Research on Rural Logistics Purchasing Auction Strategy Based on Multiple- Attribute

Xuefeng Ding[1a], Qiancheng Chen[1b*]
[1] College of Economics & Management, China Three Gorges University, Yichang 443002, China
[1a] dr.dingxfeng@qq.com, [1b*] cqc.todo@outlook.com

***Abstract*—Aiming at the development of e-commerce in rural areas, the expansion of logistics service demand and the choice of logistics service providers, a rural logistics auction mechanism model is established. Based on the buyer's score and utility function, this paper considers the decision variables such as price factor and logistics service quality attribute. The research results show that the optimal decision of both buyers and sellers of logistics services is greatly affected by the bidder's participation number and cost parameters.**

***Keywords*— multi-attribute auction; rural logistics; service procurement**

Ⅰ. INTRODUCTION

Rural logistics is the core means to matching of supply and demand of agricultural-products, but the choice of logistics service providers is the top priority which is a procurement problem, and the auction mechanism can effectively distinguish the bidders and realize the rapid and effective allocation of resources. Introducing the auction theory into the logistics services procurement which has far-reaching significance for intensive study of rural logistics service procurement mechanism.

Scholars have some researched on the application of auction theory in logistics service. Figliozzi (2005) studied the application of the auction in urban regional logistics. He believed that arranging reasonable routes and auction methods based on understanding the arrival of goods and other distributions could create good returns[1]. Semra(2008) considered the carrier's random bidding strategy and the carrier's revenue maximization problem under the carrier route and related algorithms from the perspective of the carrier in the transportation procurement auction[2]. Robu (2011) developed a logistics task allocation platform that integrated manual bidding and automated trading strategies, and applied logistics bidding to the Netherlands and Germany[3]. Su(2015) proposed a multimodal transport auction model, which combined the cost of intermodal transport services with transaction costs to solve the B2B e-commerce logistics service procurement problem[4]. Handoko(2016) studied the urban logistics in Singapore by considering constraints such as management and storage costs, shipping requirements, proposed a two-way auction mechanism, increased order sharing and maximized total cost savings [5]. Zhang(2018) built the establishment of the carrier's expected cost as the objective function and studied multi-attribute transportation procurement auction scheme under the multi-unit supply conditions [6].

The scope of research is mainly urban logistics or international multimodal transport, and there is a few literature about the choice of rural logistics service providers. Therefore, we apply multi-attribute auction theory into the selection of rural logistics service providers, and analyzes the influence of important factors such as the number of bidders and the parameters of logistics service attributes on the decision making of buyers and sellers.

Ⅱ. CONSTRUCTION OF THE AUCTION MODEL

A. *Description of the problem*

In the auction of rural logistics services, the buyer's requirements for the bidder include, but are not limited to, price, timeliness, technology and other service attributes. The auction can be used as an effective mechanism to select bidders who meet the procurement requirements from n capacity to serve as a supplier of logistics. The bid of the bidder i ($i=1,2,\dots,n$) is a vector of (p_i, Q_i) ; where $Q_i = (q_{i1}, q_{i2}, \cdots, q_{im})$, and Q represents combination of non-price attributes of the service.

Before building a model, we should make the following basic assumptions:

① All parties are risk-neutral and rational people;
② There is no conspiracy between the bidders (sellers);
③ Auction items have independent private value.

B. *Process of the mechanism*

The process for implementing the mechanism described herein is to first send a bid invitation from the buyer to the bidder. That includes, but is not limited to, auction time, non-price attribute requirements for the service, scoring rules etc. Within the specified time limit, the bidder who received the offer decides whether to participate in the bidding according to the offer and its own conditions; if the bid is involved, the bidding documents are submitted to the buyer and the contents of that is mainly the service price and value of each non-price attribute. The bidder also promises to provide the corresponding service according to the bid content once the bid is won. Subsequently, the buyer scores the received bid, signs the logistics service purchase contract with the highest bidder, and pays the bidder's required remuneration.

