Competitive Bidding Strategies in Repeated Procurement Auctions

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Abstract

We study repeated reverse auctions in the context of industrial procurement. In this environment, the competitive bidding strategies of the participating suppliers play an important role in the auction's equilibrium outcome. Using Myerson's framework for mechanism design, we study how bidders' strategies are determined in an incentive compatible and individually rational mechanism. Focusing on the symmetric incomplete information case, we analyze the cases of myopic and strategic suppliers and their equilibrium behaviors, through which we illustrate the effect of strategic thinking in this setting.

Keywords: Repeated Procurement Auctions, Competitive Bidding, e-procurement, Mechanism Design

1 Introduction

On-line procurement has evolved from a secondary function to a strategic tool in today's competitive industrial procurement markets. Firms are implementing automated procurement processes as a means to increase efficiency and reduce costs, while at the same time sustaining supply quality and delivery performance. Buying goods and services through online marketplaces and reverse auctions is a quickly emerging trend in procurement since the late 1990s. IDC Bulletin states that online sourcing in the U.S. reached \$29.0 billion in 2001, will grow to \$116.0 billion by 2003, and will grow further to \$661.8 billion by 2006.

According to Forrester, across the B2B implementations today, there is a three-to-one ratio of buyer-driven to seller-driven online auctions. Major examples of the buyer-driven markets are Covisint(automotive), Converge(electronics) and Pantellos(utility). Although buyers initially utilized these markets to procure commodity items, they have also started to use them for non-commodity items.

The equilibrium behaviors of the suppliers participating in such procurement auctions have major impact on the possible allocation outcomes and total procurement cost for the buyer. Therefore, a theoretical analysis of the suppliers' competitive bidding strategies will provide insights that might be useful for both suppliers and buyers. Another aspect of procurement activity is its repetition over time. Hence, static single period analysis might not be enough to fully explain the competitive bidding strategies of suppliers.

Motivated by these observations, our main goals in this paper are to explore procurement auctions via mechanism design perspective and to discuss the analytical properties of the competitive bidding strategies of suppliers under incentive compatible and individually rational mechanisms. We distinguish between *myopic* suppliers, those interested only in the current period, and *strategic* suppliers, those who behave strategically by considering all available information, in order to analyze the effect of future periods on the bids submitted in a given period.

We discuss related literature in section 2 and introduce the basic procurement model, providing a detailed explanation of the mechanism design perspective in section 3. In section 4, we discuss analytically the repeated procurement auction setting for both myopic and strategic suppliers. We conclude our study, stating the main observations and future research directions in section 5.

2 Related Literature

While reviewing the broad auction theory literature, we will focus on the fundamental points of the studies that are directly related with our current paper. In the economic theory literature, most of the works concentrate on forward auctions, seller-initiated auctions where there is a single seller and multiple buyers competing with each other. The analysis of auctions as games of incomplete information originates in the seminal work of William Vickrey [19] that proposes the second price sealed bid auction, while proving analytically the incentive compatibility of the mechanism. Krishna [14] discusses the theory of auctions in this tradition and gives an account of developments since Vickrey's pioneering paper. Klemperer [13] also provides an extensive survey on the economics of the auction theory. Another keystone study in the auctions theory is Myerson's study [15], in which he studies the optimal auction design for the forward auctions as a mechanism design problem and develops key concepts such as the revelation principle and general revenue equivalence. Although these studies mainly analyze the forward auctions, they are also important for our paper as they provide the essentials of the auction theory, which can be used in deriving the corresponding results for the procurement auctions.

Besides the literature of auction theory in economics, there has been recent research about auctions in the operations research (OR) and operations management (OM) literature. Kalagnanam and Parkes [12] provide an overview of the various auction mechanisms commonly encountered both in practice and in the literature, while stating the possible alternative classification schemas of auctions.

As the research on auctions has been developing in the OR literature, there have been several studies focusing on the procurement auctions in detail [4], [5], [17], [3], [16], [18], [10], and [6]. However, they focus more on the winner determination problem. They also consider iterative bidding strategies that use primal-dual information, in a single period procurement setting.

Among these studies, Beil and Wein [3] propose an iterative payoff maximizing auction procedure, for a class of parameterized utility functions with known functional forms and naive suppliers. Parkes and Kalagnanam [16] propose a family of iterative primal-dual based multiattribute auction mechanisms. Shachat and Swarthout [18] consider request for quote and an English auction with bidding credits to procure differentiated goods. Among these studies, there are two recent studies on the problem of designing multi-item procurement auctions in capacity constrained environments. Gallien and Wein [10] propose an iterative mechanism where the suppliers bid the unit costs strategically and their capacity constraints truthfully. This study focuses on designing a multi item procurement auction in a capacity oriented setting. An alternative iterative procedure, recently proposed by Dawande et al. [6], is based on descending cost of the total procurement rather than on descending price of each item.

Hence, all of the above studies provide a static analysis of a single period procurement auction from buyer's view point. The bidding strategies of suppliers have not been studied analytically in these works. Our study differs from them as we focus on the analytical derivation of the competitive bidding strategies of the suppliers.

There has been a limited number of studies on the dynamic aspects of the auctions. In the area of forward auctions, Ausubel [1] proposes a dynamic design for auctioning multiple heterogenous commodities, while Gallien [9] considers a dynamic mechanism design for sellers of multiple identical items. However, the dynamic properties considered in these studies are totally different than the dynamic nature that arises from repeating the procurement auction over time. There have been recent studies [11], [2], and [20] that consider the repeated procurement auctions.

A common property of these studies is that they all consider the highway construction environment and assume that capacity is the binding constraint throughout the periods, i.e. winning in one period might prevent the winning supplier from participating in future auctions. Another common property of these studies is that they are empirical studies, rather than theoretical.

Jofre-Bonet and Pesendorfer [11] propose an estimation method for a repeated highway construction procurement auction, while taking into account the capacity constraints. In the first stage, they assume that the bid distribution in each period is affected by some variables, such as backlog, cost and contract characteristics, those defining the state, and they implement a Kernel type estimator for each period bid distribution. In the second stage, costs are inferred from the first order condition of the optimal bids.

Voicu [20] analyzes the repeated auction in highway construction by focusing on the properties of Markov perfect equilibrium. He implements functional forms to the bid functions that depend on the period and analyzes their properties. Although these studies provide valuable insights for analyzing repeated auctions, they are not directly applicable in the industrial procurement as the capacity is not a binding issue between the periods in case of industrial procurement. Our study is a theoretical discussion of the competitive bidding strategies, providing in-depth understanding how the submitted bids are affected by various factors.

There have been two recent studies of repeated procurement auction in the industrial procurement setting. Elmaghraby [7] studies the importance of ordering in sequential procurement auctions when the suppliers have capacity constraints and therefore a single supplier cannot win both of the auctions. The aim of this study is to highlight the influence of ordering on the efficiency and optimality of an auction. Due to this restrictive assumption, the mechanism is more like an almost simultaneous auction setting rather than a repeated auction setting in the industrial procurement environment.

