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Interfaces with Other Disciplines

Procurement auctions with capacity constrained suppliers

Aadhaar Chaturvedi*

Department of Business Administration, University of Namur, Rempart de la Vierge 8, Namur 5000, Belgium

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ABSTRACT

In this paper we study two reverse auction formats in a single period setting, the sealed pay-as-bid and the open format, when suppliers are capacity constrained. In the pay-as-bid format we characterize the asymmetric bidding equilibrium for the case of two suppliers with uniformly distributed cost. We find that the pay-as-bid auction allocates business inefficiently and that a supplier's bid is nonincreasing in the opponent's capacity and is typically decreasing in its own capacity. We then characterize a descending price-clock open auction implementation and find that it is optimal and that the buyer's expected cost decreases as capacity is more evenly spread. Finally, we find that the pay-as-bid auction results in a higher expected cost to the buyer as compared to the open auction.

1. Introduction

Procurement managers frequently use reverse auctions as a tool for leveraging supply side competition when procuring standardized items. The winner-take-all is a prototypical reverse auction format in which the buyer invites the suppliers in its supply base to bid for supplying multiple units of a homogeneous good. In such an auction the buyer awards the contract to the supplier that offers the best market price for supplying that good. To successfully implement a winner-take-all auction requires, amongst other conditions, that each of the participating supplier has sufficient supply capacity to meet the buyer's demand.

However, buyer's demand for the item might exceed the available capacity of any individual supplier in its supply base. This situation arises, for example, when a big multinational firm consolidates the demand for standardized components, like customized fasteners or nuts and bolts, across its multiple divisions or when an OEM (original equipment manufacturer) consolidates the demand for standardized components required by its tier-1 sub-assembly providers, and then procures these components from multiple suppliers of such components who individually might not have the sufficient capacity to meet the OEM's cumulative demand (see Moses & Anupindi (2009)). Other situations where a buyer might face capacity constrained suppliers might arise when national or state laws require firms to procure a certain fraction of business from small and medium scale enterprises, whose individual capacities are much smaller than the fraction of business that buying firm needs to procure from such enterprizes. For example, California's Public Utilities Commission requires three large investor-owned utilities (IOUs) in the state to procure up to 1 gigawatt of energy from small renewable energy projects that have an installed capacity of 20 megawatt or less (see CPUC (2014)). In this case the utilities use reverse auctions (titled "renewable auction mechanisms") to solicit bids on price per unit of energy (dollar/megawatt hour) at which the owners of renewable energy projects would be willing to supply energy to the utility for a duration ranging from 10–20 years.

Evidently a winner-take-all auction cannot be organized when suppliers participating in the buyer's auction do not have sufficient capacity to individually meet the buyer's demand. However, auction mechanisms that multi-source (i.e., source from more than one supplier) can allow the buyer to leverage supply side competition, as long as the overall capacity in the buyer's supply base exceeds the buyer's demand. A natural question that then emerges is: what auction mechanism can the buyer use to multi-source, when participating suppliers are individually capacity constrained, but in total have the sufficient capacity to meet the buyer's demand? In this paper we present two easy to implement auction formats that a buyer can use to multi-source in such a scenario: a sealed pay-as-bid format and an open descending price-clock format. We then analyze both these auction formats in a single period setting (i.e., for a one time procurement event) to determine how the suppliers would bid in these auctions and consequently determine the buyer's expected cost of purchasing the goods from these auctions.

Analyzing these auctions is interesting from both theoretical and practical perspectives. On the theoretical front, capacity constraint introduces asymmetry between the suppliers (since each supplier might have a different capacity). Analyzing the bidding equilibrium in sealed-bid auction with asymmetric suppliers is known to be

* Tel.: +32 81 72 48 52.
E-mail address: aadhaar.chaturvedi@unamur.be

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a challenging problem to solve and not much is known about the features of the resulting asymmetric equilibrium. Thus, one objective of this paper is to characterize the asymmetric equilibrium in a simple procurement setting, i.e., a single period sealed-bid auction with two participating bidders (suppliers) whose costs are uniformly distributed.

Characterizing the equilibrium allows us to study the features of such an asymmetric equilibrium in a procurement auction. For example, the paper addresses the question regarding the efficiency of sealed auction, when suppliers are capacity constrained. A two supplier auction would be efficient if the lower cost supplier gets the maximum possible allocation (i.e., the minimum of its capacity and the buyer's demand). From the equilibrium bids of two suppliers we find that the sealed-bid format is not efficient because the higher-cost supplier can bid lower than the lower-cost supplier, if its capacity is smaller than the lower cost supplier's capacity. Characterizing the equilibrium also allows us to investigate how the suppliers' equilibrium bids would react to changes in their or the opponent supplier's capacity. We find that a supplier decreases its bid as the capacity of the opponent supplier increases and it typically decreases its bid as its own capacity increases.