C. *Bidder's cost function*

The bidder's cost function describes the time, technical, and management costs of bidder i when providing the logistics service non-price attribute combination to $\{q_{i1}, q_{i2}, \cdots, q_{im}\}$. Assume the cost function C_i is that:

$$C_i(\theta_i, q_{ij}) = \theta_i \sum_{j=1}^{m} a_{ij}(q_{ij})^{\alpha_j} \quad (1)$$

Where, q_{ij} is the value of the j-th non-price attribute of the service provided by the bidder; a_{ij} is the cost coefficient of the seller on the attribute of q_{ij}, and $a_{ij} > 0$. α_j is the bidder's single-item cost index for the non-price attribute of q_{ij}. The specific form of the cost function C_i also means that the different bidders have no difference in the cost index on the same non-price attribute. When $\alpha_j \in (0,1)$, it indicates the corresponding attribute marginal cost is decremented; when $\alpha_j \in (1, +\infty)$, it indicates the marginal cost increasing.

θ_i is the overall cost parameter and private information of bidder i, which reflects the relationship between non-price and cost. We assume θ_i is independent and evenly distributed over the interval $[\underline{\theta}, \overline{\theta}]$ $(0 < \underline{\theta} < \underline{\theta} < +\ \ )$. Therefore, the distribution function of θ_i can be written as $F(\theta_i) = \frac{\theta_i - \underline{\theta}}{\bar{\theta} - \underline{\theta}}$.

D. Bidder's utility function

The utility of the bidder is related to the combination of service price and cost. Bidder i participates the bid, then he accepts the transaction price p_i. The transaction price is the reward that bidder can obtained, which brings positive effect. According to the bidder's cost function, the bidder's utility function should be expressed as follows:

$$U_{si} = p_i - C_i(\theta_i, q_{ij}) = p_i - \theta_i \sum_{j=1}^{m} a_{ij}(q_{ij})^{\alpha_j} \quad (2)$$

E. The value function of logistics services

The process by which the seller provides the logistics service to the buyer is the process of transmitting the value of the service to the buyer, and the buyer and seller should have a uniform scale for the evaluation of the service value. The value function should be an increasing function of q_{ij}, which is the consensus of buyers and sellers. In this paper, the form of the value of logistics services is assumed to be as follows:

$$V_i(q_{ij}) = \sum_{j=1}^{m} w_j (q_{ij})^{\beta_j} \quad (3)$$

We assume $\beta_j < \alpha_j$. Similar to α_j, β_j is the value index of logistics service non-price attribute q_{ij}. When $\beta_j \in (0,1)$, it indicates the decreasing of the marginal value of its corresponding attribute; when $\beta_j \in (1, +\ \ )$, it indicates its marginal value increasing. w_j is the weight of the non-price attribute q_{ij}; the w_j is determined and announced by buyer, and the seller agrees by default if bidding. In this auction mechanism, w_j and β_j have notified the logistics service provider (bidder) before the auction through the invitation.

F. Scoring function

The scoring function describes the evaluation rules published by the buyer to bidder before the auction begins, which can select an optimal logistics service provider. The scoring function is the key to the entire logistics service auction mechanism, which is related to the choice of logistics service providers and final auction results. The bidder's score is determined by the service price and the service value. The function of the buyer's rating of the bidder i is as follows:

$$S_i = V_i(q_{ij}) - p_i = \sum_{j=1}^{m} w_j (q_{ij})^{\beta_j} - p_i \quad (4)$$

In the scoring function, w_j is the score weight given by buyer to the quality attribute q_{ij}, which is the same value as the value weight, reflecting the degree of importance that the buyer attaches to the different non-price attributes when selecting the service provider. In this auction mechanism, the bidder with the highest score win the bid.

