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Abstract

It is commonly observed in practices that prime contractors solicit subcontract bids, prior to submitting their bids in procurement auctions: the auctioneers in subcontract auctions will become bidders in a procurement auction. This point is remarkably different from the standard theory of procurement auction. We presented a simple model of such subcontract auctions and conducted a laboratory experiment to examine the bidding behavior derived theoretically. We observed that in the subcontract auction, (1) subjects bid following the equilibrium bidding function derived theoretically, (2) the revenue equivalence between first-price and second-price mechanisms breaks down, and (3) the first-price mechanism more likely achieves *ex post* efficient allocations than the second-price mechanism.

JEL Classification Numbers: C91, D44, D82

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1 Introduction

It is commonly observed in practices that, to make lower bids in procurement auctions, prime contractors solicit bids and make subcontract agreements with the agents who can complete subcontractable works with lower costs than the prime contractors do by themselves. Accordingly, the auctioneers in the "upstream" subcontract auctions will become bidders in a "downstream" procurement auction. This point is remarkably different from the standard theory of procurement auctions. (See, e.g., Rezende (2009) and references therein.) This paper casts light on how subcontractors behave in such a subcontract auction in order not only to learn about their bidding behavior but also to draw relevant policy implications towards practical procurement auctions.

We first present a simple model of subcontract bidding based on Nakabayashi (2009). It is, however, extremely difficult to collect a complete set of field data of subcontract bids in many countries: the results of procurement auctions are publicly opened to observe, whereas in subcontract auctions few agents can observe actual bids. So, by using the data obtained by the laboratory experiment, we next examine some theoretical predictions statistically.

In our model, there are two prime contractors competing for a procurement. Before the procurement auction, each prime contractor solicits bids from two subcontractors. These subcontractors cannot submit their bids to the other prime contractor. So, there are four subcontractors in total. Each subcontractor knows his or her own cost for completing the subcontract work, but no one else can observe it. In each subcontract auction, only the auctioneer and bidders can observe bids, and the lowest bidder makes a subcontract agreement with the prime contractor. If the prime contractor wins the procurement, then the subcontractor obtains the subcontract work and is paid by the prime contractor. Otherwise, the subcontractor obtains nothing.

The main observation in our experiment is as follows. (1) In the subcontract auction with the first-price mechanism, subjects bid following the equilibrium bidding function derived from our theoretical model, and the second price mechanism successfully induced the bidders' truth-telling of their cost for the subcontract work. (2) The revenue equivalence between first-price and second-price mechanisms breaks down even under the independent private value (IPV) environment, because of the aggressive bidding in the case of a first-price mechanism. (3) The first-price mechanism more likely achieves *ex post* efficient allocations than the second-price mechanism.

The above observation (1) implies that our model captures the bidding behavior in the subcontract auctions. The observations (2) and (3) are both matched with theoretical predictions. The observation (3) in particular suggests that prime contractors should employ the first-price mechanism for the subcontract auction, which is recommended also from the viewpoint of the social welfare maximization.

We assume in this paper that the prime contractors' costs for completing non-subcontractable works are all normalized as zero. Prime contractors are faced with positive amounts of those costs in practices. This situation is, however, so complicated that each subcontractor needs to estimate those costs of all prime contractors in order to decide his or her subcontract bid, while taking into account information about the costs of all subcontractors: even if a subcontractor wins a subcontract agreement with a prime contractor, he or she is paid nothing unless the prime contractor wins in a procurement auction. So, as the first step of this research strand on subcontract auctions, we simplify the situation by assuming that those costs are zero, and examine whether or not subjects in the experiment can infer the optimal bidding strategies.

We further assume in our model that any collusive arrangements are not allowed in both subcontract and procurement auctions. It is sometimes reported in practices that procurement officials use their discretion to decide which firms are qualified to submit bids. In this case, bidders may offer to those officers pecuniary incentives or well-paid private-sector employment after retirement. In our experiment, however, there is no possibility of corruption, because the computer program always selects the lowest bidders as winners in any auctions.

Collusive bidding is possible in practices, particularly when the auctions are repeatedly conducted. (See, e.g., Aoyagi, M (2003) for more detail.) Limiting number of bidders can also breed collusive bidding by alleviating competition. Accordingly, our experiment is carefully designed so that subjects are supposed to be faced with one-shot auctions; we draw dice to determine the role of each subject at the beginning of each sequence of subcontract auctions and the subsequent procurement auction, and thus each subject cannot identify which role a particular subject is playing as. Moreover, it is impossible for every subject to communicate with any other subjects during our experiment.

The remaining part of this paper is organized as follows. Sect. 2 describes our model of procurement auctions with pre-award subcontracting and provides some theoretical predictions. Sect. 3 explains the experiment procedures. Sect. 4 discusses the experiment results. Sect. 5 concludes this paper showing some future research. The instruction of the experiment is given in the Appendix B.

2 Theoretical Predictions

Consider a situation where a procurement buyer solicits bids for a project from two prime contractors (PCs), each of which is indexed by $i = 1, 2$. In practices, the project consists of subcontractable works and non-subcontractable ones. In this paper, for simplicity, there is only one subcontractable work for the project. Prior to submitting a bid in the procurement auction, each PC holds a subcontract auction by soliciting bids from two subcontractors (SCs) which can complete the subcontract work. Let $\mathrm{SC}_i = \{\mathrm{SC}_{i,1}, \mathrm{SC}_{i,2}\}$ denote the set of SCs from which PC_i solicits bids in the subcontract auction. We assume that SC_1 and SC_2 are disjoint; neither $\mathrm{SC}_{i,1}$ nor $\mathrm{S}_{\mathrm{i},2}$ is allowed to submit his or her bid to PC j, where $i \neq j$.

Given the order of decision making as above, a subcontract auction is hereafter called an upstream auction, and a procurement auction is called a downstream auction. Let $t_{i,j}$ stand for the $\mathrm{SC}_{i,j}$'s cost for completing the subcontract work. We assume that, for all i and all j, $t_{i,j}$ is independently and uniformly distributed over $[\underline{t}, \bar{t}]$. For both PCs, the lowest cost for completing the subcontract work is $\bar{t}$, and thus they make subcontract arrangement with a subcontractor. As explained in Sect.1. the cost for completing the non-contractible work is normalized to zero for simplicity. Upon solicitation of bids by PC_i, $\mathrm{SC}_{i,j}$ draws $t_{i,j}$ and submits a bid $s_{i,j}$ in the upstream auction. Collusive bidding is prohibited.

Each SC knows his or her own cost for completing the subcontract work, but no one else can observe it. In each sealed-bid subcontract auction, only the auctioneer and bidders can observe bids, and the lowest bidder makes a subcontract agreement with the prime contractor. If the prime contractor wins the procurement, then the SC obtains the subcontract work and paid by the prime contractor. Otherwise, the SC obtains nothing and no amount of money is paid to him or her.

Let p_i be the *conditional* subcontract payment PC i makes to the winning SC in the upstream auction. The payment is conditional because it is paid if the PC i actually wins in the downstream auction. For simplicity, we assume that the mechanism of the upstream auctions is given and either the first- or the second-price sealed-bid mechanism. Thus, p_i equals the lowest bid in the upstream auction if the first-price mechanism is used in the upstream auction, while p_i is the second-lowest bid if the second-price mechanism is used. Furthermore, we assume that each PC sets a reservation price equal to $\bar{t}$ in the upstream auction. Hence, the lowest-bid SC will be selected as a winning SC if his bid is equal to or below $\bar{t}$, and the PC performs the subcontractable work for himself otherwise. Since no other payment than p_i has to be made, PC i's cost is characterized as $c_i = \min\{\bar{t}, p_i\}$.