Finally, the most relevant study to our work might be a recent study of Elmaghraby and Oh [8]. They study the design of the optimal erosion rate policy and compare its performance against a second price sealed bid auction under the learning effect. They study mainly the design of the optimal erosion policy while characterizing the optimal discount price schedule as a function of the market structure. They also consider the case when suppliers take into account the impact of current actions on future periods. We come up with a generalized discussion of the repeated procurement setting in the first price sealed bid auctions and compare the myopic and strategic suppliers bidding strategies, while they provide valuable insights on a more specific setting.

3 Basic Procurement Model

We will initially state all of our assumptions to define the scope of our study. Then, we will develop the single period procurement auction as we move along the discussion of mechanism design.

In this study, we consider a risk-neutral buyer in need of Q_t units of material in each period t during the project life T. The buyer chooses the awarded supplier for each period via an auction mechanism, trying to minimize the total procurement cost. Although in many situations, there might be non-price attributes affecting the procurement decisions, it is reasonable to assume that price is the sole factor used to choose the winning supplier. This can be stated with the loss of generality if the item to be procured is somehow standardized, or the non-price attributes are fixed beforehand for all eligible suppliers participating in the auction. We assume that buyer has an outside option, i.e. spot market, to procure the material at a price of s. We also assume that buyer's valuation of the item equals the spot market price. We assume sole sourcing, which means that the buyer awards a single supplier in each round of the auction. This is a reasonable assumption so long as all suppliers have sufficient capacity to fulfill the buyer's entire order and there is no diseconomy of scales in the supplier's cost function.

Next, we will state the supplier related assumptions to complete the scope definition. We assume that all suppliers are risk-neutral and each bids to maximize her own expected profits. However, we emphasize the effect of considering the future periods on the submitted bid in a given period, by distinguishing a *myopic* supplier, who bids in a given period to maximize only that period expected profit, from a *strategic* supplier, who bids in a given period to maximize the expected profit for the total remaining project life.

We assume that all suppliers are aware of the number of suppliers participating in the procurement auction and that it is fixed exogenously throughout the project life, i.e. the supplier pool is closed to new entries, and no supplier goes out of business during the project life.

Our study depends on the private value assumption, which means that each supplier's cost is totally independent of the other suppliers' costs. Although it might seem more reasonable to consider the interdependent (affiliated) value models due to the degree of commonality of the technologies to produce a certain product in real life, we assume that there are sufficient differences in the technologies used by each supplier to support the use of private value models.

We consider the case when each supplier j's cost (private information) is drawn from the same probability distribution $F(c)$ for all suppliers on the same interval $[c_{min}, c_{max}]$. Each supplier knows his or her own cost exactly and knows that others' costs are drawn independently from $F(c)$. We assume that F admits a continuous density function $f \equiv F'$ and has full support. Throughout the study we refer to this model as the symmetric suppliers model with incomplete information, as the suppliers do not know each others' costs exactly but share the same belief about the distribution.

An auction is actually a distributed allocation problem with self-interested agents. The mechanism design approach formulates such problems as optimization problems. There are two goals, usually conflicting with each other, in the design of the mechanisms. These goals are efficiency and profit maximization, and profit maximization is replaced by cost minimization in reverse auctions. Myerson [15] studies the optimal auction design for the forward auction setting.

We study the mechanism design problem in the case of procurement auctions via Myserson's framework, utilizing the methodology explained for forward auctions by Krishna [14]. The single period procurement mechanism $(\mathcal{B}, \rho, \mu)$ can be represented as: a set of possible bids $\mathcal{B}_j$ for each supplier; an allocation rule $\rho : \mathcal{B} \to \Delta$, where Δ is the set of probability distributions over the set of suppliers $\mathcal{N}$; and a payment rule $\mu : \mathcal{B} \to \mathbb{R}^N$. An allocation rule determines, as a function of all N bids, for each supplier j, the probability $\rho_j(b)$ that supplier j will be awarded. A payment rule determines the expected payment $\mu_j(b)$ that supplier j must receive.

If the set of possible bids is unrestricted, it will not be possible to analyze the mechanism design problem due to the complication caused by the unlimited number of possible bids for each supplier. Therefore, we will refer to the revelation principle, stating that for any given mechanism and an equilibrium for that mechanism, there exists a direct mechanism in which it is an equilibrium for each bidder to report his or her true value, and the outcomes are the same as in the given equilibrium of the original mechanism. Hence, restricting the analysis only to direct mechanisms do not cause any loss of generality.

The mechanisms for which $\mathcal{B}_j = \mathcal{C}_j$ for all j, are called direct mechanisms, where $\mathcal{C}_j$ represents the set of possible costs for each supplier j. Formally, a direct mechanism $(\mathbf{P}, \mathbf{M})$ consists of a pair of functions $\mathbf{P} : \mathcal{C} \to \Delta$ and $\mathbf{M} : \mathcal{C} \to \mathbb{R}^N$ where $P_j(\mathbf{c})$ is the probability that supplier j will be awarded and $M_j(\mathbf{c})$ is the expected payment received by supplier j. We can represent the relation between a direct mechanism version of a given mechanism with the given mechanism as a composition function of the form $(\mathbf{P}, \mathbf{M}) \equiv (\rho, \mu) \circ \beta$.

Two important issues that should be considered in the design of auctions are the incentive compatibility(IC) and the individual rationality(IR). The IC property implies that the suppliers cannot gain anything by pretending to be someone else other than their true types. In case of a direct mechanism, IC implies that revealing her true cost is the equilibrium strategy for each supplier. IR property implies that the bidders prefer participating in the auction to staying out of the auction.

Given a direct mechanism $(\mathbf{P}, \mathbf{M})$, we represent the probability that supplier j will be awarded the contract when she reports her cost to be e_j instead of c_j, while all other suppliers report their costs truthfully, by $p_j(e_j)$. Similarly, $m_j(e_j)$ represents the expected payment to supplier j when her report is e_j, and all other suppliers tell the truth. The probability of winning the contract and the expected payment received depend only on the reported cost and not on the true cost. The expected payoff of supplier j when her true cost is c_j and she reports e_j, again assuming that all other suppliers tell the truth, can then be defined as:

$$m_j(e_j) - p_j(e_j)c_j \tag{1}$$

Representing the expected profit of supplier j when she submits her true cost c_j, by $\pi_j(c_j)$, the direct revelation mechanism $(\mathbf{P}, \mathbf{M})$ is said to be IC if for all j, for all c_j and for all e_j:

$$\pi_j(c_j) \equiv m_j(c_j) - p_j(c_j)c_j \geq m_j(e_j) - p_j(e_j)c_j \tag{2}$$

Hence, IC implies that: $\pi_j(c_j) \geq \max_{e_j \in C_j}\{m_j(e_j) - p_j(e_j)c_j\}$. The expected profit for a supplier reporting e_j instead of c_j is a linear function of c_j. Being the maximum of a family of linear functions, $\pi_j(c_j)$ is a convex function.

