

Bidding Strategy Model of Medicine in Composite Base Price Based on Game Theory

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Abstract: Medicine bidding purchasing is a typical competitive activity of game nature, and game theory can be used to analyze the price strategies that bidders may take under different bidding rules and the motivations of the bidders who offer prices lower than the cost under the circumstance of over-competition. In order to improve the efficiency of the medicine circulation market, bidding mechanism must be perfect and transparent. Meanwhile, market permission system should be established perfectly so as to abate over-competition and eliminate some enterprise's unfair action of bidding price less than the cost. Composite bidding base price is compound formed based on the base price of both bidders and tender, generally we take the arithmetic mean of the bidding quotations together multiplied by the corresponding weight with the tender base multiplied by the corresponding weight as a pre-tender evaluation. This article first accurately calculate the tender offer which could get the perfect score, and then find the offer range of the highest point, in which the offer in this context could win the subject matter. It will prove that compound bidding price is rational and feasible by analyzing compound bidding price with its bidder strategy and comparing bidding under compound bidding price and single stage sealed bidding.

Key word: game theory; composite base price; bidding strategy; bidding purchasing of medicine

I. Introduction

Despite the current existence of all kind of criticisms to the centralized procurement of medicines, tendering is still an effective means of the introduction of market competition and lower prices of medicines supply. So, it's still of great important practical significance to explore and study the medicine bidding purchasing laws.

We can take the bidding process as a game process between the tender and bidders by analyzing bidding activities, rules, mechanisms and basic features. There are different forms of tender to explain different game model according to the bidding rules. The major results of the study on bidding offer strategy are in the follows:

Friedman^[1-2] model proposed by Friedman (1956), the target of this model is to calculate probability of a separate winning other competitors by calculating the probability of

the odds on a project. He assumed that the contractor is of noninterference to the win rate from each other, and use these rates to calculate the win rate of the odd winning all competitors. Marin Gates^[2-3] improved Friedman model (1967), He believed that the personnel resources and goods in the market can move freely, competitor's offer is not irrelevant with each other. Morin and Clough^[4-6] put forward the best offer margin model (1969) based on Friedman model, The model to achieve the contractor's business objectives by identifying the best gross profit in a certain period. It suggested that the number of competitors can be forecasted according to the average value that competitors have faced before and the type of tendering affect our probability of winning. Willenbrock^[7] proposed Willenbrock model (1973), indicated that under competitive bidding environment, the determination of the optimal offer can be transformed into risk decision-making problems, that is each offer is equivalent to the various program, Victory or failure is the only two natural state of the proposed offer, we can use a corresponding model of expected amount or expected utility value to determine the optimal pricing. The utility function introduced in model explicitly addressed bidding offer decision-making preferences and risk attitude of the bidding side under different size of tendering. Cart^[8] bring forward the opportunity cost pricing model (1982). He improved the optimal profitability pricing model and the opportunity cost is included in the analysis of competitive bidding, So that the decision-making on the project throughout the company or individual can reflect the company's position in a competitive market more deeply. Seydel and Olson^[9] (1991) presented multiple risk factors determine the tender offer method based on AHP. Deng Ju-long^[10] (1975) proposed Grey System, based on which Cao Li-wen use non equivalent weight objective situation decision-making method for foundation engineering bidding decision-making. It determines the gray decision-making goals and the weight vector from the factors affecting the bidding decision, uses the decision tree and the standard slip (VAR) as a quantified decision-making goals, so that the source of data of gray decision-making approach is more theoretical. Neural network pricing model was presented by Rumelhart and McClelland^[11] (1986), it use error back-propagation algorithm to eliminate errors. Dr. Yang Lan-rong^[12] in Central China University of Science and Technology proposed reported high rate model (CBRMBMD) based on case- reasoning, and Chua (2001)

established case-based reasoning Quotation System (CASEBID) according to the four categories of factors that affecting the pricing, and have verified the effectiveness of the system by Monte Carlo method.

