Combinatorial Procurement Auctions – a Collusion Remedy?*

by

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Abstract
This paper presents the outcome of an experiment where different procurement auction mechanisms are compared to allocate multiple contracts that exhibits non-linear cost. A standard one shot sealed bid mechanism and a combinatorial auction used. Both mechanisms are first run without, and then with the possibility for subjects to communicate prior to bidding over a chat line. It is demonstrated that the combinatorial mechanism is able to enhance efficiency. Subjects are also less inclined or able to cooperate under the combinatorial auction than under the standard bidding format. The paper therefore provides indications of that the possibility to submit combination bids may throw some sand into collusive schemes.

Key words: collusion, combinatorial auction, multiple object auctions, procurement mechanisms

JEL Classification: C90, D44

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1. Introduction

Many public procurement auctions comprise a large number of identical or similar contracts allocated at the same time. One example is the procurement of services for cleaning local community offices, schools and homes for elderly etc. During fall 2002, Stockholm City Council for instance invited bids for 168 separate objects of this nature. Another example is the procurement of contracts for road maintenance activities. The Swedish road authority annually lets about 50 similar contracts for painting of road markings. Moreover, the market for road pavement renewals at the national level includes some 100 objects per year, costs adding up to substantial amounts of money.

One concern with the simultaneous letting of many similar contracts is that entrepreneurs' costs may not be linear in the number of contracts awarded. Because of capacity constraints, small firms may have low initial costs that increase with the number of contracts while large firms, with extensive capacity, may have considerable scale economies in winning an increasing number of contracts. As a result, a standard one shot, sealed bid procurement auction may fail to allocate contracts efficiently. In such cases, the uses of more flexible bidding mechanisms, like the simultaneous ascending (descending) auctions or combinatorial auctions have shown to increase efficiency and lower the procurer's cost (seller's revenues).[1]

A second concern is that the simultaneous or sequential letting of a large number of similar contracts facilitates coordination of bidder behavior. The contracts may be awarded for short time periods, often for a year at a time, and then again up for bidding. This makes it possible for colluders to punish possible deviators from an agreement soon after that a break takes place. Anecdotal evidence also suggests that bidders sometimes win a larger number of

[1]See Lunander & Nilsson (2004) for a listing of some studies.

contracts than they have capacity to handle and therefore have to negotiate with the bidders that have not won contracts – i.e. that have free capacity – to be able to honor their submission. Ex post communication of this sort lowers the barrier for ex ante communication at subsequent events.

Collusion and bid rigging schemes is a serious problem in many auctions and the number of studies within the auction literature addressing different aspects of collusive behavior grows (see for example summaries in Pesendorfer 2000, Krishna 2002 and Aoyagi 2003). One branch of these studies investigates bidding behavior in multiple-object auctions when bidders collude by signaling or communicating. The research on signaling has to a large extent been inspired by the allocation of spectrum licenses in the US, where a multiple-object version of the English auction – the simultaneous multiple-round auction (SMA) – was used.[2]

Although the SMA has many advantages, one concern is that it is likely to be more vulnerable to collusion than the single-object English auction. Cramton and Schwartz (2000) discuss different kinds of bid signaling for collusive ends that occurred in the FCC auctions and how the SMA design can be modified to make life more difficult for colluders. Brusco and Lopomo (2002) show that in a private values model with two objects, bidders can take advantage of the signaling opportunities provided in the SMA to increase their expected surplus. The coordination by signaling, however, becomes more difficult as the number of bidders increases, keeping the number of objects fixed. They also show that the size of any complementarities does not affect the likelihood for collusive behavior. Furthermore, Kwasnica and Sherstyuk (2003) study bidder behavior in laboratory ascending auctions for

[2] For studies on signaling in a single object environment, see for example Sherstyuk (1999, 2002)

multiple objects with and without complementarities, not allowing for communication. Their experiment indicates that large complementarities do make collusion less likely.

A couple of auction experiments with multiple objects analyze bidding behavior when bidders are allowed to engage in pre play communication. Kwasnica (2000) analyses the choice of cooperative strategies in private values sealed bid auctions. In his experiment five subjects bid in five simultaneous single object first price sealed bid auctions. Allowing his subjects to communicate between periods, he found that bidders formed collusive agreements and in general used bid rotation as strategy, that is, each of the five bidders was selected to be the sole bidder on one contract each.[3] Phillips *et al* (2003) investigate bidding behavior in repeated laboratory English auctions of multiple objects. Bidders are given decreasing redemption values for eight objects, where the auctioneer sells one object at a time. Between 19 objects and 30 objects are sold in each repeated auction, and the experiment compares the outcome from a two-buyer that of a six-buyer market. In both types of markets, bidders were in some sessions allowed to communicate through a chat box prior to bidding. When bidders are allowed to communicate data indicate that the average winning bid is 50-60% of the object's competitive value. More surprisingly, however, is that the collusion in the in the six-buyer market is similar to that in the two-buyer market. The reason is said to be that in the two-buyer market, bidders seek equity – comparing earnings and adjusting differences - when colluding, which opens the door for disagreement, while in the six-buyer market bidding rings are based on simple bid sharing plans. [4] A related theoretical study is Aoyagi (2003) which presents a dynamic bid rotation scheme where bidders collude through communication in repeated auctions. In this environment, bidders that communicate can compensate each other through dynamic bid rotation instead of using side payments.

[3] Subjects were, however, neither allowed to reveal their private values nor to discuss the use of side payments.
[4] See also Goswani *et al* (1996) for an experiment on the effect of pre play communication in uniform-price and discriminatory auctions of share.

Within the multiple objects auction environment, very few studies have investigated cooperative agreements in combinatorial auctions. Kelly and Steinberg (2000) describe a combinatorial auction procedure which essentially is a simultaneous multiple-round auction, but where bidders are allowed to submit package bids at a later stage of the auction. The auction mechanism should make it more difficult for price-level signaling and thus reduce the possibility of collusion.

Based on a wind-tunnel experiment, the purpose of our study is to test how vulnerable combinatorial auctions are to collusive behavior. In particular, we consider the role of pre play communication in different types of sealed bid procurement auctions where the procurer seeks to acquire multiple contracts with cost complementarities. One difference between our environment and that of previous experiments on collusion in multiple object auctions is that we, except for the human subjects, also make use of a computerized bidder that cannot be part of any collusive agreement. This mimics the potential threat from outsiders that the members of a cartel have to take into account when forming cooperative agreements.