Given c_i, PC i submits a sealed-bid b_i in the downstream auction which is undertaken with the first-price mechanism. Let $V > \bar{t}$ be the value of the project to the procurement buyer. We assume that the procurement buyer sets a reservation price equal to $\bar{t}$ in the downstream auction. Hence, the lowest-bid PC will be awarded and receive a payment equal to his bid if the bid is equal to or below $\bar{t}$.

Throughout this paper, we assume private values. The $\mathrm{SC}_{i,j}$'s cost $t_{i,j}$ is known only to $\mathrm{SC}_{i,j}$. Furthermore, the PC i's cost c_i is known only to PC i (and possibly the

SCs who bid for PC_i), but not to any other agents in the game including the opponent PCs.

In this setting, a dominant strategy for each SC in upstream auctions is to submit $s_{i,j} = t_{i,j}$ if the second-price mechanism is used in upstream auctions.[1] In contrast, no dominant strategy exists in upstream auctions if the first-price auction is used. Instead, a symmetric increasing equilibrium bidding function in upstream auctions can be characterized as follows. Suppose that all SCs other than $SC_{i,j}$ follow an increasing bidding function $\sigma : t \to s$ where $t \geq 0$ and $s \geq 0$ are the SC's cost and bid. Suppose also that all PCs follow a symmetric increasing bidding function in the downstream auction. Then, $SC_{i,j}$ wins if and only if his subcontract bid $s_{i,j}$ is the lowest among all four SCs'. Hence, his maximization problem is given by

$$\max_{s_{i,j}} (s_{i,j} - t_{i,j}) \left[1 - \sigma^{-1}(s_{i,j})\right]^3 . \tag{1}$$

This implies that in the symmetric equilibrium SC will bid as if he competes in a procurement auction with 4 bidders. To see this, we take the derivative with respect to $s_{i,j}$ and replace $\sigma^{-1}(s_{i,j}) = t_{i,j}$. Then, we have the first-order condition $(1 - t_{i,j})^3 \sigma'(t_{i,j}) - 3(1 - t_{i,j})^2 \sigma(t_{i,j}) = t_{i,j} [1 - t_{i,j}]^2$. Solving the differential equation for $s_{i,j}$ yields the SC's equilibrium bidding function as[2]

$$\sigma(t_i|\text{With DC}) = t_i + \frac{\bar{t} - t_i}{4}. \tag{2}$$

The symmetric equilibrium bidding function in the standard (no downstream competition) procurement auction with two bidders is given by

$$\sigma(t_i|\text{Without DC}) = t_i + \frac{\bar{t} - t_i}{2}. \tag{3}$$

These illustrate that only the first-price auction induces SCs to bid more aggressively, *i.e.,* bid lower prices, as the downstream competition becomes more intense. Because of the aggressive bidding, revenue equivalence between the first- and second-price mechanisms breaks down in the upstream auction.

As for efficiency, the first-price mechanism in upstream auctions always leads to an *ex post* efficient allocation, whereas the second-price mechanism may not. To illustrate, consider the case in which the realized private signals satisfy $t_{1,1} < t_{2,1} < t_{2,2} < t_{1,2}$. In

[1] In this setting, revenue equivalence holds between English (ascending) auction and Vickery (second-price sealed-bid) auction. Revenue equivalence in these two second-price mechanisms breaks down in more general cases. See, for example, Chew and Nishimura (2003) for more detail.

[2] The equilibrium bidding strategy in the upstream auction with the case in which the signal is drawn from a general probability distribution is shown in Nakabayashi (2009).

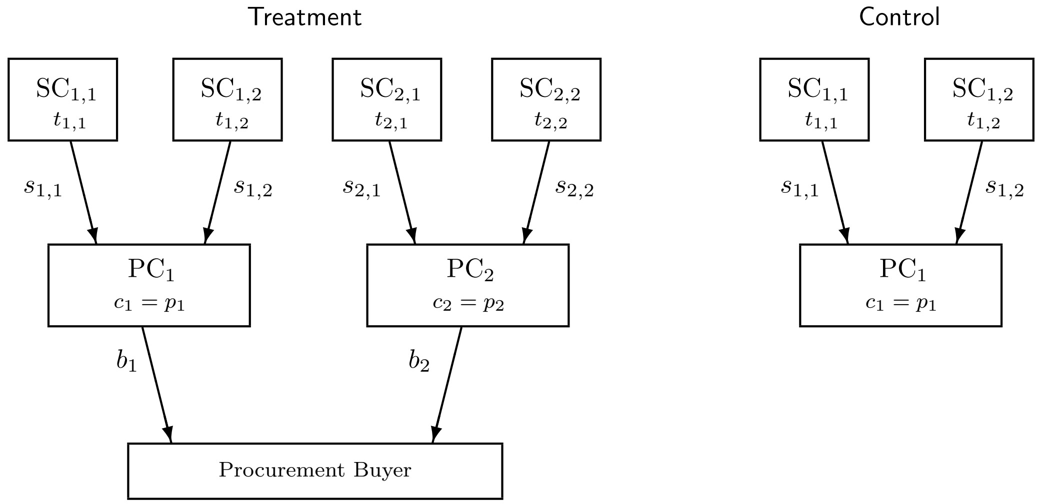

Figure 1: Experimental design

this case, $SC_{1,1}$ receives the subcontract if the first-price mechanism is used; however, if the second-price mechanism is used, the cost of PC_1 is $t_{1,2}$ which is greater than the cost of PC_2, which is equal to $t_{2,2}$. Therefore, the most efficient SC may not obtain the subcontract due to the loss of his PC if the second-price auction is used in upstream auctions.

Theoretically, the *ex ante* probability with which an inefficient allocation occurs under the second-price mechanism 1/3. Let t_α denote the cost of the SC who actually receives the subcontracted work. If we measure efficiency by computing the ratio of the actual surplus of the allocation obtained by $V - t_\alpha$ to the maximum possible surplus $V - \min\{t_{1,1}, t_{1,2}, t_{2,1}, t_{2,2}\}$, the dead weight loss created by the second-price mechanism in upstream competitions is 8.3 percent[3] in expectation.

3 The Experiment Procedures

Our experiment consists of six sessions. Thirty six subjects of undergraduate freshman students are split into six groups and each session uses one group. There is no previous research on subcontract auctions, and thus subject's behavior is unpredictable. To conduct detailed analysis on experimental observations, this research adopts the treatment in which two PCs compete in the downstream auction in comparison with the control in which there is a single PC (no downstream competition) as shown in Fig. 1.

Each experimental session is divided into three subsessions. Subsession 1 is a controlled experiment; two subjects out of six are chosen as an SC to compete for a

[3]See the Appendix for how to obtain the value.

	# of PC(s)	PC(s) played by machine ?	# of SCs per PC	# of subcont. auctions	# of periods	# of subj. used per period
Subsession 1	1	Yes	2	20	10	4
Subsession 2	2	Yes	2	10	10	4
Subsession 3	2	No	2	20	20	6
Subsession G1	2	Yes	3	10	10	6
Subsession G2	3	Yes	2	10	10	6

Subcont. auction mechanism	Showup fee (JPY)	Earned point to JPY ratio	Number of subjects	Experiment date	Mean earnings (JPY)
First-price	1,000	.2	6	Jan. 28, 2010	1,318
Second-price	1,000	.2	6	Jan. 28, 2010	1,599
First-price	3,500	1	6	Feb. 6, 2010	5,485
Second-price	3,500	1	6	Feb. 6, 2010	5,899
First-price	3,500	1	6	Feb. 7, 2010	4,927
Second-price	3,500	1	6	Feb. 7, 2010	6,335
First-price*1	1,500	1	6	Mar. 26, 2010	2,185
Second-price*1	1,500	1	6	Mar. 26, 2010	2,154
First-price*2	1,500	1	6	Sep. 24, 2010	2,976

Note: *1: Subsession (SS) 2 is conducted, followed by SS G1 and by SS G2.
*2: SS 2 is conducted, followed by SS 3 and by SS 1.
Downstream competition is always undertaken with the first-price auction.