In order to guarantee the people a safe and effective medication to prevent the company unrestricted access to let down the quoted price, medicine bidding should not only have to limit high-low circumscription, but also set the base price and standard top scientifically as a guidance^[13-14]. In view that drug and its circulation is an major issue related to public health, and its importance is self-evident, while China's drug procurement market is not standardized, it's inappropriate to adopt one-level sealed bidding, but rather the gradual introduction of composite base price bidding.

II .Modeling of Medicine Bidding Purchasing Based on Composite Base Price with Game Theory

Ideas and Target of Medicine Bidding Purchasing Based on Game Theory

The model is divided into four major sections that is proposing question, analyzing of data and information, modeling, model solution. In mathematic model, after determining pharmaceutical purchasing by composite base bidding, bidders involved in medicine bidding must work out the budget presentation after the synthesis of various costs (including logistics costs and production costs, etc.), profit and risks factors, and then adjust the quotation with a coefficient β on the basis of the budget, track and simulate hospital's base price. At the same time estimate other bidders quoted price by analogy to its own. As a result of that the determination of the tender's based price and the bidding quotation is an iterative process of fitting game, after repeated simulation, you can find quotes will become a stable value, so that can form a theoretical best quoted price. Finally in view of consideration of the risks and profits, we have to re-adjust the theoretical quotation with minimum-maximum limit coefficient β_1 and β_2 , so as to enable the quotation in a certain circumscription win the bidding target. Ideas and target of medicine bidding is as shown in figure 1. As the final offer should not only within the framework of the composite pre-tender, but the lowest, so the date especially deeding estimating and predicting should be as exact as possible.

Description of the problem and symbols explanation

Composite base price medicine bidding model can be described as follows: There is a medicine tender side and x medicine bidders, tender side gives a base price A

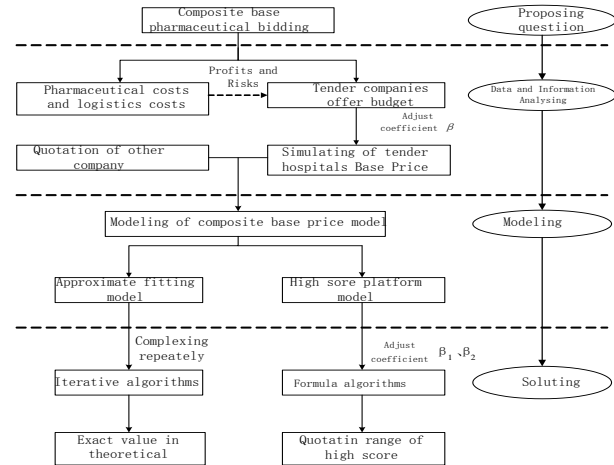


Figure 1 Ideas and target of pharmaceutical tendering based on game theory

according to the budget presentation, the bidders give according to their own budgets base price, $B_1, B_2 \dots B_n$. Suppose that

$$B = \sum_{i=1}^m \frac{B_i}{m} \quad (1)$$

(B is the arithmetic mean value of the quotations $B_1, B_2 \dots B_n$). Suppose in medicine bidding the weight coefficient of the tender side is λ , then weight coefficient of bidder's is $1-\lambda$, so that composite base number T can be expressed as

$$T = \lambda A + (1 - \lambda) B \quad (2)$$

In order to determine their own price, Bidders will consider the following factors comprehensively, such as the budget presentation, the estimated cost, expected profit of drugs, as well as the tender base price, composite base price and the effective average offer of all the bidders. The function relationship is,

$$Y = f \{ A, b, D, T, R, C, \pi \} \quad (3)$$

In this formula, A -the tender base, b -mean value of other bidders, D - bidder estimates (according to budget presentation), T - composite base price, R - risk factors, C -cost determined by bidder according to their own situation, π -expected profit after winning the bidding^[15].