The purpose of this paper is to see whether bidding behavior in general, and the choice of cooperative strategies in particular, is affected by the option to submit bundle bids, given complementarities and the presence of an automata bidder. Do bidders have more difficulties to collude under a combinatorial auction than under standard simultaneous sealed bid auction? Our conjecture is that the combinatorial environment creates fewer incentives for bidders to set up and maintain a cartel as a means to fully realize synergies. A bidder can fully exploit synergies using bundle bids without facing the exposure problem and thereby bid more competitively against non-cartel bidders.

To this end, the paper systematically compares the allocation efficiency and the participants´ behavior in three different mechanisms. The first is a standard one shot sealed bid auction; the second is the same mechanism but with scale efficiencies in the number of contracts awarded; and the third is a combinatorial auction also with scale economies in the number of contracts. Each session first includes eight periods with the base-line design followed by a number of periods where subjects are able to communicate via a chat line prior to bidding in each period. Our results indeed indicate that subjects are less inclined to form collusive agreements in a combinatorial auction than in the standard first price auction when synergies are present. Also, the combinatorial auction generates higher efficiency and lower procurement cost.

The paper starts with a short description of the recent disclosure of a bidding ring for pavement contracts (section 2). We then present the experimental design (section 3) and the results (4) followed by a summary (5).

2. The Swedish Asphalt Cartel

In 2001, *Konkurrensverket* (the Swedish Competition Authority, KKV henceforth) received indications of that bids for most asphalt contracts in the southern part of the country, for several years had been coordinated in beforehand by entrepreneurs that were supposed to compete. An asphalt contract concerns the cooking of bitumen and stone, the transport of the asphalt mix to where it is to be laid and the spreading of the mix. Both the National Road Administration, in charge of the national road network, local communities (the third tier of the country's public sector) handling the local road network and private customers buy asphalt.

After a dawn raid, KKV therefore made an application for a summons for a fee totalling almost SEK 1 700 million (US$ 200 million) from 9 different defendants. KKV claims that at least since 1995, representatives for four major companies (which included the two overall largest building enterprises in Sweden) have met several times per year in the different regions where they have been active. The purpose of these meetings was to establish how national, local and private contracts for asphalt works were to be split between the companies and to control for the outcome of agreements struck the year before. Information about volumes and prices were exchanged. The parties are also said to have had hoc meetings and conversations over the phone.

Since resurfacing can only be done during the warmest 5-8 months of the year, asphalt contracts are typically awarded at the beginning of each year. Before the start of a new bidding process, the four companies have split contracts between them primarily according to their respective market shares in different regions; if company A had 40 percent in one region and 10 percent in another, this was accounted for. The designated winner coordinated the bidding behavior for each contract; this was referred to as ‘to give and take price’. Another part of the coordination was to award potential competitors for abstaining from bidding or for submitting non-competitive bids. The outside, smaller firms were remunerated by being awarded sub-contracts, by being provided with services that never were charged for or by being paid against invoices for work which was never done. In single cases where the four companies could not agree, there was an actual competition for the contract.

At least at one occasion, the ‘gang of four’ has tried to keep an entrant out of one of the regional markets. The mechanism seems to have been to threaten the (potential) entrant that he would have difficulties to buy inputs such as bitumen, vital for the production process, from some of the dominant firms in control of that input. It should be noted that one of the four large companies is a wholly owned subsidiary of the National Road Administration.[5]

3. The Experimental Design

The three core features of our procurement experiment are the non-linearity of costs, the risk for collusion and the possibility to use combination bids to curb the propensity to collude. To start with the cost aspect, this was handled in the following way. Subjects were invited to submit bids for two identical objects, A and B. Under the first treatment, the standard one-shot sealed bid auction, bids on A and B were submitted simultaneously and evaluated independently and contracts awarded to the lowest bidder. Costs c_i, $i=A,B$ were induced by independent draws from a uniform distribution with the support [200, 300]. Under the second and third treatments, subjects had scale economies in that the cost for each object decreased with 10 or 20 percent – two different scale parameters were tested – if the same subject won both items. Profits (π) for a bidder j submitting the lowest bid $\tilde{b}_i^j$ on both objects $i=A, B$ and therefore awarded both contracts was therefore $\pi^j = \tilde{b}_i^j - \alpha \times c_i^j$ where α is the scale factor ($\alpha=0.8$ or 0.9).

The second feature of the experiment was to design a structure that allowed for collusion. In order to make it as simple as possible for bidders to collude, only two physical subjects plus an automated bidder were submitting bids for the contracts. Computer bids were used to avoid making the collusion sessions trivial. Subjects were informed that the computer would always submit a bid $\hat{b} = 100 + \frac{2}{3}c$ with c independently drawn from the same distribution as for the human subjects. $\hat{b}$ is the Risk Neutral Nash Equilibrium (RNNE) prediction for an optimal

[5] The Road Administration no longer has in-house resources but procures all construction and maintenance activities on a competitive basis.

bid with three players having constant costs drawn from the distribution $U \sim [200,300]$. A draw of 240 would therefore generate a bid of 260 and the computer would never bid below 233 or above 300. The computer had no scale economies in the number of contracts awarded.

The collusion design was benchmarked against an initial number of periods where bidders could not communicate, where after a chat line was opened in order to facilitate collusion. Subjects were informed about different ways to cooperate; (a) after observing the cost draw, they could agree about which bid that each was to submit; (b) they could agree to take turns, and; (c) they could let one win all periods and share profits after leaving the classroom. The risk of being tricked by the other party was also emphasized. We did no policing of non-competitive behavior, i.e. no penalties for collusion were metered out.

The experiment's third feature was the possibility to use combination bids as a means to reduce the extent of collusion. Under the third treatment, the two human subjects were therefore given the possibility to submit bids not only on A and B in isolation but also on the combination AB. The bidder(s) behind the combination of bids that generated the lowest cost – i.e. awarding A and B to different subjects or both going to the same – was designated to be the winner.

To summarize, a subject was before each bidding period informed about which two independent costs draws that had been made for her. The subject knew that the other human subject and the automated bidder were given draws from the same distribution but did not know which draws that others got. Based on this information, bids were to be submitted in order to maximize profits. Our first treatment used the standard simultaneous first price sealed bid mechanism to award contracts and the second treatment introduced non-linearities in costs but still used the standard bidding principle. Also the third treatment had cost non-linearities but in addition, human subjects were given the possibility to submit bids not only on A and B in isolation but also on the combination AB.