Table 1: Features of experimental treatments

subcontract from a PC who has already been received a construction project at a price equal to 2000. Each subject draws a production cost that is known only to him from a uniform distribution on $[1000, 2000]$ that is known publicly. Then, subjects place a sealed-bid on the computer screen and earn payoff if their bid is lower. The subject's payoff is calculated based on the mechanism (first-price or second-price) of upstream auctions which is given and announced by the experimenters. The remaining nineteen projects are auctioned in the same manner. Two projects are undertaken in a period so that there are ten periods in Subsession 1.

In Subsession 2, a procurement buyer auctions off a procurement contract for which the procurement buyer sets a reservation price equal to 2000. In this downstream auction, two computer-played PCs are solicited. Prior to bidding, each PC randomly chooses two subjects as SCs. Note that the subjects chosen by a PC are different from those chosen by another PC so that four subjects in total are chosen in a period. Similar to Subsession 1, selected subjects draw private information from the same uniform distribution and submit a bid to a PC. Following an auction mechanism *i.e.* the first-price or second-price sealed-bid auction, which is preliminarily and publicly announced by the experimenters, a computer-played PC selects an SC who submits a lower bid in the upstream auction and decides the subcontract payment. In other words, the cost of the PC to complete the construction project is exactly the same as the subcontract payment. Given the production cost that is unknown to both the procurement buyer and the competitor, the computer-played PC submits a bid in the downstream procurement auction. The bidding strategy the computer-played PC follows is the risk-neutral Nash equilibrium strategy provided that the SCs follow (2). The remaining nine projects are auctioned in the same manner for nine periods.

Subsession 3 is the same as Subsession 2 except that PCs are played by subjects. In each period, four subjects are randomly chosen as SCs and remaining two are as PCs. Although PCs are played by subjects, their action space is restricted on submitting a bid in the downstream auction. That is, the computer program chooses the lowest bidder in the upstream auction as the SC and makes the subcontract payment according to the given auction mechanism of the upstream competition.

Other subsessions are conducted in a control experiment in order to check whether the theoretical prediction holds even in more general cases. In subsession G1, the number of PCs is three and each PC solicits 2 SCs in the upstream auction while in Subsession G2, the number of PCs is two and each PC solicits 3 SCs in the upstream auction.

The minimum unit of sealed-bids subjects can type on the computer is ¥1. Each subject have an initial balance of either ¥1,000 or ¥3,500. Subjects who lose more than the amount of the initial endowment will be bankrupt although nobody got bankrupt in this experiment.

Since subjects randomly selected as a PC or an SC in each round, they have no idea about whom they compete with in both up- and downstream competitions. This is expected to help deterring the subject's incentive to collude.

At this time, a computer program makes a bid on behalf of each potential PC so that it maximizes the potential PC's expected profit, given the amount the PC has to pay to its SC. We assume that the PC does not do any on the public construction project; all of the work is done by the SC. So, the cost of a public construction project for the PC is just the expenses it pays to the SC. So, the points for the PC is the difference between the amount received from the government and the payment to the SC. At last the payment to the SC is made by the PC who wins the project. The payment received by a subject is counted for the sum of the total points the subject earns in the experimental session plus the showup fee.

4 The Experimental Results

4.1 Overview

Fig. 2 and 3 plot subject' bids and costs in upstream auctions which take place, respectively, with the forms of the first- and the second-price mechanisms. Fig. 2 illustrates that, in the upstream auction with the first-price mechanism, markups (differences between bids and costs) are larger in Subsession 1 (no downstream competition) than in other subsessions (a downstream competition between 2 PCs). In contrast, Fig. 3 show that if the second-price mechanism is used in upstream auctions, subjects tend to bid truthfully regardless of the situation in the downstream competition.

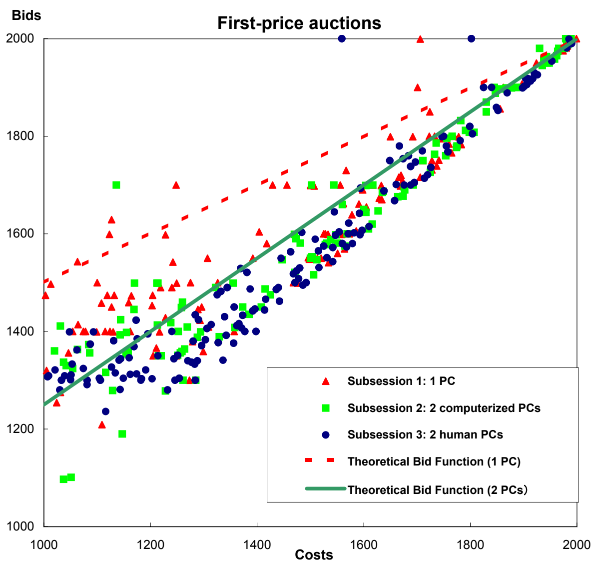

Figure 2: First-price auctions

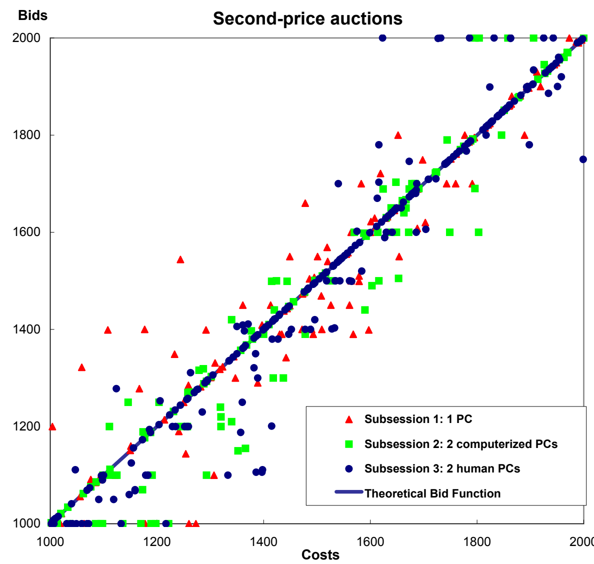

Figure 3: Second-price auctions

		FPA			SPA		
	Subsession No.	1	2	3	1	2	3
Average	Bids	1,592	1,583	1,548	1,461	1,436	1,506
	Costs	1,446	1,498	1,457	1,491	1,480	1,536
	Markups	146	84	91	-31	-44	-30
Variance	Bids	32,831	53,707	46,466	88,479	111,809	91,446
	Costs	76,975	86,291	74,161	78,914	87,992	77,271
	Markups	18,116	8,626	8,240	5,781	7,085	4,388
Observations		80	80	160	80	80	160

Table 2: Descriptive statistics

Table 2 reports the descriptive statistics of the results. The third row shows that the average markups drop significantly in Subsession 2 and 3 (84 and 91, respectively) from that in Subsession 1 (146) if the first-price mechanism is used in upstream auctions. On the other hand, the average markups are almost the same between Subsession 1 and Subsession 2 and 3 (Subsession 1: -31, 2: -44, and 3: -30).

Another statistical analysis also supports this evidence. Table 3 reports the Welch's t-test statistics which examine whether the means of bids, costs and markups are different between the paired subsessions described on the first column. These show that the means of the markups in upstream auctions are lower with statistical significance in subsession 2 (t-value: 3.360) and 3 (t-value: 3.027) than in Subsession 1 if (and only if) the first-price mechanism is used in upstream auctions. The results suggest that, as theoretical model predicts, subjects bid aggressively in upstream auctions taking into account the increase in the downstream competition if the first-price mechanism is used in upstream subcontract auctions.