Calculation of evaluation score

We provide the full score is 100 points, if the offer is 1% higher than the value of full score, reduce 2 points from 100 proportionately. That's to say, the evaluation score of B_i is

$$R_i = 100 - \frac{200(B_i - Y)}{Y} \quad (4)$$

Mathematical Model

Objective function:

If the quotation is equivalent to the value that composite base price reduced by β , and this quotation could get the full mark, well we call β the full score coefficient. So

$$Y = (1 - \beta)T = (1 - \beta)[\lambda A + (1 - \lambda)B] \quad (5)$$

Constraints:

- (1) Range of composite base price, $[-u, v]$, both u and v are percentage greater than zero, $Y \in [(1-u)T, (1+v)T]$.
- (2) The offer of bidders $B_i \in [(1-\sigma)T, (1+\sigma)T]$, σ is the coefficient of random quotes deviating from the standard normal distribution.
- (3) Ensure that quotation is above the bottom line of cost, and should guarantee the profit gains of the project, that is $Y \in [C, C + \pi], \pi \geq 0$.

III. Solution of Model

Solution of Approximate fitting model

Quotation will be within a certain range, also, the more participants, quotes will be more inclined to a stable value, which can be regarded as the limit of the objective function Y , which is the optimal solution. The quotation Y must be the minimum of the range to obtain the target because of the competitiveness. In practice, under compound bidding tender activities, evaluation standards are given; bidders can make use of game theory to predict the actual quotes according to the possible base, different quotations and the situation of its competitors. To a rational person, after repeated analysis in gambling, the quotation is always toward the optimal bidding price which could get the highest mark. Thus, the relationship between Y and D is fitting repeatedly again and again. That is $Y_{n+1} = f(Y_n)$

$$Y_{n+1} = (1 - \beta)[\lambda A + (1 - \lambda)B_n] = (1 - \beta)[\lambda A + (1 - \lambda)Y_n]$$

$$Y_n = (1 - \beta)[\lambda A + (1 - \lambda)B_{n-1}] = (1 - \beta)[\lambda A + (1 - \lambda)Y_{n-1}]$$

When $n=0$,

$$Y_1 = (1 - \beta)A;$$

When $n=1$,

$$Y_2 = (1 - \beta)[\lambda A + (1 - \lambda)Y_1] = (1 - \beta)A\{\lambda + (1 - \lambda)(1 - \beta)\};$$

So, $Y_2 - Y_1 = -\beta(1 - \lambda)(1 - \beta)A$,

$$(Y_{n+1} - Y_n) = (1 - \beta)(1 - \lambda) \times (Y_n - Y_{n-1}),$$

So

$$\frac{Y_{n+1} - Y_n}{Y_n - Y_{n-1}} = (1 - \beta)(1 - \lambda)$$

$$(Y_{n+1} - Y_n) = -\beta(1 - \lambda)(1 - \beta)A \times (1 - \beta)^n (1 - \lambda)^n = -\beta A (1 - \beta)^{n+1} (1 - \lambda)^{n+1}.$$

For $0 < 1 - \beta < 1$, $0 < 1 - \lambda < 1$, when $n \rightarrow \infty$,

$-\beta A (1 - \beta)^{n+1} (1 - \lambda)^{n+1} \rightarrow 0$, Means that after calculating

repeatedly, its impact on the final quotation would be negligible. At this time there are approximately: $Y_{n+1} = Y_n$,

That is: $Y_{n+1} = Y_n = (1 - \beta)[\lambda A + (1 - \lambda)Y_n]$, we get

$$Y_n = \frac{(1 - \beta)\lambda A}{1 - (1 - \beta)(1 - \lambda)} \quad (6)$$

Solution of High score platform model

However, since the price is the so-called perfect score price, it will cause the following two questions if this price be reported directly.

1) We should strive for the highest score to get the subject, but the relative maximum is OK. If you ensure that your score is of full mark, the offer price will be the lowest valid quoted price, so the profit will be reduced.

2) If the mean value of the random quotations is higher, so as the Composite base price, so that optimal price in theory will be eliminated for deviating (below) too much from the composite base price^[16].