G. Buyer's utility function

After the scoring rule made by the buyer, the bidder is likely to deviate from the real utility function in order to pursue its maximum utility. Therefore, the buyer should set a utility function that confidential to the seller. When setting the utility function, W_j is used to represent the utility weight assigned to the non-price quality attribute q_{ij}, and the buyer gives the utility weight different from the logistics service non-price attribute score weight, that is, setting w_j different from W_j to prevent possible deviation. If the buyer purchases the logistics service from the bidder i at the price p_i, the utility function U_{bi} has the following specific form:

$$U_{bi} = \sum_{j=1}^{m} W_j (q_{ij})^{\beta_j} - p_i \quad (5)$$

Where, $W_j \in (0, +\infty)$ reflects the buyer's preference for different non-price attributes of the service. The value of W_j is known only to the buyer and is kept confidential to all sellers.

III. THE OPTIMAL DECISION OF THE BIDDER AND THE BUYER

A. The optimal decision of the bidder

Based on the scoring function in the buyer's invitation document of the logistics service and the cost and utility function of the bidder, the bidder should determine the bid amount and bid price of the non-price attribute of the logistics service in turn.

Optimal decision of bidders' non-price attributes

According to David(2006)[8], the optimal bidder's bidding vector of non-price should satisfy:

$$q_{ij}^*(\theta_i) = \arg\max[V_i(q_{ij}) - C_i(\theta_i, q_{ij})] \quad (6)$$

To obtain the optimal value for the non-price attribute, the FOC of $V_i(q_{ij}) - C_i(\theta_i, q_{ij})$ at q_{ij} must equal to zero, so we get the next equation:

$$H = \frac{\partial [V_i(q_{ij}) - C_i(\theta_i, q_{ij})]}{\partial q_{ij}} \quad (7)$$

Substitute the functions $V_i(q_{ij})$ and $C_i(\theta_i, q_{ij})$ into (7):

$$H = \sum_{j=1}^{m} \left(w_j \beta_j (q_{ij})^{\beta_j - 1} - \theta_i a_{ij} \alpha_j (q_{ij})^{\alpha_j - 1} \right) \quad (8)$$

Let it be equal to 0, so as to obtain the optimal bid amount of each non-price attribute in the bidder i bidding vector:

$$q_{ij}{}^{*}(\theta_i)=\left(\frac{w_j\beta_j}{\theta_i a_{ij}\alpha_j}\right)^{\frac{1}{\alpha_j-\beta_j}} \tag{9}$$

The SOC of $V_i(q_{ij})-C_i(\theta_i,q_{ij})$ at $q_{ij}^*(\theta_i)$ is:

$$\frac{\partial H}{\partial q_{ij}{}^2}=\sum_{j=1}^{m}\left[(q_{ij})^{\beta_j-2}(w_j\beta_j(\beta_j-\alpha_j))\right] \tag{10}$$

And $\beta_j<\alpha_j$, such that $\partial^2[V_i(q_{ij})-C_i(\theta_i,q_{ij})]/\partial q_{ij}^2<0$ is always true at $q_{ij}^*(\theta_i)$. In summary, $q_{ij}^*(\theta_i)$ is a necessary and sufficient condition for $V_i(q_{ij})-C_i(\theta_i,q_{ij})$ to obtain the maximum value.

The optimal bidding decision of the non-price attribute indicates that the optimal bid amount of the bidder's non-price attribute has nothing to do with the bid price. It is only the bidder's own cost coefficient, index and buyer's published attribute score weight and utility index. According to the nature of the power function, the optimal bid amount of the non-price attribute changes positively with w_j under the rule of $\alpha_j>\beta_j$, and changes inversely with the single attribute cost coefficient a_{ij}. This shows that in the case where the cost index is greater than the utility index, the buyer's bidding amount should be larger for the same non-price attribute of the logistics service; due to cost constraints, the larger the cost coefficient θ_i, the smaller the bid amount should be.

