DEPARTMENT OF FOOD AND RESOURCE ECONOMICS
UNIVERSITY OF COPENHAGEN

MSAP Working Paper Series

No. 02/2013

A Multi-attribute Yardstick Auction Without Prior Scoring

(A Sealed-bid Two-attribute Yardstick Auction Without Prior Scoring)

Jens Leth Hougaard

Department of Food and Resource Economics

University of Copenhagen

Kurt Nielsen

Department of Food and Resource Economics

University of Copenhagen

Athanasios Papakonstantinou

Department of Food and Resource Economics

University of Copenhagen

A Sealed-bid Two-attribute Yardstick Auction Without Prior Scoring

Jens Leth Hougaard Kurt Nielsen
Athanasios Papakonstantinou

Revised version by March 11,

2014

Abstract

We analyze a two-attribute procurement auction that uses yardstick competition to settle prices. The submitted sealed bids are replaced by yardstick bids, computed by a linear weighting of the other participants' bids. The auction simplifies the procurement process by reducing the principal's articulation of preferences to simply choosing the most preferred offer as if it was a market with posted prices.

We show that there is only one type of Nash equilibria where some agents may win the auction by submitting a zero price bid. Using a simulation study we demonstrate that following this type of equilibrium behavior often leads to winner's curse. The simulations show that in auctions with more than 12 participants the chance of facing winner's curse is around 95%.

Truthful reporting, on the other hand, does not constitute a Nash equilibrium but it is ex post individually rational. Using a simulation study we demonstrate that truthful bidding may indeed represent some kind of focal point.

Keywords: Multi-attribute auction, yardstick competition, articulation of preferences, simulation.

1 Introduction

Efficient and flexible procurement systems are often crucial for the success of any organization. As a buyer, organizations obviously want to minimize their spending but attributes such as various types of qualities, delivery time etc. may represent equally important objectives. Consequently, the development of procurement systems faces an ongoing challenge in designing trading systems that facilitate transparent competition on both price and other attributes as well as ensuring sufficient flexibility for operational purposes while keeping the transaction costs low.

A traditional negotiation approach allows full flexibility in this two-sided matching of buyers and sellers, but it is typically ill-structured and opaque. Multi-attribute auctions (scoring auctions), on the other hand, specify *a priori* transparent rules for the procurement "game" but obviously allow for less flexibility. In either case the transaction costs are usually high, e.g., in a traditional negotiation it is time consuming to ensure competition across many sellers and in a traditional scoring auction it is time consuming to decide on a weighting of price and other attributes *a priori*. In this paper we analyze a multi-attribute auction that uses yardstick competition to facilitate competitive prices in a simple two-dimensional setting (a price and a quality measure) without any a priori weighting of the two. The auction replaces the submitted price bids with *yardstick prices* and the buyer's decision is simply to choose the desired service or commodity as if it was a market with posted prices.

To be more precise we consider the following procurement mechanism: A group of sellers (with private information about their production cost) each submit a sealed price-quality bid, to be interpreted as the quality level they are willing to deliver if compensated by at least their asking price. The sealed price-bid is replaced by a *yardstick price* which is determined as a convex combination of the two efficient "neighbor" price-bids. The buyer then selects one of these bids as a winning bid (without having to articulate his preferences, via a scoring function, in advance). The winner commits to deliver and is compensated with his associated *yardstick price*.

As such, this mechanism is a special case of what is called a Data Envelopment Analysis (DEA) based auction in a recent paper by Bogetoft and Nielsen (2008). Although they consider a mechanism with known scoring function, their paper already noted that when the buyer's preferences are unknown to the sellers, their strategies become too complicated to analyze and that they are likely to deviate from truth-telling by bidding above their true cost.

In the present paper we follow up on these conjectures. We show that there does not exist Nash equilibria where all sellers submit a strictly positive price bid. For instance, the seller with the highest quality level can always win the auction by submitting a zero price bid and being reimbursed the computed yardstick price. Yet, bidding zero may prove to be a fatal strategy since the seller will often win the auction with a loss. Using a simulation study we show that in auctions with 4 participants the chance of winning the auction with a gain for the seller with the highest quality level is only 20% and this number drops quickly to 5% as the number of participants increases. In other words, it appears that equilibrium behavior in the sense of zero price bidding is highly risky for the sellers who easily end up facing winner's curse.

On the other hand, we shall argue that even though truth-telling is not a Nash equilibrium it is still very likely to be some kind of focal point when using the mechanism in practice. The basic intuition is the following: Since improving a seller's chances of winning the auction requires bidding quite substantially above or below the true cost, the sellers run into two problems; bidding substantially above increases the risk of being excluded from the auction (in the sense that the bid lies above the yardstick price); bidding substantially below increases the risk of winning the auction with a loss since the compensation is likely to be below actual true cost.

