When the supervisor chooses to supervise the contractor and does not cooperate with it, the owner shall pay the contractor \( w(S)c \), and the compensation to the supervisor shall be \( w(S)s \); When the supervisor chooses not to supervise the contractor and form a complicity with it, it means that it will cover the contractor’s laziness and will falsely report the performance of the project, The owner's remuneration to the contractor is still \( w(E)c \), and the remuneration given to the supervisor is still \( w(E)s \). The specific three-party game path is shown in figure 4.

Assign a value to the model for the next step. The input-output function of the contractor's hard work is still \( 5e^{-e^2} \), the effort is level 2, the laziness is the effort level 1, and the negative effect of the effort \( E=2 \), the lazy negative effect \( S=1 \), and then \( w(E)c=6 \), \( w(E)s=4 \), \( w(S)c=3 \), and \( w(S)s=1 \). The final game operation results are shown in Figure 5 below. As can be seen from figure 5, for the owner, the best result is of course to entrust the contractor to carry out the construction of the project, and the contractor works hard, and finally can reach the output of 6. But for the contractor, the benefit it gets after working hard is 4, and if the conspiracy relationship with the supervisor is reached after being lazy, the income is still 4. Therefore, it may choose to slacken and work with the supervisory party to deceive the owner to obtain higher returns with a lower level of effort. For a third-party supervisor, the contractor does not participate in the game when the contractor works hard, and the income is fixed at 4; when the contractor is lazy, if it chooses to collude with it, the income will be 4; when the supervisor chooses to supervise the contractor and does not cover it, the income is only 1. Therefore, the final contractor will choose to slack off the work, and the supervisor will choose to form a complicity relationship with it, falsely reporting false performance to obtain higher returns.

In the process of the three principal entrusted agents of the owners, contractors and supervisors, the owner is the top-level principal, and the information on the third layer is missing: The owner can
choose to control the contractor's commission, but it is impossible to know the contractor's work after being contracted, because at this time, the third-party supervisor is added. As another agent of the owner, the supervisory party actually plays an uploading role in the construction of the project. Once it forms complicity with the contractor, the owner will also completely lose the judgment on the accuracy of the contractor's performance information because of the supervisor's cover of the contractor. The existence of such incomplete information makes the owner at a disadvantage in the three-subject game of engineering project construction. The conspiracy of the contractor and the supervising party is actually not conducive to the sound development of the project construction, so it needs to be extra vigilant.

![Game of the three main players in the construction of the project](image1)

![Game of the three main players in the construction of the project(example)](image2)

**4. Countermeasures and suggestions for the construction of engineering project team**

**4.1. Establish a team incentive pool to avoid “free rider” behavior.**

The original team incentive method directly uses team performance as the sole evaluation criterion, and the performance appraisal of members is not clear, which leads to the “egalitarianism” in a certain sense, which makes the “free rider” behavior appear. In the long run, there will be more “free-riding” team members and the enthusiasm of the members who actively participated in the team contribution will be hit, thus reducing contributions and even not contributing. At this time, the phenomenon of “social inertia” will appear, and the growth rate of human capital of the team will decline or even show a negative growth trend, and the team performance will also decline. Therefore, in order to improve the human capital of the engineering project team, managers need to optimize the performance appraisal system to avoid the emergence of “one size fits all”, On the basis of team incentives with team performance as the incentive standard, the individual performance appraisal of team members is carried out, and the performance appraisal dimension of knowledge contribution is added to compensate for the cost loss caused by individual knowledge contribution, thereby further enhancing the members' willingness and degree, and ultimately the improvement of the team's human capital.

The current preferred method is to establish a team incentive pool\(^{[10]}\). The incentive pool, as its name implies, is to form a large pool according to multiple performance appraisal factors, and each performance appraisal factor has a different proportion. When the organization conducts performance appraisal for each member, in addition to the overall performance review, it also participates in the performance review of each dimension. Each dimension is divided into four levels: unqualified, qualified, good and excellent, corresponding to different scores. Finally, the weights of each dimension are multiplied by the scores of each dimension and summed to obtain the incentive pool
incentive amount of individual members. In the face of the situation that the individual’s willingness to contribute knowledge is not strong, the weight of the knowledge contribution can be increased in an appropriate amount, thereby stimulating the individual’s contribution to the knowledge and information sharing within the team.