Each session was initiated with two (trial) periods with an exchange rate of 0.5 followed by eight non-communication periods with the exchange rate 1.5. The session was then finalized with another eight plus a variable number of periods where communication was allowed, still with the 1.5 exchange rate. The final number of periods (U~[1,6]) was decided by having the experiment leader throwing a dice, which was not shown to the subjects until after the conclusion of the experiment. This was done to make subjects uncertain about which period was the final, i.e. to curb the risk for backward induction.

Bidders' show-up fee was SEK 150, with SEK 100 being a guarantee amount and SEK 50 a buffer against losses; also this part of the fee was to be kept if such losses were not incurred. Importantly, each human player in the auction was a team of two physical individuals. We did this in order to make it feasible for the two to talk to each other, and so to enhance the chance that they grasped the nature of the problem put to them. All earnings were therefore to be split between the two, all being economics students at Örebro University. Actual earnings for the two-hour sessions ranged from SEK 250 to 1200.[6]

4. Results: Efficiency and Costs

A total of 14 experimental sessions were concluded during spring and fall semesters 2002. Table 1 summarizes the number of sessions allocated to each treatment and the number of periods concluded.

[6] At the time of the experiments, the price for a US$ was about SEK 9.

Table 1: Number of sessions and number of periods under different treatments

Treatment	# Sessions	Thereof with scale parameter		# periods with no chat	# periods allowing for chat	Total periods	
I. Standard	4	-	-	32	52		84
II. Standard with non-linear costs	5	0.9	3	24	38	62	
		0.8	2	16	28	44	106
III. Combinatorial with non-linear costs	5	0.9	3	24	43	67	
		0.8	2	16	27	43	110
Sum	14			112	188		300

Results from the two initial trial periods in each session have been omitted throughout the analysis. We start by describing efficiency (4.1) and cost (4.2) properties of the mechanisms in this section. Section 5 then reports about bidding behavior and communication within each of the three mechanisms.

4.1 Efficiency

Our measure of efficiency (E) is defined in equation (1) where *A* is the actual costs for the winners of fulfilling contracts, *M* is the lowest induced cost of fulfillment and *N* is the expected induced cost of a random allocation. For each period, *N* is computed as the total sum of the induced cost of all possible allocations of the two contracts among the three bidders. This sum is then dived by the number of possible allocations, which are (3^2) 9. Table 2 summarizes efficiency under the three treatments.

$$E = 1 - \frac{A - M}{N - M} \tag{1}$$

*Table 2: Efficiency Across Mechanisms**

Mechanism	Average efficiency - all periods	*N*	Average efficiency - periods with no communication	*n*	Average efficiency - periods allowing for communication	*n*
I. Standard	0.92	84	0.9	32	0.93	52
II. Standard with non-linear cost						
All	0.73	106	0.74	40	0.72	66
$\alpha=0.9$	0.76	62	0.75	24	0.76	38
$\alpha=0.8$	0.68	44	0.71	16	0.67	28
III. Combinatorial with non-linear cost						
All	0.89	110	0.91	40	0.88	70
$\alpha=0.9$	0.86	67	0.88	24	0.85	43
$\alpha=0.8$	0.95	43	0.97	16	0.93	27

* See Appendix for a table with std. dev. and t-tests of mean efficiency across mechanisms

The introduction of scale economies in a standard first-price auction significantly reduces efficiency; only an average 73 percent of potential gains are actually realized in contrast to 92 percent when there are no scale economies. It is, however, not the possibility to communicate that affects efficiency, but rather the complexity generated by the non-linearity in costs; there is no significant difference in efficiency within treatments between chat and no-chat conditions.

When the possibility to submit combination bids is introduced in treatment III, efficiency goes back to about 90 percent. Efficiency is significantly higher with the combinatorial than with the standard auction when synergies are present both in periods not allowing for communication and in periods allowing for communication. This confirms the favorable qualities of the combinatorial auction demonstrated in our previous study (e.g. Lunander and Nilsson (2003)).

4.2 Costs

We use the winners' profits, i.e., $\pi_i^j = b_i^j - c_i^j$, as the measure of the procurement cost in each period. Running regression equation (2) on payments under treatment I where $D_i = 1$ if communication allowed, and excluding the computerized bids, we obtain a significant coefficient for the dummy variable (table 3). Hence, allowing communication prior to bidding increases the payments (procurement cost) made to the subjects. The increase is, however, relatively small.

$$\pi_i^j = \alpha_1 + \alpha_2 D_i + \beta \text{cost} + u_i, \tag{2}$$

*Table 3. Estimated payments to subjects under treatment I**

Variable	Estimate
α_1	94.31
	(12.09)
D	3.17
	(2.28)
Cost	-0.35
	(-10.41)
N	131
R^2	0.44

* SEK, robust standard errors, t-ratios in parenthesis

Figure 1 illustrates the earnings under treatment II and III in 104 periods (40 periods without and 64 periods with communication), the vertical line indicating where in the sequence of periods the chat line was opened. Payments under the combinatorial mechanism are centered on SEK 20 throughout the periods and the possibility to communicate after period eight seems to have had little effect on procurement costs. The last observation also applies to treatment II, but the distribution of payments is more scattered. Also, in a number of periods, winning bidders in the standard mechanism (treatment II) incurred losses due to the exposure problem.

Figure 1. Payments under treatment II and III in identical periods.