	First-price			Second-price		
	Bids	Costs	Markups	Bids	Costs	Markups
Subsession 1 vs. 2	-1.150	0.300	3.360**	0.179	0.349	0.729
Subsession 2 vs. 3	1.083	1.153	-0.522	-1.026	-1.163	-1.003
Subsession 3 vs. 1	0.280	-1.596	-3.027**	0.831	0.788	0.076

Note: Null hypothesis that the paired subsessions have the same mean is rejected with * significant level at 5%; ** significant at 1%

Table 3: Two sample t-test

For more qualitative analyses, we implement OLS and fixed effect (FE) regression methods. Observed bids are regressed on costs, and FE controls for subject heterogeneity. The result is reported in Table 4. It shows that the aggressive bids initiated by the downstream competition are observed only in the upstream auctions held with the first-price mechanism. Regression (1) and (2) show that the observed bids in Subsession 2 and 3 are 38.89 and 50.82 lower on average than those in Subsession 1 if the first-price mechanism is used in upstream auctions. In contrast, Regression (3) and (4) have no statistically significant dummies for Subsession 2 and 3.

Finally, the descriptive statistics of bids and costs for each of 18 subjects used in our experiment are available in Table 5 and 6.

4.2 Aggressive bids in first-price mechanisms

Throughout the experiment sessions, we observe the first-price mechanism induces aggressive bids in upstream auctions. Regression (5) through (7) and (8) through (10) in Table 7 are the results of OLS regressions conducted separately for each experiment session,[4] which is conducted with its unique subject group. Subsession 2 and 3 dummies are insignificant in all experiment sessions when upstream auctions are held

[4]Day 1 experimental session is conducted on conducted on January 28th, 2010, Day 2 session is on February 6th, 2010, and Day 3 is on February 7th. In each day, we run two sessions; i) the session in which the first-price mechanism is used for upstream auctions, and ii) the second-price mechanism is used for upstream auctions. The payment scheme in each day session is shown in Table 1.

	(1)	(2)	(3)	(4)
	First-price		Second-price	
	OLS	FE	OLS	FE
Cost	0.7**	0.7014**	1.03**	1.03**
	(60.28)	(63.95)	(80.79)	(98.91)
Subsession 2 dummy	-38.89**	-41.23**	-16.66	-11.24
	(4.21)	(4.73)	(-1.67)	(-1.4)
Subsession 3 dummy	-50.82**	-53.02**	-5.76	-2.90
	(6.36)	(7.04)	(-0.67)	(-0.42)
Constant	586.10**	585.58**	-52.154*	-49.182*
	(32.31)	(32.53)	(-2.56)	(-2.44)
Observations	480	480	480	480
R-squared	0.89	-	0.93	-
No. subject IDs	-	18	-	18

Note: Absolute value of t-statistics in parentheses;
* significant at 5%; ** significant at 1%
Subject ID is taken as fixed effect in regression (2) and (4).

Table 4: Regression result for bids and costs 1

with the second-price mechanism, and except for Subsession 2 in Day 1, these dummies in all experiment sessions exhibit a statistical significance if the first-price auction is used in upstream competitions. These indicate that, regardless of groups and payment schemes, subjects in an upstream auction recognize the intensity of the downstream competition and respond the change of the competitive environment as predicted by the theoretical model.

Because of the aggressive subcontract bids, the revenue equivalence fails in upstream auctions. Table 8 shows that the costs of PCs are 10 percent lower on average if the first-price auction is used in upstream competition than if the second-price auction is used.

4.3 Overbidding in the second-price mechanism

As shown in Section 2, truth-telling is a weakly dominant strategy for SCs in upstream auctions held with the second-price mechanism regardless of their risk attitudes and the intensity of the downstream competition. Nevertheless, subjects in upstream auctions frequently bid below their costs as illustrated in Fig. 3. It is also noteworthy that the "overbids" are observed regardless of the intensity of the downstream competition.

Furthermore, overbids are continuously observed regardless of whether PCs are computerized or played by subjects. Table 3 reports the difference of mean markups between Subsession 2 and 3 is statistically insignificant. This evidence may shed light

Subject ID	1	2	3	4	5	6	7	8	9
Cost	0.7508**	0.7053**	0.8198**	0.8484**	0.8731**	0.6814**	0.6974**	0.6521**	0.7190**
	(13.81)	(18.28)	(16.27)	(9.81)	(9.53)	(35)	(18.95)	(12.89)	(8.8)
Subsession 2 dummy	-66.3807†	-30.9366	-69.2456†	-154.456**	-53.3512	-35.863*	12.3755	-73.0283*	-77.5159
	(-1.92)	(-1.29)	(-2.03)	(-3.08)	(-0.88)	(-2.50)	(0.46)	(-2.13)	(-1.31)
Subsession 3 dummy	-4.4841	-35.0349	-84.0447*	-128.068*	4.6802	-69.7916**	2.2465	-113.157**	-106.261
	(-0.12)	(-1.35)	(-2.82)	(-2.60)	(0.08)	(-4.81)	(0.09)	(-3.23)	(-1.73)
Constant	453.6981**	564.1471**	402.3877**	411.3615**	297.8266*	651.9299**	544.5605**	665.2329**	603.6409**
	(4.99)	(8.83)	(5.61)	(3.31)	(2)	(22.65)	(9.54)	(8.06)	(5.76)
Observations	20	26	18	17	21	18	24	22	17
R-squared	0.93	0.95	0.96	0.88	0.84	0.99	0.95	0.92	0.87

Note: Absolute value of *t*-statistics in parentheses, † significant at 10%; * significant at 5%; ** significant at 1%

	10	11	12	13	14	15	16	17	18
Cost	0.7321**	0.6312**	0.7554**	0.6898**	0.6957**	0.7225**	0.8129**	0.5435**	0.5854
	(15.69)	(9.86)	(18.96)	(13.72)	(21.01)	(20.97)	(15.06)	(5.75)	(8.83)
Subsession 2 dummy	-72.631**	-59.5574	63.8519*	-79.8105†	-32.7227	24.4083	-6.3647	-3.0319	-30.8003
	(-2.94)	(-1.22)	(2.19)	(-2.11)	(-1.26)	(1.04)	(-0.23)	(-0.06)	(-0.69)
Subsession 3 dummy	-78.4707**	-88.8808†	46.055	-100.738*	-49.7609†	-27.1427	101.7514*	-127.357*	-82.8041†
	(-3.11)	(-1.91)	(1.47)	(-2.36)	(-2.02)	(-1.26)	(2.54)	(-2.40)	(-2.07)
Constant	583.6617**	710.9265**	399.9216**	638.7810**	621.2752**	502.2879**	353.6076**	891.0282**	799.5253**
	(9.19)	(7.95)	(6.37)	(8.35)	(12.47)	(9.6)	(3.86)	(6.21)	(8.1)
Observations	21	19	17	17	23	18	22	22	18
R-squared	0.94	0.87	0.97	0.94	0.96	0.97	0.95	0.7	0.86

Note: Absolute value of *t*-statistics in parentheses, † significant at 10%; * significant at 5%; ** significant at 1%

Table 5: Each subjects in first-price upstream auctions

	1	2	3	4	5	6	7	8	9
Cost	1.0847**	1.0447**	0.9803**	1.1588**	1.0000**	0.9901**	1.0447**	0.9894**	1.1573**
	(27.34)	(15.59)	(34.09)	(25.36)	(.)	(35.26)	(19.17)	(18.65)	(18.18)
Subsession 2 dummy	-64.6784†	-75.3185	70.4701**	29.3833	0	-18.7174	26.7783	-66.0274†	34.2005
	(-1.99)	(-1.41)	(3.18)**	(0.77)	(.)	(-0.98)	(0.58)	(-1.83)	(0.88)
Subsession 3 dummy	-29.2049	-101.686*	93.2345**	-0.0524	0	14.8787	21.935	-36.5959	34.6084
	(-1.01)	(-2.25)	(4.64)	(0)	(.)	(0.88)	(0.59)	(-1.17)	(0.98)
Constant	-132.846*	-128.919	-67.7436	-268.288**	0	-50.5447	-63.4697	15.0233	-283.945**
	(-2.23)	(-1.21)	(-1.64)	(-3.33)	(.)	(-1.19)	(-0.76)	(0.17)	(-2.83)
Observations	30	26	27	31	23	23	27	27	28
R-squared	0.97	0.92	0.99	0.96	1	0.99	0.95	0.94	0.93