So, usually the best price should be slightly higher than the theoretical optimal price. In fact, we should estimate a certain range below composite base price, the quotation in this range could get the target. This needs to revise the model, suppose that quoted price lower $\beta_1 \sim \beta_2$ than composite base price can get the highest mark. We call $[\beta_1, \beta_2]$ the region of highest score, $[\beta_1, \beta_2] \in [0, a]$. The estimates need to be applied flexibly in practice according to different requirements and characteristics of quotations, and in practice experience the range of $[\beta_1, \beta_2]$ is smaller 1% to 3% than β .

Suppose the deviation of quotations to composite base price is obedient to normal distribution, the probability of the quotations of bidders within the framework $[(1 - \sigma)T, (1 + \sigma)T]$ is relatively large.

$$\sigma = \frac{1}{n} \sqrt{\sum_{i=1}^n \left(\frac{B_i}{T_i} - 1 \right)^2} \quad (7)$$

n is the number of selected previous tender, σ is the coefficient of random quotes deviating from the standard normal distribution, B_i is the i th quotation, T_i is the i th the composite base.

(1) If quotations of all bidders is at the lower limit of the region of highest score, then

$$B_i = T_{\max} \times (1 - \beta) = T \times (1 + \sigma_i) \times (1 - \beta), \beta \in [\beta_1, \beta_2].$$

$$T_{\max} = \lambda A + (1-\lambda) \frac{\sum_{i=1}^m B_i}{m} = \lambda A + (1-\lambda) \frac{\sum_{i=1}^m T \times (1+\sigma_i) \times (1-\beta)}{m} \quad (8)$$

(2) If quotations of all bidders is at the lower limit of the region of highest score, then

$$B_i = T_{\min} \times (1-\beta) = T \times (1-\sigma_i) \times (1-\beta)$$

$$T_{\min} = \lambda A + (1-\lambda) \frac{\sum_{i=1}^m B_i}{m} = \lambda A + (1-\lambda) \frac{\sum_{i=1}^m T \times (1-\sigma_i) \times (1-\beta)}{m} \quad (9)$$

And

$$T_{\min} + T_{\max} = 2T \quad (10)$$

Combine (8) (9) (10), we get

$$T_{\min} = \frac{\lambda A \left\{ m + (1-\lambda)(1-\beta) \left[\sum_{i=1}^m (1-\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta)} \quad (11)$$

$$T_{\max} = \frac{\lambda A \left\{ m + (1-\lambda)(1-\beta) \left[\sum_{i=1}^m (1+\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta)} \quad (12)$$

So, $T_{\min} < T < T_{\max}$.

Then we can launch the range of quotation according to composite base price T .

$$B_{\min} = T_{\min} \times (1-\beta) = \frac{\lambda A (1-\beta) \left\{ m + (1-\lambda)(1-\beta) \left[\sum_{i=1}^m (1-\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta)} \quad (13)$$

$$B_{\max} = T_{\max} \times (1-\beta) = \frac{\lambda A (1-\beta) \left\{ m + (1-\lambda)(1-\beta) \left[\sum_{i=1}^m (1+\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta)} \quad (14)$$

For $\beta \in [\beta_1, \beta_2]$, There are four threshold:

$$\text{When } \beta = \beta_1, \quad B_{\min}(\beta_1) = \frac{\lambda A (1-\beta_1) \left\{ m + (1-\lambda)(1-\beta_1) \left[\sum_{i=1}^m (1-\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta_1)} \quad (15)$$

$$B_{\max}(\beta_1) = \frac{\lambda A (1-\beta_1) \left\{ m + (1-\lambda)(1-\beta_1) \left[\sum_{i=1}^m (1+\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta_1)} \quad (16)$$

When $\beta = \beta_2$,

$$B_{\min}(\beta_2) = \frac{\lambda A (1-\beta_2) \left\{ m + (1-\lambda)(1-\beta_2) \left[\sum_{i=1}^m (1+\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta_2)} \quad (17)$$

$$B_{\max}(\beta_2) = \frac{\lambda A (1-\beta_2) \left\{ m + (1-\lambda)(1-\beta_2) \left[\sum_{i=1}^m (1+\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta_2)} \quad (18)$$

