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Model and Simulation of Benefit Distribution of Collaborative Cooperation in the Supply Chain of General Contracting Projects

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Abstract: In the supply chain of general contracting projects, there are many participating entities, which can easily lead to conflicts of interest and resources. In order to fully mobilize the enthusiasm of general contractors and subcontractors, achieve stability, maximize the benefits of the supply chain system, and improve the operational efficiency of the supply chain, it is necessary to design a scientifically reasonable mechanism for benefit distribution to coordinate the relationships between all members. This paper takes the general contractor and subcontractor in the supply chain of the general contracting project as the research objects and uses the Cobb–Douglas function to establish the benefit distribution model of the cooperation between the two in the supply chain system and analyzes the benefit distribution problem of the one-time cooperation and multiple cooperation between the two parties in the two decision-making modes of egoism and collectivism. The results show that in the case of one-time cooperation between general contractors and subcontractors, regardless of the decision mode, the degree of effort of both parties is positively related to their contributions and negatively related to each other's contributions; the overall benefit of the supply chain system is positively proportional to the degree of contribution of the general contractor and inversely proportional to the share of benefit distribution of the subcontractor. In multiple cooperation, the equilibrium result of both parties achieving Pareto optimality at each stage is that both parties choose to cooperate.

Keywords: general contracting engineering supply chain; collaboration; profit distribution; Cobb–Douglas function

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1. Introduction

With the development of economic integration and the engineering construction market, as well as more transparent and competitive engineering projects, owners are increasingly inclined to adopt the general contracting model for engineering projects to obtain more comprehensive services [1]. In 2019, the Ministry of Housing and Urban–Rural Development and the National Development and Reform Commission formulated the Measures for the Management of General Contracting for Housing Construction and Municipal Infrastructure Projects [2], which emphasize that "general contracting activities shall follow the principles of legality, fairness, honesty, and trustworthiness, reasonably share risks, ensure project quality and safety, save energy, protect the ecological environment, and shall not harm the public interests of society and the legitimate rights and interests of others". Due to the needs of engineering construction project management and the implementation of national policies, as well as the fact that Chinese construction enterprises currently have no way to form an enterprise with general contracting capability in a short period, the consortium of construction general contracting projects has become a trend, and each enterprise can achieve the purpose of reducing costs, sharing risks and improving the efficiency of cooperation by establishing a good cooperative relationship and

through resource sharing. The supply chain of general contracting projects is a network structure formed by the general contractor as the core and members of enterprises such as subcontractors and material suppliers to meet the owners' construction needs.

There are many participating subjects in the supply chain of general contracting projects [3], and interests are the bond and driving force for the development of relationships between members [4], making the benefit allocation issue a very critical and complex one requiring the consideration of various factors. Generally speaking, the distribution of interests of general contractors and subcontractors and other subjects should be distributed according to their contribution degree, but in reality, it is also necessary to consider the competitive environment and market supply and demand [5]. When the interests of each party cannot be fairly and reasonably distributed, it will affect the enthusiasm of cooperation among members or directly lead to the failure of cooperation so that each subject cannot achieve a win–win situation. To achieve the management goal of maximizing the interests of the supply chain itself and sustainable development, it is necessary to design a good mechanism for the distribution of interests among the participating subjects [6], balance the interests obtained by each participating party, ensure that each subject can obtain reasonable benefits, and solve the contradiction of interests of all parties, which is an urgent problem for general contracting projects and is important for fully mobilizing the enthusiasm of general contractors and subcontractors to participate in the construction and for mutual achievement. It is of great significance to fully mobilize the enthusiasm of general contractors and subcontractors to participate in construction and then to maximize the interests of both parties. Therefore, this paper focuses on the distribution of the benefits between general contractors and subcontractors in China's EPC supply chain and discusses the cooperation mechanism in one-time cooperation and multiple cooperation.

2. Research Overview

Domestic and international research on the issue of benefit distribution mainly includes the following aspects.

2.1. Research on the Distribution of Engineering Benefits

Bai, Z.Y. [7] studied the optimal decision of benefit distribution between general contractors and procurement service providers under two situations of cooperation and dispersion based on revenue-sharing theory and Stackelberg's game idea; Guan, B.H. [8] used the basic principles of contract theory and game theory to analyze the benefit distribution mechanism between different units of the general contractor; Sun, G.S. et al. [9] studied the benefit distribution problem of PPP projects by constructing a game model and used a case study to investigate the effects of different situations on the outcome of government and social equilibrium strategies. Ren, K. et al. [10] studied the use of the Shapley model to solve the problem of uneven profit distribution between general contractors and subcontractors in EPC projects in railways; Lv, P. et al. [11] studied and pointed out that the improved Shapley model was more reasonable for the benefit distribution of the general contractor's engineering construction supply chain based on cooperative alliance; Shi, Q.Q. et al. [12] used the Cobb–Douglas function to analyze the benefit distribution problem of one-time cooperation between major engineering contractors and suppliers; Feng, J.C. et al. [13] discussed the benefit distribution of BIM-based collaborative construction projects under the EPC model and proposed a two-level benefit distribution mechanism based on the dual management system under the EPC model at the macro level and a three-stage benefit distribution mechanism based on the application characteristics of BIM in the whole project life cycle at the micro level.