Note: Absolute value of *t*-statistics in parentheses, † significant at 10%; * significant at 5%; ** significant at 1%

	10	11	12	13	14	15	16	17	18
Cost	1.0243**	1.0074**	1.0084**	0.9918**	0.9717**	0.9983**	0.9728**	1.0730**	0.9642
	(29.84)	(210.56)	(226.96)	(153.83)	(32.45)	(15.24)	(84.75)	(20.74)	(36.29)
Subsession 2 dummy	9.5282	-3.311	-5.2028	-17.7103**	-38.6731	-110.744*	11.6079†	67.3693	-6.2779
	(0.32)	(-0.95)	(-1.31)	(-4.15)	(-1.57)	(-2.12)	(1.8)	(1.58)	(-0.33)
Subsession 3 dummy	46.1905	0.5843	-5.1481†	-20.0374**	-16.9798	-54.0736	-9.1776	110.1054**	-40.4766*
	(1.62)	(0.21)	(-1.81)	(-5.97)	(-0.87)	(-1.25)	(-1.49)	(2.95)	(-2.27)
Constant	-144.638*	-12.1677	-7.9444	32.2414**	108.9002*	116.3042	50.4509*	-158.158	97.7049*
	(-2.54)	(-1.48)	(-1.14)	(3.22)	(2.49)	(1.16)	(2.68)	(-1.71)	(2.15)
Observations	29	29	20	30	26	32	21	25	26
R-squared	0.97	1	1	1	0.98	0.9	1	0.96	0.99

Note: Absolute value of *t*-statistics in parentheses, † significant at 10%; * significant at 5%; ** significant at 1%

Table 6: Each subjects in second-price upstream auctions

	(5)	(6)	(7)	(8)	(9)	(10)
		First-price			Second-price	
Session No.	1	3	5	2	4	6
Cost	0.67**	0.68**	0.77**	0.98**	1.05**	1.07**
	(32.58)	(39.12)	(36.05)	(50.49)	(54.32)	(51.55)
Subsession 2 dummy	-22.38	-38.90**	-53.41**	-26.94	-11.63	-14.05
	(-1.35)	(2.72)	(3.38)	(-1.87)	(-0.78)	(-0.82)
Subsession 3 dummy	-49.43**	-48.59**	-51.90**	-17.75	8.71	-13.03
	(3.46)	(3.93)	(3.78)	(-1.42)	(0.68)	(-0.88)
Constant	648.17**	613.54**	474.96**	80.99**	-98.64**	-145.94**
	(19.99)	(23.46)	(14.03)	(2.62)	(-3.15)	(-4.47)
Observations	160	160	160	160	160	160
R-squared	0.88	0.91	0.90	0.94	0.95	0.95

Note: Absolute value of *t*-statistics in parentheses * significant at 5%; ** significant at 1%

Table 7: Regression result for bids and costs 2

Subcont. Auc. Form	Mean	S.D.	Median	Max	Min
1st-price	1595.366	237.884	1555.5	2000	1100
2nd-price	1740.758	242.024	1788.5	2000	1002
Total	1668.062	250.595	1659.5	2000	1002

Table 8: Costs of PCs

on the theoretical explanation for overbidding in second-price auctions.

There are a group of studies which attempt to explain overbidding in second-price auctions theoretically (*e.g.*, Morgan, Steiglitz and Reis' (2003)). A majority of these studies assume that bidders have the non-standard preferences, which are broadly categorized into either *spite* or *joy of winning*.

In Subsession 3 of our experiment, three subjects form a team in which one plays a PC and remainders play SCs to compete with another team. A team, on the other hand, consists of two SC subjects in Subsession 2. Hence, in subsession 3, a lower subcontract bid is a spite to the opponent SC but, at the same time, is a goodwill to the PC subject since the PC subject will have more cost advantage in the downstream competition. In contrast, no goodwill effect exists in a lower subcontract bid in Subsession 2 where PCs are computerized. If SC subjects not only care about the payoff of the rival SC but also about the payoff of the PC subject, subcontract bids should be higher in Subsession 3 than in Subsession 2. However, we do not observe any difference in subcontract bids in between Subsession 2 and 3. From this evidence, overbids are in general attributed more plausibly to *joy of winning*.

4.4 Efficiency

Our laboratory data show that the first-price mechanism in upstream auctions contributes more likely to the realization of an *ex post* efficient allocation. To measure allocative efficiency, we use the ratio between the sample mean of realized social surplus (the social value of the project minus the cost of the awarded SC) and the sample mean of maximum-possible social surplus (the social value of the project minus the production cost of the lowest SC). All the descriptive statistics are reported in Table 9. The numerator of the ratio is denoted by (A) and the denominator is denoted by (B).

		Social Surplus Realized (A)	Social Surplus Maximum (B)	(A)/(B)	Variance of (A)/(B)	t-statistics FPA vs. SPA
FPA	Subsession 1	671.9	699.2	96.1%	0.84%	2.4885**
	Subsession 2	778.9	798.6	97.5%	0.25%	1.9914*
	Subsession 3	792.8	820.9	96.6%	0.54%	3.7110**
SPA	Subsession 1	673.1	677.9	99.3%	0.14%	
	Subsession 2	772.8	835.9	92.4%	1.72%	
	Subsession 3	660.0	755.3	87.4%	3.64%	

* significant at 5%; ** significant at 1%

Table 9: Efficiency

Two-sample t-test statistics in the table compare efficiency between the first- and the second-price auction in upstream auctions for each subsession. It is shown that the first-price mechanism improves efficiency with 1 percent significant level for Subsession 1 and 3 and 5 percent significant level for Subsession 2. In addition, Table 10 describing the ratio for each experimental session and for each subsession reports that the first-price mechanism in Subsession 2 and 3 always yields higher efficiency than the second-price mechanism (*e.g.*, 97.4 percent vs. 93.2 percent in Subsession 2 on Day 1). On the other hand, there is no such tendency in Subsession 1. The efficiency in Subsession 1 on Day 1 under the first-price auctions is approximately 6 percent lower than that under the second-price auctions while on Day 2 that is approximately 7 percent higher under the first-price auctions.

4.5 Risk Attitude

Although observed subjects' strategies are off the theoretical bidding functions, the discrepancy can be well-explained by the subject's risk attitude. As presented in Cox,

	First-price			Second-price		
Session No.	1	3	5	2	4	6
Subsession 1	93.2%	99.1%	95.8%	98.2%	92.6%	99.6%
Subsession 2	97.4%	98.7%	96.6%	93.2%	92.0%	92.2%
Subsession 3	97.3%	95.6%	96.8%	92.6%	89.3%	80.6%

Table 10: Efficiency rate for each experiment session

Smith, and Walker (1982), bidders bid more aggressively as they are more risk-averse. Suppose the bidder i's utility function is expressed as a power function:

$$U_i(y) = y^{r_i},$$

where y is the experimental payoff and $(1-r_i)$ represents the Arrow-Pratt measurement of constant relative risk aversion. Then, (2) becomes [5]

$$b_i = t_i + \frac{\bar{t} - t_i}{4} r_i.$$

whereas (3) becomes

$$b_i = t_i + \frac{\bar{t} - t_i}{2} r_i.$$

These imply that both strategies move toward the 45 degree line although these are never coincident with each other. In other words, regardless of the SC's risk attitude, the aggressive bidding caused by the downstream competition will be observed only in the case where the first-price auction is used in the upstream competition.

