Research on Multi-round First-price Sealed Bidding Strategy Based on Bidders' Incomplete Information Game

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Abstract: Bidding mechanisms are essential for the market and policies because bidding patterns have an impact on economic rationality and are crucial for the functioning of the construction industry. Thus, this paper consolidates the findings from the multiple rounds of combinatorial auctions, the winner's curse in incomplete information auctions, and game theory. There is no doubt that bidding mechanisms play an important role in markets and policies in economic activities. This paper's related topics of interest would be multi-round combinatorial auctions, winner's curses in project bidding, and game theory in incompletely informed auctions. This paper reviews the literature and employs the models based on the Nash equilibrium. There are many types of bidding strategies such as first, second, and successive bid bidding strategies, cooperative bidding, non-cooperative bidding, and how information asymmetry plays a critical role in these strategies. As mentioned before, criterion-based adaptive bidding strategies are not sensitive to market conditions and can provide near-optimal solutions. In the same way, iterative learning also prevents the occurrence of the winner's curse in the multi-stage bidding context. UK auctions are seen as more efficient relative to other locations because information costs are lower, while game-theory-based strategies improve mechanisms for obtaining tasks and cost optimization in mobile crowdsourcing tasks. The use of electronic auctions can help a market become more fully rational and efficient. The methodology of game theory helps explain the outcomes of auctioning and emphasizes innovations in automation as well as policies. Therefore, this paper's implications are significant to the current and ongoing literature on efficiency, strategic behaviour, and policy in bidding mechanisms across different markets.

Keywords: Bidding mechanisms, Combinatorial auctions, incompletely informed auction, Game theory.

1. Introduction

The study of bidding mechanisms in economic activities is crucial for understanding market dynamics and improving policy decisions [1]. Bidding behavior, particularly in the construction industry, has significant implications for economic efficiency and rationality [2]. This summary explores the key findings from various research studies on bidding mechanisms, including multi-round combinatorial auctions, the winner's curse in construction bidding, and the role of game theory in auctions with incomplete information.

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Literature Review: Arai and Morimoto analyzed the economic rationality of bidding behavior in the construction industry in Shikoku, highlighting the inefficiencies of new market entrants in bidding lower prices and the importance of these findings for policymaking. Sui and Leung proposed an adaptive bidding strategy for multi-round combinatorial auctions, demonstrating its effectiveness in various market environments without prior knowledge. Ahmed et al. examined the winner's curse in construction bidding, suggesting that a multistage bidding environment can mitigate this issue through learning from past decisions. Milgrom provided a primer on auction formats, discussing their efficiency and common pitfalls for bidders. Coppinger, Smith, and Titus compared different auction formats, revealing that English auctions are the most efficient. Wang et al. introduced a multi-round bidding strategy based on game theory for crowdsensing tasks, showing its superiority in task acquisition and cost reduction. Harsanyi explored games with incomplete information, emphasizing the strategic uncertainty and the role of Nash equilibria. Engelbrecht-Wiggans and Katok investigated the impact of regret on bidding behavior in sealed-bid auctions, highlighting behavioral anomalies. Bag et al proposed SEAL, a sealed-bid auction protocol without auctioneers, enhancing transparency and integrity. Levin provided a comprehensive overview of auction theory, including the concepts of revenue equivalence and the winner's curse.

Research Findings: Arai and Morimoto found that new entrants in the construction industry were less efficient in bidding lower prices, emphasizing the need for informed policymaking to address these inefficiencies. Sui and Leung's adaptive bidding strategy in multi-round combinatorial auctions demonstrated robustness in adapting to different market conditions and achieving near-optimal outcomes. Ahmed et al. highlighted the prevalence of the winner's curse in construction bidding and suggested that multistage bidding environments could help mitigate its effects through iterative learning. Milgrom identified that auction formats like the English auction are more efficient due to their simplicity and lower information costs. Coppinger, Smith, and Titus confirmed the higher efficiency of English auctions compared to Dutch auctions and sealed-bid formats. Wang et al. showed that their game theory-based multi-round bidding strategy significantly improved task acquisition and cost efficiency in mobile crowdsensing. Harsanyi underscored the complexity of strategic interactions in games with incomplete information, proposing probabilistic models to manage uncertainties. Engelbrecht-Wiggans and Katok demonstrated that regret significantly influences bidding behavior, often leading to overbidding in sealed-bid auctions. Bag et al. introduced an innovative auction protocol that ensures transparency and integrity without the need for auctioneers. Levin explained that while revenue equivalence holds in certain auction formats, common value auctions can lead to the winner's curse, which can be mitigated through information aggregation in large auctions.

In conclusion, these studies collectively enhance our understanding of bidding mechanisms, revealing critical insights into efficiency, strategic behavior, and policy implications in various auction formats and market environments.

2. Theoretical basis

2.1. Game theory

Games are defined as the organismic relationship existing between two or more individuals, each of which tries to impose on the others the fulfillment of his own volition under threat of equivalent retaliation [3].