2.2. Research on the Benefit Distribution of Supply Chain Cooperation

Wang, L. et al. [14] used the idea of the Stackelberg game to establish a quantitative model of the benefit distribution mechanism of supply chain members' cooperation; Zhong, C.B. et al. [15] proposed a new two-stage distribution method of supply chain bene-

fits, the orthogonal projection entropy method, based on the importance of the supply chain benefit distribution mechanism and some existing problems; Han, T. and Li, D.F. [16] used the Shapley value method to regulate the benefit allocation game problem among enterprise members with an intuitionistic fuzzy alliance; Zou, Y. [17] used the maximum entropy method to allocate the profits obtained from the VMI and TPL model in the upstream segment of the supply chain; Mahjoub, S. and Hennet, J.C. [18] used cooperative game analysis to solve strategic problems such as maximum profit generation and sharing among supply chain companies; Chen, C.L. et al. [19] proposed a two-stage fuzzy decision-making method to maximize the profit of each participating company for a typical multi-echelon supply chain network; Xi, Y.H. and Cheng, Y.Y. [20] studied the benefit distribution mechanism of supply chain partnership in depth, introduced the benefit distribution principle of supply chain partnership, and constructed a model of benefit distribution ratio of supply chain partnership; Kumoi, Y. and Matsubayashi, N. [21] analyzed the supply chain benefit distribution problem on the basis of cooperative game theory and clearly proposed that the profits of the alliance must be allocated more to retailers and higher-cost members in the revenue distribution; Liao, R. et al. [22] took the supply chain alliance under the decoupling before and after all-round tourism as the research object and established a dynamic benefit distribution model under the three stimuli of self-interest, altruism, and immutability. In order to study the interest coordination of the wind power supply chain, Liu, J.C. and Bao, H.Y. [23] established qualitative cooperation and non-qualitative cooperation models based on considering the cost of dual efforts and proposed four benefit distribution strategies. In order to research the issue of cooperative interests between e-commerce platforms and manufacturers in the supply chain of e-commerce platforms, Xu, B. et al. [24] established a differential game model and compared the equilibrium solutions under different decisions. They conducted numerical analysis and identified several important parameters that influence the equilibrium solution.

2.3. Research in Benefit Distribution Models

A large number of cooperative game studies can be further divided into two types—ex-ante allocation and ex-post allocation—in which the specific forms of ex-ante allocation generally include revenue sharing contracts [25–30], quantity flexibility contracts [31], repurchase contracts [32–34], etc.; export profit allocation is carried out using the Shapley value method [10,11,16,35–41], the minimum core method [35], the bargaining model [42], the Nash bargaining model [43], and the maximum entropy method [17] among other models. Raza, S.A. [25] proposed solutions for control decisions by analyzing the demand profiles of a quantitative model of joint pricing, inventory (order quantity), and investment used for supply chain social responsibility decisions under three games of decentralized, centralized, and revenue-sharing contracts; Heydari, J. et al. [26] applied quantity elasticity contracts to study the stochastic demand situation of a two-level supply chain consisting of one product and two members (manufacturer and retailer); Luo, C.L. [31] analyzed that when a supply chain can be coordinated through a buy-back contract, the coordination benefits of the supply chain can be arbitrarily distributed between suppliers and retailers; Xiao, Q. and Ma, S.H. [33] demonstrated that repurchase contracts can be used to eliminate the risk aversion effect and the double marginal effect in the cooperation of the second-level supply chain; Tan, Z.F. et al. [37] applied the Shapley value method to solve the problem of benefit distribution in the cooperation between the generation side and the supply side; Wang, L. et al. [38] combined individual characteristic weight coefficients with the Shapley values of each hydropower plant and proposed the coefficient of variation–Shapley value method for the compensation benefits of multi-owner step hydropower plants; Li, L. and Liu, S.H. [39] combined the minimum core method and the Shapley value method to find a practical method for the benefit distribution of cooperative cooperation. In order to solve the benefit allocation problem among members of the consortium of whole-process-engineering consulting projects, Sun, L.L. et al. [44] constructed a benefit allocation model of whole-process-engineering consulting projects with modified Shapley value using

the AHP and fuzzy comprehensive evaluation methods and verified the feasibility and effectiveness of the model; Wang, X.S. et al. [42] proposed a dynamic game benefit allocation scheme based on the bargaining model for the benefit allocation of shared contract water conservation management; Liu, Z.C. et al. [45] constructed a benefit distribution model for full-process consulting consortia based on the asymmetric Nash negotiation model, which corrects the shortcomings of the asymmetric Nash negotiation model in terms of benefit distribution averaging.

From the above analysis of the existing literature, the study of the supply chain of general contracting projects has received much attention from scholars, but there is less research on the distribution of benefits among members within general contracting projects. The utilization distribution models used are relatively fixed—mostly the Shapley value method—and most of them are limited to the one-time cooperation between subjects within the supply chain system, and less involved in the problem of multiple cooperation. However, in real life, general contractors and subcontractors will choose to cooperate multiple times based on satisfactory one-off cooperation, which makes it more important to deal with the distribution of benefits when they cooperate. Therefore, in the context of the general contracting market, taking general contractors and subcontractors in the supply chain of general contracting projects as the research object, it is of practical guidance to consider the distribution of benefits between the two parties in the supply chain system in one-time cooperation and multiple cooperation, which is of practical significance to the distribution of benefits among the subjects within general contracting projects in China.

3. Basic Assumptions and Modeling

In general contracting construction, a general contract is signed between the owner and the general contractor, leaving the construction work solely in the hands of the general contractor. Due to the asymmetry of information between the owner and the general contractor, the general contractor may take advantage of this to generate opportunism and lose project output. To achieve a win–win situation, the owner will often adopt an incentive mechanism to reduce the opportunistic behavior of the general contractor by signing a fixed lump sum price and bonus contract with the general contractor, while the general contractor will likewise establish an incentive bonus with its subcontractors to obtain the incentive bonus itself. The general contractor, to obtain incentive bonuses for itself, will likewise ensure the quality and progress of the project by establishing an incentive mechanism with its subcontractors and allocating bonuses according to a certain percentage, thus achieving a win–win outcome.

