Game Analysis of Software Development Price

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Abstract

How to effectively control the cost of software development and improve the cost efficiency has always been the focus of party A. Software cost estimation process is discussed in this paper, we studied the purchasing behavior of both sides, based on the game theory to build the party A and party B the purchase price game model of the enterprise, won the party A and party B to take different strategies of Nash equilibrium, the two sides are discussed under different parameters of the strategy, the analysis result was combing inductive. It is pointed out that demonstration + price review is the best choice of party A's price control method, which can reduce the cost of audit and have a deterrent effect on party B's enterprises, so as to standardize the quotation behavior of enterprises. The analysis also points out that the control of software development cost should be balanced comprehensively, and economic benefit should not be emphasized blindly.

Keywords

Software procurement, Demonstration, Price review, Game

1. Introduction

Software is a special product, which is the crystallization of mental work. With the rapid development of modern information technology, the requirements of equipment interconnection are becoming higher and higher. Software plays an increasingly important role in national and social economic life. The economic research on software originated from the United States, Britain and other countries, among which Boehm B. W and Putnam L.H And Banard L. Boehm put forward the Constructive Cost Model (COCOMO) in the process of studying cost calculation, and provided the workload calculated by software scale, so as to determine the empirical statistical model of cost and duration. In 2000, he published the monograph Software Cost Measurement -- COCOMOII Model Method [1]. The U.S. Department of Defense supported the publication of Software Development Cost Estimation Manual, which clearly defined the process of software cost estimation and recommended some parametric cost tools, such as COCOMOII, Price-S, SEER-SEM, SLIM, etc. [2].

Development enterprises can calculate the cost of software system according to the above methods. However, due to various reasons, development enterprises tend to over report development costs in order to obtain higher income. How to analyze the behaviors of party A and party B and their influence on software procurement, game theory provides an effective path.

Game theory is the study of decision-making and the equilibrium of decision-making when the behavior of decision-making bodies directly interacts with each other. In economics, game theory studies the decision-making problem and equilibrium problem when the decision of an economic subject is affected by the decision of other economic subjects, and the corresponding decision of the economic subject in turn affects the choice of other economic subjects [3]. Based on game theory, Baoping Liu et al. [4] established a game model between party A and party B, analyzed the drawbacks of the current military product pricing model and proposed solutions.Shihui Wu et al. [5] established a game model between party A and party B under the incentive and constraint pricing model, and drew guiding conclusions and suggestions through analysis of the model. Guojiang Hou et al. [6] conducted in-depth analysis on Nash equilibrium of pricing negotiation game, expansion of model and negotiation

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strategy, and obtained the key factors affecting pricing negotiation. Qin Wang et al. [7] used the multi-stage game theory to construct a model and studied the business motivation and strategic behavior of enterprises participating in the open source movement. They believed that the fundamental reason for enterprises participating in the open source movement was the expectation of future benefits of this innovative model. Game theory is an important theoretical tool to study the behavior of both sides of procurement, but there are few related literatures in software procurement.

At present, party A mainly adopts two price control modes of price review + price review and price review for the purchase of single-source software. This paper establishes a game model based on these two modes for party B's enterprise to overstate/overstate costs, and makes a detailed analysis of the model [8]. Firstly, the software cost estimation process is introduced, and the possible reasons for overstatement of software cost are pointed out. Then, the game matrix of party A and party B is established to calculate the Nash equilibrium point, analyze the parameter characteristics of the Nash equilibrium point and the conditions for its establishment, and discuss the strategy selection tendency of both parties under different parameter conditions. The influence of the value of verification reduction coefficient on party A (buyer) and party B's enterprise (supplier) is studied. At the end of the paper, the results are analyzed and the suggestions for party A to control the purchase cost are given.