¿From equations 1 and 2, we can obtain the following relation:

$$\pi_j(e_j) \geq \pi_j(c_j) + p_j(c_j)(c_j - e_j) \tag{3}$$

The relation defined by equation 3 implies that for all c_j, $-p_j(c_j)$ is the slope of a line that supports the function π_j at the point c_j. As this convex function is absolutely continuous, it can be differentiable almost everywhere in the interior of its domain:

$$\pi_j^{'}(c_j) = -p_j(c_j) \tag{4}$$

Equation 4 implies that p_j is a nonincreasing function since π_j is convex. Finally, we can define $\pi_j(c_j)$ as the definite integral of its derivative:

$$\pi_j(c_j) = \pi_j(c_{max}) + \int_{c_j}^{c_{max}} p_j(t_j)\, dt_j \tag{5}$$

Equation 5 implies that the shape of the expected profit function is completely determined by the allocation rule $\mathbf{P}$ alone. The payment rule $\mathbf{M}$ only determines the constant $\pi_j(c_{max})$.

In order to show that incentive compatibility is implied by the statement that p_j is a nonincreasing function, we can rewrite equation 3 by using equation 5 as:

$$\int_{e_j}^{c_j} p_j(t_j)\, dt_j \geq p_j(c_j)(c_j - e_j) \tag{6}$$

The relation defined by equation 6 certainly holds if p_j is nonincreasing. The expected payment to j under an incentive compatible direct mechanism $(\mathbf{P}, \mathbf{M})$ is given by:

$$m_j(c_j) = m_j(c_{max}) + p_j(c_j)c_j + \int_{c_j}^{c_{max}} p_j(t_j)\, dt_j \tag{7}$$

With the implicit assumption that the supplier can guarantee herself a profit of zero by not participating in the auction, a direct mechanism $(\mathbf{P}, \mathbf{M})$ is individually rational if, for all j and c_j, the equilibrium expected profit $\pi_j(c_j) \geq 0$. If the mechanism is incentive compatible, then this is equivalent to the requirement that $\pi_j(c_{max}) \geq 0$, and hence $m_j(c_{max}) \geq 0$.

Considering the buyer as the designer of the mechanism, we provide the properties of the optimal mechanism among the mechanisms that are incentive compatible and individually rational. In the optimal mechanism, the buyer minimizes the total procurement cost, defined by the following equation:

$$\sum_{j \in \mathcal{N}} E[m_j(C_j)] = \sum_{j \in \mathcal{N}} \int_{c_{min}}^{c_{max}} m_j(c_j) f_j(c_j)\, dc_j \tag{8}$$

Substituting equation 7 to equation 8, we can rewrite the expected total procurement cost as:

$$\sum_{j \in \mathcal{N}} E[m_j(C_j)] = \sum_{j \in \mathcal{N}} m_j(c_{max}) + \sum_{j \in \mathcal{N}} \int_{c_{min}}^{c_{max}} \left(c_j + \frac{F_j(c_j)}{f_j(c_j)}\right) p_j(c_j) f_j(c_j)\, dc_j \tag{9}$$

As the first term in equation 9 is constant, the buyer will focus on the second term, which is dependent on the allocation rule, to minimize the total expected procurement cost.

We can simplify equation 9 by defining $\psi_j(c_j) \equiv c_j + \frac{F_j(c_j)}{f_j(c_j)}$. This term can be named as the virtual cost of a supplier with true cost c_j. Rewriting $p_j(c_j)$ explicitly as $\int_{C_{-j}} P_j(e, \mathbf{c}_{-j}) f_{-j}(\mathbf{c}_{-j})\, d\mathbf{c}_{-j}$, the expected total procurement cost can be reexpressed as:

$$\sum_{j \in \mathcal{N}} m_j(c_{max}) + \int_C \left(\sum_{j \in \mathcal{N}} \psi_j(c_j) P_j(\mathbf{c}) \right) f(\mathbf{c})\, d\mathbf{c} \tag{10}$$

The function defined by equation 10 can be considered as a weighting function. Therefore, the optimal solution will be to assign positive weight to the smallest virtual costs since the objective is to minimize the function. If the buyer has an option of buying the item from the spot market at a price of s, then the optimal allocation and payment rules can be defined as:

$$\begin{aligned} &P_j(\mathbf{c}) > 0 \Leftrightarrow \psi_j(c_j) = \min_{i \in \mathcal{N}} \psi_i(c_i) \leq s \\ &M_j(\mathbf{c}) = P_j(\mathbf{c}) c_j + \int_{c_j}^{c_{max}} P_j(e_j, \mathbf{c}_{-j})\, de_j \end{aligned} \tag{11}$$

As the virtual cost is an increasing function of the true cost, the optimal mechanism can be restated as:

$$P_j(\mathbf{c}) = \begin{cases} 1 & if \psi_j(c_j) < \min_{i \neq j} \psi_i(c_i) \; and \; \psi_j(c_j) \leq s \\ 0 & otherwise \end{cases}$$

$$M_j(\mathbf{c}) = \begin{cases} y_j(\mathbf{c}_{-j}) & if P_j(\mathbf{c}) = 1 \\ 0 & if P_j(\mathbf{c}) = 0 \end{cases} \tag{12}$$

In equation 12, $y_j(\mathbf{c}_{-j})$ is defined by:

$$y_j(\mathbf{c}_{-j}) = sup\{e_j : \psi_j(e_j) \leq s \; and \; \forall\, i \neq j,\; \psi_j(e_j) \leq \psi_i(c_i)\} \tag{13}$$

The optimal mechanism is defined to be a second price auction with a reserve price, r, equal to $\psi^{-1}(s)$ for a single period procurement auction in the symmetric suppliers with incomplete information model.

However, the first price sealed bid auction is the most widely used auction type for industrial procurement, especially in the private sector. Therefore, we focus on the analysis of the first price sealed bid auction. We also do not consider open auction as it is not possible to keep the privacy of suppliers in such a setting, and it is more open to possibilities of coalition between suppliers.

Before studying the repeated procurement setting, we explain the derivation of the bidding strategy of a myopic supplier, $\beta^M : \mathcal{C}_j \to \mathcal{B}_j$, in a single period first price sealed bid auction. Then, we present the corresponding direct mechanism.

As the suppliers are risk neutral, any supplier j will determine her bid function by maximizing her expected profit. We denote the expected profit of a myopic supplier j by π_j^M, which is defined in the following equation:

$$\pi_j^M = (1 - F(\phi^M(b_j)))^{(N-1)}(b_j - c_j)Q \tag{14}$$

The first term in equation 14 denotes the probability of winning the auction while bidding b_j. A supplier j will win the auction if and only if she submits the lowest bid. Since β^M is an increasing function of c, submitting the lowest bid is equivalent to stating that the supplier j will win whenever she has the lowest cost among all the participating suppliers. We denote the inverse bidding function by $\phi^M(b_j)$ to represent the relation between the submitted bids and revealed cost of the supplier. The second term shows the profit margin of supplier j. Therefore, the supplier is actually facing a tradeoff while determining the optimal bid. An increase in the bid will increase the profit margin, while reducing the probability of winning at the same time. The optimal bid is determined at the point where these effects balance off.