The basic assumptions in the text are as follows:

1. The general contractor engineering supply chain is a consortium consisting of two parts: the general contractor and the subcontractors.
2. The quality of products provided by the upstream supply chain of subcontractors is qualified, i.e., there will not be any problems with the quality of work due to material aspects.
3. The Cobb–Douglas function [42,43] is used to express the bonus function $F(e_1, e_2)$ given by the owner to the general contractor, i.e., $F(e_1, e_2) = e_1^{\alpha} e_2^{1-\alpha} + \varepsilon$. The expected bonus for the general contractor and the subcontractor is $E(F) = e_1^{\alpha} e_2^{1-\alpha}$, where e_1 represents the level of effort of the general contractor and e_2 represents the level of effort of the subcontractor; α represents the general contractor's level of contribution, and $(1 - \alpha)$ represents the level of contribution of the subcontractor. In the past two years, with the normalization of the new COVID-19 epidemic, the general contractor and subcontractors are subject to uncertainties such as epidemics and natural disasters in engineering construction, and the field of engineering construction has encountered challenges. Let the risk factor ε obey the standard normal distribution, i.e., $\varepsilon \sim N(0, \sigma^2)$.

The benefit-sharing contract model in the current research includes a revenue-sharing contract model, the Shapley value method, a bargaining model, the Nash negotiation

model, a resource and contribution rate allocation model, etc. The revenue-sharing contract model can ensure that the benefits of both the general contractor and subcontractors are higher than the state when they are scattered and achieve the optimal performance of the supply chain system, but it is only suitable for the situation that the management cost is low and the level of effort has little impact on the supply chain system. Although the Shapley value method considers key factors such as cooperation ability and resource complementarity in the supply chain system, it cannot effectively reflect the incentives for technological innovation of members in the supply chain system. Although the bargaining model and the resource and contribution rate allocation model conform to the principle of allocation according to contribution size and factor allocation, both methods can lead to inefficiency of the supply chain system. The Nash negotiation model mainly focuses on non-cooperative games and is not suitable for the distribution of cooperative benefits in supply chain systems.

Compared to the above five methods, the Cobb–Douglas function has the following advantages:

(1) It not only considers the incentive policy of the owner but also focus on the decision-making behavior and strategic selection and influencing factors of the general contractor and subcontractors.

(2) In the Cobb–Douglas function, when the labor input of the general contractor and subcontractor in the supply chain system is zero, the output is zero, so for the supply chain system, in order to obtain more benefits, the level of effort and contribution of both must be incentivized.

(3) By introducing the Cobb–Douglas function, the supply chain system can be objectively required to coordinate the interests of both parties and achieve a balance of people, finances, and materials.

4. The owner and the main contractor enter into a contract in the form of a fixed lump sum price plus bonus, i.e., $W = p_1 + F$; the contract between the main contractor and the subcontractor, which is also a fixed lump sum price plus bonus incentive, is $P = p_2 + (1 - \beta)F$, where W is the total price of the benefits received by the main contractor at the end of the project, P is the total price of the benefits received by the subcontractor at the end of the project, p_i $(i = 1,\ 2)$ is the fixed total price of the project contracted by the general contractor and subcontractors, β $(0 < \beta < 1)$ is the bonus allocation coefficient of the general contractor, and $1 - \beta$ is the bonus allocation coefficient of the subcontractors.
5. The effort cost function paid by the general contractor in the construction of the project is $C_1 = \frac{1}{2}k_1{e_1}^2$, and the effort cost function paid by the subcontractor in the construction process is $C_2 = \frac{1}{2}k_2{e_2}^2$, where k_1 represents the effort–cost coefficient of the general contractor and k_2 represents the effort cost coefficient of the subcontractor.
6. Assume that the general contractor is risk-neutral in the cooperation process, while the subcontractor is risk-averse, i.e., the general contractor—as the general manager—is neither risky nor conservative in its decision, but the subcontractor—as a member of the project—will choose the riskier option when the expected benefits are the same, as it may bring them greater benefits. For a subcontractor, the cost of risk is $c_2 = \frac{1}{2}f_2(1 - \beta)^2\sigma^2$, where f_2 represents the degree of risk preference of the subcontractor, and $0 \leq f_2 \leq 1$; $f_2 = 0$ represents that the subcontractor is in a risk-neutral state, and $f_2 \to 1$ represents the increasing risk preference possessed by the subcontractor.
7. The final benefit to the general contractor is:

$$X = p_1 - p_2 + \beta E(F) - C_1 = p_1 - p_2 + \beta e_1^{\alpha} e_2^{1-\alpha} - \frac{1}{2}k_1{e_1}^2 \quad (1)$$

The ultimate benefits to subcontractors are:

$$Y = p_2 + (1 - \beta)E(F) - C_2 - c_2 = p_2 + (1 - \beta)e_1^{\alpha} e_2^{1-\alpha} - \frac{1}{2}k_2{e_2}^2 - \frac{1}{2}f_2(1 - \beta)^2\sigma^2 \quad (2)$$

The ultimate benefits of a general contractor's engineering supply chain system are:

$$Z = X + Y = p_1 + e_1^{\alpha} e_2^{1-\alpha} - \frac{1}{2} k_1 {e_1}^2 - \frac{1}{2} k_2 {e_2}^2 - \frac{1}{2} f_2 (1-\beta)^2 \sigma^2 \quad (3)$$

8. In the one-time cooperation, the Cobb–Douglas function is applied to obtain the optimal allocation share, optimal effort level, and optimal return of the general contractor and subcontractor and supply chain system as a whole under the egoistic decision-making mode and the collectivist decision-making mode, respectively. For the distribution of benefits during multiple cooperations, the effort level of one-time cooperation is used to calculate the conditions under which the two parties will still choose cooperation in the n + 1 stage so as to realize the continuation of the two parties from one-time cooperation to multiple cooperation.