$B_{\min}(\beta_2) < B_{\min}(\beta_1) < B_{\max}(\beta_2) < B_{\max}(\beta_1)$, the range

most likely to be successful is in the middle, and the final range of offer is

$$Y \in [B_{\min}(\beta_1), B_{\max}(\beta_2)]$$

In practice, the lower limit of the range is usually taken as the final offer, the final offer is

$$B_{\min}(\beta_1) = \frac{\lambda A (1-\beta_1) \left\{ m + (1-\lambda)(1-\beta_1) \left[\sum_{i=1}^m (1-\sigma_i) - m \right] \right\}}{m - m(1-\lambda)(1-\beta_1)} \quad (19)$$

We can see from the expression that the optimal offer is determined by the following factors, that is the highest score coefficient (β_1 and β_2) of composite base price, the weight coefficient (λ) of the tender, the coefficient (σ) of quotations of each bidders deviating from the composite base price, and the base price (A) of tender made after budget presentation. In the circumstance of giving the evaluation method, β_1 , β_2 and λ as known data, A and σ can be predicted based on historical data, so you can quote the above formula directly.

IV. Case of Example

Application of Composite Base Price Bidding

Suppose there is a hospital planned to purchase a batch of medicine by composite base bidding and there are 12 pharmaceutical enterprises to participate in bidding. Evaluation rules are as follows.

(1) The perfect score of evaluation is 100 points.

(2) Composite base price is compounded of the base price of the hospital with a weight coefficient of 70% and the effective average quotation of bidders with a weight coefficient of 30%.

(3) Quotation equivalent to the value that composite base price reduced by 8% get the highest score point, that is, 100 points.

(4) Quotation 8% less or 5% higher than composite base price will be abandoned and eliminated. Evaluation will be reduced 2 points if quotation is 1% higher than the highest score quotation proportionally.

(5) Effective average quotation is in the range of - 8% ~ 5% deviated from Composite Base Price.

One pharmaceutical enterprise (M company) in bidder side, after collecting information, combining the cost of drugs and the normal industry profit level, got the prediction that the base price of the hospital is ¥800000, and the budget presentation of M company is ¥776000, and cost is ¥615000. Suppose after the estimation, M company believe quotation equivalent to the value that composite base price reduced by [5%, 7%] \subset [0, 8%] can get the maximum evaluation points.

By making 12 simulations, we have the following results (see Table 1).

Table 1 Series dates about quoted price

Yn	budget	lower ratio β	base of hospital	random quote	evaluation base	optimal offer	lower ratio
Y1	800000	3%	776000	713920	757376	696786	12.90%
Y2	800000	3%	776000	696786	752236	692057	13.49%
Y3	800000	3%	776000	692057	750817	690752	13.66%
Y4	800000	3%	776000	690752	750426	690391	13.70%
Y5	800000	3%	776000	690391	750317	690292	13.71%
Y6	800000	3%	776000	690292	750288	690265	13.72%
Y7	800000	3%	776000	690265	750279	690257	13.72%
Y8	800000	3%	776000	690257	750277	690255	13.72%
Y9	800000	3%	776000	690255	750276	690254	13.72%
Y10	800000	3%	776000	690254	750276	690254	13.72%

We can see from the above table that after the seventh operation, the best fitting price fluctuates slightly, and gradually stabilized at the value of 690254.

For $\sigma = \frac{1}{n} \sqrt{\sum_{i=1}^n \left(\frac{B_i}{T_i} - 1\right)^2}$, Assumpt that based on previous

opening record, $\sum_{i=1}^{10} \sigma_i \approx 1.0946$, then

$$\sum_{i=1}^{10} (1 - \sigma_i) \approx 8.9054, \quad \sum_{i=1}^{10} (1 + \sigma_i) \approx 11.0946$$

And substitute data into the formula (7)

$$Y = \frac{(1-\beta)\lambda A}{1-(1-\beta)(1-\lambda)} = \frac{(1-8\%) \times 70\% \times 776000}{1-(1-8\%)(1-70\%)} = 690250$$

it's consistent with the data in the table, which shows the correctness of formula (7).