The optimal decision of the bidder's bid price

According to the model proposed by Chen (2004) [8], the optimal bid price of bidder i can be expressed as follows:

$$p_i^*(\theta_i)=C_i+\int_{\theta_i}^{\bar\theta}\left[C_i'(\varphi,q_{ij})\left(\frac{1-F(\varphi)}{1-F(\theta)}\right)^{n-1}\right]d\varphi \tag{11}$$

After obtained $q_{ij}(\theta_i)$, $[C_i(\varphi,q_{ij})]'=\sum_{j=1}^{m}a_{ij}(q_{ij})^{\alpha_j}$. Substitute $q_{ij}^*(\theta_i)$ into (11), the optimal price $p_i^*(\theta_i)$ in the bidding vector of bidder i can be written as:

$$p_i^*(\theta_i)=\sum_{j=1}^{m}\left[\begin{array}{l} a_{ij}^{\frac{\beta_j}{\beta_j-\alpha_j}}\left(\frac{w_j\beta_j}{\alpha_j}\right)^{\frac{\alpha_j}{\beta_j-\alpha_j}}\times \\ \left(\begin{array}{l}\theta_i^{\frac{\beta_j}{\beta_j-\alpha_j}}+ \\ (\bar\theta-\theta_i)^{1-n}\int_{\theta_i}^{\bar\theta}\varphi^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-\varphi)^{n-1}d\varphi\end{array}\right)\end{array}\right] \tag{12}$$

The optimal decision of the bidder's bid price indicates that not only the bidder's overall cost parameter distribution interval $[\underline\theta,\bar\theta]$, the bidder's participation quantity n, and the buyer's scoring weight affect the optimal bid price, but the bidder's own non-price overall and single-item cost coefficient also have an impact on the optimal bid price. It can be seen that the positive and negative correlation between the optimal bid price $p_i^*(\theta_i)$ and w_j and the positive and negative correlation between $q_{ij}^*(\theta_i)$ and w_j are consistent. The more the buyer values an attribute, the bidder's quotation will be relatively high. This is because the bidder has to provide the corresponding amount of service, so that the income must be obtained to balance the cost, so the corresponding quotation should be provided. P and q remain in the same direction, which is consistent with reality.

B. Buyer's optimal strategy

It is known that the bidder i's optimal bid vector is $(p_i^*,q_{i1}^*(\theta_i),q_{i2}^*(\theta_i),\cdots,q_{im}^*(\theta_i))$, then the buyer's expected utility $E(U_{bi})$ is $\int_{\underline\theta}^{\bar\theta}U_{bi}n[1-F(\gamma)]^{n-1}f(\gamma)d\gamma$ and $[1-F(\gamma)]^{n-1}f(\gamma)$ is the probability that a single bidder wins. Because there are total of n bidders, it multiplies n. When $\theta=\bar\theta$, $E(U_{bi})=0$. And when $\underline\theta<\bar\theta$, the seller's expected utility is:

$$E(U_{bi})=\frac{n}{(\bar\theta-\underline\theta)^n}\sum_{j=1}^{m}a_{ij}^{\frac{\beta_j}{\beta_j-\alpha_j}}\left\{\begin{array}{l} W_j\left(\frac{w_j\beta_j}{\alpha_j}\right)^{\frac{\beta_j}{\alpha_j-\beta_j}}\int_{\underline\theta}^{\bar\theta}\gamma^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-\gamma)^{n-1}d\gamma- \\ \left(\frac{w_j\beta_j}{\alpha_j}\right)^{\frac{\alpha_j}{\alpha_j-\beta_j}}\left[\begin{array}{l}\int_{\underline\theta}^{\bar\theta}\gamma^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-\gamma)^{n-1}d\gamma+ \\ \int_{\underline\theta}^{\bar\theta}\int_{\gamma}^{\bar\theta}\varphi^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-\varphi)^{n-1}d\varphi d\gamma\end{array}\right]\end{array}\right\} \tag{13}$$