4. Model Solving and Analysis

From Equations (1) and (2), we can see that the interests of the general contractor are related to the subcontractors, and the interests of the subcontractors are also related to each other, which shows that in the general contracting supply chain, to maximize their own interests, both parties must consider the interests of the other party. If both parties do not consider each other's interests but only their own interests, egoistic decision-making will occur. If the two parties consider the maximization of the overall benefit—that is, the maximum benefit of the general contracting project supply chain system—there will be a situation of collectivist decision-making. (Since both p_1 and p_2 are fixed values and not directly related to the conclusion, both p_1 and p_2 are assumed to be zero in the subsequent calculation).

4.1. Egoistic Decision-Making Model (Model I)

Under egoistic decision-making, in the whole supply chain system of general contracting projects, it is a Stackelberg game between them for two subjects, general contractor and subcontractor. The general contractor is the leader, who first determines its own level of effort and the share of allocated benefits, aiming at maximizing its own benefits, while the subcontractor—as a follower—can determine its own level of effort only after the general contractor has made a decision.

Taking the derivative of X with respect to e_1 and making it equal to zero gives: $\frac{\partial X}{\partial e_1} = \alpha\beta e_1^{\alpha-1} e_2^{1-\alpha} - k_1 e_1 = 0$, which gives: $e_1 = \left[\frac{\alpha\beta}{k_1} e_2^{1-\alpha}\right]^{\frac{1}{2-\alpha}}$.

After determining the choice of the general contractor, the subcontractor chooses its own level of effort in conjunction with the aim of maximizing its own interest. Taking the derivative of Y with respect to e_2 and making the derivative equal to zero gives: $\frac{\partial Y}{\partial e_2} = (1-\alpha)(1-\beta) e_1^{\alpha} e_2^{-\alpha} - k_2 e_2 = 0$, which gives: $e_2 = \left[\frac{(1-\alpha)(1-\beta)}{k_2} e_1^{\alpha}\right]^{\frac{1}{1+\alpha}}$.

Substituting the resulting e_2 into X yields:

$$X = \beta \left[\frac{(1-\alpha)(1-\beta)}{k_2}\right]^{\frac{1-\alpha}{1+\alpha}} e_1^{\frac{2\alpha}{1+\alpha}} - \frac{1}{2} k_1 e_1^2 \quad (4)$$

Finding the derivatives of Equation (4) concerning e_1 and β, respectively, and making the two derivatives equal to zero as well as relating the system of equations yields:

$$\begin{cases} \left[\frac{(1-\beta)(1-\alpha)}{k_2}\right]^{\frac{1-\alpha}{1+\alpha}} e_1^{\frac{\alpha-1}{1+\alpha}} - \frac{\beta(1-\alpha)}{1+\alpha} \left(\frac{1-\alpha}{k_2}\right)^{\frac{1-\alpha}{1+\alpha}} e_1^{\frac{\alpha-1}{1+\alpha}} (1-\beta)^{\frac{-2\alpha}{1+\alpha}} = 0 \\ \frac{2\alpha\beta}{1+\alpha} \left[\frac{(1-\beta)(1-\alpha)}{k_2}\right]^{\frac{1-\alpha}{1+\alpha}} e_1^{\frac{\alpha-1}{1+\alpha}} - k_1 e_1 = 0 \end{cases} \quad (5)$$

The final solution gives:

The optimal decision allocation share of the general contractor is: $\beta^{I^*} = \frac{1+\alpha}{2}$.

The optimal level of effort for the general contractor and subcontractor respectively is:

$$e_1^{I^*} = (\frac{\alpha}{k_1})^{\frac{1+\alpha}{2}} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{\frac{1-\alpha}{2}}$$

$$e_2^{I^*} = (\frac{\alpha}{k_1})^{\frac{\alpha}{2}} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{\frac{2-\alpha}{2}}$$

The optimal returns for the main contractor, subcontractors, and the supply chain system of the main contracting works are, respectively:

$$X^{I^*} = p_1 - p_2 + \frac{1}{2}(\frac{\alpha}{k_1})^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha}$$

$$Y^{I^*} = p_2 + \frac{1-\alpha^2}{4}(\frac{\alpha}{k_1})^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha} - \frac{1}{2}f_2(1-\beta)^2\sigma^2$$

$$Z^{I^*} = X + Y = p_1 + \frac{3-\alpha^2}{4}(\frac{\alpha}{k_1})^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha} - \frac{1}{2}f_2(1-\beta)^2\sigma^2$$

The optimal allocation sharing decision for the general contractor shows that the magnitude of this value is positively related to the degree of contribution of the general contractor, and it can be concluded that the allocation share of the general contractor is greater than $1/2$ because the degree of contribution of the general contractor α and the degree of contribution of the subcontractor $1-\alpha$ are both greater than 0. It can be concluded that $0 < \alpha < 1$, and thus the allocation share of the general contractor is greater than $1/2$. The optimal benefit results for the subcontractor show that the larger the subcontractor's share of benefit distribution, the smaller the benefit it receives, and conversely, the smaller its share of benefit distribution, the greater the benefit obtained. The relationship between the optimal return of the general contracting supply chain system as a whole and the share of benefits allocated to subcontractors is consistent with the variation between subcontractors and their share of benefits, because as subcontractors have a risk appetite, the supply chain system as a whole also has a risk appetite.

4.2. Collectivist Decision-Making Model (Model II)

In collectivist decision-making, the two parties collaborate in terms of maximizing the overall benefits of the supply chain system for turnkey projects, thereby determining the level of effort of both parties.