2. Game analysis of price management mode of party A and quotation mode of party B

2.1. Behaviors of both parties

In the principal-agent relationship between party A and party B's enterprise, the price department of party A plays a core role in the process of software development and pricing, playing games with party B's enterprise on behalf of party A; The enterprise of party B has a large amount of information about its own development status and is in an information advantage position. According to the existing laws and regulations, party A mainly controls the software price through demonstration and evaluation [8]. Demonstration, that is, party A shall demonstrate the development cost of the project in the demonstration stage of the project establishment, estimate the development cost and profit based on the objective laws of software development and historical data on the basis of the project's realization objectives and work required. Evaluation can not only restrain the false software development cost, but also identify some unnecessary software functions and management process, and control the project work structure from the source, so as to control the development consumption.

Due to the superiority of the enterprise in cost information and the lack of strong punishment measures from party A, the enterprise always tends to falsely report the cost in order to maximize the benefits. This section studies the quotation mode of party B's enterprise. It is assumed that party A can choose two strategies, namely, false or actual cost reporting.

2.2. Nash equilibrium

A Nash equilibrium is a situation in which each player cannot improve his situation as long as the others do not change their strategy. Nash proved that Nash equilibrium exists on the premise that each participant has only a limited number of strategies to choose from and mixed strategies are allowed. Its definition is as follows:

Assuming that there are n players involved in the game, if in a certain situation no player can act alone to increase the returns (that is, in order to maximize their own interests, no single party is willing to change its strategy), then the strategy combination is called Nash equilibrium.

All player strategies constitute a Strategy Profile. Nash equilibrium is essentially a non-cooperative game state.

2.3. Building a game model

Assuming that the actual cost of software system development of party B's enterprise is C_0, the standard income of the enterprise is $C_0(1+\alpha)$, where α is the cost profit margin of party B's enterprise. At this time, party A gain of R, to carry out the appraisal can produce consumption, for $C(p)$, p for the master degree of software development, information of party A, which is held by party A the information such as the software realization function, technical requirements, and party B enterprises or social software system efficiency, the average person month rate, etc., might as well assume that $C(p)$ is a continuous function of p, $0 \le p \le 1$, $C'(p)>0$, and $C(0)=0$. In addition, the software development cost C_0 declared by party B's enterprise will produce consumption, which is recorded as x_0. If the price is falsely stated, the declared consumption is x_1, and $x_1 \ge x_0$.

The strategic combination and corresponding benefits of party A and party B are as follows:

(1) party A conducts price review and party B's enterprise falsely reports costs. After price examination, The revenue of party A is $R-C(p)-(1-p)X$, where X is the false revenue of party B's enterprise, $X=C_0(1+\alpha)(x_1-x_0)/x_0$. The total revenue of party B shall be cost revenue plus false revenue minus declaration consumption, namely $C_0(1+\alpha)+(1-p)X-x_1$.

(2) party A shall evaluate the price, and party B shall report the actual cost. After verification by party A, the profit shall be $R-C(p)$. The revenue of party B's enterprise is $C_0(1+\alpha)-x_0$.

(3) party A fails to evaluate the price and party B's enterprise falsely reports the cost. If party A does not evaluate the price, the profit will be $R-X$. The profit of party B's enterprise's false cost statement is $C_0(1+\alpha)+X-x_1$.

(4) party A does not evaluate the price, and party B's enterprise reports the actual cost. In this case, party A's revenue is R, and enterprise revenue is $C_0(1+\alpha)-x_0$.

The above analysis is shown in the benefit matrix in **Table 1**.

Table 1. Enterprise benefit matrix of party A and party B

party A	party B	
	Misrepresentation of costs	Actual cost
Implement price review	$R-C(p)-(1-p)X$, $C_0(1+\alpha)+(1-p)X-x_1$	$R-C(p)$, $C_0(1+\alpha)-x_0$
No price review	$R-X$, $C_0(1+\alpha)+X-x_1$	R, $C_0(1+\alpha)-x_0$

Assume that the probability of party B's enterprise falsely reporting costs is r, $1 \ge r \ge 0$, and the probability of party A verifying the true costs by means of price evaluation is s, $1 \ge s \ge 0$.