Due to the symmetric Bayesian-Nash equilibrium result, we can argue that $\phi^M(b_j) = c_j$. Making this substitution in the necessary first order condition equation for maximization, and rearranging the terms to solve the first order differential equation, the optimal bidding strategy for a myopic supplier, whose cost is not higher than the reserve price (i.e. $c_j \leq r$), is given by:

$$\beta^M(c_j) = c_j + \int_{c_j}^{r} \left(\frac{1 - F(x)}{1 - F(c_j)} \right)^{(N-1)} dx \tag{15}$$

Although, $\beta^M(c_j)$ is derived from the necessary condition, the following proposition verifies that it is indeed the optimal strategy.

Proposition 3.1. *The symmetric equilibrium strategies of myopic suppliers for a single period procurement auction are given by equation 15, given that* $c_j \leq r$.

Proof. We can prove this proposition, by arguing that while all but supplier j follow the strategy β^M defined by equation 15, it is optimal for a given supplier j to follow the same strategy β^M. In other words, we prove the proposition by showing that this bidding strategy is incentive compatible and individually rational for a given supplier.

The corresponding direct mechanism $(\mathbf{P}, \mathbf{M})$ for this mechanism can be defined:

$$\begin{aligned} P_j(c_j) &= (1 - F(c_j))^{(N-1)} \\ M_j(c_j) &= P_j(c_j)c_j + \int_{c_j}^{r} (1 - F(x))^{(N-1)} \, dx \end{aligned} \tag{16}$$

In order to show that the corresponding direct mechanism is incentive compatible, we need to show that $P_j(c_j)$ is a decreasing function of c_j. Taking the partial derivative leads to the following equation: $\frac{\partial P_j(c_j)}{\partial c_j} = (N-1)(1 - F(c_j))^{(N-2)}(-f(c_j))$. Since $\frac{\partial P_j(c_j)}{\partial c_j} \leq 0$, this proves that the corresponding direct mechanism is incentive compatible. As $M_j(c_{max}) = 0$, the corresponding direct mechanism is also individually rational. ■

In terms of efficiency and optimality, the given direct mechanism results in an ex-post efficient allocation in the absence of a reserve price, as the awarded supplier will be the one with the lowest cost. Before discussing the efficiency of the mechanism in the presence of a reserve price, we will derive the optimal reserve price for the mechanism defined by equation set 16. The buyer sets the reserve price to minimize the total expected procurement cost, donated by $\hat{C}_B$, which is defined as:

$$\hat{C}_B = N\left[\int_{c_{min}}^{r}\left(c(1-F(c))^{N-1}+\int_{c}^{r}(1-F(x))^{N-1}\,dx\right)f(c)\,dc\right]+(1-F(r))^N s \tag{17}$$

The first term in equation 17 shows the expected cost of procurement to the buyer in case a trade occurs at the auction, whereas the second term is the expected procurement cost of buying the item from the spot market. Therefore, the buyer faces a trade-off while setting the optimal reserve price between the outside (spot market) option and the possibility of trade as a result of the auction.

The optimal reserve price derived from the first order condition is defined by the following equation:

$$r^* + \frac{F(r^*)}{f(r^*)} = s \tag{18}$$

We can restate the optimal reserve price as $r^* = \psi^{-1}(s)$. In the presence of this optimal reserve price, given that r^* is smaller than c_{max}, the mechanism is no longer efficient, since there is a positive probability that the buyer will procure from the spot market although there might be a supplier who can provide the item at lower cost.

We characterize the symmetric equilibrium bidding strategies of a myopic supplier in the following propositions and provide some basic numerical examples to visualize the results of these propositions.

Proposition 3.2. *The symmetric equilibrium bid of a given myopic supplier j under the original mechanism, or equivalently the expected payment to the supplier under the direct mechanism, is an increasing function of its cost c_j, while the expected profit margin (mark-up) is a decreasing function of its cost c_j.*

Proof. Analytically, taking the first order partial derivative of $\beta^M(c_j)$ with respect to c_j will prove the proposition showing that the partial derivative of bid is positive while the partial derivative of the mark-up is negative. Intuitively, the higher the cost of a supplier, the higher the bid she will submit to cover her costs. However, she needs to decrease the added mark-up at the same time due to the loss of competitive advantage as her cost comes closer to the upper limit of the possible cost space. ■

Proposition 3.3. *As the number of suppliers participating in the procurement auction increases, the bid decreases as a result of the reduction in the mark-up. Specifically, the submitted bid converges exponentially to the true cost as the number of participating suppliers increases.*

Proof. The intuition is that with the increasing number of suppliers participating in the auction, the competition increases. This will lead to the conclusion that the probability of a lower cost supplier increases and hence the suppliers reduce their mark-ups to be more competitive. Analytically, taking the first order partial derivative of $\beta_1^M(c_j)$ with respect to N will prove the proposition by showing that the partial derivative is indeed negative. ■

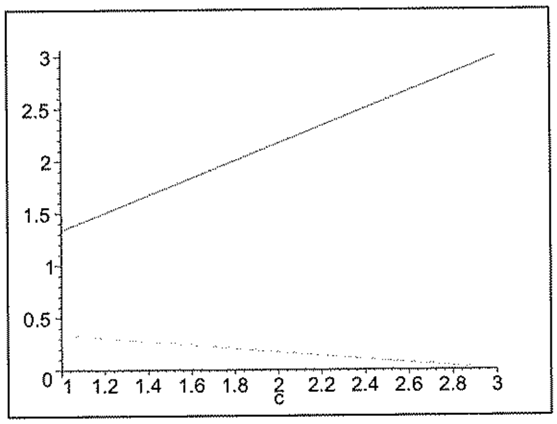

Figure 1: A Myopic Supplier's Bid vs. Her True Cost

We assume that the costs of the suppliers are independently and identically distributed according to uniform distribution defined on the closed interval [1,3], donated by U(1,3). In figure 1, the upper linear function represents the equilibrium bidding strategy of a myopic supplier competing with five other suppliers, while the lower linear function represents the added mark-up of the same supplier, as functions of her true cost. Next, in figure 2, we provide the equilibrium bidding strategy of a myopic supplier, with a true cost of 1.4, as a function of the number of participating suppliers.