Under collectivist decision-making, the two cooperating parties seek to maximize the benefits of the supply chain system, i.e.,:

$$maxZ = max\ p_1 + e_1^{\alpha}e_2^{1-\alpha} - \frac{1}{2}k_1e_1^2 - \frac{1}{2}k_2e_2^2 - \frac{1}{2}f_2(1-\beta)^2\sigma^2 \tag{6}$$

Finding the derivative of the above equation concerning e_1, e_2 and making the derivative equal to zero as well as the system of joint cubic equations leads to

$$\begin{cases} \alpha e_1^{\alpha-1}e_2^{1-\alpha} - k_1e_1 = 0 \\ (1-\alpha)e_1^{\alpha}e_2^{-\alpha} - k_2e_2 = 0 \end{cases} \tag{7}$$

From this, it can be found that:

The optimal level of effort for the main contractor and the subcontractor are, respectively:

$$\begin{cases} e_1^{II^*} = \left(\frac{\alpha}{k_1}\right)^{\frac{1+\alpha}{2}} \left(\frac{1-\alpha}{k_2}\right)^{\frac{1-\alpha}{2}} \\ e_2^{II^*} = \left(\frac{\alpha}{k_1}\right)^{\frac{\alpha}{2}} \left(\frac{1-\alpha}{k_2}\right)^{\frac{2-\alpha}{2}} \end{cases}$$

The optimal return of the overall supply chain system for a turnkey project is:

$$Z^{II^*} = X + Y = p_1 + \frac{1}{2}\left(\frac{\alpha}{k_1}\right)^{\alpha} \left(\frac{1-\alpha}{k_2}\right)^{1-\alpha} - \frac{1}{2} f_2 (1-\beta)^2 \sigma^2$$

By summarizing the above two decision models, we can produce Table 1.

Table 1. Results for each decision variable in the two decision models.

Decision Variables	Egoistic Decision Making	Collectivist Decision-Making
β^*	$\frac{1+\alpha}{2}$	
e_1^*	$\left(\frac{\alpha}{k_1}\right)^{\frac{1+\alpha}{2}} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{\frac{1-\alpha}{2}}$	$\left(\frac{\alpha}{k_1}\right)^{\frac{1+\alpha}{2}} \left(\frac{1-\alpha}{k_2}\right)^{\frac{1-\alpha}{2}}$
e_2^*	$\left(\frac{\alpha}{k_1}\right)^{\frac{\alpha}{2}} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{\frac{2-\alpha}{2}}$	$\left(\frac{\alpha}{k_1}\right)^{\frac{\alpha}{2}} \left(\frac{1-\alpha}{k_2}\right)^{\frac{2-\alpha}{2}}$
X^*	$p_1 - p_2 + \frac{1}{2}\left(\frac{\alpha}{k_1}\right)^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha}$	
Y^*	$p_2 + \frac{1-\alpha^2}{4}\left(\frac{\alpha}{k_1}\right)^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha} - \frac{1}{2} f_2 (1-\beta)^2 \sigma^2$	
Z^*	$p_1 + \frac{3-\alpha^2}{4}\left(\frac{\alpha}{k_1}\right)^{\alpha} \left[\frac{(1-\alpha)^2}{2k_2}\right]^{1-\alpha} - \frac{1}{2} f_2 (1-\beta)^2 \sigma^2$	$p_1 + \frac{1}{2}\left(\frac{\alpha}{k_1}\right)^{\alpha} \left(\frac{1-\alpha}{k_2}\right)^{1-\alpha} - \frac{1}{2} f_2 (1-\beta)^2 \sigma^2$

4.3. Numerical Analysis

To further analyze the relationship between each decision variable and the degree of contribution α and the share of benefit distribution β, GeoGebra is applied for numerical simulation calculation. Assuming the basic parameters $\sigma^2 = 100$ and $f_2 = 1/2$, and since p_1 and p_2 are fixed values that do not affect the analysis results, three simulations are made in the simulation process, assuming that p_1 and p_2 are both 0:

Simulation 1: set $k_1 = 0.2$, $k_2 = 0.8$;

Simulation 2: set $k_1 = 0.5$, $k_2 = 0.5$;

Simulation 3: set $k_1 = 0.8$, $k_2 = 0.2$.

The following images of the degree of contribution α and the share of benefit distribution β concerning each of the other variables can be obtained, as shown in Figures 1 and 2.

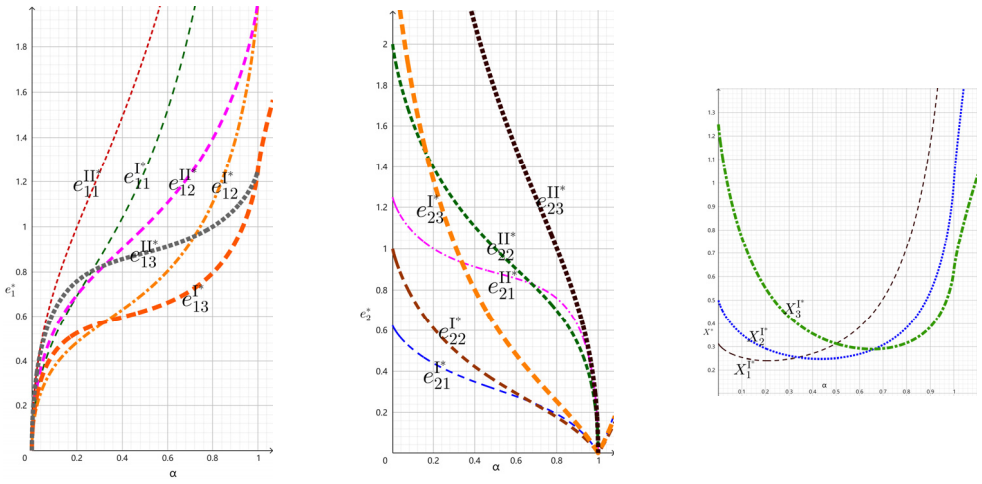


Figure 1. Comparison of e_1, e_2, X, and α.