(1) Given r, The expected revenue of party A in the case of implementation of review (s=1) and non-implementation of review (s=0) is:

$$U_1(1,r)=r[R-C(p)-(1-p)X]+(1-r)[R-C(p)] \tag{1}$$

$$U_2(0,r)=r[R-X]+(1-r)R \tag{2}$$

When there is no difference between party A and party B, the optimal solution of false cost is obtained. If $U_1=U_2$, we can get:

$$r^*=\frac{C(p)}{pX}=\frac{C(p)}{pC_0(1+\alpha)(x_1/x_0-1)} \tag{3}$$

When the probability of party B's enterprise falsely reporting costs is less than r^*, The optimal choice of party A is not to carry out the evaluation; when the probability is greater than r^*, the optimal choice is to carry out the evaluation; When the probability of party B's enterprise falsely reporting costs is equal to r^*, party A randomly chooses to implement or not to implement the evaluation.

(2) Given s, the expected benefits of party B's enterprise's falsely reported cost (r=1) and actual reported cost (r=0) are:

$$U_3(s,1)=s[C_0(1+\alpha)+(1-p)X-x_1]+(1-s)[C_0(1+\alpha)+X-x_1] \tag{4}$$

$$U_4(s,0)=s[C_0(1+\alpha)-x_0]+(1-s)[C_0(1+\alpha)-x_0] \tag{5}$$

When there is no difference between the software cost falsely reported by party B's enterprise and the actual software cost reported by party B, party A can obtain the optimal solution of price evaluation. If $U_3=U_4$, we can get:

$$s^*=\frac{X-x_1+x_0}{pX}=\frac{1}{p}[1-\frac{x_0}{C_0(1+\alpha)}] \tag{6}$$

When the probability of price evaluation by party A is less than s^*, the optimal choice of party B's enterprise is to falsely report the cost; when the probability of price evaluation by party A is greater than s^*, party B's enterprise chooses to report the actual cost; When the probability of price evaluation of party A is equal to s^*, party B's enterprise randomly selects false or actual cost.

According to Equations (3) and (8), the mixed strategy Nash equilibrium of the game [3] is:

$$(r^*,\ s^*)=(\frac{C(p)}{pC_0(1+\alpha)(x_1/x_0-1)},\frac{1}{p}[1-\frac{x_0}{C_0(1+\alpha)}]) \tag{7}$$

According to (9), this Nash equilibrium is related to cost C_0 of party B's enterprise, cost profit margin α, party A's price examination consumption $C(p)$, and enterprise declaration consumption x_0.

2.4. Game model analysis

If $\beta=C_0(1+\alpha)/x_0$ is the declared comprehensive rate, that is, the consumption rate of party B's declared software development income, and $\Delta=x_1-x_0$ is party B's falsely reported input, then

$$r^*=\frac{C(p)}{p\beta\Delta} \tag{8}$$

r^* is inversely proportional to the reported comprehensive rate and false report input of party B's enterprise, that is, the higher the software development cost of party B's false report, the lower the probability of false report. It will be found later that party A has a higher degree of software information and the higher the false report amount, the higher the probability of false report being detected, which will reduce the probability of false report by party B.

We take the partial derivative of r^* star with p

$$\frac{\partial r^*}{\partial p}=\frac{C'(p)p-C(p)}{p^2X}$$

If $p\neq0$, d[$C'(p)p-C(p)$]/d$p=C(p)p$.

1) If the $C''(p)<0$, because front assumption $C'(p)>0$, $C(0)=0$, $C'(p)p-C(p)<0$ ($p>0$), r^* is the reduction function of p.

2) If the $C''(p)>0$, because front assumption $C'(p)>0$, $C(0)=0$, $C'(p)p-C(p)>0$, ($p>0$), r^* is increasing function of p.

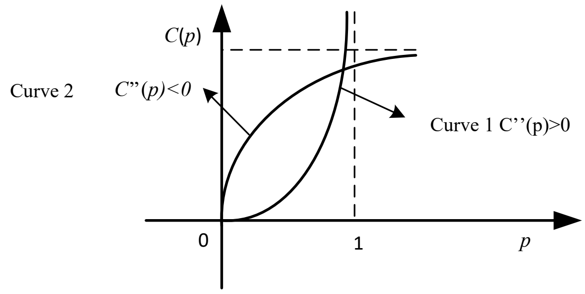

Figure 1. *C(p)* Schematic diagram.