First, we consider the bidder who wins the auction if everyone tells the truth and then we examine if this bidder will remain the winner even if we allow the other bidders to misreport their true cost with up to 20% both above and below. We show that allowing the other bidders to misreport rarely results in a new winner that wins with a gain. It happens in less than 11-20% of all cases. Combined with the fact that truth-telling guarantees non-negative pay-offs (is ex post individually rational) our results point towards truth-telling as a focal point in practice.

The outline of the paper is as follows: Section 2 relates the paper to the existing literature and Section 3 introduces the procurement setting and the notion of yardstick prices. Section 4 defines the yardstick auction and discusses strategic bidding by the sellers. Section 5 introduces the simulation framework and the results are presented in Section 6 along with a discussion of our parameter choices. Section 7 concludes.

2 Relation to the literature

Unlike auctions in general, the theoretical literature on multi-attribute auctions is relatively sparse. A related line of literature, however, concerns the widely used systems for e-procurement which have several similarities with multi-attribute auctions, for example in how they automate negotiations (see e.g. Burmeister et al. (2002) for an introduction to some of these systems). There are several papers suggesting an incorporation of multi-attribute auctions into the so-called Request for Quote (RFQ) systems, see e.g. Milgrom (2000) and Bichler et al. (2003). RFQ systems use the Internet to improve the searching and matching process between buyers and sellers in general. Lai et al. (2004), Teich et al. (2004) and Teich et al. (2006) provide a survey as well as an elaborate introduction to various multi-attribute negotiation and auction systems.

The seminal paper on multi-attribute auctions by Che (1993) analyzes the two most common scoring auctions: the *first score* and the *second score auction*.[1] These two auctions have many similarities with the first and second *price*

[1] In a first score auction, the bidder with the highest score wins and has to meet the highest

auctions. In fact, Che (1993) proves that the *revenue equivalence theorem* also holds for the first and second score auctions[2] and shows that the second score auction is efficient and strategy proof.[3]

However, there is no particular reason to expect that in practice the buyer (principal) knows *a priori* the scoring function. The determination of the scoring function may be complicated for several reasons. For instance, when the principal is a single person and the scoring represents the principal's intra-personal trade-offs; these complications are a central topic of a large literature on Multiple Criteria Decision Making (MCDM), see e.g. Tzeng and Huang (2011). Furthermore, when the principal represents a group of persons (e.g., an organization), the construction of the scoring function may involve inter-personal conflicts. The complication of this is reflected on the large literature on Social Choice, see e.g. Arrow (1963), Moulin (1991). Empirical cases support the claim that determination of a scoring function is a difficult matter. For instance, in the conservation reserve program the USDA (United States Department of Agriculture) rank the bids into a score. The actual determination of these scoring rules has been widely discussed, see e.g. Babcock et al. (1996, 1997). The applied scoring has also been an issue in the wholesale market for electricity in California, where the choice of an unsuitable scoring rule had severe consequences, see Bushnell and Oren (1994) and Chao (2002).

In the literature on multi-attribute auctions there are only a few papers relaxing the assumption of an *a priori* given value function for the principal. Cripps and Ireland (1994) investigate the issues of setting quality thresholds that are unknown to the bidders. Beil and Wein (2003) study the sequential learning of the value function and bidders' cost functions by a sequence of scoring auctions with different scoring functions. However, Beil and Wein (2003) do not directly address the risk of strategic bidding and basically presume truthful revelation in the sequence of trial auctions.

In this paper we analyze a yardstick auction which basically replaces the principal's scoring with a yardstick competition: The principal simply chooses among "posted" yardstick prices. As a starting point for this research we use the paper on DEA auctions by Bogetoft and Nielsen (2008). However, we relax their assumption that the principal will announce *a priori* his scoring function[4].

score. In a second score auction, the bidder with the highest score wins and has to meet the second highest score.

[2]Using the revenue equivalence theorem as it is presented in Riley and Samuelson (1981).

[3]However, it is not given that the second score auction is the most preferred auction by the principal. Bogetoft and Nielsen (2008) show that it is possible for the principal to extract more informational rent while the auction remains efficient and strategy-proof.

[4]The idea of a yardstick auction can also be found in Aparicio et al. (2008). They suggest an auction design for so-called combinatorial auctions based on the same type of yardstick principle.

3 The model

We consider a procurement setting along the lines of the model in Che (1993). Assume that a risk neutral principal is seeking to procure a commodity (or a service) from one of n risk neutral agents, $i \in N = \{1, ..., n\}$. The commodity supplied by agent i is characterized by a one-dimensional quality level $y^i \in \mathbf{R}_+$. In addition to this, in order to focus on the adverse selection problems we further assume that delivery of the promised qualities can be costlessly enforced (e.g. by a harsh penalty for deviations).