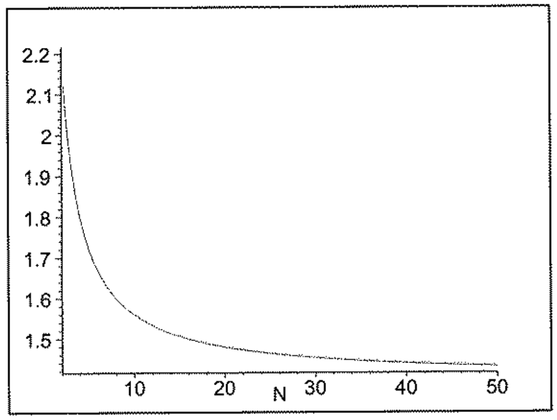

Figure 2: A Myopic Supplier's Bid vs. Number of Suppliers

4 Repeated Procurement Model

Having completed the detailed analysis of the single period procurement auction, we move on to the analysis of the repeated procurement model. As we have stated earlier, studies of repeated auctions in the literature use the capacity as the binding component between periods. They all assume that winning in a given period decreases the available capacity for further periods and therefore will affect the bidding strategy. However, in the repeated procurement auction settings for the industrial procurement this is not a reasonable assumption, as the capacity is a binding constraint mainly in the individual period, not among the periods.

Therefore we consider other properties that couple the periods. Setting the reserve price in a given period according to the winning bid of the previous period is an alternative way of coupling the periods. We show that this policy is a weakly dominant strategy for a buyer to use under the repeated procurement auction setting. Another way might be to consider cost updates for each supplier based on whether the supplier is the winner of the auction in the previous period or not. However, this method requires the players to keep track of the full history of the procurement auctions and might not be applicable in the generalized repeated setting.

Besides emphasizing the difference between equilibrium behaviors of the myopic and strategic suppliers, we also discuss the buyer's attitude for the repeated procurement auction throughout our analysis. Our main assumption is that the buyer commits himself in advance to a set of allocation and payment rules credibly. Thus, we assume that the buyer will not alter his strategy, as he obtains information at the end of each period and suppliers believe the buyer will keep the rules exactly the same during the whole project life. Later in our analysis, we will show that committing is not actually the best strategy for a buyer.

We start our analysis by considering the myopic suppliers and then elaborate the repeated setting discussion with the case of strategic suppliers. We assume that the costs of the suppliers are drawn once and remain the same throughout the project life.

4.1 All Myopic Suppliers

As the name implies, myopic suppliers consider neither the past nor the future periods while deciding on the bidding strategies in a given period. However, they might gain profitable information by evaluating the past periods, and their future possible bids might be bounded above by their current bids as they might affect the winning bid in the current period. Hence, any myopic supplier j will determine her bid function for any period t by maximizing the expected profit in that period, and the repeated auction will be just the repetition of independent single period auctions with continuously decreasing reserve price, which is determined for each period by the winning bid of the previous period. The symmetric equilibrium bidding strategy for a given myopic supplier j in any period t will be given by:

$$\beta_t^M(c_j) = c_j + \int_{c_j}^{r_t} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \tag{19}$$

The submitted bids of any myopic supplier during the project life will follow a pattern similar to the representative one shown in figure 3, where it can be observed that the submitted bids of the myopic supplier converge exponentially to her true cost.

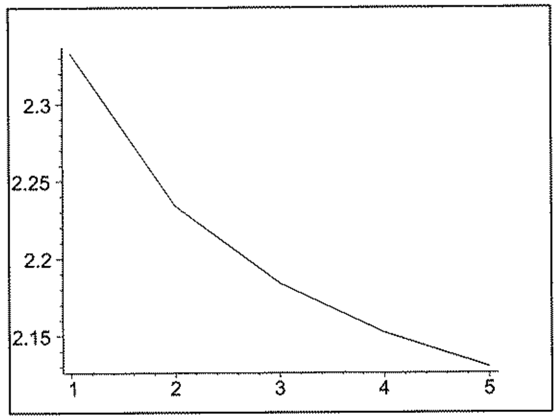

Figure 3: Submitted Bids of a Myopic Supplier During Project Life

4.2 All Strategic Suppliers

Next, we can analyze the case of all strategic suppliers. A strategic supplier considers the future expected profits while bidding in a given period t, therefore the structure defining the auction has a crucial impact on the submitted bids, an equivalently critical impact on the incentive compatible direct mechanism payment rule. As we assume that the costs are constant during the project life, we consistently assume that there is no time value of money concept, i.e there is no discount factor for the expected future profits.

We restrict our analysis to the case in which the bidding strategies of the suppliers are fixed at the beginning of the project and are not altered according to the outcomes of the interim stages. In the absence of such an assumption, due to the perfect correlation of the cost through the periods, all the probability distribution beliefs should be updated conditionally. Hence, asymmetries with varying levels, depending on whether the winning bid is announced or not, occur between suppliers at the end of the first period, and this complicates the analytical discussion of the bidding strategies.

We start with two periods in order to show the intuition beyond the equilibrium bidding strategy of a given supplier j when all suppliers are strategic. The second period expected profit, π_{j2}^S is given by:

$$\pi_{j2}^S = (1 - F(\phi_2^S(b_{j2})))^{(N-1)}(b_{j2} - c_j)Q_2 \tag{20}$$

The profit function defined by equation 20 looks exactly the same as the profit function defined by equation 14. At first thought, it is expected to see some additional terms due to the uncertainty about the reserve price of the second period at the beginning of the first period. However, due to the special attributes of the model, which are symmetry, constant fixed cost in both periods, and assumption that bidding strategies are fixed for both periods in the initial period, each supplier will set the reserve price to her own submitted first period bid by each supplier. Therefore, there is no explicit term due to the reserve price affecting the expected profit. This fact will come into play while defining the optimal bidding strategy.

The optimal bidding strategy to maximize the expected profit defined by equation 20, as a result of solving the necessary first order condition, is given to be:

$$\beta_2^S(c_j) = c_j + \int_{c_j}^{r_2} \left(\frac{1 - F(x)}{1 - F(c_j)}\right)^{(N-1)} dx \tag{21}$$

The important point is that r_2 will be replaced by b_{j1} as a result of the above reasoning about the attributes of the model. Those attributes guarantee that it will not be possible for different suppliers to be winners at different periods. The same supplier will be the most efficient supplier in both periods, and no supplier can gain by pretending to be someone else, i.e. submitting bid based on some fictitious cost. Therefore, we can include the optimal strategy given by equation 21 after replacing r_2 by b_{j1} into the expected profit function of the project, denoted by $\tilde{\pi}_j^S$.

$$\tilde{\pi}_j^S = \left[(1 - F(\phi_1^S(b_{j1})))^{(N-1)}\right] \cdot \left[Q_1(b_{j1} - c_j) + Q_2 \int_{c_j}^{b_{j1}} \left(\frac{1 - F(x)}{1 - F(c_j)}\right)^{(N-1)} dx\right] \tag{22}$$