Curve 1 and curve 2 in **Figure 1** correspond to $C''(p)>0$ and $C''(p)<0$ respectively. Curve 1 shows that with the increase of party A's mastery of information, when p approaches 1, the evaluation cost rises rapidly and has an infinite trend of increase. Curve 2 indicates that *C(p)* is also meaningful when $p>1$, and there is an upper limit. Theoretically, both of these scenarios are possible, but in general, $0\le p\le 1$ makes sense, and curve 1 is more consistent with the hypothesis.

If $C''(p)<0$, then with the increase of party A's information mastery, The probability of party B identifying the false statement increases and party B's willingness to false statement decreases. The implied condition is that There is an upper limit for party A's consumption of price review, and party A can try to improve its information mastery.

If $C''(p)>0$, party B's willingness to falsely report will increase with the increase of party A's information mastery. The increase of implied information in this leads to a sharp rise in the cost of party A's evaluation, which reduces the willingness of party A to evaluate, so that the probability of false reporting by party B increases.

From (3), it is easy to know that $r^*\ge 0$. To make r^* meaningful, there should also be $r^*\le 1$, i.e

$$\frac{C(p)}{pC_0(1+\alpha)(x_1/x_0-1)}\le 1\Rightarrow\frac{C(p)}{C_0(1+\alpha)(x_1/x_0-1)}\le p \tag{9}$$

It is easy to know from (6) that if $s^*\ge 0$ is always true, and if s^* makes sense, there should also be $s^*\le 1$. Combining with (9), there is

$$1-\frac{x_0}{C_0(1+\alpha)}\le p\le 1 \tag{10}$$

(9) and (10), from the perspective of rationality, easy to know

$$\frac{C(p)}{C_0(1+\alpha)(x_1/x_0-1)}\le 1-\frac{x_0}{C_0(1+\alpha)}\le p$$

According to the analysis of $C''(p)$ in Figure 1, the cost of evaluation should not be too high. On the other hand, according to the actual project experience, the application cost should be far less than the software development income.

It is easy to know from Formula (6) that s^* is a decreasing function of p, that is, with the increase of party A's grasp of software information, the probability of price evaluation decreases. This is because the fuller the information is, the more party A knows about the cost of software development, which leads to the lower willingness of party A to evaluate the price. Second, s^* is an increasing function of β. The larger β is, the higher the income obtained by unit investment when party B reports, which means that the cost of party B's false report is lower. party A tends to restrain the impulse of party B's false report with price review, which also reduces the probability of party B's false report. In addition, the higher the cost C_0, the higher the cost margin α, the higher the probability of party A's evaluation, the larger the project, the more party A is inclined to know the cost base of the evaluation, so as to avoid the loss caused by false reporting, which is also the reason for the decrease of the actual reporting probability of party B.

Finally, the influence of x_0 and x_1 is discussed.

1) Under normal circumstances, the application of *r&d* price according to existing software price regulations will always produce certain consumption x_0. The partial derivative of equation (3) r^* to x_0 can be obtained

$$\frac{\partial r^*}{\partial x_0}=\frac{C(p)}{pC_0(1+\alpha)}\frac{x_1}{(x_1-x_0)^2}>0 \tag{11}$$

That is, r^* is an increasing function of x_0. The greater the declared investment of party B, the greater the probability of false report. party B shall make up for the loss caused by the declaration.

From (6), it is easy to know that s^* is the subtractive function of x_0. The greater the investment declared by party B, the less probability party A will evaluate the price. Whether party B makes false statements does not affect party A's willingness to review prices, because before the start of the review, It is difficult for party A to judge whether party B makes false statements based on the information it has mastered.

2) In extreme cases, if x_0 is small, it will be approximately 0 (such situation is reported according to other price regulations), and then (7) will become $(r^*, s^*) = (0,1/p)$. To make s^* meaningful,

p=1. This means that under the condition of 0 declaration consumption, on the one hand, when the probability of party B's false declaration is greater than 0, party A always implements the appraisal; On the other hand, party B always misstates the cost when the probability of party A's evaluation is less than 1. That is, in the declaration does not produce consumption, party B always choose false report, and party A always choose to review the price. From the perspective of benefit matrix, since p=1, party B will not obtain additional income, and party A will pay the highest price evaluation cost, and party A can only choose the price evaluation to avoid the risk because of the risk of losing party B's falsely reported income.