Now, agents can produce different levels of quality, however their costs will depend on their efficiencies. More formally, an agent producing the quality level y^i, has a cost $c^i(y^i, \epsilon^i) \in \mathbf{R}_+$. The parameter ϵ^i represents this efficiency, and is randomly drawn from the interval $(\underline{\epsilon}, \bar{\epsilon})$ which is agent i's private information. Meanwhile, all involved parties know that their costs belong to some unknown common cost structure $C(y) \subseteq \mathbf{R}^{\mathbf{2}}_+$.

Regarding this cost structure, we assume that

$$C(y) = \min\{x \mid y \text{ can be produced at cost } x\}$$

satisfies $A1$ and $A2$ below:

$A1$. C(.) is weakly increasing : $y' \geq y \Rightarrow C(y') \geq C(y)$,
$A2$. C(.) is convex : $C(\gamma y + (1-\gamma)y') \leq \gamma C(y) + (1-\gamma)C(y'), \forall \gamma \in [0, 1]$.

We assume that the actual quality level y^i is verifiable and fixed for each agent i. Thus, possible strategic manipulations by the agents can only regard the costs, and the signal from each agent i is simply a price-quality bid

$$(x^i, y^i) \in \mathbf{R}^{\mathbf{2}}_+ \tag{1}$$

with the interpretation that agent i will produce his quality level y^i if he is paid at least x^i.

We assume throughout that the aim of the agent is to maximize (expected) profit:

$$\pi^i = x^i - c^i(y^i, \epsilon^i). \tag{2}$$

The aim of the principal is to maximize (expected) net private value, i.e., the value generated by the good minus the compensation to the agent. That is, the principal seeks to maximize,

$$V(y^i, \alpha) - x^i \tag{3}$$

where $V(.)$ is a weakly increasing concave value function and α is randomly drawn from an interval $[\underline{\alpha}, \overline{\alpha}]$. The assumption that the principal is unaware of the specific value function is modeled by the parameter α.

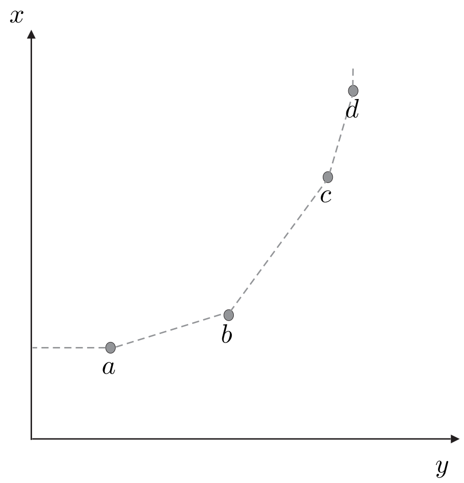

Figure 1: Convex envelopment of the submitted bids

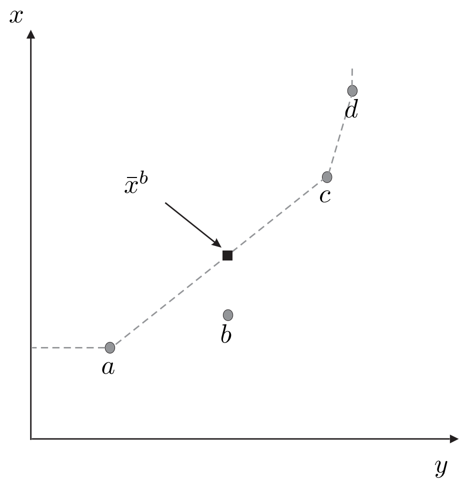

Figure 2: The yardstick price for agent b

3.1 The Yardstick Prices

From the number of different cost models satisfying requirement $A1$ and $A2$, we will select a model where the cost structure (illustrated in Figure 1) is estimated using the smallest convex envelopment of the observed bids $\{(x^j, y^j)\}_{j \in N}$, i.e.,

$$\widehat{C}(y) = \inf\{x \in \mathbf{R}_+ \mid x \geq \sum_{j \in N} \lambda^j x^j, \quad y \leq \sum_{j \in N} \lambda^j y^j, \\ \sum_{j \in N} \lambda^j = 1, \lambda^j \geq 0, \forall j \in N\}. \tag{4}$$

For each agent $i \in N$ we define a *yardstick price* $\bar{x}^i$ using the estimated cost structure (4) on the reduced bid-sample where agent i's bid is excluded (illustrated in Figure 2):

$$\bar{x}^i = \inf\{x \in \mathbf{R}_+ \mid x \geq \sum_{j \in N \setminus \{i\}} \lambda^j x^j, \quad y^i \leq \sum_{j \in N \setminus \{i\}} \lambda^j y^j, \\ \sum_{j \in N \setminus \{i\}} \lambda^j = 1, \lambda^j \geq 0, \forall j \in N \setminus \{i\}\}. \tag{5}$$

For agent i, the above solution identifies a single point $(\bar{x}^i, y^i)$ on the frontier estimated by the smallest convex envelopment of the submitted bids except for agent i's own bid.