When $\partial E(U_{bi})/\partial w_j=0$ and $\partial^2E(U_{bi})/\partial w_j^2<0$ are true at the same time, the buyer maximize utility. When $\partial E(U_{bi})/\partial w_j=0$, W_j and w_j have the following equation:

$$W_j=w_j\left[1+\frac{\int_{\underline\theta}^{\bar\theta}(\int_{\gamma}^{\bar\theta}\gamma^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-1)^{n-1}d\varphi)d\gamma}{\int_{\underline\theta}^{\bar\theta}\gamma^{\frac{\beta_j}{\beta_j-\alpha_j}}(\bar\theta-1)^{n-1}d\gamma}\right] \tag{14}$$

At the same time, $\partial^2E(U_{bi})/\partial w_j^2<0$ is also established. It can be seen that the buyer obtains the optimal utility when $W_j\geq w_j$. And only if $\varphi=\bar\theta$, the equal sign is established. The buyer's sensible behavior will not choose the highest overall cost parameter $\bar\theta$ corresponding to the bidder as a supplier of logistics services. At this time, $E(U_{bi})=0$, the buyer cannot obtain the maximum utility, so $W_j>w_j$ must be established, that is, the utility weight W_j is greater than the score weight w_j. The functional relationship between W_j and w_j indicates that the setting of the utility weight should fully consider the distribution of the bidder's cost parameters and the number of bidders' participation.

Ⅳ. Decision Analysis

Logistics is a general term for activities such as transportation, packaging, unloading, processing and storage, which serve the people's life, production, economy and trade. Compared with the logistics characteristics of the city, rural logistics highlights differences, seasonality and diversity. It is supposed that an e-commerce company decides to comprehensively consider five indicators of four non-price attribute indicators, such as price (p) and timeliness level(q_1), transportation preservation(q_2), logistics informationization level (q_3) and transportation response(q_4), when selecting logistics service providers, we assume the company's utility index and scoring weight is $(\beta_1,\beta_2,\beta_3,\beta_4)$=(1.5, 1.5, 0.5, 0.5), (w_1,w_2,w_3,w_4)=(4,3,2,1); for the cost of the logistics service provider, we assume $(\alpha_1,\alpha_2,\alpha_3,\alpha_4)$=(2.5, 2, 0.8, 0.8).

A. Bidder's decision analysis

Bidder participation number n and bid price

In order to study the impact of the bidder's participation number n on the bid price, we consider n as an unknown number. Meanwhile, we fix the value of the single attribute cost coefficient a_{ij} to 1. Assuming that the overall cost parameter θ_i obeys the uniform distribution on $[0.5,1]$, we substitute the values of the parameters α_j and β_j into the bidder's optimal bid price $p_i^*(\theta_i)$. The image of $p_i^*(\theta_i)$ about n is as follows:

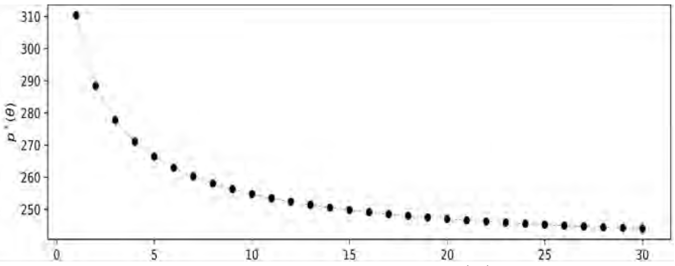

Fig 1. Bidder participation number n and bid price $p_i^*(\theta_i)$

As can be seen from Figure 1, the bidders should attach timely attention to the number of competitor when they make bidding decisions. As the number of bidders increases, the optimal bid price becomes lower and lower. It can be seen from the gradual trend of the scatter point in the figure that the sensitivity of the optimal bid price to the number of bidders' participation decreases as n increases. The buyer can also use the relationship shown in the figure to distribute the solicitation documents to more potential logistics service providers. Only in this way can the logistics service reduce the purchase price and improve the total utility obtained from the logistics service.