Cooperative and non-cooperative games It is important to categorize games as cooperative or non-cooperative games. In the framework of cooperative games, which participants can make and give promises in advance, there are cooperative and non-cooperative games.

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There are yet two more classifications that can be made regarding games: the zero-sum games and the non-zero-sum games. A zero-sum game means that the entire benefit, especially in terms of power, goes to only one of the participants while in a non-zero-sum game, the benefit that goes to the participants is otherwise.

As with other approaches, games can also be classified according to the extent of information that is revealed among the players: complete information games and incomplete information games. In complete information games, the strategy set of the players is perfectly known by each of the players; in incomplete information games, the strategy set of the players is only partially known by each of the players [4].

Overview of Nash equilibrium:

The Nash equilibrium refers to the specific strategies where a player will not have an incentive to alter their strategy if the other players in the game are going to play those strategies involved [5].

This is the best defensible strategy of participants in the game, given the strategic move of the opponents. It is one of the major theories that govern the interaction of players in the game, and it defines the reasonable behavior of the players.

It is important to note that in some cases, a game's positive solution is not unique, meaning that there might be several Nash equilibria. Nash equilibrium can be applied to many situations and can explain and even predict outcomes in social situations.

2.2. Single-round first-price sealed auction model

This is where the bidders put forward bids simultaneously without seeing what others have bid, typical of oral auctions. Finally, whoever bid the highest gets the object of auction and he pays for the amount bid by him. All participants provide the offer at the same time enclosed in envelopes and no participant has the knowledge of the offers of the others [6]. According to the rules of the auction the participant with the greatest offer gets the object, and the price is the offer he gives.

This mechanism is rather rigid and can be implemented on its own, and while it has no major complications, it is not without drawbacks. For instance, envisage the participant understating its true worth, which means that the object is overpriced on sale [7].

Common multi-round bidding mechanisms include English auction and Dutch auction. In English auction, players are allowed to either raise a bid or pass on passing the bidding back and forth until typically only one bid remains [8]. The last person bidder pays his bid. In Dutch auction, the first price that the auctioneer announces is quite high, and as the price drops, the participants are expected to buy at any price offered. Communicative bidding can be multiple rounds because each round is aimed at participants' improvements of their valuations based on the bidding signals they saw.

2.3. Incomplete information game

There is always imperfect information in incomplete information games, and this leads to there being some information that some of the players have that the other players don't. Some of the variables involved in a game, for example, the costs and preferences of the other players, cannot be known by the other participants and therefore, participants must have a look at their opponents through some signals. Some of these signals may involve, but are not limited to, analyzing the opponent's track record, and their utterances, among others by synthesizing the signals, participants will develop a set of beliefs that act as the basis of decisions.

However, the participant behavior can also involve selective information sending to modify the conative plan of other participants. For instance, by acting appropriately, individuals can effectively demonstrate that they are a certain type of participant, and therefore stand out from all other types of participants. This signal transmission is thus a significant communication tool for the parties to

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engage in negotiations in a way that may optimally balance the information gap. Thus, the actual decision-making behavior of the contributors is determined by the beliefs of other contributors. This is possible because, in the conditions of incomplete information, the only way for the participants to get the best benefits is to make the best decision as they see their opponents.

3. Equilibrium Analysis

3.1. Single-round bidding equilibrium

In a single-round bidding scenario with two participants, A and B, the true value V of the bidding target is uncertain and follows a specific probability distribution. Participants A and B each have their own valuations, vA and vB respectively, and must choose their bids accordingly. The set of strategies available to each participant includes all possible bids. If A bids bA and B bids bB, the outcome depends on the comparison of these bids. If $bA>bB$, A wins the target and earns a profit of $V-bA$, while B's profit is zero. Conversely, if $bA<bB$, B wins and earns V−bB, while A earns nothing. If the bids are equal, the target is randomly assigned, and the expected profit for each participant is $(V-bA)/2$ or $(V-bB)/2$.

To determine the Nash equilibrium, consider the optimal strategies for both participants. If Participant B adopts strategy bB, participant A's optimal strategy is to bid $bA=vA$. Similarly, if participant A adopts strategy bA, participant B's optimal strategy is to bid $bB=vB$. This leads to the conclusion that the strategy pair ($bA=vA$,$bB=vB$) is the Nash equilibrium in this single-round incomplete information bidding game.

If Participant A deviates from the equilibrium strategy and bids $bA' \neq vA$, while Participant B continues to bid vB, A's profit is reduced to $V-bA'$, which is less than $V-vA$. If A bids bA while B deviates to $bB' \neq vB$, A's profit becomes zero, resulting in a loss compared to following the Nash equilibrium strategy. Similarly, any deviation by B from $bB=vB$ leads to a reduction in B's benefits when A bids vA.

Therefore, any deviation from the equilibrium strategy results in lower benefits for the deviating participant, confirming that the strategy pair ($bA=vA$, $bB=vB$) constitutes a stable Nash equilibrium [9].