Note that for some values of y, the associated yardstick price may be infinite (e.g., bid d in the figure). In the yardstick auction presented below this is dealt by asking the principal to announce an upper bound on the bids, i.e. the highest value of y and its associated reservation price x that the principal is willing to accept. In this way every agent is guaranteed a yardstick price. Consequently there is no need for a specification of a lower bound on quality.

Based on the model above the auction process runs as illustrated on the timeline in Figure 3.

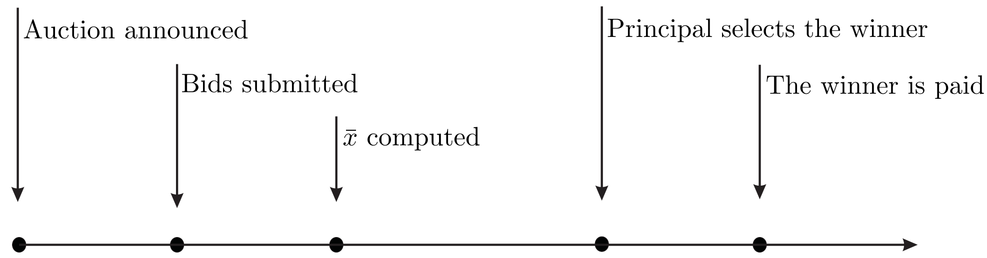

Figure 3: The auction process on a timeline

4 The Yardstick Auction

We analyze a procurement auction defined by a stepwise procedure. In Step 0, the principal starts the auction by publicly announcing z^P stating the maximum value of the attribute in question y^P and its reservation price x^P for y^P. z^P enters the auction as a submitted bid and thereby, x^P addresses the problem of non-existing yardstick price for the maximal value of y among the bidders. Then, in Step 1, the bidders submit sealed bids. In Step 2, the yardstick prices ($\bar{x}^i$) are computed (as illustrated in Figure 2). If $\bar{x}^i \geq x^i$ the bidders original price-bid is replaced by the computed yardstick price. In Step 3, the principal reviews the yardstick bids and selects a single yardstick bid as the winner of the auction. Step 4 finalizes the auction by compensating the selected winner with his yardstick price. Formally,

The mechanism:

Step 0: The principal announces the procurement proposal and an upper bound on the bids $z^P = (y^P, x^P)$, where y^P is the highest acceptable value of y and x^P is the highest acceptable price for y^P.

Step 1: Each participant $i \in N$ submits a single sealed bid $z^i = (x^i, y^i)$. Let Z be the set of bids including z^P, i.e., $Z = \{z^i\}_{i \in N} \cup z^P$.

Step 2: A yardstick price $\bar{x}^i$ for all $i \in N$ is computed using (5) and replaces x^i when $x^i \leq \bar{x}^i$. Let $\bar{z}^i = (\bar{x}^i, y^i)$ be the yardstick bid of agent $i \in N$ and let $\bar{Z}$ be the set of such yardstick bids. Hereby $\bar{Z} \subseteq Z$.

Step 3: The set $\bar{Z}$ is presented to the principal, who selects the winning bid $\bar{z}^{i^*}$.

Step 4: The winner i^* is compensated by $\bar{x}^{i^*}$ and losers are not compensated.

The auction may be seen as a mechanism for settling posted prices on services or commodities with linear weighting of price and other attributes. In fact in comparing with the second score auction with linear weighting, the mechanism settles the most pessimistic prices seen from the principal's point of view. To see this, note that the yardstick prices are equal to the highest possible second score compensation with linear scoring.

4.1 Bidders' Strategic Behavior

We now turn towards the bidders' strategic behavior. As mentioned in the introduction, we consider the situation where it is impossible (or very costly) for the principal to articulate a scoring function *a priori*. For instance, in case of a public institution that represents social (aggregate) preferences. However, we assume that it is possible for the principal to make a unique selection in Step 3 of the mechanism. This is consistent with the existence of some kind of underlying concave scoring function for the principal (albeit unknown).

The fact that the principal cannot announce (and commit to) a scoring function *a priori* complicates the analysis of the bidders strategic behavior. Yet, it is clear that there is ample room for manipulation.

Observation 1: *Consider a given agent $i \in N$. By increasing the price-bid x^i up to at most the yardstick price $\bar{x}^i$ both neighbor yardstick bids increase and thereby weakly increases i's chance of winning the auction.*

The argument is straightforward: Since changes in agent i's price-bid x^i have no influence on i's computed yardstick price $\bar{x}^i$ (as this is determined excluding agent i's bid from the data set), it is free for agent i to increase his price-bid up to his yardstick price. Bidding his yardstick price, given the bids of the other agents, increases the yardstick-price of agent i's neighbors and thereby weakly increases his chance of being selected by the principal. Note that if agent i bids above his yardstick price bid he will loose the auction for sure.