The total expected profit from the project can be expressed as a function of the first period bid. As it can be seen from the equation 22, there is again a trade off in choosing the optimal bid value. However, the main difference from the myopic suppliers case is that the positive effect of increasing the bid is weighted more due to the future period consideration. The optimal bidding strategy, β_1^S, of any supplier is defined by:

$$\beta_1^S(c_j) = c_j + \int_{c_j}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx + \frac{Q_2}{Q_1} \int_{\beta_1^S(c_j)}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \quad (23)$$

Proposition 4.1. *The optimal bidding strategy of a given strategic supplier j, $\beta_1^S(c_j)$, is defined by equation 23.*

Proof. The intuition beyond the optimal bidding strategy given by equation 23 is that the suppliers are trying to compensate the opportunistic loss in the second period due to the reserve price adjustment according to the winning bid of the first period, by inflating their first period mark-ups. In case there is a constant reserve price of r_1 for both periods, the bidding strategies in each period will be given by:

$$c_j + \int_{c_j}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \quad (24)$$

and the total profit will be:

$$(Q_1 + Q_2) \int_{c_j}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \quad (25)$$

However, due to the adjustment of the reserve price according to the winning bid, there is a difference of $\left(\int_{\beta_1^S(c_j)}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx\right)$ that can be considered as an opportunistic loss between equations 24 and 21. Suppliers will add this amount after weighting with the quantity ratio to their first period bids to compensate the loss totally. It can be analytically shown that this bidding strategy satisfies the first order condition. ■

Proposition 4.2. *The optimal bidding strategy of a given strategic supplier j, $\beta_1^S(c_j)$, is a nondecreasing function of c_j, while the profit mark-up and compensation amounts are decreasing functions of c_j.*

Proof. Analytically, taking the partial derivatives of the mentioned functions with respect to c_j shows that the partial derivatives of the bidding strategy is nonnegative where as the others are negative. The intuition is that as the bids are increasing function of the cost, the amount of opportunistic loss is decreasing and therefore the compensation amount is also decreasing. The profit margin also decreases as the cost increases, since the competitiveness decreases as the cost increases. ■

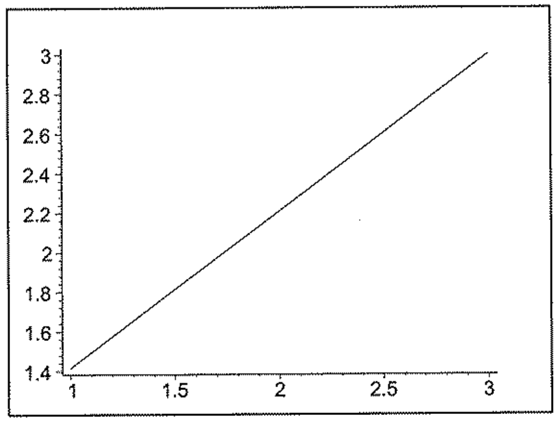

Figure 4: First Period Equilibrium Bids of a Strategic Supplier

The graph in figure 4 represents a strategic supplier's first period symmetric equilibrium bid as a function of her true cost, while she is competing against five other strategic suppliers. We again assume the costs are drawn from U(1,3). In figure 5, the upper linear function represents the added mark-up while the lower linear function shows the compensation amount for future opportunistic losses.

Proposition 4.3. *The submitted bids of the strategic players are more dense, i.e. the deviation of the submitted bids in the all strategic suppliers case is less than the deviation of submitted bids in the all myopic supplier case.*

Proof. Analytically it is possible to show that the standard deviation of the submitted bids in the all strategic suppliers case is lower. This is because of the fact that the extra term, compensation amount, which strategic suppliers add to the myopic suppliers' bid, is a decreasing function of the true cost. Therefore, the submitted bids are closer to each other.

We can represent the multi period repeated procurement mechanism by $(\mathcal{B}_t, \rho_t, \mu_t)$ with the same definitions of single period mechanism for each period. Similarly,

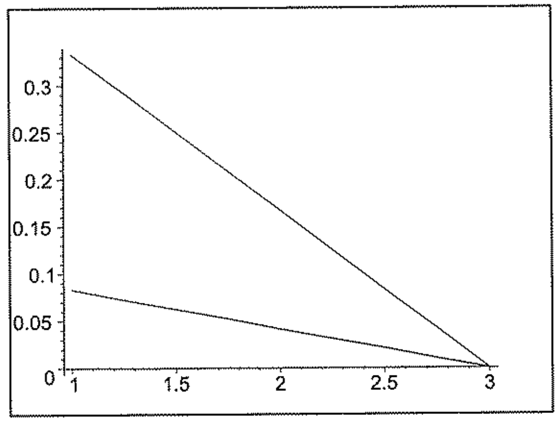

Figure 5: First Period Mark-up and Compensation of a Strategic Supplier

the corresponding direct mechanism will be defined by $(\mathbf{P}_t, \mathbf{M}_t)$ consisting a pair of functions $\mathbf{P}_t : \mathcal{C}_t \longrightarrow \Delta_t$ and $\mathbf{M}_t : \mathcal{C}_t \longrightarrow \mathbb{R}^N$ where $P_{jt}(c_t)$ is the probability that supplier j will be awarded in period t and $M_{jt}(c_t)$ is the expected payment received by supplier j in period t.

The accompanying direct mechanism, $(\mathbf{P}_t, \mathbf{M}_t)$, for the mentioned two period problem can be represented by:

$$\begin{aligned}
P_{j1}(c_j) &= (1 - F(c_j))^{(N-1)} \\
M_{j1}(c_j) &= P_{j1}(c_j)c_j + \int_{c_j}^{r_1} (1 - F(x))^{(N-1)}\, dx + \frac{Q_2}{Q_1} \int_{\frac{M_{j1}(c_j)}{P_{j1}(c_j)}}^{r_1} (1 - F(x))^{(N-1)}\, dx \\
P_{j2}(c_j) &= (1 - F(c_j))^{(N-1)} \\
M_{j2}(c_j) &= P_{j2}(c_j)c_j + \int_{c_j}^{\frac{M_{j1}(c_j)}{P_{j1}(c_j)}} (1 - F(x))^{(N-1)}\, dx
\end{aligned} \tag{26}$$

The direct mechanism $(\mathbf{P}_t, \mathbf{M}_t)$ defined by equation 26 is an incentive compatible and individually rational mechanism. The allocation rule in each period, $P_{jt}(c_j)$, is a decreasing function of c_j, and this implies the incentive compatibility. As the expected payments received by a supplier in each period, $M_{jt}(c_j)$, are nonnegative, the mechanism is also individually rational.

In case there is a reserve price for the initial period, r_1 set to $\psi_1^{-1}(s)$, the mentioned mechanism is not ex-post efficient as there is always a positive probability that the buyer will procure the item from spot market although there is a more efficient supplier than the spot market. However, if there is no reserve price set for the initial period, then the mechanism is ex-post efficient as the least cost (most efficient) supplier will be awarded. Since the allocation rule is the same for both periods, and costs are perfectly correlated, the same supplier will be the winner in each period. Hence, the reserve price set in the second period does not cause inefficiency.