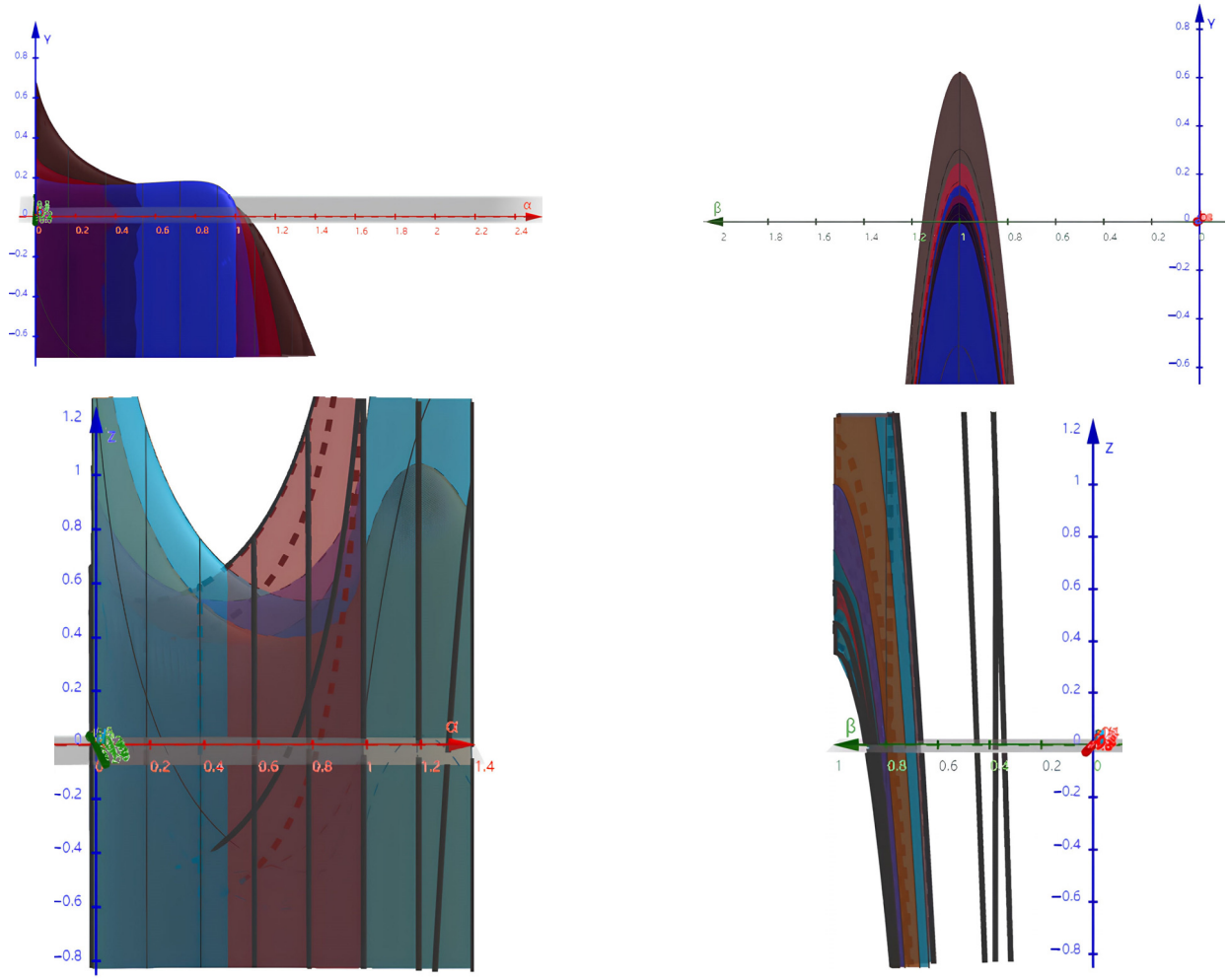


Figure 2. Comparison of the positive lateral relationship between Y, Z and α and β.

Figure 1 shows that: (1) the effort level of the main contractor, e_1, increases with the increase of its contribution level, α; the increase in e_1 decreases and then increases with the increase in α; the increase in e_1 decreases with the increase in k_1; and the effort level in the collectivist decision is greater than that in the egoist decision. (2) The level of effort of subcontractors decreases as the level of effort of the general contractor increases, the magnitude of the decrease decreases and then increases as k_2 decreases, and the level of effort is also higher in the collectivist decision than in the egoist decision. (3) Until the contribution level α reaches a certain value α_0^X, the optimal benefit X obtained by the general contractor increases as its effort cost coefficient k_1 becomes larger and decreases as k_1 becomes larger after α_0^X. Moreover, under the egoistic decision, the tendency of X to decrease gradually increases as k_1 increases, and the tendency to increase gradually after reaching α_0^X slows down. This may be because as k_1 increases, the cost to the general contractor will increase, and when the benefits are certain, the benefits will be reduced accordingly. The highest profit of the general contractor is obtained when $\alpha < 0.5$, $k_1 > k_2$ and $\alpha > 0.5$, $k_1 < k_2$.