In a similar fashion we can show that if agent i decreases his price bid both neighbor agents will get decreasing yardstick price bids which in turn weakly decreases i's chance of winning the auction. Thus, bidding below ones true bid is disadvantageous *unless* the bid is so low that it in effect excludes the neighbor agent from the auction (in the sense that it makes the neighbor agent j's yardstick bid go below j's price bid). Such a situation is illustrated in Figure 4, where i decreases his bid z^i to z'^i and hereby exclude j from the auction.

We record this by the following observation.

Observation 2: *There may be situations where an agent by bidding sufficiently below its true cost can exclude a neighbor bid and thereby weakly increase the chance of winning the auction.*

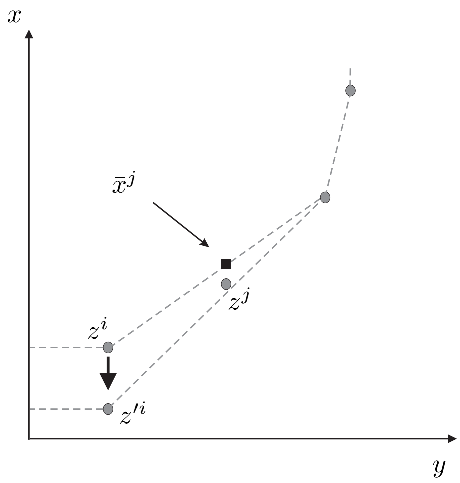

Figure 4: Excluding the neighbor yardstick bid

As indicated by Observation 2, there may exist perverse Nash equilibria where some agent (say, the one with highest quality level) excludes the other agents by a 0-price bid.

Example: Consider three agents with true quality-cost combinations; $(y^1, c^1) = (2,1), (y^2, c^2) = (4,2)$ and $(y^3, c^3) = (7,3)$. Assume that the principal decides on $z^P = (8,6)$. Now, let agents 1 and 2 submit their true bids $z^1 = (2,1)$ and $z^2 = (4,2)$ while agent 3 submits the bid $z^3 = (7,0)$. Clearly, the profile $z = (z^1, z^2, z^3)$ is a Nash equilibrium since yardstick prices become $\bar{x} = (0,0,5)$. Therefore the principal is presented with the singleton set of yardstick bids $\bar{Z} = \{(7,5)\}$ which he then chooses as winner independent of his preferences. Hence, agent 3 is optimizing and agent 1 and 2 cannot do better given the strategy of agent 3. Consequently, the strategy profile z is a Nash equilibrium. $\triangle$

The example above reveals the existence of Nash equilibria of the form where the k'th agent (ordered according to quality level) submits a 0-price bid while agents with higher quality levels submit the truth and agents with lower quality levels can submit any bid. What determines the number k is whether the k'th agent has a yardstick price, given a 0-price bid of agent $k-1$, which is above k's true cost such that he does not win with a loss: by bidding the truth, agents $k+1$ to n ensure that they do not win with a loss. Agents 1 to $k-1$ are in effect excluded from the auction by agent k's 0-price bid.

In fact, such "perverse" equilibria are the only type of Nash equilibria in the model. Indeed, we can show that there does not exist equilibria where all bidders submit a positive price-bid. We record this as Observation 3 below.

Observation 3: *No Nash equilibrium exists for which $x^i > 0$ for all $i \in N$.*

Sketch of proof: By contradiction assume that an equilibrium exists for which $x^i > 0$ for all $i \in N$. By Observation 1, no agent will bid below his yardstick price. Neither can bids be above the yardstick since this would lead to exclusion and thereby zero pay-off. Thus, all bids must lie on a horizontal line where $x^i = x^P$ for all $i \in N$. In this case the agent i^* with the highest quality level y^{i^*} can win the auction by bidding $(y^{i^*}, 0)$ contradicting that the strategy profile is a Nash equilibrium. Q.E.D.

In practice, 0-price bidding is a risky strategy though. Often it will lead to winner's curse as we demonstrate by a simulation study in the next section. In fact, we also demonstrate that truthful bidding (which does not constitute a Nash equilibrium) may well turn out to be a focal point in practice because, among other things, it is ex post individually rational.

5 Simulation Framework

Based on the Yardstick Auction described in the previous section, we now introduce the simulation framework that allows us to analyze two scenarios: a) 0-price Nash equilibrium behavior of the bidder with highest quality level, and b) truth-telling as an alternative focal point.

In the proposed framework the principal's value function is given by $V(y, \alpha) = \alpha y$, with α independently drawn from the uniform distribution $\mathcal{U}(6, 16)$ and y the agents' reported quality levels, independently drawn from the uniform distribution $\mathcal{U}(1, 10)$. Most importantly, drawing parameter α from a random distribution, models the principal's uncertainty of its preference function before receiving the agents' bids.