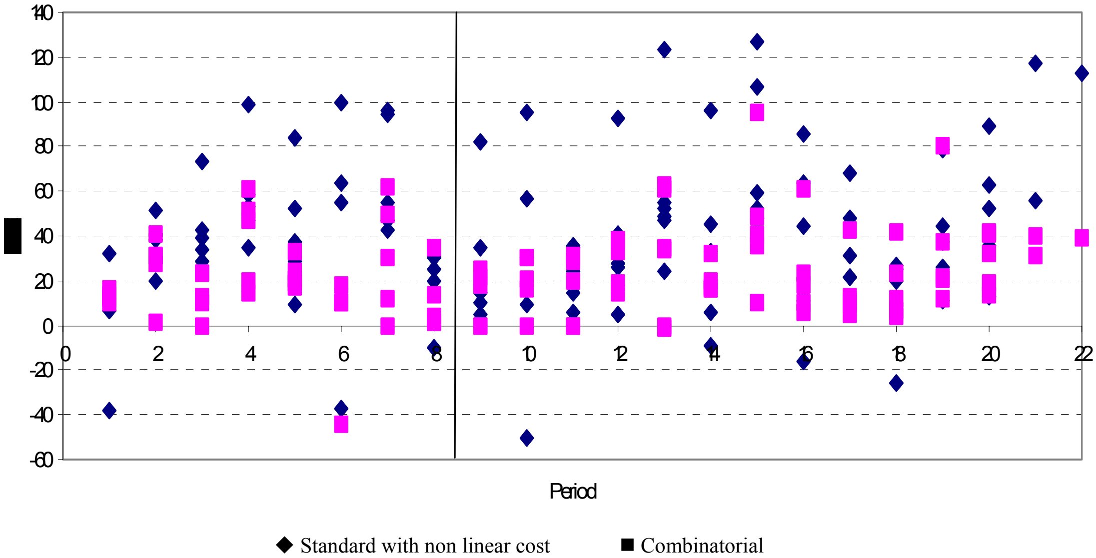


Table 4 summarizes the payments in the two mechanisms, for the whole sample and separated for weak and strong synergies. Although winning bidders in some periods under treatment II incurred substantial losses – which decreases the mechanism's reported cost – it is clear from table 4 that the combinatorial auction generated significantly lower profits for bidders (i.e. lower payments) than the standard mechanism. When the synergy effect of winning both contracts increases from $\alpha = 0.9$ to $\alpha = 0.8$, the results suggest that the increase in procurement cost of using the standard mechanism is greater than the corresponding increase in the combinatorial mechanism.

Table 4: Comparison of Average Period Payments (SEK) to Subjects

	Treatment			
Environment	III. Combinatorial	II. Standard with non linear cost	Number of periods	Test statistics (t-ratio)*
Whole sample				
Chat	25.40	41.35	64	3.77
No chat	19.68	38.98	40	3.32
Synergy 0.9				
Chat	21.39	30.84	38	3.10
No chat	19.0	32.17	24	1.93
Synergy 0.8				
Chat	31.27	56.73	26	2.43
No Chat	20.69	49.19	16	2.64

* t-tests for equal mean values across mechanisms

5. Observed Bidding Behavior

Results summarized in tables 2 and 4 indicate that the combinatorial auction outperforms the standard mechanism both in terms of efficiency and costs to the procurer. This is basically the same result as was reported in our previous paper. However, the possibility to communicate does not seem have a strong impact on efficiency. In order to provide a deeper understanding of differences between environments without and with communication, this section provides an analysis of individual's bidding behavior under the respective mechanisms.

We use the following definitions of how bidders have used the option to communicate in order to reach a collusive agreement. The first is to *divide the market*. The two human bidders then decide to take one contract each. The second type of agreement is referred to as *bid rotation*. Bidders agree that one of them is to win both contracts. Sometimes the designated loser abstains from bidding altogether, and at other instances a 'high' bid is submitted, sometimes even SEK 300, the highest possible bid.[7] The third type of observed collusive agreement is *side payment*, where one of the bidders adjusts bidding behavior in exchange for receiving remunerations afterwards. Finally, *no agreement* refers to situations where pre-play communication is not observed or where the parties have been unable to strike a deal. Table 5 summarizes the collusion behavior – if any – under the three treatments.

Table 5: Types of pre bidding agreements under three treatments

	Treatment I		Treatment II		Treatment III	
Type of agreement	# periods	%	# periods	%	# periods	%
No agreement	10	19	29	44	46	66
Divide the market	36	69	14	21	5	7
Bid rotation	4	8	9	14	19	27
Side payments	2	4	14	21	.	.
Number of periods	52	100	66	100	70	100

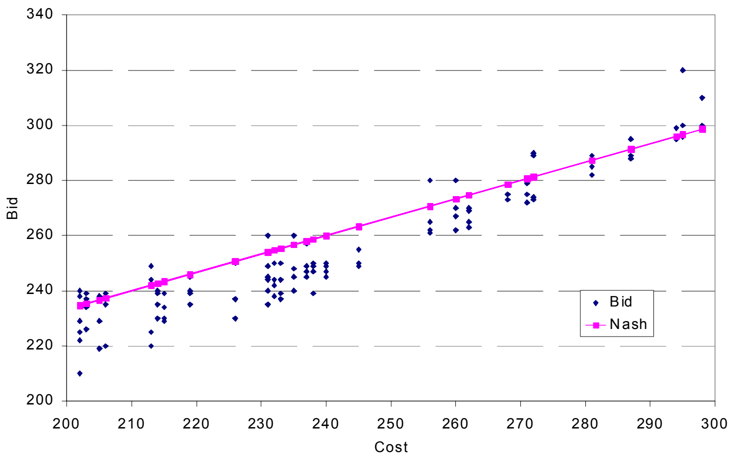
[7] In the analysis, we have coded non-bidding as if the bid is SEK 300.

In some cases but not always, information about private costs for each contract was revealed during the communication phase. There were some situations where one bidder may have tried to fool the other, but this may alternatively have been due to that the parties did not fully understand the implications of competing against the automated bidder.