Bidder's overall cost parameters and bidder bid price

When studying the impact of the bidder's overall cost parameter distribution on the bidder's bid price, we consider θ_i as an unknown number. At the same time, we fix the value of the single attribute cost coefficient a_{ij} and the overall cost parameter upper limit $\overline{\theta}$ to 1, assuming 10 bidders bid. The image of $p_i^*(\theta_i)$ about θ_i is as follows:

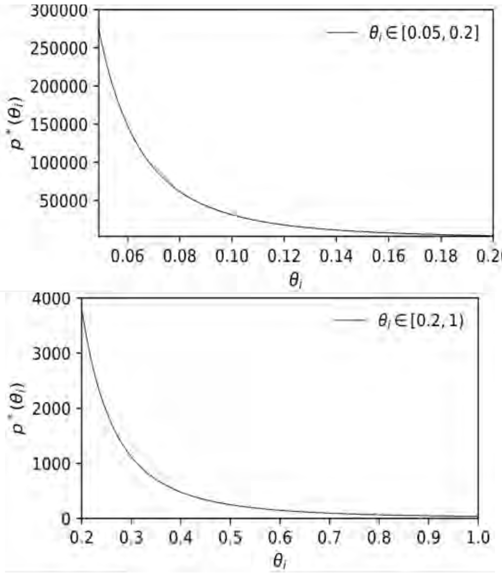

Fig 2. Bidder's overall cost parameters and bid price $p_i^*(\theta_i)$

It can be seen from Fig. 2 that the closer the bidder's overall cost parameter θ_i is to the upper limit of the overall cost parameter, the lower the bid price. When θ_i is small, the bidder can propose a higher offer to obtain greater utility; Conversely, in the case of a higher θ_i, the smaller the selectable range of the quotation, the more careful the bidder should be ; the quotation should not be too high, otherwise the score will be lowered and the risk of bidding failure will increase; the quotation should not be too low, although it will increase the chance of winning the bid, it will reduce the utility obtained from the buyer.

B. Buyer strategy analysis

Bidder participation number n and buyer utility weight

In order to facilitate the study of the relationship between the utility weight W_j and the scoring weight w_j, we regard the bidder participation number n as an unknown number, assuming that the overall cost parameter θ_i obeys a uniform distribution on$[0.5,1]$. Meanwhile, we substitute the values of α_j and β_j into the optimal decision function of the buyer to determine the utility weight, and draw the images of W_j about n as follows:

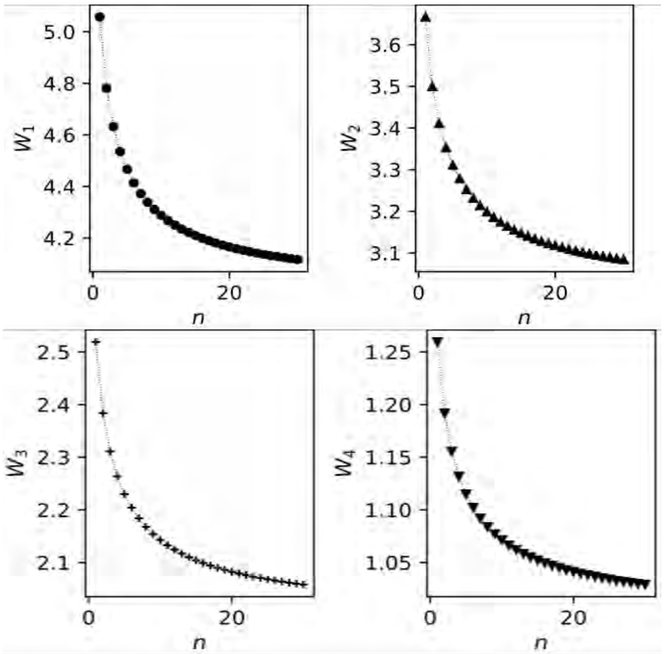

Fig 3. Number of bidders n and buyer utility weight W_j

It can be seen from Fig. 3 that as the number of bidders n increases, the value of W_j is closer to w_j, and the curve changes more slowly. That is, the utility weight of each non-price attribute of the buyer is also closer to the weight of the published scoring function, but the sensitivity to the number of bidders is also reduced. Therefore, for the buyer, the greater the bidder's participation, the closer the buyer's utility weight decision should be to the published scoring weight. When the number of bidders reaches a certain level, the buyer's optimal effect weight can be reduced, and it is not necessary to pay too much attention to the number of bidders.