3. Enlightenment from analysis results

(1) Due to the characteristics of the software, party A has a high degree of software information, which has a great impact on suppressing the false cost reporting of party B's enterprise and reducing party A's consumption of price evaluation: Because of software core functions are proposed or approved by party A, party A can also according to their own needs to adjust the project, such as the function of the change and increase or decrease, running environment, *etc*., so party A can according to master the information such as the historical experience, social average cost appraisal cost upper limit, which means the appraisal cost is controllable. At this time, with the increase of party A's information level, the probability of party B's false cost report will decrease, and party A's willingness to evaluate price will also decrease accordingly. This is different from the conclusion in literature [4].

(2) The greater the declared investment of party B, the greater the probability of false statement, which is to supplement the declared loss. Therefore, we should take measures to reduce party B's consumption of declaration, so as to reduce various losses caused by false declaration and benefit both party A and party B.

(3) The amount overstatement has a negative impact on the probability of party B's overstatement. As party A has a high degree of information about the software project, the higher the amount overstatement by party B, the greater the risk of being discovered, which results in the lower willingness of party B to overstatement. False quota does not directly affect party A's willingness to evaluate.

(4) The larger the project is, the more Inclined party A is to evaluate the price, and the less impact of the evaluation consumption is, which also leads to the lower willingness of party B to falsely report.

4. Advice

(1) The characteristics of the software project require party A to master a high degree of information, so party A shall, on the one hand, strengthen the preliminary demonstration and try to refine the functions of the software; On the other hand, we should focus on establishing software information (including price information) collection mechanism, constantly collect and update software information, identify reusable functions, and calculate the average consumption of work society.

(2) Innovate party B's contract declaration or party A's software cost evaluation method.

(3) party A is inclined to adopt whichever price control means bring more economic benefits. However, the economic benefit is only one aspect of party A's evaluation of the purchase price. The use value and technological development also need to make comprehensive trade-offs in the process of cost control. This requires party A's price management department and demonstration institutions to deal with the relationship between short-term economic benefits and long-term social and use benefits, so that software development, procurement, maintenance and security work benign development, so that the limited development funds to play the most effective.

(4) If The enterprise of party B always chooses to falsely report the cost, the optimal choice of party A is to determine the development cost by means of evaluation. The software development process is controlled by price planning, the development activities of enterprises are restrained, the false cost is eliminated, the final software purchase price is determined by price audit, and the software development cost information base is improved to provide support for a new round of software purchase price argument.

If the software enterprise overstate the cost, the main method is to overstate the software function, such as adding unnecessary function modules, overstate the number of lines of code, etc. The evaluation can identify unnecessary software functions according to party A's purchase requirements, but it requires the support of relevant expert teams and large investment in training professionals. The pro-phase investment is large and the demonstration cost is high. If the project cost is small, the price review should be more cost-effective.

The above suggestions are put forward according to the analysis results and problems encountered in the process of software development price demonstration, which is feasible but relatively broad. It is suggested that Party A and Party B should further study to find a software pricing method that meets the interests of both parties.

5. Conclusion

At present, party A mainly adopts two methods to control software development costs: price review and no price review, but there is no theoretical explanation on which method is more advantageous. This paper first analyzes the process of software development cost estimation, points out the false software development cost and then analyzes the influence of party A's software purchase price control mode on party A and party B by using game model. A game model is established to obtain the Nash equilibrium when party A and party B adopt different strategies. The analysis results indicate that whether party B's enterprises falsely report or actually report costs, demonstration + price review can play a good role in reducing audit costs and producing a deterrent effect on party B's enterprises. The price control mode to be selected is directly related to its reduction capacity. party A shall make a comprehensive balance based on market conditions and technological development and other factors, instead of blindly pursuing economic benefits. In general, the purchase price control mode of party demonstration + price review is the best choice for party A and can achieve the best results.

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