Furthermore, the agents' costs are determined by the common underlying cost function $x(y) = y^2$ and the individual inefficiencies in production modeled by the parameter $\epsilon^i \sim \mathcal{U}(1, 1.5)$ resulting in individual costs $x^i(y) = \epsilon^i y^2$.

We simulate the mechanism 10^3 times for $4, 8, 12, 16, 20, 24, 28, 32$ participating agents. In every iteration we simulate for each one of the agents a set of bids (y^i, x^i) by randomly drawing y^i and ϵ^i and the principal's preference by randomly drawing α. For every iteration there is also an upper bound bid $z^P = (y^P, x^P)$ with y^P being equal to the upper bound of the distribution of the reported quality (hence $y^P = 10$) and $x^P \sim U(90, 110)$. We compute the yardstick bids and corresponding scores, identify the winner of the auction and calculate the utility that the winner of the auction derives after producing the promised quality. We then introduce deviation from truth-telling for all agents but one (labeled as the 'selected agent') by multiplying the agents' costs with a parameter randomly drawn from a uniform distribution centered in 1. For a deviation up to X% above and below the true cost we use $\mathcal{U}(1 - X, 1 + X)$. For example, a deviation up to 20% above and below the true cost we use $\mathcal{U}(0.8, 1.2)$.

Identifying the 'selected agent' depends on the scenario. Specifically, for the 0-price Nash equilibrium case the selected agent is the agent with the highest reported quality, while in the truth-telling scenario we focus our analysis on the agent identified as the 'winner' of the auction in a trial run where everyone reports the truth.

Assuming that all agents, except for the initial winner, are capable of under or over reporting their costs we proceed to compute their yardstick bids based on these 'misreported' bids, and examine whether the selected agent in each scenario remains a winner despite the misreporting of the others.

Technically, all simulations are done in R and all DEA programs are solved using the "Benchmarking" package for R, cf. Bogetoft and Otto (2011) and Bogetoft and Otto (2012). Our parameter choices will be further discussed in section 6.1 below.

6 Simulation Results

Having described the simulation's input parameters and objectives we now present our numerical findings grouped into two sets of simulations. First, we present the simulation results for the 0-price Nash equilibrium behavior of the bidder with the highest quality level and then, we present the simulation results of truth-telling as focal point.

The simulation results for the 0-price equilibrium scenario are reported in Figure 5. In Figure 5 (a) we show that as the number of participating bidders increases the percentage of auctions in which the bidder with the highest reported quality, say i^*, wins the auction with a gain ($\pi^{i^*} \geq 0$) by bidding sufficiently below his true cost, drops significantly. The misreporting, X, of all other agents is equal to 10% and 20% (cu=0.1 and 0.2) respectively[5]. In particular, we see that for more than 12 bidders only approximately 5 % of all auctions are successful for i^*. Moreover, as demonstrated in Figure 5 (b) the required misreporting of i^* approaches 100% (i.e. 0-price) proving that, in fact, aggressive bidding is needed to win the auction by 'price-dumping'.

With the 0-price Nash equilibrium behavior being both highly risky for the manipulating bidder and potentially unrealistic in practice due to the close to 0-price bids, we now turn to the simulation results concerning the truth-telling strategy. By definition, a bidder can not win the auction with a loss by telling the truth, however, others misreporting may cause the otherwise winning bidder to lose the auction. The results from this simulation is reported in Figure 6. We fix the misreporting parameter X again to be between 0.1 and 0.2 and vary the number of participating agents. In Figure 6 (a) we show the percentage of auctions in which the initial winner remains the winner despite the fact that all other agents misreport. In Figure 6 (b) we focus on the cases where the other agents misreporting results in a new winner (henceforth referred as "new-winner") and report the percentage of these cases where the new-winner wins with a loss.

[5] Note that if the other bidders were allowed a higher degree of misreporting our results will be even stronger in the sense that there will be even fewer cases where the auction is won with a gain.

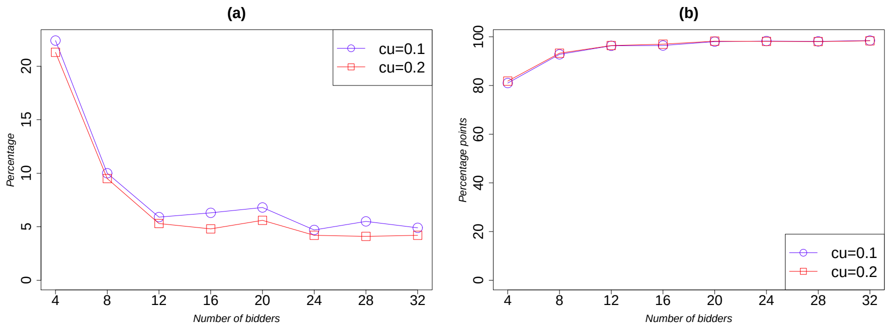

Figure 5: 0-price Nash equilibrium behavior: (a) the percentage of auctions won with a gain; (b) downward deviation in percentage of actual cost.