An observation about the optimal bidding strategy is that the quantity demanded has an impact on the magnitude of the markup added by the supplier to compensate the opportunistic loss. Specifically, there is an inversely proportional relation with the first period quantity demanded and a directly proportional relation with the second period quantity. As the second period quantity increases, the opportunistic loss to be considered increases, and as the first period quantity increases the opportunistic loss is compensated by adding smaller mark-up to unit item. Inflating the markup due to this intuition results in the following proposition.

Proposition 4.4. *The optimal bidding strategy of a supplier in case all suppliers are strategic will result in submitting a higher bid than the optimal bidding strategy of a supplier in case all suppliers are myopic, or at least equal for the special case $c_j = r_1$.*

Proof. It can easily be proven by using the definitions of the optimal bidding strategies given by equations 23 and 15. The difference between the strategic bid and the myopic bid equals to $\frac{Q_2}{Q_1}\int_{\beta_1^S(c_j)}^{r_1}\left(\frac{(1-F(x))}{(1-F(c_j))}\right)^{(N-1)} dx$ and is positive since $\beta_1^S(c_j) < r_1$ as long as $c_j < r_1$. If $c_j = r_1$, then the submitted bids will be the same in both cases. As all integral terms equal to zero, the submitted bid equals to r_1 in both cases. ■

We can easily generalize this intuition of compensating future losses to any finite T period auction, such that the opportunistic loss in period t will be compensated partially in each of the prior periods. In other words, while determining the optimal bid in a given period t, the supplier will consider the opportunistic losses in all future periods, from $t+1$ to T, caused by bidding b_{jt} in the current period t, leading to an additional mark-up to compensate for each future period.

Therefore, the optimal bidding strategy for a given period t can be stated as:

$$\begin{aligned}\beta_t^S(c_j) &= c_j + \int_{c_j}^{\beta_{t-1}^S(c_j)} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \\ &+ \sum_{j=t+1}^{T} \left[\left(\frac{Q_j}{Q_t}\right) \cdot \int_{\beta_t^S(c_j)}^{\beta_{t-1}^S(c_j)} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \right] \qquad (27)\end{aligned}$$

where the last period bidding strategy is given by:

$$\beta_T^S(c_j) = c_j + \int_{c_j}^{\beta_{T-1}^S(c_j)} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N-1)} dx \qquad (28)$$

The equations 27 and 28 are obtained using a dynamic program logic. First, we define the optimal bidding strategy for the last period in the project life. Next, we substitute this strategy in the expected joint profit equation of the previous period in order to find the previous period optimal strategy. We continue to substitute each found strategy in the previous period's expected joint profit equation till we reach the initial period. Finally, we can evaluate the bidding strategies of each period in a forward procedure.

Proposition 4.5. *The path followed by the submitted bids for a T period auction will be dependent on the distribution of the quantity demanded throughout the periods.*

Proof. As the optimal bidding strategy in any period t is defined by equation 27, it is easy to see that the mark-up in any period is directly proportional to the ratio of the further period quantities to the current period quantity. The more fluctuation in the demand, the more fluctuation will be in the mark-ups, leading to changes in the path followed by the optimal bids. ■

An extension that we have considered for the case of strategic suppliers is the stochastic demand for the second period. As the quantity demanded does not have any role in the determination of the submitted bid for the myopic suppliers, it is not important whether the demands are deterministic or not. However, the quantity demanded has a significant role in setting the equilibrium bids for the strategic suppliers. The stochastic quantity demanded will be a straight forward extension of the studied model, as the costs are independent of the quantity demanded. Therefore, a given supplier j will submit a weighted average of the bids that she will submit in case that quantity demanded is realized with certainty, based on the probability distribution of the quantity demanded.

$$
\begin{aligned}
\beta_1^S(c_{j1}) &= c_{j1} + \int_{c_{j1}}^{r_1} \left(\frac{1 - F(x)}{1 - F(c_{j1})} \right)^{(N-1)} dx \\
&\quad + \delta \frac{\sum_\omega p_\omega Q_{2\omega}}{Q_1} \int_{\beta_1^S(c_{j1})}^{r_1} (1 - F(x))^{(N-1)} \left(\frac{1 - F(c_{j2})}{1 - F(c_{j1})} \right)^{(N-1)} dx \quad (29)
\end{aligned}
$$

The only difference from the deterministic demand will be in the adjustment of compensation mark-up. The supplier will adjust the compensation mark-up based on the expected value of the quantity demanded in the second period, instead of the actual quantity demanded in the second period. The same type of extension will hold for all the strategic supplier bidding strategies.

4.3 Mixed Pool of Suppliers

After analyzing myopic and strategic supplier pools separately, we consider the mixed pool of both myopic and strategic suppliers. We assume that the number of each type of suppliers is fixed and common knowledge to all suppliers. We denote by N_M the number of myopic suppliers, and by N_S the number of strategic suppliers.

We start with the myopic suppliers. The bidding strategies of them will be independent of the future periods, and therefore, in case the winning bid of the previous period is announced, the expected profit function of a myopic supplier for any period t will be given by:

$$
\pi_{jt}^{MM} = \left(1 - F(\phi_t^{MM}(b_{jt}^M))\right)^{(N_M-1)} \left(1 - F(\phi_t^{SM}(b_{jt}^M))\right)^{N_S} \left(b_{jt}^M - c_j\right) \quad (30)
$$

The first order condition yields the optimal bidding strategy of a myopic supplier to be defined by the following equation:

$$
\beta_t^{MM}(c_j) = c_j + \int_{c_j}^{P_{I_{t-1}}} \left(\frac{1 - F(x)}{1 - F(c_j)} \right)^{(N_M-1)} \left(\frac{1 - F(\phi_t^{SM}(\beta_t^{MM}(x)))}{1 - F(\phi_t^{SM}(\beta_t^{MM}(c_j)))} \right)^{N_S} dx \quad (31)
$$

We initially consider a two period auction to observe the optimal bidding strategies of the strategic suppliers. First, we define the optimal bidding strategy for the second period, and after substituting that in the total expected project profit, we will define the optimal bidding strategy for the initial period. The second period expected profit is defined by:

$$\begin{aligned}\pi_{j2}^{SM} &= \left(1 - F(\phi_2^{MM}(b_{j2}^S))\right)^{N_M} \left(1 - F(\phi_2^{SM}(b_{j2}^S))\right)^{(N_S-1)} \left(b_{j2}^S - c_j\right) \cdot \\ &\quad \left[1 - \left(1 - F(\phi_1^{MM}(b_{j2}^S))\right)^{N_M} \left(1 - F(\phi_1^{SM}(b_{j2}^S))\right)^{(N_S-1)}\right] \qquad (32)\end{aligned}$$

which leads to the second period optimal strategy to be:

$$\begin{aligned}\beta_2^{SM}(c_j) &= c_j + \int_{c_j}^{b_{j1}^S} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N_S-1)} \left(\frac{1-F(\phi_2^{MM}(\beta_2^{SM}(x)))}{1-F(\phi_2^{MM}(\beta_2^{SM}(c_j)))}\right)^{N_M} \cdot \\ &\quad \left(\frac{\left[1-(1-F(x))^{N_M}(1-F(x))^{(N_S-1)}\right]}{\left[1-(1-F(\beta_2^{SM}(c_j)))^{N_M}(1-F(\beta_2^{SM}(c_j)))^{(N_S-1)}\right]}\right) dx \qquad (33)\end{aligned}$$

where, the first two terms in the integral represent the markup against the competitors in the second period, and the last term represents the markup against the random reserve price of the second period, depending on the first period bidding strategies.