5.1 Standard auction with linear cost (treatment I)

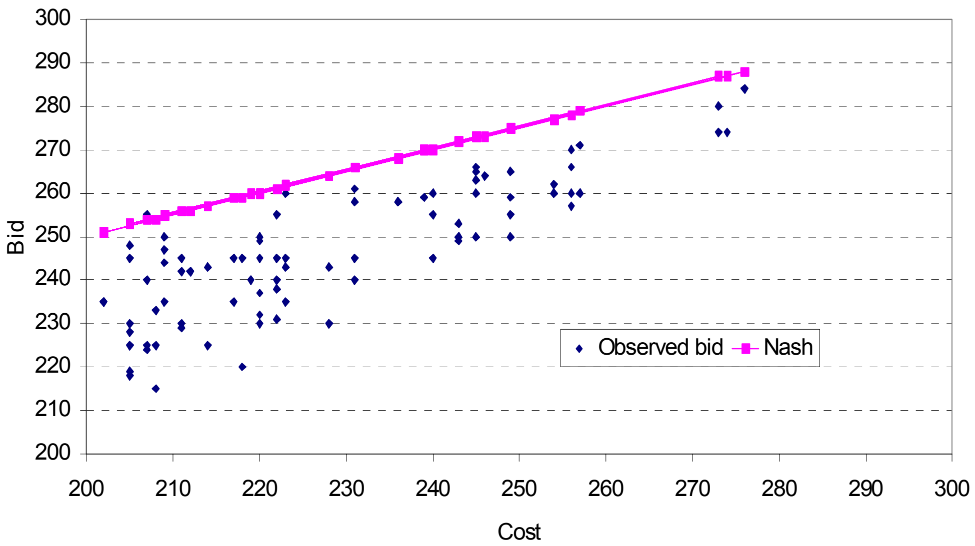
To provide a benchmark for the discussion, we start with analyzing the bids submitted under non-communication periods only. Figure 2 indicates that the bidding behavior is similar to the standard findings in most experiments with first-price sealed bid (procurement) auctions within the private values model, with bids being significantly below the RNNE prediction. Using the relevant parameter values, the RNNE bid function is $\beta_i^j(c) = 100 + 0{,}67c$. Table 6 (column *a*) reports the estimated linear relationship.

Figure 2: Observed and predicted bids in periods with no communication (SEK)



Turning to bids under communication, our persistent problem is that any form of collusion means that an assigned looser submits a bid with poor information, i.e. which may defy any systematic analysis which tries to capture the logic of these bids. Even if only a few bids are rigged in this way, this may destroy the possibility to derive any valuable information from the dataset of all bids. To take a broad grip over data, we therefore present observed bidding behavior both when all bids that have been submitted (columns (a) and (b) in table 6) are included and also the winning bids only (columns (c) and (d)). Throughout the analysis, bids from the computerized bidder are excluded. In this situation, the optimal bid for the person assigned to be winner and who competes only with the computerized bidder can be derived from the expected profit $\Pi = (b_i - c_i) \times (1 - \Pr[0{,}67 c_{j_{j \neq i}} + 100 \leq b_i])$, generating the bid function $\beta(c_i) = 150 + 0{,}5 c_i$. Figure 3 and column (d) of the table confirms that observed bidding is well below this predicted RNNE behavior.

Figure 3: Observed winning bids and predicted bids under the assumption of market division when bidding only against the computerized bidder, SEK.



In order to see whether the option to communicate has affected the magnitude of the bids, we pool the winning bids and run equation *(3)* with *D=1* for bids submitted in periods allowing for communication.

$$bid_i = \alpha_1 + \alpha_2 D_i + \beta_1 Cost_i + \beta_2 \times D_i \times Cost_i + \varepsilon_i, \qquad (3)$$

Column (e) in table 6 shows that the hypothesis $\alpha_2=0$ and $\beta_2=0$ cannot be rejected, suggesting that the possibility to chat has not affected bidding behavior. Although bidders to a large extent have formed collusive agreements (divided the market) these have had little effect upon designated winner's mark up on cost.

*Table 6: Bidding behavior under treatment I**

Parameter	All bids Periods not allowing for communication	 allowing for communication	Winning bids Periods not allowing for communication	 allowing for communication	Pooling winning bids – t-ratio
	(a)	(b)	(c)	(d)	(e)
α_1	68.2 (12.28)	79.9 (10.75)	87.50 (9.22)	104.25 (8.98)	$\alpha_2=0$ (1.097)
β_1	0.77 (35.15)	0.75 (26.81)	0.68 (16.18)	0.62 (12.71)	$\beta_2=0$ (-0.93)
N	128	208	52	79	
R^2	0.92	0.72	0,84	0.62	

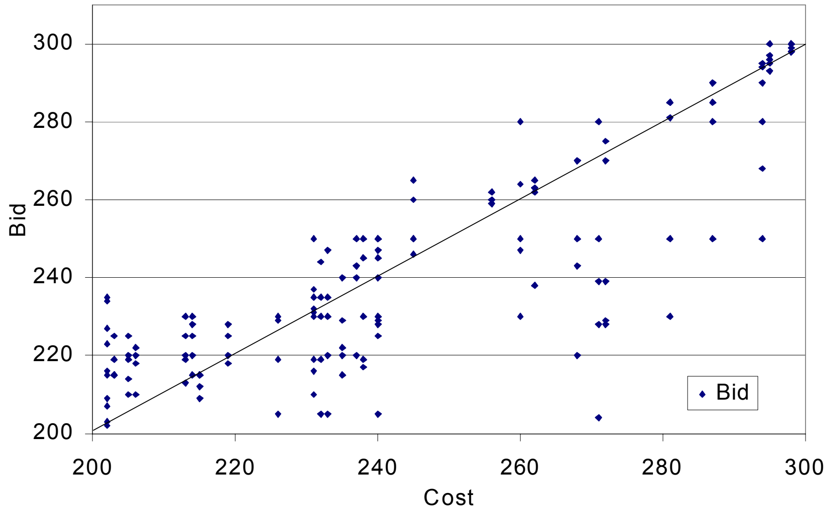
* SEK, robust standard errors, t-ratio in parenthesis

5.2 Standard auction with non linear cost (treatment II)

In periods where collusive agreements have been reached, table 5 (above) shows that all three classes of collusion strategies have been used under treatment II. The side payments were, however, primarily concentrated to one specific session. Most striking is that it has now become much more difficult to strike a deal.

Since we lack a clear theoretical prediction of individual bidding behavior in a situation with two bidders having non linear, and one constant costs, the analysis is based on a comparison of observed bidding in periods without and with a chat line open. In the former periods about a third of all single bids were below the induced cost (figure 4), indicating that bidders tried to win both contracts using their synergies. In several periods these bidders incurred losses.

Figure 4. Observed bids in treatment II, periods not allowing for communication (SEK).



In order to study the impact of pre-play communication on bidding behavior, table 7 provides the regression results from periods not allowing for communication and periods allowing for communication. In the same way as in table 6 we present both the results from explaining bidding behavior when all bids and when only winning bids are included in the comparison of periods without and with the chat option. We also include observed behavior under different scale parameters. In both datasets the estimated bidding behavior resembles the bidding behavior we observed in treatment I; the intercept of the estimated slope increases whereas the coefficient decreases when subjects are given the option to communicate prior to bidding. Pooling the winning bids into one dataset, and using equation (3) , the results indicate a difference in bidding behavior across periods not allowing for chat and allowing for chat, respectively. When subjects can communicate, they seem to be changing there behavior relative to treatment I where earnings were lower. The estimated difference is, however, primarily attributable to the case when synergies in the number of won contracts are large.