4.2. **Accelerate the transition to the IPD mode and improve the efficiency of team operations.**

The existing engineering project construction modes are mostly PPP mode, DB mode, and DBB mode \(^{[11-13]}\). These modes have their own merits, but the common problem is the lack of integrity. Each subject is independent and coordinated, which is difficult to coordinate management. Therefore, a new engineering project construction method is needed to optimize the existing model—the IPD mode came into being. As a centralized project payment model, the IPD model is based on the joint efforts of the team. It integrates engineering systems, human resources, experience and business systems to achieve a shorter project and cost savings \(^{[14]}\). This team has all kinds of professional talents, implements unified and integrated management of the project, operates along the entire project life cycle, and pays full responsibility for the project \(^{[15]}\). The above research shows that mutual trust, active knowledge contribution and increased team knowledge of engineering project team members will greatly enhance the efficiency of team human capital and project construction. In the IPD mode, the team is built longer, the task is more dependent, the goal is more consistent, and the trust between the members is stronger. Therefore, the more the team's human capital is increased, the engineering project construction efficiency will be higher. Therefore, promoting the transformation of the existing project delivery model to IPD has an extremely important and fundamental role in engineering project team building and engineering project performance improvement.

4.3. **Weaken the principal-agent relationship and realize the joint management of the three parties.**

Under the principal-agent relationship, the principal's game choice for the agent is not fully grasped, resulting in incomplete symmetry with the agent's information, so that the principal is subject to the agent in the relationship. Therefore, in the construction of engineering projects, the traditional principal-agent relationship should be appropriately weakened to give full play to the main role of the owners: Specifically, the owner should not only be a full-fledged principal in the tripartite relationship, but should participate in the whole process of construction of the project. Reduce the supervisory authority of the supervisory party and increase the supervisory share of the owner, thus reducing the lazy behavior of the contractor (which can also be considered as the engineering project team), reducing the possibility of conspiracy behavior between the supervisor and the contractor, and improving the efficiency of project construction.

**Acknowledgments**

This paper is one of the phased achievements of the National Natural Science Foundation of China, “Research on Functional Transformation and Incentive of Old Industrial Buildings Guided by Green Energy Saving” (51678479).

**References**

[1] Xiong, Z. M., Lu, H., Wang, M. Y., Qian, Q. H., Rong, X. L. (2018) Research progress on safety risk management for large scale geotechnical engineering construction in China. Rock and Soil Mechanics, 39: 3703-3716.

[2] Mao, X. P., Lu, H. M., Li, Q. M. (2012) Research on Stakeholders of Sustainable Construction of China's Engineering Projects. Journal of Southeast University (Philosophy and Social Science), 14: 47-50.

[3] Khanzadi, M. (2016) A Game Theory approach to the analysis and selection of partners in public private partnership projects. Journal of Civil Engineering and Management, 22: 1066-1077.
[4] Zhang, F. L., Liu, L., Dong, W. Z., Zhang, W. (2002) Application of Game Theory in Safety Management of Construction Projects. Systems Engineering, 20: 33-37.

[5] Han, C. F., Yin, W. (2006) Game theory analysis of the owner’s payment guarantee system to solve the arrears of engineering funds. Construction Economy, 27: 24-27.

[6] Jiang, X., Zhang, W. (2009) Analysis and Countermeasures of Difficulties in Construction Claims Litigation Based on Game Theory. Yangtze River, 40: 107-109.

[7] An, H., Zheng, C. J., Li M. N. (2012) Research on Engineering Claim Strategy Based on Game Model. Construction Economy, 33: 57-60.

[8] Li, M., Yin, D. L., Wang, X. (2018) Research on Government Rent-seeking Behavior Regulation of PPP Project Based on Full Life Cycle. Construction Economy, 39: 70-74.

[9] Cao, Q. L., Sheng, Z. H., Zhou, J., Li Q. (2015) PPP project rent-seeking behavior and incentive supervision model from the perspective of contract. Scientific Decision Making, 22: 51-67.

[10] Liu, H., Li, G. J., Xin, X. W. (2015) Research on incentive pool allocation in construction project under IPD mode. J. Xi’ an Univ. of Arch. & Tech. (Natural Science Edition), 50: 913-918.

[11] Li, J. H., Li, X. Q., Ma, H. (2018) Research on the Model Selection of Prefabricated Building Project Based on Cost Optimization. Construction Economy, 39: 33-35.

[12] Qiang, M, Wen, Q, Jiang, H. (2015) Factors governing construction project delivery selection: A content analysis. International Journal of Project Management, 33: 1780-1794.

[13] Hale, D. R., Shrestha, P. P., Gibson, G. E. Empirical Comparison of Design/ Build and Design/ Bid/ Build Project Delivery Methods. Journal of Construction Engineering & Management, 135: 579-587.

[14] El-Adaway, I. H. (2010). Integrated project delivery case study: Guidelines for drafting partnering contract. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 2: 248-254.

[15] Zhao, H., Qiu, W. T., Qu, W. L., Wang Y. (2019) Research on incentive mechanism of engineering project team in IPD mode. Journal of Qingdao University of Technology, 40: 15-21.