It can be seen from Figure 2 that: (1) the optimal benefit Y obtained by the subcontractor decrease in the egoistic decision model and becomes progressively greater as k_2 decreases. The highest returns to subcontractors are obtained when $\alpha < 0.5$, $k_1 > k_2$ and $\alpha > 0.5$, $k_1 < k_2$. The image of the optimal return Y obtained by the subcontractor about the share of the general contractor's benefit distribution β conforms to a normal distribution, and the optimal return of the subcontractor is proportional to the general contractor's benefit distribution in the range of $0 < \beta < 1$. (2) The optimal return of the general contractor's supply chain system as a whole decreases and then increases as α increases, and the return

under collectivist decision-making is higher than that under egoistic decision-making. As k_1 increases, the decreasing trend of Z gradually increases before reaching α_0^Z, and the increasing trend becomes slower after reaching α_0^Z, which is consistent with the change in the general contractor's optimal benefit, further highlighting that the influence of the general contractor's effort cost coefficient on the overall return of the supply chain of general contracting works can also be understood: under the collectivist decision-making model, the overall return of the supply chain system is highest when $\alpha < 0.5$, $k_1 > k_2$ and $\alpha > 0.5$, $k_1 < k_2$. The optimal return of the supply chain system as a whole is positively related to the share of benefits allocated to the general contractor, which means that as the share of benefits allocated to the general contractor β increases, the overall benefits of the supply chain system of general contracting projects also gradually increase.

5. Distribution of Benefits from Multiple Collaborations

Collaboration between teams reduces the cost for the main contractor to find other subcontractors and reduces the benefit-gaming process at the beginning of each collaboration between the two parties. Cooperation between the main contractor and subcontractors is based on both parties being satisfied with the last benefit distribution result, i.e., if one party questions the benefit distribution result, the next cooperation will not be established, and only when both parties receive the contracted bonus percentage and are satisfied with the benefit distribution result will the opportunity for further cooperation arise. As the amount of cooperation increases, the subcontractors gradually tend from risk-averse to risk-neutral, i.e., $f_2 \to 0$. (Assuming that subcontractors are risk-neutral in the following analysis.)

The cooperation between the subjects of the supply chain system of general contracting works is often based on the repeated game between the two parties. At the beginning of the cooperation, the two parties will reach some kind of agreement, promising that both parties will give priority to the overall interests of the supply chain system, and the level of effort exerted by both parties will be $e_1^{II^*}$ and $e_2^{II^*}$, respectively, and when one party defaults, the level of effort of both parties will change to the sub-optimal $e_1^{I^*}$ and $e_2^{I^*}$.

If in a certain cooperation the general contractor does not pay the level of effort $e_1^{II^*}$ and the subcontractor still proceeds according to the agreement, i.e., if the general contractor defaults in this cooperation, his level of effort is $e_1^{I^*}$ and the subcontractor pays the level of effort $e_2^{II^*}$, but after the end of this cooperation, the subcontractor will discover the default of the general contractor. Then, in this cooperation, the general contractor's gain from default is:

$$W_1 = \left(\beta' \lambda u e_1^{I^{*}\alpha} e_2^{II^{*}1-\alpha} - \beta' \lambda u e_1^{II^{*}\alpha} e_2^{II^{*}1-\alpha}\right) + \frac{1}{2} k_1 \left(e_1^{II^{*}2} - e_1^{I^{*}2}\right) \tag{8}$$

After this default, the subcontractor will not comply with the agreement in its subsequent actions, so the loss of the main contractor in each subsequent period is:

$$S_1 = \left(\beta' \lambda u e_1^{II^{*}\alpha} e_2^{II^{*}1-\alpha} - \beta' \lambda u e_1^{I^{*}\alpha} e_2^{I^{*}1-\alpha}\right) + \frac{1}{2} k_1 \left(e_1^{I^{*}2} - e_1^{II^{*}2}\right) \tag{9}$$

If the discount rate for the general contractor is γ_1, the present value of the cost of default is:

$$\sum_{n=1}^{\infty} \left(\frac{1}{1+\gamma_1}\right)^n S_1 = \frac{1}{\gamma_1} \left[\left(\beta' \lambda u e_1^{II^{*}\alpha} e_2^{II^{*}1-\alpha} - \beta' \lambda u e_1^{I^{*}\alpha} e_2^{I^{*}1-\alpha}\right) + \frac{1}{2} k_1 \left(e_1^{I^{*}2} - e_1^{II^{*}2}\right)\right] \tag{10}$$

The case of no default by the general contractor is Equation (8) $\leq$ Equation (10), and the critical value of the general contractor discount rate when taking the critical condition is:

$$\gamma_1 = \frac{\left(\beta' \lambda u e_1^{II^{*}\alpha} e_2^{II^{*}1-\alpha} - \beta' \lambda u e_1^{I^{*}\alpha} e_2^{I^{*}1-\alpha}\right) + \frac{1}{2} k_1 \left(e_1^{I^{*}2} - e_1^{II^{*}2}\right)}{\left(\beta' \lambda u e_1^{I^{*}\alpha} e_2^{II^{*}1-\alpha} - \beta' \lambda u e_1^{II^{*}\alpha} e_2^{II^{*}1-\alpha}\right) + \frac{1}{2} k_1 \left(e_1^{II^{*}2} - e_1^{I^{*}2}\right)} \tag{11}$$

Similarly, if a subcontractor defaults in a particular collaboration, its gain from default is:

$$W_2 = (1-\beta')\left(\lambda u e_1^{II^*\alpha} e_2^{I^*1-\alpha} - \lambda u e_1^{II^*\alpha} e_2^{II^*1-\alpha}\right) + \frac{1}{2}k_2\left(e_2^{II^*2} - e_2^{I^*2}\right) \tag{12}$$