*Table 7: Bidding behavior under treatment II**

Parameter	All bids Periods not allowing for communication	 allowing for communication	Winning bids Periods not allowing for communication	 allowing for communication	Pooling winning bids
Whole sample					
α	51.4	76.9	89.78	154.11	$\alpha_2=0$
	(5.54)	(7.60)	(4.04)	(12.04)	(**2.51**)
β	0.78	0.72	0.60	0.34	$\beta_2=0$
	(19.57)	(18.07)	(5.97)	(6.12)	(**-2.27**)
N	160	268	72	120	
R^2	0.71	0.46	0.50	0.24	
Synergy 0.9					
α	51.57	39.77	62.87	75.91	$\alpha_2=0$
	(5.52)	(6.72)	(3.28)	(6.09)	(0.57)
β	0.79	0.86	0.74	0.69	$\beta_2=0$
	(20.04)	(37.28)	(8.71)	(12.62)	(-0.46)
N	96	156	43	69	
R	0.81	0.83	0.73	0.66	
Synergy 0.8					
α	51.14	129.24	112.71	205.77	$\alpha_2=0$
	(2.81)	(5.90)	(3.22)	(11.64)	(**2.39**)
β	0.76	0.52	0.47	0.11	$\beta_2=0$
	(9.62)	(6.01)	(3.00)	(1.58)	(**-2.10**)
N	64	112	29	51	
R	0.63	0.19	0.36	0.04	

* SEK, robust standard errors, t-ratios in parenthesis

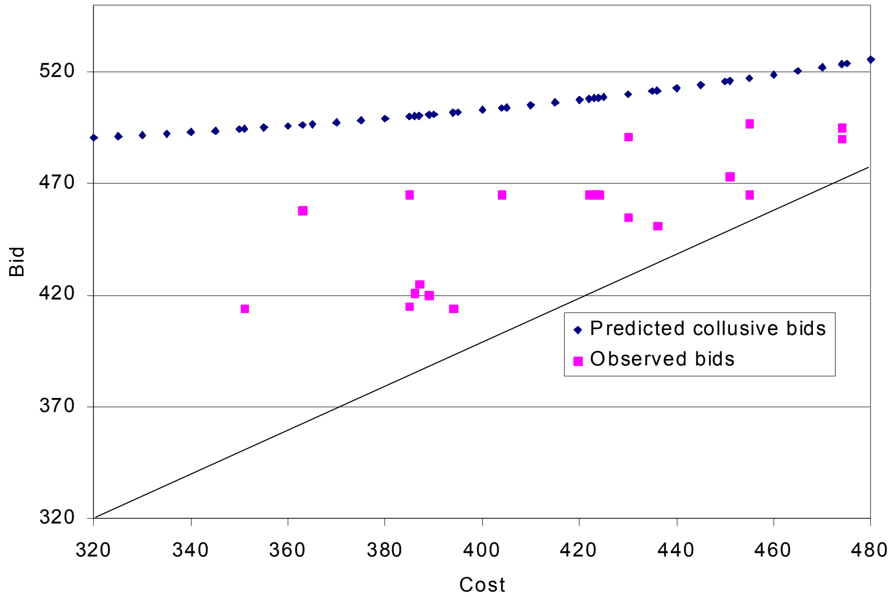
5.3 Combinatorial auction (treatment III)

Table 5 (above) indicates that far fewer collusive agreements were formed under the combinatorial mechanism than in the other two mechanisms. In most of the cases where an agreement was reached, one of the bidders was designated to bid for both contracts against the computerized bidder's two single bids. Bid data also indicate that the designated bidder in general only submitted the package bid for AB and not any single bid. The risk neutral bid function for the designated cartel bidder, given that he only submits a package bid for AB, is given by equation (4); see appendix B for a proof. The optimal collusive bid function and the observed bids from periods where bidders agreed on bid rotation are illustrated in figure 7.[8] Again, the observed mark-up over cost is relatively low compared to predicted mark-up.

[8] In all observed agreements, the designated bidders cost was below 499,5.

$$b(c_{AB}) = \begin{cases} 466 + 67 \times \left[\sqrt{\left(\frac{c_{AB} - 466}{201} \right)^2 + 0{,}67} + \left(\frac{c_{AB} - 466}{201} \right) \right] & \text{if } c_{AB} \leq 499{,}5 \\ 200 + 0{,}67 c_{AB} & \text{if } c_{AB} > 499{,}5 \end{cases} \quad (4)$$

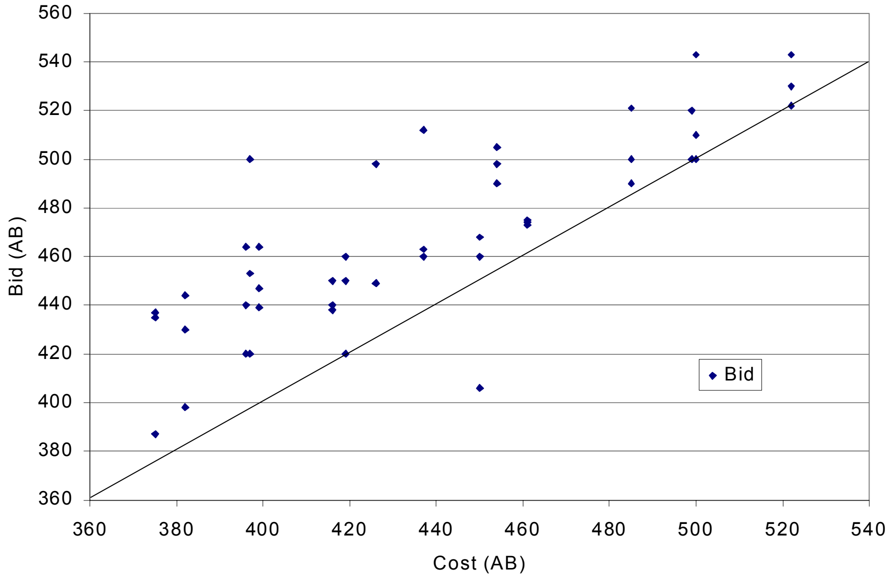
Figure 7. Collusive Bids and predicted collusive RNNE bids in the Combinatorial Auction.