Similarly, we end up with the following first period optimal strategy, although not possible to express in a nice closed form expression:

$$\begin{aligned}\beta_1^{SM}(c_j) &= c_j + \int_{c_j}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N_S-1)} \left(\frac{1-F(\phi_1^{MM}(\beta_1^{SM}(x)))}{1-F(\phi_1^{MM}(\beta_1^{SM}(c_j)))}\right)^{N_M} + \\ &\quad \int_{\beta_1^{SM}(c_j)}^{r_1} \left(\frac{1-F(x)}{1-F(c_j)}\right)^{(N_S-1)} \left(\frac{1-F(\phi_2^{MM}(\beta_2^{SM}(x)))}{1-F(\phi_2^{MM}(\beta_2^{SM}(c_j)))}\right)^{N_M} \cdot \\ &\quad \left(\frac{\left[1-(1-F(x))^{N_M}(1-F(x))^{(N_S-1)}\right]}{\left[1-(1-F(\beta_2^{SM}(c_j)))^{N_M}(1-F(\beta_2^{SM}(c_j)))^{(N_S-1)}\right]}\right) dx \qquad (34)\end{aligned}$$

In terms of structure, the first period bidding function of a strategic supplier in the case of mixed pool is the same as the one in the case of all strategic suppliers model. The main difference is the adjustment of the profit mark-up and compensation amounts. These amounts have been adjusted due to the presence of the two different types of suppliers at the same time in the participating suppliers pool. The compensation amount has also an additional adjustment due to the randomness of the reserve price, actually the randomness of the winning bid in the first period. The statement that we have in the all strategic suppliers model about the same supplier being the winner in both periods is no longer valid in the mixed pool. As the bidding strategies of myopic and strategic suppliers are asymmetric, there is no guarantee of the same supplier being the winner. Finally, because of this same reason, this mechanism is no longer ex-post efficient. There is a positive chance that a higher cost (inefficient) myopic supplier might be winner instead of a lower cost strategic supplier due to the difference in the bidding strategies.

4.4 Discussion From Buyer's View

As we have mentioned while starting the analysis of repeated setting, the reserve price policy used in the studied models is a weakly dominant strategy for a buyer under the assumption of full commitment to the mechanism. We will also discuss briefly the commitment issue at the end of this section.

Starting with the all strategic suppliers model, we would like to show that although the reserve price has an impact on the expected periodical payments, it does not change the expected total project procurement cost. As the strategic suppliers consider the future periods while setting their current period bids, they compensate for the future expected losses. Therefore, changing the reserve price will only change these adjustments, and at the end the total will remain the same. The only significant reserve price affecting the expected total procurement cost is the first period reserve price. In terms of mechanism design perspective, the total expected payment to a single supplier is given by:

$$\bar{M}_j(c_j) = \sum_{t=1}^{T} \left[Q_t \left((1 - F(c_j))^{(N-1)} c_j + \int_{c_j}^{r_1} (1 - F(x))^{(N-1)} \, dx \right) \right] \qquad (35)$$

As it can be seen from equation 35, the expected total procurement cost is independent of the reserve prices set in periods other then the first period.

However in the case of all myopic suppliers, the reserve price policy is affecting significantly the expected total procurement cost since the myopic suppliers do not consider the future periods and do not compensate for future possible losses in their current period bids. Therefore, the buyer's best response will be to set a declining reserve price policy to capture the surplus instead of leaving it totally to the suppliers. As the buyer should commit from the beginning, the best policy he can deploy is setting the reserve price of a period to the winning bid of the previous period.

All these discussions depend on the credibility of the buyer's commitment to the rules up front. Actually, the buyer gives away the value of information that he can gather after each stage of the auction throughout the project life by committing himself to the strategies from the beginning. Even if he does not know the distribution of the costs after gathering some data, he might be able to come up with a reasonable estimate for the cost distribution and use this information to lower the total procurement cost. However, a detailed analysis is required to state the cost of commitment, by including the change in the behaviors of the suppliers under no commitment setting to see how they penalize the buyer's non-commitment.

5 Conclusion

In this paper, we consider the derivation of suppliers' competitive bidding strategies in a repeated procurement auction setting. We discuss the incentive compatibility and individual rationality of the driven strategies via mechanism design perspective. We distinguish between the myopic and strategic suppliers to emphasize the impact of the strategic thinking on determining the competitive bids, and hence the impact on the total procurement cost for the buyer.

What we can summarize from the models considered so far is that the strategic supplier of a given cost inflates the bid of a myopic supplier of the same given cost by some amount which is a function of different attributes in any period. This can be considered as a compensation (hedging) amount against the possible loss in the future due to the current period bid. In terms of mechanism design perspective, if the suppliers are strategic, the payment rule should provide an additional subsidy to the suppliers so that the corresponding direct mechanism could be incentive compatible and individually rational. The extent of compensating opportunistic losses depends on the information availability and market structure.

Strategic suppliers have higher expected total profit than the myopic suppliers even in the case of mixed pool, although there is a positive chance for a more inefficient myopic supplier to beat an efficient strategic supplier in a given single period.

¿From the buyer's point of view regarding the repeated procurement auction, once he is committed to the mechanism from the beginning of the project, setting the reserve price to the winning bid of the previous period is a weakly dominant strategy. The reserve price does not affect the expected total profit of a strategic supplier. It only changes the periodical expected profits, but on the overall they all end up to the same expected total profit. However, in the case of myopic players, the reserve price plays a significant role in determining the expected total profit. Therefore, the buyer could gain some of the surplus that would otherwise go totally to the suppliers, by setting the reserve price to the winning bid in the case of myopic suppliers.

We believe this study provides a basic framework on which more advanced auction settings can be built. We will extend this study to consider non-price attributes that play crucial roles in selecting the awarded supplier in the industrial procurement setting. The price still being a major decision factor, non-price attributes such as quality, delivery performance, or service level might be equally important in choosing the awarded supplier in practice. While studying non-price attributes, a related extension might be to consider generalized cost models to capture economies/diseconomies of scales. Another challenge will be to study the optimal strategies of suppliers in case of bundling option for multi-item auctions in the presence of non-price attributes.

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