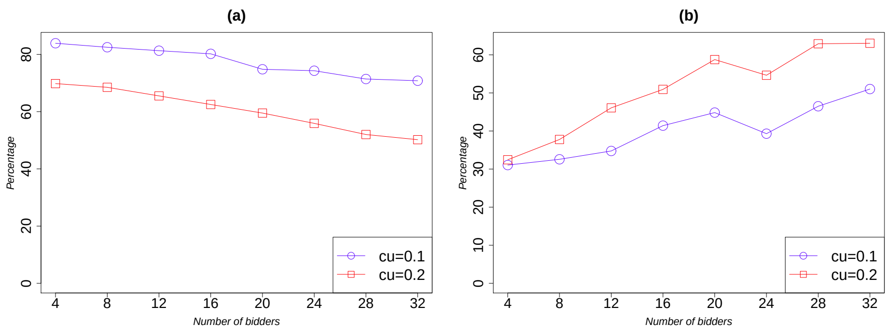

Figure 6: Truth telling as a focal point for the initial winner of the auction: (a) the percentage of auction where the initial winner remains the winner; (b) the percentage of new winners facing winner's curse.

The simulation indicates that for a reasonable degree of misreporting (up to 20%) the initial winner remains the winner in the vast majority of the simulation iterations despite the fact that all other agents misreport. Overall we consider this a positive result, especially given that both simulations also suggest that for the majority of the cases where misreporting results in a new winner, this new-winner faces a loss in utility. In fact in Figure 6 (b) we demonstrate that as the number of bidders increases, so does the percentage of new-winners facing losses in their utilities.

To sum up, simulations show that it requires a significant deviation to win, while that significant deviation involves an increasing chance of winner's curse, i.e., that the winner wins with a loss. Combining the results from both scenarios shows that irrespective of the number of competing bidders as well as the degree of misreporting, 80 to 89% of all auctions will either have the same winner (the initial winner) or a new winner who wins with a loss.

Consequently, we conclude that bidding truthful may very well be a focal point in practice. It is ex post individually rational and the optimal strategy in the vast majority of cases.

6.1 Discussion of the simulation assumptions

In the simulation framework we make use of the uniform distribution in connection with various parameter choices. We shall here briefly discuss these choices and how they will influence the result of our simulation study.

Concerning the principal (or buyer) we have made two assumptions:

i) $\alpha \in \mathcal{U}[6, 16]$. The uniform distribution's limits for the parameter α have been set to 6 and 16 in order to represent a suitably broad range of potential preferences of the principal. Since we assume to have a common underlying cost function of the form $x(Y) = y^2$, then truth-telling and no inefficiency in production (i.e. $\epsilon^i = 1 \; \forall \; i$) for all bidders, would imply that the principal picks a quality-price bid where the quality level is between 3 and 8 (recall that $y \in \mathcal{U}[1, 10]$). Obviously more extreme quality levels can be selected when we allow for individual inefficiencies in production. Narrowing or spreading the interval $[6, 16]$ will have a negligible influence on our simulation results as confirmed by further simulations.

ii) $x^P \in \mathcal{U}[90, 110]$. The limits of the uniform distribution of x^P is determined as a plus-minus 10% deviation from the true underlying cost of 100. This reflects the principal's uncertainty when choosing z^P in the initial step of the mechanism. Unlike the choice of α the choice of x^P has a direct impact on the simulation results in the sense that it influences the yardstick price of the agent with the highest quality level. As x^P increases so does the yardstick price of the bidder with the highest quality level. Therefore, the higher the value of x^P the more it favors the 0-price bidding of the bidder with the highest quality level. By randomly drawing a level which is in a

10% range above and below true costs for $y = 10$ (maximum quality level) we therefore try to neutralize this effect.

Concerning the bidders (or sellers) we have made one assumption:

i) $\epsilon^i \in \mathcal{U}[1, 1.5]$. That production units may have up to 50% technical inefficiency is supported by several empirical productivity studies (see e.g.Bogetoft and Otto (2011)). The effect on our simulation study from changes in this parameter choice is at least two-fold. On the one hand, higher inefficiency tend to exclude more bidders from the auction. On the other hand, increasing inefficiency also tends to increase yardstick prices. Consequently, the probability of winning with a gain by playing the 0-price strategy weakly increases with increased inefficiency level. Looking at truth-telling as a focal point the effect of changing the inefficiency level is far less obvious though. Further simulations tend to show that the effect is marginal.

7 Conclusion

We have analyzed a two-attribute procurement auction that uses yardstick competition to simplify the procurement process. The yardstick auction reduces the cost of articulating preferences to a mere problem of picking a favored alternative, as with posted prices.