If you use the formula (12) (15):

$$B_{\min}(\beta_1) = \frac{0.7 \times 776000 \times (1-5\%) \times [10 + (1-0.7)(1-5\%)(8.9054-10)]}{10-10 \times (1-0.7) \times (1-5\%)} = 699219$$

$$B_{\max}(\beta_2) = \frac{0.7 \times 776000 \times (1-7\%) \times [10 + (1-0.7)(1-7\%)(11.0946-10)]}{10-10 \times (1-0.7) \times (1-7\%)} = 722058$$

Quotation range is [699219, 722058], take the lower limit, M company finally offers the quotation of 699220.

The results of tendering opening are shown in table 2 according to the offer of each pharmaceutical company.

Table 2 The results of tendering opening

N	Bidder	quotation	lower ratio1	effective offer	lower ratio2	score	rank	rank of sealed price
1	bidder1	780670	-2.77%					9
2	bidder2	715160	5.86%	715160	5.69%	94.99	3	5
3	bidder3	631190	16.91%					1
4	bidder4	730740	3.81%	730740	3.64%	90.52	6	8
5	bidder5	690250	9.14%					2
6	bidder6	720190	5.20%	720190	5.03%	93.55	4	6
7	bidder7 (M)	699220	7.96%	699220	7.80%	99.56	1	3
8	bidder8	810330	-6.67%					10
9	bidder9	714290	5.97%	714290	5.81%	95.24	2	4
10	bidder10	723200	4.80%	723200	4.63%	92.68	5	7
11	average quotation	721524		717133				
12	Base of hospital	776000						
13	initial base A0	759657						

14	Evaluation baseA1			758340				
15	highest score			697673				

Comparison between composite base price and one-level sealed bidding

Optimal quotation of Composite Base Price tendering

Full score quotation:

$$Y = \frac{(1-\beta)\lambda A}{1-(1-\beta)(1-\lambda)} = \frac{(1-8\%) \times 70\% \times 776000}{1-(1-8\%)(1-70\%)} = 690250$$

Highest score quotation:

$$B_{\min}(\beta) = \frac{0.7 \times 776000 \times (1-5\%) \times [10 + (1-0.7)(1-5\%)(8.9054-10)]}{10 - 10 \times (1-0.7) \times (1-5\%)} = 699219$$

Optimal quotation of one-level sealed bidding^[17-18]:

$$Y = \frac{x}{x-1} C = 615000 \times \frac{10}{10-1} = 683333$$

We can see from the formula from above that the bidding strategies and the quotation is different under different tendering method. The reason is that under one-level sealed bidding, the strategy is striving for the lowest offer and the one who quotes the lowest price get the target. While under composite base price bidding, strategy is to simulate the price of highest evaluation score gradually and approximately, the bidder side quote in a effective limited range, in which the one offers the lowest price win the target. Bidding in the composite case, companies are in danger of been eliminated if the quoted price is too low, that is why the offer is always lower in one-level sealed price tender than in composite base price bidding.

V. Conclusions

This paper established a medicine bidding model on both bidders and tender with their weight coefficient, Analyzed bidding strategies and best quotes through game theory and the problem calling for paying attention. 1. In the aspect of model building and solving, first establish a theoretical model of optimal pricing, that if the bids are all very rational, this offer is most promising to obtain the subject. Then also take into account the randomness of bidding offer, so estimated the revised model, and work out the offer range that the quotation in which could get the highest mark to receive the subject, no need to offer the price which could get full score. 2. In the aspect of application, showed the use of composite base price method with the example. 3. In the aspect of applicability, compared composite base price and one-level sealed bidding to illustrate that it is scientific.

This paper illustrated the use of composite base price bidding only according to the drug safety and bidders how to improve the probability of getting the subject matter. Medicine price in composite base is higher than in sealed tendering. So from the perspective of ordinary people, Medicine price is higher than before, which cannot let people get direct benefits from this tendering method, while drug manufacturers can obtain higher profits. This is also a

major limitation of this study. So in the future research of pharmaceutical tendering, we should pay more attention to the benefits of ordinary people.

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