Our experimental result was fully consistent with such theoretical prediction. The mean value of r obtained in our data was 0.76 with the standard deviation is .010, indicating that subjects are risk averse. Nevertheless, they tend to bid lower prices in the upstream first-price auction if there is a downstream competition. We thus conclude that risk attitude is not the cause of the aggressive bidding in the upstream auction.

4.6 Unserious Subjects

For subjects to be serious throughout the session, some experiments for auctions introduce the procedure in which the subject's actual earning is the sum of the payoffs earned in some limited rounds which have randomly chosen by the computer. Subjects are informed of the randomization but do not know which rounds are chosen. We do not, however, employ such a random payment procedure for the following reason. In

[5] See Cox, Smith, and Walker (1982) for more detail.

our experiment subjects are randomly assigned to be an SC or to have a rest. Therefore, they do not know how many times they will be able to submit a subcontract bid at any period in every session. This design helps them play seriously in every period.

In fact, we have no evidence that subjects' bidding behavior changes significantly through subsessions. Regression (11) through (16) in Table 11 are conducted to compare the subjects' bidding behaviors in the first- vs. the last-half periods. The fact that the "first-half" dummies are statistically insignificant in five out of six regressions suggests that subjects behave the same in between the first and the last half rounds in most subsessions.

	(11)	(12)	(13)	(14)	(15)	(16)
	First-price			Second-price		
Subsession No.	1	2	3	1	2	3
Cost	0.59**	0.74**	0.73**	0.96**	1.06**	1.05**
	(22.12)	(33.98)	(49.12)	(33.47)	(43.31)	(62.67)
First-half auc. dummy	-33.88*	-3.14	1.96	29.6	-14.8	-17.4
	(-2.31)	(-0.25)	(0.24)	(1.84)	(-1.07)	(-1.91)
Constant	759.5**	490.5**	495.2**	37.54	-102.9*	-83.05**
	(18.42)	(14.43)	(22.37)	(0.86)	(-2.82)	(-21.62)
Observations	120	120	240	120	120	240
R-squared	0.81	0.91	0.91	0.91	0.94	0.94

Note: Absolute value of t-statistics in parentheses
* significant at 5%; ** significant at 1%

Table 11: Comparison between the first- and last- half rounds

It is thus hardly concluded that subjects turn to be less serious to play in our experiment as sessions go on due to a sufficiently large amount of showup fees or to the lack of the random payment procedure.

4.7 More PCs or more SCs

Aggressive subcontract bids as a result of the increased downstream competition are observed in more generalized settings. We conduct a supplemental experimental session which begins with the control subsession where 2 PCs bid in the downstream auction in 10 rounds and each PCs solicits 2 SCs in the upstream auction. Then, in the next treatment subsession (Subsession G1), the number of PCs is raised to three keeping other things constant. In the final control subsession (Subsession G2), the number of

PC's costs

Subsession 2,3			
mechanism	mean	N	sd
First-price	1,439.1	180	153.47
Second-price	1,655.8	180	250.14
Total	1,547.4	360	233.92

Subsession 2			
mechanism	mean	N	sd
First-price	1,459.8	60	176.31
Second-price	1,618.2	60	264.88
Total	1,539.0	120	237.74

Subsession 3			
mechanism	mean	N	sd
First-price	1,428.7	120	140.33
Second-price	1,674.6	120	241.38
Total	1,551.7	240	232.37

PC's profit

Subsession 2, 3			
mechanism	mean	N	sd
First-price	147.21	90	77.20
Second-price	163.07	90	111.04
Total	155.14	180	95.69

Subsession 2			
mechanism	mean	N	sd
First-price	211.77	30	36.51
Second-price	178.20	30	72.15
Total	194.98	60	59.16

Subsession 3			
mechanism	mean	N	sd
First-price	114.93	60	71.80
Second-price	155.50	60	125.96
Total	135.22	120	104.10

Table 12: Mean winning bid and PC's profit

PCs is back to two while the number of SCs for each PC to solicit becomes three. Throughout the session, subjects bid as SCs. Since the number of necessary subjects are four in the first subsession, two subjects out of six are randomly selected in each round to stay away from bidding.

Regression 17 through 24 in Table 13 report the statistical results. In the odd numbered regressions, the first subsession (*i.e.,* 2 PCs with 2 SCs for each PC), is identified by putting Dummy 1 and 2 on the subsequent subsessions while in the even numbered regressions, the second subsession (*i.e.,* 3 PCs with 2 SCs for each PC), is identified by putting Dummy 2 and 3 on the other subsessions. The t-statistics of Dummy 1 and 3, which are 4.28 in regression 17 and 18 and 2.01 in 21 and 22, imply that the increase in the number of PCs from two to three in the downstream auction induces lower subcontract prices if (and only if when considering only the first- and second-price sealed-bid auction) the first-price auction is used in upstream competitions. Dummy 2 in both regression 17 and 19 is significant and that in both regression 18 and 20 are not, which supports the theoretical argument that SCs follow the same equilibrium bidding strategy in both cases i) 3 PCs, each soliciting 2 SCs and ii) 2 PCs, each soliciting 3 SCs.[6] Similar results are also obtained when the subject IDs are controlled as fixed

[6]The SC's winning probability in the upstream auction is $\left[1-\sigma^{-1}(s_{i,j})\right]$ in Subsession G1 and $\left[1-\sigma^{-1}(s_{i,j})\right]^2$ in Subsession G2. The conditional probability that his PC wins in the downstream auction given that the SC bids $s_{i,j}$ is $\left[1-\sigma^{-1}(s_{i,j})\right]^4$ in Subsession G2 and $\left[1-\sigma^{-1}(s_{i,j})\right]^3$ in Subsession G2. Hence, in both cases, the SC's objective function is

$$\max_{s_{i,j}} (s_{i,j}-t_{i,j})\left[1-\sigma^{-1}(s_{i,j})\right]^5 .$$

The optimal bidding strategy is thus identical in both cases.

effect.

	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
	1st-price				2nd-price			
	OLS		FE		OLS		FE	
Cost	0.8041**	0.8041**	0.806**	0.806**	0.9877**	0.9877**	0.9942**	0.9942**
	(63.49)	(63.49)	(68.57)	(68.57)	(43.36)	(43.36)	(47.84)	(47.84)
Dummy 1	-40.86**	-	-42.15**	-	32.70*	-	27.44	-
3 PCs (2 SCs)	(4.28)	-	(4.77)	-	(2.01)	-	(-1.86)	-
Dummy 2	-49.40**	-8.53	-50.71**	-8.56	26.68	-6.01	21.69	-5.76
2 PCs (3 SCs)	(5.17)	(-1)	(5.74)	(-1.09)	(-1.64)	(-0.41)	(-1.47)	(-0.44)
Dummy 3	-	40.86**	-	42.15**	-	-32.70*	-	-27.44
2 PCs (2 SCs)	-	(4.28)	-	(4.77)	-	(2.01)	-	(-1.86)
Constant	416.28**	375.41**	414.71**	372.56**	-41.67	-8.978	-46.32	-18.87
	(20.43)	(18.70)	(20.08)	(18.23)	(-1.13)	(-0.25)	(-1.28)	(-0.53)
Observations	320	320	320	320	320	320	320	320
R-squared	0.93	0.93	-	-	0.86	0.86	-	-
Number of IDs	-	-	12	12	-	-	12	12

Note: Absolute value of t-statistics in parentheses, * significant at 5%; ** significant at 1%
Subject ID is taken as fixed effect in regression (18), (19), (23), and (24).

Table 13: 3 PCs with 2 SCs for e.a., 2 PCs with 3 SCs for e.a.