Similar to the analysis of bids submitted under the standard mechanism when costs are non-linear, we are not able to test observed behavior under treatment III against theoretical predictions. In each of the periods where communication was not allowed, and in each of the five sessions, both human bidders submitted a combinatorial bid for AB. Figure 5 shows that the mark-up over cost was rather modest, on average 7,5 percent, which is likely to be below equilibrium.[9]

[9] Note that the average RNNE mark-up in a simple environment (without synergies) is about 8%, given our random costs for contract A and contract B (see figure 2).

Figure 5. Package bids on AB in periods not allowing for communication



Except for their package bid on AB, the bidders could also submit a single bid on contract A and a single bid on contract B. These bids are illustrated in figure 6 where also the "virtual" Nash behavior, i.e. interpreting singleton bids as if no combination bid could be submitted, is indicated.

Figure 6: Singleton bids under treatment III in periods not allowing for communication

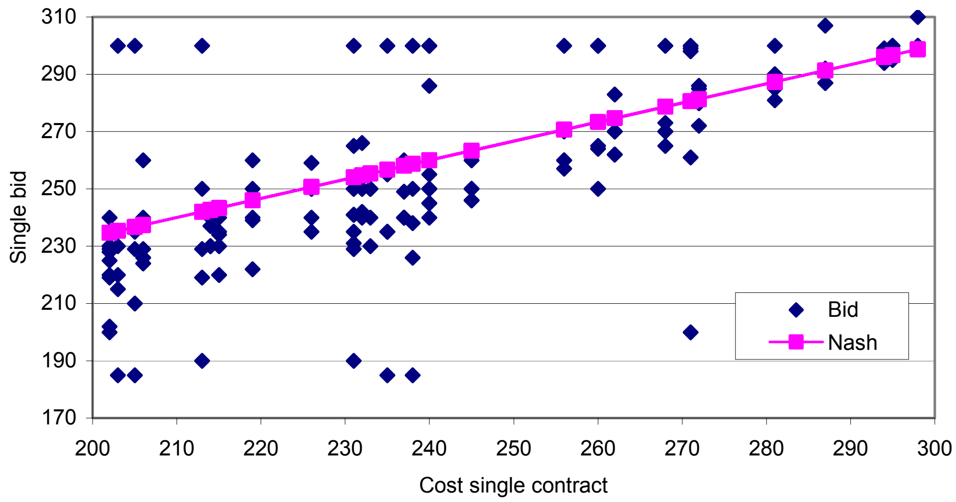


Table 8 reports the estimated coefficients from both treatment I and III, using these singleton bids. Pooling the data we cannot reject the hypothesis of identical intercepts and coefficients. Thus, when submitting singleton bids in the combinatorial auction, bidders' adopt the same strategy as they do in a standard auction, neglecting the interdependence between their single bids and their combinatorial bids. A number of subjects have, however, either refrained from submitting singleton bids or submitted singleton bids equal to the highest possible bid by the computerized bidder (SEK 300).

Table 8. Estimated bid function for single bids in treatments I and III, periods not allowing for communication

	Auction (treatment)	
Parameter	Standard auction (I)	Combinatorial auction (III)
α	68.21	63.77
	(12.28)	(4.80)
β	0.77	0.79
	(35.15)	(15.34)
N	128	156
R^2	0.92	0.57

* SEK, robust standard errors in parenthesis

Finally, we investigate the impact of allowing pre-play communication on bidding behavior. In this, we focus only on the observed package bids. Table 9 presents the same sort of comparison as table 7 above. Pooling the winning bids (last column) we cannot reject the hypothesis of identical bidding behavior in periods without and with communication. We therefore conclude that subjects seem to be less inclined or able to engage in cooperative bidding in a combinatorial auction that when the standard auction format is used. This strengthens our maintained hypothesis that the possibility to submit combinatorial bids makes it more difficult to collude.

Table 9: Bidding behavior under combinatorial auction

Parameter	All bids Periods not allowing for communication	 allowing for communication	Winning bids Periods not allowing for communication	 allowing for communication	Pooling winning bids
Whole sample					
α	77.02	217.69	106.87	160.40	$\alpha_2=0$
	(2.21)	(5.20)	(3.97)	(6.50)	(1.47)
β	0.89	0.59	0.78	0.69	$\beta_2=0$
	(10.19)	(6.42)	(11.80)	(12.43)	(-1.16)
N	80	140	38	63	
R^2	0.61	0.19	0.80	0.72	
Synergy 0.9					
α	108.18	231.84	138.60	215.99	$\alpha_2=0$
	(1.92)	(4.47)	(2.55)	(7.50)	(1.27)
β	0.83	0.56	0.73	0.57	$\beta_2=0$
	(6.17)	(5.07)	(5.76)	(9.01)	(-1.12)
N	48	86	22	39	
R^2	0.53	0.18	0.65	0.70	
Synergy 0.8					
α	130.56	182.63	173.14	191.56	$\alpha_2=0$
	(4.56)	(1.78)	(6.38)	(3.04)	(0.27)
β	0.73	0.68	0.60	0.60	$\beta_2=0$
	(8.73)	(2.67)	(8.90)	(3.76)	(-0.001)
N	32	54	16	24	
R^2	0.44	0.10	0.86	0.36	

*SEK, t-ratio in parenthesis

6. Summary

A couple of previous studies have demonstrated that combinatorial bidding is better at establishing efficient allocations than the standard one shot, sealed bid institution when there are non-linearities in the number of contracts awarded to a bidder. The research reported here indicates that the possibility to submit combinatorial bids also may have an impact on the possibility to collude. By allowing for combination bids it gets more difficult for colluders to agree on a policy which boosts their earnings at the expense of the procurers' costs or of efficiency. We can therefore think about this augmentation of the bidding space as an additional policy device for reducing the chances of initial collusion forming or increasing the chances of an existing collusion to break down (see Coate 1985).