3.2. Multi-round bidding dynamic equilibrium

In a multi-round bidding game, participants need to determine the optimal bidding behavior in each round based on a dynamic equilibrium strategy [10]. To solve this type of dynamic equilibrium strategy, dynamic programming is required.

First, it is necessary to define the strategy space of participants in each round, such as "bid" or "give up". Secondly, it is necessary to design the profit function of each round, considering not only the profit of the current round, but also the expected profit of future rounds.

Taking a two-round bidding game as an example, in the second round, the optimal strategy of the participant is to bid equal to his own valuation. In the first round, the bidding strategy of the participant needs to be combined with the expected profit of the second round. The optimal bidding strategy of the first round can be determined by the dynamic programming method, that is, the bid must be less than or equal to the expected profit of the second round.

Suppose there are two rounds of bidding games, the valuation of participant A is 100, and the valuation of participant B is 80. According to the dynamic equilibrium strategy, the optimal bid of A in the first round should be less than or equal to the expected profit of the second round, that is, 100. If A chooses to bid 90, he will get a profit of 90 in the first round and continue to get a profit of 100 in the second round, with a total profit of 190. If A chooses to bid higher than 100 in the first round,

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although he may get higher returns in the first round, he will lose the target in the second round because he cannot afford the bid, and the total return will be reduced. Therefore, bidding 90 is A's optimal strategy, which conforms to dynamic equilibrium.

Through the above steps, the dynamic equilibrium strategy of each round in the multi-round bidding game can be determined. Next, it is necessary to analyze the stability of this dynamic equilibrium strategy. Specifically, it is necessary to consider whether the participants will deviate from the equilibrium strategy, what changes will occur in the benefits if the deviation occurs, and finally determine whether there is an incentive to change the strategy.

In the two-round bidding game, it is assumed that the equilibrium strategy of the first round is to bid less than or equal to the expected return of the second round. Participants may consider deviating in the first round and bidding higher than the expected return of the second round [11]. However, through analysis, it can be found that doing so will obtain higher returns in the first round but may lose the target in the second round because they cannot afford the bid. Overall, participants cannot obtain higher dynamic expected returns by changing the first-round strategy, so the dynamic equilibrium is stable.

3.3. Impact of incomplete information on equilibrium

In premise to the following proposition, when the undertakings are thrashing out the dynamic equilibrium strategy in a multi-round bidding game with incomplete information, the following factors are bound to play a major role. Firstly, the unclear value of participants themselves will affect the bid of them, and hence, influence the balance of the whole process in games. Second, since the valuation of the opponent is not certain, the participants will also be able to forecast the possible bidding strategy by the opponent which in turn influences the right bidding strategy the participants need to take to maximize profitability [12]. Due to the information insufficiency, it is equally challenging for the participants to predict the expected payoffs for future rounds where they intend to bid; this aspect will also have an impact on the current bidding decision.

Simultaneously, because of these stochastic factors, participants must achieve dynamic equilibrium on the playing field. On the other hand, they may also decrease the level of bidding aggressiveness for the decrease of risks. On the other hand, they can also proactively accrue more market information to eliminate gaps where possible [13]. In cases of significant unknown risks, people can choose strategies of expressionless bidding and make decisions based on probability distribution.

4. Conclusion

This paper analyses the phenomenon of bidding in economic activities, more so the winner's curse in construction bids and the use of game theory in incomplete information auctions. According to the analysis, it can be concluded that criteria-based adaptive bidding strategies which are able to withstand shocks in the market environment are close to optimal. In the context of multi-stage bid scenarios, iterative learning is able to substantially lessen the impact of the curse of the winning bidder and enhance the rationality and efficiency of the bid. Mobile crowdsourcing activities can be analyzed using Game theory techniques, especially in the bidding process with multiple bidders and where the cost is a critical factor. Furthermore, the fact that electronic auctions are deemed a means of enhancing market rationale suggests the proposition that strategic innovation can help make auction transactions more efficient.

As this study has both theoretical and practical findings, it is of commercial benefit to policy-forming institutions. It can therefore be concluded that by detailing the bidding strategies and their economic consequences, this research advances the understanding of how bidding practices should

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be enhanced in order to rationalize the market. In construction organizations, this knowledge enables them to come up with more effective bidding strategies; avoid the winner's curse, and generally, control for the cost of acquiring projects. These insights will be helpful to policymakers to frame laws, which will act as a level playing field and encourage companies to carry out transparent bidding processes.

However, it is worthy to note that this study has its own limitations: The main source of data used in the study was secondary data hence limits the insights of the study. This involves a lack of first-hand information such as questionnaires or interviews which may restrict bidder behaviour and preference information. Future research could fill this gap by conducting primary data collection to capture the bidding strategies' trends in action. Additionally substantiated by other studies done to identify the specific aspects of the market environment that affect bidding strategies. By broadening the concept, the subsequent research can use such findings to enhance the precision and relevance of bidding structures in various domains.

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