The cost of default for a subcontractor is:

$$\sum_{n=1}^{\infty}\left(\frac{1}{1+\gamma_2}\right)^n S_2 = \frac{1}{\gamma_2}\left[(1-\beta')\left(\lambda u e_1^{II^*\alpha} e_2^{II^*1-\alpha} - \lambda u e_1^{I^*\alpha} e_2^{I^*1-\alpha}\right) + \frac{1}{2}k_2\left(e_2^{I^*2} - e_2^{II^*2}\right)\right] \tag{13}$$

The case in which the subcontractor does not default is Equation (12) $\leq$ Equation (13), and the critical value of the subcontractor discount rate when taking the critical condition is:

$$\gamma_2 = \frac{(1-\beta')\left(\lambda u e_1^{II^*\alpha} e_2^{II^*1-\alpha} - \lambda u e_1^{I^*\alpha} e_2^{I^*1-\alpha}\right) + \frac{1}{2}k_2\left(e_2^{I^*2} - e_2^{II^*2}\right)}{(1-\beta')\left(\lambda u e_1^{II^*\alpha} e_2^{I^*1-\alpha} - \lambda u e_1^{II^*\alpha} e_2^{II^*1-\alpha}\right) + \frac{1}{2}k_2\left(e_2^{II^*2} - e_2^{I^*2}\right)} \tag{14}$$

From the above analysis, the condition that the general contractor and subcontractor will still choose to cooperate at stage n + 1, i.e., Equation (8) $\leq$ Equation (10) and Equation (12) $\leq$ Equation (13) hold, and the equilibrium result of achieving Pareto optimality at each stage is that both parties choose to cooperate. Thus, the equilibrium result of repeated games between the main bodies of the general contracting engineering supply chain system is that both parties choose to cooperate.

6. Discussion

First, all benefits are inversely proportional to the effort cost factor [46,47]. In a general contracting supply chain, the optimal benefits for the general contractor, subcontractors, and the supply chain system as a whole are inversely proportional to the respective effort cost coefficients of the general contractor and subcontractors, i.e., the larger the cost coefficients of both, the smaller their benefits. This is because when general contractors and subcontractors do not play a role in the supply chain system, they must pay more costs to achieve the same level of effort, which will cause both of them to obtain fewer benefits, making the supply chain system generate fewer benefits, as Ma, D.Q., and Hu, J.S. [48] found that the optimal benefits are inversely proportional to their own cost coefficients. This indicates that in the engineering supply chain, attention should be paid to the efforts of the general contractor and subcontractors themselves and that the level of effort of both should be monitored.

Secondly, the benefits of the supply chain system are proportional to the contribution of the general contractor [47] and inversely proportional to the share of subcontractor benefits. Both in egoistic decision and in collectivist decision, the optimal gain of the total supply chain system gain of the general contracting project increases with the increase in the general contractor's contribution degree α and decreases with the increase of the share of subcontractor's benefit distribution, that is, the greater the general contractor's contribution degree or the smaller the share of subcontractor's benefit distribution, the more the overall gain of the supply chain system gain, which is because the general contractor either wants to This is because the general contractor must contribute whether it wants to receive the maximum benefit for itself or create the maximum benefit for the supply chain as a whole, and the greater its contribution, the more the total benefit of the supply chain system will be, which is in line with the objective situation. From this, it can be understood that the general contractor can be motivated to improve its own efforts by appropriately increasing its benefit distribution ratio [49,50], thus making the cooperation between the general contractor and subcontractors more efficient.

Finally, cooperation leads to optimal benefits for the supply chain system [51]. The cooperation selection mode of the general contractor and subcontractor is not related to the degree of contribution, and the general contractor prefers the egoistic decision mode,

while the subcontractor prefers the centralist decision mode. Although both decisions can make the supply chain system gain, the overall supply chain system should prefer the centralist decision mode to achieve the optimal gain [46,52]. Wu, C.F. et al. [46] showed in a study that "under decentralized decision-making, manufacturers and retailers are independent subjects pursuing the maximization of their own interests, while centralized decision-making is an idealized optimal decision, which is the benchmark for comparing the actual situation". The research subjects are different, but the research results are similar. At the same time as Wang, Z.S. et al. [53] found that government departments and social capital sectors can gain more benefits after adopting the cooperative model. The same is true for the general contractor and subcontractor; both of them can only cooperate to obtain the maximum benefit, and the optimal outcome of both sides of the game many times is cooperation [54], which is consistent with reality.

7. Conclusions

In the supply chain system of general contracting projects, the benefit allocation problem between general contractors and subcontractors is related to the synergistic cooperation between them, and the effective and reasonable allocation of benefits between them can promote further cooperation between them. By using the Cobb–Douglas function to establish the benefit distribution model between general contractors and subcontractors in engineering projects and solving and simulating, we find that all benefits are inversely proportional to the effort cost coefficient; in any case, the effort level of general contractors and subcontractors is positively related to their own contribution degree and negatively related to each other's contribution degree, and the benefits of the general contracting supply chain system are positively proportional to the contribution degree of general contractors and subcontractors. The benefit distribution between the general contractor and subcontractor is inversely proportional to the share of the subcontractor's benefit; analyzing the benefit distribution between the general contractor and subcontractor when they cooperate many times, we can understand that the condition that both parties will still choose to cooperate at stage n + 1 is that the benefit of default is not greater than the respective cost of default, and the equilibrium result of achieving Pareto optimality at each stage is that both parties choose to cooperate.

The paper only considers the benefit distribution of synergistic cooperation between general contractors and subcontractors in the supply chain of general contracting projects when they are risk-neutral and risk-averse and fails to consider the benefit distribution between them when they are both risk-averse, and further discussion and analysis of the benefit distribution of synergistic cooperation between general contractors and other subcontractors and material suppliers are needed in future research.

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