When analyzing actual bidding behavior during the experiments, we have been a bit surprised that the introduction of a possibility to communicate does not generate more collusion and worse efficiency performance than we actually see. The detailed analysis of bidding behavior has however established that there is a difference between bids submitted under the standard mechanism (treatment II) between periods without and with chat possibilities. This difference disappears when the possibility to submit package bids is introduced in treatment III. This is confirmed when we count the number of collusive agreements reached under the respective treatments. Our main result is therefore that the standard one shot, sealed bid procurement auction provides possibilities for collusion which evaporates under the new set of bidding rules.

One reason for that the impact of communication on efficiency and cost still is small could be that our environment is a bit “kind” in this respect; since there are only three bidders and two contracts to be awarded, there are not so many incorrect allocations that can be established. Another possible reason is that since the outside (automata) bidder may disturb any collusive agreement, it is difficult for the two colluders to establish a solution where they both win reasonably many times. It is an obvious challenge for further research to test whether or not our conclusion is robust against alternative experimental designs. The second explanation may also provide an illustration of the importance for participants in the asphalt cartel described in section 2 to get rid of outsiders. The presence of just one single competitor who breaks up the bidding pattern in the cartel is sufficient to almost wipe out the profits from controlling the market.

Although we inadvertently created an environment where it is fairly difficult to collude – where participants can only to a degree make use of the possibility to coordinate behavior – it has still been possible to establish that combinatorial bidding affects behavior and enhances efficiency. Real applications of combinatorial auctions may involve ten or more contracts and therefore a large number of feasible bid combinations. In addition, the number of bidders is often more than three. This means that there may be an even better efficiency-enhancing potential for the mechanism under real-life conditions than in our stylized lab.

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Appendix A

Table A1: Efficiency Across Mechanisms (standard dev in parenthesis)

Mechanism	Average efficiency - all periods	*n*	Average efficiency - periods with no chat	*n*	Average efficiency - periods allowing for chat	*n*
Standard	0,92 (0,15)	84	0,9 (0,19)	32	0,93 (0,12)	52
Standard with linear cost						
Synergy 0,9+0,8	0,73 (0,39)	106	0,74 (0,37)	40	0,72 (0,72)	66
Synergy 0,9	0,76 (0,30)	62	0,75 (0,33)	24	0,76 (0,28)	38
Synergy 0,8	0,68 (0,49)	44	0,71 (0,42)	16	0,67 (0,53)	28
Combinatorial with linear cost						
Synergy 0,9+0,8	0,89 (0,20)	110	0,91 (0,15)	40	0,88 (0,25)	70
Synergy 0,9	0,86 (0,23)	67	0,88 (0,18)	24	0,85 (0,26)	43
Synergy 0,8	0,95 (0,15)	43	0,97 (0,19)	16	0,93 (0,19)	27

Table A2: Test of Mean Efficiency Across Mechanisms

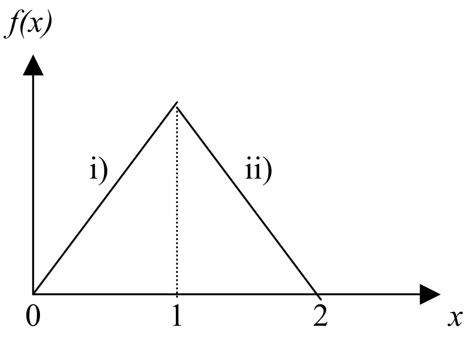
H_0: *Efficiency* $_{Comb.}$ = *Efficiency* $_{Standard\ with\ non\ linear\ cost}$	*t-ratio*	*Combinatorial* *n*	*Standard with non linear cost* *n*
All periods (both $\alpha= 0,9$ and $\alpha=0,8$)	3,79	110	106
Periods with chat line closed	2,69	40	40
Periods with chat line open	2,81	70	66
All periods when $\alpha= 0,9$	2,11	67	62
Periods with chat line closed	1,69	24	24
Periods with chat line open	1,57	43	38
All periods when $\alpha=0,8$	3,49	43	44
Periods with chat line closed	2,45	16	16
Periods with chat line open	2,43	27	28

TableA 3: Test of Mean Efficiency Across Size of Synergy

H_0: Efficiency$_{\alpha=0,8.}$ = Efficiency$_{\alpha=0,9}$	*t-ratio*	*n* α =0,9	*n* α=0,8
Standard with non linear cost			
All periods	1,04	62	44
Periods with chat line closed	0,34	24	16
Periods with chat line open	0,82	38	28
Combinatorial			
All periods	2,27	67	43
Periods with chat line closed	1,92	24	16
Periods with chat line open	1,38	43	27

Appendix B

$$\text{Let } b_i^C \sim U[0,1] \quad i = A, B$$
$$f\left(b_A^C + b_B^C\right) = f(x)$$



$$i)\, f(x) = x \Rightarrow F(b) = \int_0^b x\,dx \Rightarrow 1 - F(b) = 1 - \frac{b^2}{2}$$
$$\Pi = (b - k) \times \left(1 - \frac{b^2}{2}\right)$$
$$\frac{d\Pi}{db} = 0 \Rightarrow b = \sqrt{\frac{k^2}{9} + \frac{2}{3}} + \frac{k}{3}$$

$$ii) F(b) = \int_0^1 x dx + \int_1^b (2-x)dx \Rightarrow 1 - F(b) = \frac{(b-2)^2}{2}$$

$$\Pi = (b-k) \times \frac{(b-2)^2}{2}$$

$$\frac{d\Pi}{db} = 0 \Rightarrow b = \frac{2}{3} + \frac{2}{3}k$$

Transformation of variables

$k = \dfrac{c-2a}{z-a}$ where $c =$ designated winner's cost for AB, a = lower limit for b_i^C (233)

z = upper limit for b_i^C (300).

$\beta = 2a + b(z-a)$ where β is the designated winner's bid

$$i) \quad \beta(c_{AB}) = 466 + 67 \times \left[\sqrt{\frac{\left(\frac{c_{AB} - 466}{67}\right)^2}{9}} + \frac{2}{3} + \frac{\frac{c_{AB} - 466}{67}}{3} \right]$$

$$= 466 + 67 \times \left[\sqrt{\left(\frac{c_{AB} - 466}{201}\right)^2} + \frac{2}{3} + \frac{c_{AB} - 466}{201} \right]$$

$$ii) \quad \beta(c_{AB}) = 466 + 67 \times \left[\frac{2}{3} + \frac{2}{3} \times \left(\frac{c_{AB} - 466}{67} \right) \right] = 200 + \frac{2}{3} c_{AB}$$