Besides uncovering such theoretical insights, there are also practical motivations for investigating these auctions. First amongst these is that the implementation of an open descending auction, when suppliers are capacity constrained, is not obvious. A winner-take-all auction (when suppliers have no capacity constraints) can be easily implemented through a descending price-clock mechanism: in such an auction the suppliers drop out of the auction as the price-clock reaches their per-unit cost and the buyer awards the business to last remaining supplier and pays it the price at which the second last supplier dropped out. But how can such an auction be implemented when the buyer has to multi-source (due to the capacity constraints of its suppliers)? In this paper we present a descending price clock format that can be used when suppliers are capacity constrained. We find that the equilibrium bidding strategy of suppliers in such an open auction is to drop out of the auction when the price clock reaches their per-unit production cost. Moreover, analysis of the sealed-bid and the open-descending format allows us to compare the buyer's ex-ante (expected) cost in both these formats. Interestingly, we find that under the standard regularity conditions (à la Myerson (1981)), the open descending auction is optimal for the buyer and that the sealed-bid auction results in a relatively higher expected cost for the buyer. These finding are managerially relevant since they point to the fact that a buyer can reduce its procurement cost by organizing an open descending auction rather than a sealed bid auction, when suppliers are constrained on their capacity.

The rest of the paper is organized as follows: In Section 2 we present the related literature. In Section 3 we present the model and analyze the asymmetric equilibrium in the pay-as-bid auction. In Section 4 we present the open-auction implementation and compare the open auction with the pay-as-bid auction. Finally, we present our concluding remarks in Section 5. All the proofs are presented in the online supplement to this paper.

2. Literature review

The existing work on asymmetric auctions can be grouped into five broad categories: (1) asymmetric auctions with two bidders that draw their types from heterogeneous distributions; (2) asymmetric auctions with $n \geq 2$ bidders; (3) auctions in which the principal asymmetrically discriminates against the bidders; (4) asymmetric procurement auctions; and finally (5) asymmetric multi-unit auctions in electricity markets.

We first discuss the work that investigates asymmetric auction with two participating bidders whose types are drawn from heterogeneous distributions. Criesmer, Levitan, and Shubikt (1967) characterize the equilibrium with two bidders whose private values are uniformly distributed in the interval [0, 1] and [0, β]. Plum (1992) extends that result to Power distribution $F_1(x) = x^{\mu}$ and $F_2(x) = (x/\beta)^{\mu}$. Lizzeri and Perisco (2000) establish equilibrium with two bidders that have inter-dependent values and reserve price. Maskin and Riley (2000) derive comparative static results on the bidding equilibrium with two bidders whose valuations have the same form of distribution, but over different supports $[\beta_i, \alpha_i]$ for each bidder/buyer i. They show that typically "strong" buyers shade their bid and "weak" buyers bid more aggressively resulting in allocation going to "weak" buyers. They also show that revenue equivalence typically does not hold with asymmetric bidders. In our paper we find that bidders/suppliers with higher capacity bid less aggressively whereas suppliers with lower capacity bid more aggressively, thus resulting in high cost (and low capacity) bidders getting higher than necessary allocation. Moreover, we show that revenue equivalence between pay-as-bid and open bid format fails with asymmetric bidders. Kaplan and Zamir (2012) characterize the bidding equilibrium with two bidders whose valuations are uniformly distributed over a generic support. We too characterize asymmetric equilibrium with two bidders, however the source of asymmetry in our model is suppliers' limited and heterogeneous capacity. Moreover, our model investigates multi-sourcing, which is in contrast to the work discussed above that looks at sole-sourcing. Thus our work complements to this stream of literature by characterizing asymmetric bidding equilibrium in a multi-sourcing procurement context.

Literature that investigates asymmetric auctions with $n \geq 2$ bidders typically focuses on the question regarding the existence of equilibrium (and does not characterize the equilibrium in closed form). Lebrun (1999) establishes the existence of equilibrium when bidders have independent private values and when the value distribution has common support. Maskin and Riley (2003) establish equilibrium under affiliated private values and positive value interdependence but do not consider reserve prices. Athey (2001) establishes existence of equilibrium for a general class of auctions under the single crossing condition. All of the work mentioned above focuses on winner-take-all auction. In the best of our knowledge, we are the first to establish and characterize asymmetric equilibrium in multi-unit split-award auctions.

Asymmetry might also arise when the principal biases against a bidder. Balestrieri (2008, chap. 3) analyzes bidding equilibrium with two buyers when the auctioneer/seller has a preference bias towards one bidder. Mares and Swinkels (2014) analyze a first price sealed bid auction when the two suppliers' costs are distributed asymmetrically and when the buyer biases one of the supplier (e.g., better quality). Haruvy and Katok (2013) conduct laboratory experiments with auctions in which the auctioneer/buyer exercises its discretion on winner determination based on non-price "quality" attributes of the suppliers. In our paper we do not model the buyer as having discretionary power, on the contrary the auction rules are clearly specified upfront, which according to Jap (2007) has a positive impact on buyer-supplier relationships.

In the literature that investigates the use of asymmetric reverse auctions for procurement, Arozamena and Cantillon (2004) study the incentives of suppliers to invest in cost improvement, when that investment is observed by competitors. Cantillon (2008) analyzes the effect of a buyer sponsoring its suppliers' cost reduction on to its expected cost. She finds that asymmetries hurt the buyer's revenue and therefore the buyer is better off in investing uniformly in its suppliers. We too find that asymmetries increase the buyer's expected cost and that for a given total capacity the buyer can minimize its expected cost if capacity is symmetrically endowed to each supplier. However, our work differs from Cantillon's work in the sense that asymmetry is not induced by buyer/supplier investments in cost improvements, rather asymmetry in our model is exogenous and arises due to suppliers having different capacities.