Bidder's cost distribution and buyer's utility weight

In order to facilitate the influence of the bidder's cost distribution on the buyer's utility weight decision, we assume that the number of bidders is 15. Let $\overline{\theta} = 1, \theta$ as an unknown, and $\underline{\theta} \in (0,1)$. Similarly, the α_j and β_j are substituted into the optimal decision function of buyer to determine the utility weight. The figure of W_j about $\underline{\theta}$ is as follows:

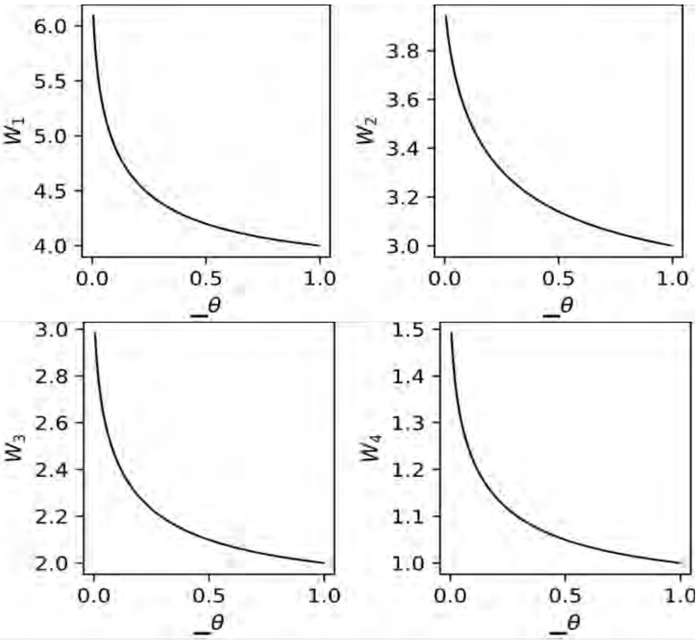

Fig 4. Bidding cost distribution and buyer utility weight W_j

It can be seen from Fig. 4 that the difference between $\underline{\theta}$ and $\overline{\theta}$ decreases gradually as $\underline{\theta}$ increases, and the value of W_j becomes closer to w_jd, and the curve changes more slowly. From the perspective of the buyer, this indicates that when the bidder's overall cost parameter distribution is more tight, it is the buyer's dominant strategy to choose to set the utility weight to be closer to the scoring weight; after the bidder's overall cost parameter distribution reaches a certain degree of tightness, the optional range of utility weights is smaller and smaller, so that the buyer's sensitivity will be reduced, and the attention to the bidder's cost parameter can be reduced.

Ⅴ. CONCLUSION

How to realize the comprehensive optimization of rural logistics services under the consideration of factors other than price is an urgent requirement of many logistics projects. This paper introduces the auction theory into the transaction of rural logistics. According to the multi-attribute requirements of many enterprises for logistics services, the multi-attribute auction mechanism and the optimal function of the scoring function and the bidding parties are designed.

Based on the multi-attribute auction of rural logistics service procurement, the bidder needs to determine the optimal bidding strategy according to the bidder's cost distribution and the scoring function provided by the logistics service buyer; the buyer needs to determine the optimal utility weight to obtain the maximum benefit. When bidders and buyers choose strategies, they must fully consider the influence of the parameters of the bidding parties and the positive and negative correlation between the parameters. Therefore, the research results of this paper have certain theoretical significance.

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