Although the individual bidders cannot influence the compensation if winning, the auction is not strategy-proof. We showed that there only exist Nash equilibria of the type involving extreme 0-price bidding. Clearly, 0-price bidding behavior is highly risky as illustrated by our simulations which showed that with sufficient competition among bidders the chance of facing winner's curse is around 95%. Truthful bidding on the other hand is ex post individually rational and as demonstrated by our simulations it is very likely that the bidder that wins if all bidders report the truth, remains the winner even if all other bidders are allowed to deviate substantially from the truth. Again it was shown that if deviation from the truth results in a new winner he is very likely to face winner's curse. In practice truthful reporting therefore seems to be an alternative focal point of the yardstick mechanism.

Assuming that the bidders report truthfully in practice it is possible to measure the cost of not investing in articulating a traditional "scoring function" for the principal. Additional simulations indicate that in the majority of cases the yardstick auction selects that same winner as a traditional second score auction with a priori announced scoring function. This confirms that the yardstick auction is not an efficient auction, however the simulations also indicate that the actual drop in social value from not having a scoring function decreases significantly. In fact, as the number of participants reaches approximately 10 there is only a marginal drop in social value from not having to articulate a scoring function.

Further adjustments of the auction set-up may strengthen the conjecture that truthful reporting is a focal point. For example we may try to limit bidding above true cost by using the principals choice to elicit potential scoring functions and use these along the lines of a traditional scoring auction. We leave the details for future research.

References

Aparicio, J., Landete, M., Monge, J. and Sirvent, I.: 2008, A new pricing scheme based on DEA for iterative multi-unit combinatorial auctions, *Top* **16**(2), 319–344.

Arrow, K. J.: 1963, *Social Choice and Individual Values*, Yale University Press.

Babcock, B. A., Lakshminarayan, P. G., Wu, J. and Zilberman, D.: 1997, Targeting Tools for the Purchase of Environmental Amenities, *Land Economics* **73**, 325–339.

Babcock, B., Lakshminarayan, P., Wu, J. and Zilberman, D.: 1996, The Economics of a Public Fund for Environmental Amenities: A Study of CRP Contracts, *American Journal of Agricultural Economics* **78**(4), 961–971.

Beil, D. R. and Wein, L.: 2003, An inverse-optimization-based auction mechanism to support a multiattribute RFQ process, *Management Science* **49**(11), 1529–1545.

Bichler, M., Kersten, g. and Strecker, S.: 2003, Towards a Structured Design of Electronic Negotiations, *Group Decisions and Negotiations* **12**(4), 311–335.

Bogetoft, P. and Nielsen, K.: 2008, DEA based auctions, *European Journal of Operational Research* **184**, 685–700.

Bogetoft, P. and Otto, L.: 2011, *Benchmarking with DEA, SFA, and R*, SPRINGER, New York.

Bogetoft, P. and Otto, L.: 2012, Benchmark Package for R, *Technical report*, The R Project for Statistical Computing.

Burmeister, B., Ihde, T., Kittsteiner, T., Moldovanu, B. and Nikutta, J.: 2002, A practical approach to multi-attribute auctions, *Database and Expert Systems Applications, 2002. Proceedings. 13th International Workshop on*, pp. 670–674.

Bushnell, J. B. and Oren, S. S.: 1994, Bidder Cost Revelation in Electric Power Auctions, *Journal of Regulatory Economics* **6**, 5–26.

Chao, H.-p.: 2002, Multi-Dimensional Procurement Auctions for Power Reserves: Robust Incentive-Compatible Scoring and Settlement Rules, *Journal of Regulatory Economics* **22**(2), 161–183.

Che, Y.-K.: 1993, Design Competition Through Multidimensional Auctions, *RAND Journal of Economics* **24**(4), 668–680.

Cripps, M. and Ireland, N. J.: 1994, The design of auctions and tenders with quality thresholds: The symmetric case, *The Economic Journal* **104**(423), 316–326.

Lai, G., Li, C., Sycara, K. and Giampapa, J.: 2004, Robotics Institute: Literature Review on Multi-attribute Negotiations, *Technical Report CMU-RI-TR-04-66*, Carnegie Mellon University.

Milgrom, P.: 2000, An economist's vision of the b-to-b marketplace, *Technical report*, Perfect.com.

Moulin, H.: 1991, *Axioms of Cooperative Decision Making* , cambridge University Press.

Riley, J. G. and Samuelson, W. F.: 1981, Optimal Auctions, *American Economic Review* **71**(3), 381–392.

Teich, J. E., Wallenius, H., Wallenius, J. and Koppius, O. R.: 2004, Emerging multiple issue e-auctions, *European Journal of Operational Research* **159**, 1–16.

Teich, J. E., Wallenius, H., Wallenius, J. and Zaitsev, A.: 2006, A multi-attribute e-auction mechanism for procurement: Theoretical foundations, *European Journal of Operational Research* **175**, 90–100.

Tzeng, G.-H. and Huang, J.-J.: 2011, *Multiple Attribute Decision Making*, Methods and Applications, Chapman and Hall.