Now, we compare the first subsession in this experiment with Subsession 2 in the previous experiment; in both subsessions, there are 2 PCs, each soliciting 2 SCs in the upstream auction. We regress the observed bids on the private signals. The dummy is equal to one if the dependent and independent variables are picked from the previous experiment Subsession 2 and is equal to zero otherwise. Unlike the theoretical prediction, the regression result in Table 14 shows that it is statistically significant that subjects in Subsession 2 bid lower prices than those in the first subsession in this supplemental experiment. Taking into account the fact that all subject groups are randomly selected, it is hard to conclude that this difference comes from the subject heterogeneity. Hence, the subject's bidding behavior may be affected by the competitive environment of the previous subsession. However, subjects in upstream competition do recognize the competition in the downstream auction and bid differently if the first-price mechanism is used.

4.8 Change in the order of subsessions

We conclude this section by reporting the result that the aggressive bids are observed regardless of the order of subsessions. In the final experimental session, we begins by Subsession 2 in which 2 PCs solicit 2 SCs for each upstream competition based on the first-price mechanism. Then, we conduct Subsession 3 followed by Subsession 1 in which a paired subjects bid for a PC and there is no downstream competition. The regression result of the observed bids on the costs in Table 15 shows that the order of

	(25)	(26)	(27)	(28)
	1st-price		2nd-price	
	OLS	FE	OLS	FE
Cost	0.722**	0.722**	0.9969**	1.0027**
	(37.89)	(39.01)	(28.27)	(36.48)
Dummy	-38.6841**	-32.6429**	16.4836	8.6942
	(3.44)	(2.71)	(-0.8)	(0.16)
Constant	578.108**	571.006**	-72.1702	-65.6597
	(17.18)	(17.05)	(-1.13)	(-0.73)
Observations	160	160	160	160
R-squared	0.9	-	0.84	-

Note: Absolute value of t-statistics in parentheses, * significant at 5%; ** significant at 1%
Subject ID is taken as fixed effect in regression (26), (28).

Table 14: 2 PCs, 2 SCs for e.a. PC

subsessions does not affect our previous results; subjects bid lower prices in Subsession 2 and 3 even if Subsession 1 is conducted afterward.

	(29)	(30)	(31)	(32)
	1st-price		2nd-price	
	OLS	FE	OLS	FE
Cost	0.769**	0.769**	0.769**	0.769**
	(51.49)	(51.49)	(51.49)	(51.49)
Subsession 1 dummy	-	-	40.186**	40.186**
	-	-	(3.84)	(3.84)
Subsession 2 dummy	-26.139*	-26.139*	14.046	14.046
	(2.17)	(2.17)	(1.35)	(1.35)
Subsession 3 dummy	-40.186**	-40.186**	-	-
	(-3.84)	(-3.84)	-	-
Constant	459.448**	459.448**	419.263**	419.263**
	(19.66)	(19.66)	(17.86)	(17.86)
Observations	160	160	160	160
R-squared	0.94	-	0.94	-

Note: Absolute value of t-statistics in parentheses, * significant at 5%; ** significant at 1%
Subject ID is taken as fixed effect in regression (30), (32).

Table 15: Changing subsession orders

5 Concluding remarks

In this paper, we conduct a laboratory experiment to examine the bidding behavior in upstream subcontract auctions that take place prior to a downstream procurement auction.

To answer the following three questions, we conduct a laboratory experiment; 1) whether subjects play the symmetric equilibrium the theoretical research by Nakabayashi (2009) proposes, 2) whether the revenue equivalence breaks down in the upstream auction, and 3) which mechanism yields higher efficiency, the first- vs. second-price auction.

As suggested by the theoretical model, subjects tend to bid more aggressively in upstream competitions if upstream auctions are held with the first-price mechanism. Although the observed bids in our experiment has a discrepancy from the theoretical bid functions due presumably to the subject's risk attitude, the aggressive bidding in the first-price upstream auction is indeed observed with statistical significance that causes the failure of the Revenue Equivalence in upstream auctions. On the other hand, despite the theoretical prediction that expected profits of PCs who use the first-price mechanism to select an SC is higher than those who use the second-price counterpart, the subject's earnings as a PC in our experiment are lower if they use the first-price mechanism in the upstream auction.

Unlike the existing experimental research regarding the efficiency on auctions, we obtain a clear ranking in upstream auctions. Efficiency is higher if the first-price auction is used in the upstream auction. Although the second-price mechanism tends to yield higher efficiency in our controlled experiment, the existing of the downstream competition overcompensates the efficiency created by the first-price upstream auction.

An extension from this study can be the examination of the case where a PC uses the first-price sealed bid auction to select an SC while another PC uses the second-price sealed-bid auction. Dividing two cases; one in which all subjects know every PC's mechanism to select an SC, and the other is that PC's mechanism is known only to the relevant subjects (the PC and SCs who bid for the PC), we will investigate the impact of such mechanism choices on the strategy in the upstream auction and the PC's profitability as well as the *ex post* efficiency.

Furthermore, the optimal reservation price in the downstream auction can be analyzed in the laboratory experiment. As theory predicted, the downstream auction satisfies the standard IPV environment since the PC's cost is drawn from a distribution function which depends on the number of competitors. As a result, the optimal reservation price in the downstream auction depends on the number of bidders. We will conduct an experimental session for the inspection of optimal reservation price, the results of which will be attractive for the real-world procurement buyers who have always wondering such issues.

Appendix A

The social surplus is equal to

$$SS^{FP} = \frac{4}{5}$$

if the first-price mechanism is used in upstream competitions.

To compute the social surplus in the case of the second-price mechanism in upstream competitions, let $t_{i,j}$ denote the lowest signal among those of the four SCs. Let also $t_{i,j'} \in \{1, 2\}$ be an index that satisfies $j' \neq j$. Then, the probability with which is not the highest is 2/3 regardless of the value of $t_{i,j}$. Therefore, if $t_{i,j'}$ is not the highest and $\text{SC}_{i,j}$ gets the subcontract, then the conditional social surplus is given by

$$\frac{4}{5} \cdot \frac{2}{3} = \frac{8}{15}.$$

On the other hand, if $t_{i,j'}$ is the highest, then $t_{i',(1)}$ gets the subcontract where $i' \neq i$ and (1) is the lowest order statistic among 2 signals, $t_{\cdot,1}, t_{\cdot,2}$. Regardless of the values $t_{i,j}$ and $t_{i,j'}$, this situation happens with probability equal to 1/3. Therefore, the conditional social surplus is given by

$$\frac{3}{5} \cdot \frac{1}{3} = \frac{3}{15}.$$

Therefore, the social surplus of the second-price mechanism in upstream competitions is given by

$$SS^{SP} = \frac{8}{15} + \frac{3}{15} = \frac{11}{15},$$

which is 8.3 percent smaller than SS^{FP}.

6 Appendix B: An Experiment in Subcontract Bidding for Public Works

In this experiment, each subject (starting with you) is initially given 3,500 points. Throughout the experiment, you may bring in more points, or you may use up all your initial points. Each subject will be given a reward according to the total points he or she has at the end of the experiment at the rate of 1 yen per point.

All the information we pass out here is for use by the subject only. None of the information in this instruction is to be shared with any other subject. There is to be no talking during the experiment. If someone breaks these rules, the experiment will be halted at that point.

6.1 Summary of Experiment

In regard to a public construction project, the procurement buyer (government) chooses a company to commission the project and decides the amount it will pay out to the company by means of public bidding, from the standpoint of fairness and cost reduction. This company is called a "prime contractor". The prime constructor usually has to contract much of the project out to the construction agents. Each of these agents is called a "subcontractor", and each part of the project assigned to the subcontractor is called a job. From the viewpoint of cost reduction, the prime contractor chooses its subcontractors by having the agents make bids to see which agent has the lowest estimate of costs for the job, where these bids are not disclosed to the public. This experiment is done in order to investigate the interactions of these two types of bidding.

We have the subjects play the role of either potential prime contractors or construction agents. The role of the government is played by us. The government first announces a public construction project. Then, it is shown on your computer screen whether you are a potential prime contractor or a construction agent. If you are assigned to a construction agent, you must make a bid for subcontracting the project indicated by a prime contractor. If you are assigned to a prime contractor, you must make a bid to the government for the public construction project.

6.2 Process of Experiment

6.2.1 Subsessions and the Order of Bidding

This experiment consists of three sessions. Before each subsession starts, there is a trial run of 3 periods. The results of the bids in this trial run account for nothing of your total points. Any necessary information is shown on your computer screen.

Subsession 1 has ten periods. At the beginning of each period, two subjects are randomly chosen as construction agents. The prime contractor is chosen by the government a priori and it is commissioned a public construction project. Thus, there is no public bidding for any projects. Each of the two construction agents is first randomly given an integer that ranges from 1001 to 2000 point as its construction cost for the job of the construction project. This construction cost is the agent's private information. The agent who makes the lowest bid wins the subcontract bidding and receives the same amount as the second lowest bid (the sealed-bid second-price auction). The payment you receives as a subject is counted for your total point, but nothing is counted unless you are chosen as a subject.

Subsession 2 also has ten periods. At the beginning of each period, four subjects are randomly chosen as construction agents. The government announces a public construction projects and two potential prime contractors participate in bidding for the project. Prior to this bidding, each potential prime contractor asks two construction agents to make a subcontract bid. These two construction agents are randomly assigned to a potential prime constructor, and each construction agent are first randomly given an integer that ranges from 1001 to 2000 points as its construction cost for the job of the construction project. This construction cost is the agents private information.

A computer program assigns to each potential prime contractor one subcontractor, choosing the agent who makes the lowest bid as the subcontractor. Each potential prime contractor commits to a contract that if the potential prime contractor wins the public construction project, it will (1) ask the subcontractor to do a job and (2) pay the same amount as the second lowest bid in the subcontract bidding to the subcontractor. If the potential prime contractor makes the lowest bid for the project, it wins the project and receives exactly the same amount as its bid from the government.

At this time, a computer program makes a bid on behalf of each potential prime contractor so that it maximizes the potential prime contractor's expected profit, given the amount the prime contractor has to pay to its subcontractor. We assume that the prime contractor does not do any on the public construction project; all of the work is done by the subcontractor. So, the cost of a public construction project for the prime contractor is just the expenses it pays to the subcontractor. So, the points for the prime contractor is the difference between the amount received from the government and the payment to the subcontractor. At last the payment to the subcontractor is made by the prime contractor who wins the project. The payment you receives as a subject is counted for your total point, but nothing is counted unless you are chosen as a subject.

Subession 3 proceeds in the same way as Subsession 2 except the following three points. (1) Subsession 3 has twenty periods. There is an intermission of one minute after ten periods. (2) Each of the two potential prime contractors is handled by a subject, although a computer program assigns to each potential prime contractor one subcontractor, choosing the agent who makes the lowest bid as the subcontractor. So, (3) at the beginning of each period, six subjects are randomly chosen. Two of the subjects are randomly assigned to potential prime contractors, two of them are randomly assigned to construction agents who can bid only for a designated subcontract bidding, the remaining two are randomly assigned to construction agents who can bid only for the other designated subcontract bidding. The payment you receives as a subject is counted for your total point, but nothing is counted unless you are chosen as a subject (the sealed-bit first-price auction).

Bidder asymmetry by Estache and Iimi (2010): Asymmetric auctions are among the most rapidly growing areas in the auction literature. although traditional symmetric framework is still attractive for analyzing general bidding behavior in a tractable manner, it is not always applicable in practice because bidders are potentially heterogeneous in various dimensions. The existence of weak bidders – also referred to as fringe or entrant bidders – is particularly important from a competition policy perspective. they can promote bidding competition and break hidden collusive arrangement among strong bidders–also referred to as incumbent bidders.

6.2.2 More on the Process

The subcontractor's construction costs are independently drawn from a uniform distribution between 1,001 and 2,000. The closest example is drawing a dice. The probability of a two coming up is 1/6, the others also being 1/6. In the same way, the probability that the construction costs for the subcontractor is 1,033 is 1/1,000. On the computer , the range of bidding for both potential prime contractors and construction agents is also limited to integers that ranges from 1,001 to 2,000.

The winner of bidding is determined randomly in the case of a tie. Any periods in any sessions should be completed in 60 seconds. When 60 seconds elapses, we urge subjects to complete the period as soon as possible. For each period during a session, he necessary information is shown on your computer screen,. Based on this information,

6.2.3 How to Calculate Profits

If you are the potential prime contractor, the profit you make from a public construction project is

$$\begin{aligned}\text{yuor profit} &= \text{the amount you receive from the government}\\ &\quad -\text{the amount paid to the subcontractor}\end{aligned}$$

This profit may be gained if you are awarded the contract by being the lowest bidder in the public construction project. On the other hand, if you are the subcontractor, the profit you make from a job of a public construction project is

$$\text{profit} = \text{the ayment from the prime Contractor} - \text{your construction cost}$$

This profit may be gained not only if you are the lowest bidder in the subcontraction bidding but also if the potential prime contractor you are working with is fortunate enough to be commissioned the public construction project.

6.2.4 Practice Questions

1. Suppose that you are a construction agent and your construction cost is 1,390 points. Now, you bid 1,390 points. How much profit will you gain, when you wins the subcontract bidding?

2. Suppose that you are a construction agent and your construction cost is 1,202 points. If, in the next period, you are chosen as a construction agent again, what is the probability of your construction cost being higher than 1,500 points?

3. Suppose that in Subsession 2 or 3, you are a subcontractor of a potential prime contractor. The difference between your bid and your construction cost is 265 points. If, later, your potential prime contractor is commissioned a public construction project, what is your profit?

4. Suppose that in Subsession 2 or 3, you are a construction agent and your construction cost is 1,530 points. Now, you won the subcontract bidding at 1,300 points, but your potential prime contractor lost the bidding for a public construction project. How much profit will you make?

5. Suppose that in Subsession 2 or 3, you are a construction agent and your construction cost is 1,880 points but you won the subcontract bidding at 1,700 points. Let's say that the potential prime contractor you are working with was commissioned a construction project. How much profit will you make?

6. Suppose that you are a construction agent and your construction cost is 1,240 points. What is the probability of your rival construction agent having his oe her cost of over 1,500 points?

7. Suppose that in Subsession 3, you are a potential prime contractor and your subcontractors bid 1,350 points and 1,504 points. How much will be the costs for the subcontractor you choose?

8. Suppose that in Subsession 3, you are a potential prime contractor and your subcontractors bid 1,090 points and 1,950 points. How much will be your expense?

9. Suppose that in Subsession 3, you are a potential prime contractor and your subcontractors bid 1,090 points and 1,950 points. If you bid 1,057 points and were awarded the public construction project, how much profit will you gain?

Morgan et al. (2003)

We study auctions where bidders have independent private values but attach a disutility to the surplus of rivals, and derive symmetric equilibria for first-price, second-price, English, and Dutch auctions. We find that equilibrium bidding is more aggressive than standard predictions. Indeed, in second-price auctions it is optimal to bid above one's valuation; that is, bidding "frenzies" can arise in equilibrium. Further, revenue equivalence between second-price and first-price auctions breaks down, with second-price outperforming first-price. We also find that strategic equivalence between second-price and English auctions no longer holds, although they remain revenue equivalent. We conclude that spiteful bidding rationalizes anomalies observed in laboratory experiments across the four auction forms better than the leading alternatives.

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