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Kenju Akai, Tatsuyoshi Saijo, and Shigehiro Serizawa

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GCOE Secretariat
Graduate School of Economics
OSAKA UNIVERSITY
1-7 Machikaneyama, Toyonaka, Osaka, 560-0043, Japan

Auctions for Public Construction with Corner-cutting

Kenju Akai[a,b,*], Tatsuyoshi Saijo[b,†], Shigehiro Serizawa[b,†]

[a] *Japan Society for the Promotion of Science, 1-6 Chiyoda-Ku, Tokyo 1028471, Japan*

[b] *Institute of Social and Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka 5670047, Japan*

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Abstract: This paper reports the theoretical and experimental results of auctions for public construction in which firms cut corners. We show that winning bids and qualities of the constructed buildings are both zero in equilibria if there are at least two firms whose initial cash balances are zero. The experimental results support that firms with zero-initial cash balance win and that the winning bids and the qualities of the constructed buildings are considerably low.

JEL classification: C92; D44; L15

Key words: Corner-cutting; Public procurement; First-price auction; Experiment;

*Corresponding author: k-akai@iser.osaka-u.ac.jp, Institute of Social and Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka 5670047, Japan. Tel.: +81-6-6879-8552; Fax: +81-6-6879-8584.

†E-mail: saijo@iser.osaka-u.ac.jp (T. Saijo), serizawa@iser.osaka-u.ac.jp (S. Serizawa)

1. Introduction

Auctions are a transparent and fair method of public procurement, and are commonly employed in the public sector. Corner-cutting is a critical issue to consider in construction contracts. In this context, corner-cutting refers to the construction of low-quality buildings to save costs and/or time. Corner-cutting may have serious consequences in construction, including even the high death toll[1]. However, most of the literature on auction do not take it into account. This article aims to explicitly introduce corner-cutting into procurement auctions, theoretically investigate its effect, and examine the theoretical predictions through experiments.

In our model, the firms chosen by auction as contractors have the option to cut corners in construction. The more the contracting firms cut corners, that is, the more they save construction cost, the lower the qualities of the constructed buildings, which result in the higher probability that corner-cuttings are detected. If corner-cutting is detected, a contracting firm is required to pay a penalty in accordance with the scale of corner-cutting. However, the penalty payment is limited by the firm's initial cash balance owing to bankruptcy. Thus, the profit maximizing level of corner-cutting depends on the cost of constructing buildings of the specified quality, penalty rates, initial cash balances, and contract prices (winners' bids).

We assume that *there are at least two firms whose initial cash balances are zero.* In this paper, we focus on problems that will occur when the auction authorities of public sectors do not limit participant qualification and auctions are opened to any firms. The cash balances of firms on the brink of bankruptcy are virtually zero. If several such firms participate in the auctions, the above assumption holds. During recessions, many construction firms become bankrupt. Thus, if auctions in public sectors are made open to any firms during that time, then the above assumption becomes reasonable. Even in non-recessionary periods, statistically some construction firms go bankrupt. If the auctions are open to any firms, the firms on the brink of bankruptcy would be more eager to participate in the auctions, and the assumption would be plausible.

We find that if the above assumption holds, then *in equilibria, zero-initial cash balance firms win auctions by bidding zero amount, and construct buildings of zero quality.* Our experimental results support this theoretical result, and indicate that the firms with zero initial cash balance win and that the winning bids and the quality of the constructed buildings are considerably low.

There are many special rules in public construction auctions to prevent corner-cutting, most of which are ignored in auction theory. For example, many public procurement authorities in Japan and European countries such as Belgium, Italy, Portugal, Spain, and Greece set a minimum price to exclude or detect abnormally low tenders. Alternatively, only designated bidders—as deemed qualified on the basis of factors such as locality, technological ability, and initial cash balance—are invited to procurement auctions. Although such special rules curb competition in auctions and are often criticized for affecting the transparency and fairness of auction, our results suggest the necessity of these special rules in public procurement auctions.

[1] For example, the New York Times (September 4, 2008, China Admits Building Flaws in Quake) reported the following: "Chinese government committee said on Thursday that a rush to build schools during the country's recent economic boom might have led to shoddy construction that resulted in the deaths of thousands of students during a devastating earthquake in May. It is well known that construction firms and other companies often cut corners in China's rapidly growing economy."

Calveras et al. (2004) show that when cost is common but uncertain for firms, firms with a small amount of initial cash can make a profit by bidding low and declaring bankruptcy if the cost is found to be high in the second-price auction. By conducting experiments, Cox et al. (1996) discover that too-low bids in the first-price auction under post-auction cost uncertainty lead to cost overruns. These articles also suggest the necessity of the above special rules in public procurement auctions. However, to the best of our knowledge, our article is the first to introduce corner-cutting into an auction model and to analyze its effect.

The remainder of the paper is organized as follows. Section 2 develops the theoretical model. Section 3 analyzes the equilibrium. Section 4 details the experimental procedures. Section 5 analyzes the results, and section 6 summarizes the conclusions.

2. Model Description and Notations

There are n construction firms, from which a public sector chooses a contractor for construction. Each firm i has an initial cash balance w_i. Each firm i also has a "proper cost" d_i. This means that the firm needs to spend d_i to construct a building of the quality specified by the public sector. Firms' initial cash balances and proper costs represent their financial conditions and technological competence, respectively.

The public sector employs the first price auction in choosing a contractor. Each firm i submits its bid b_i to the procurement authority of the public sector. The firm with the minimum bid wins and is awarded the contract. Ties are broken with equal probability. The contract price is the winner's bid.

The firm chosen as a contractor, say firm i, does not necessarily spend its proper cost on construction. Instead, the contractor might "cut corners" and spend a smaller amount. Denote by c_i the actual cost firm i spends on construction. We assume that the scale of corner-cutting is represented by $d_i - c_i$, and the quality of the constructed building is determined by $q_i = c_i/d_i$. For example, suppose that $d_i = 100$, but firm i spends only $c_i = 80$ for construction. Then, the scale of corner-cutting is 20, and the quality is 0.8.

After the contractor constructs a building, the procurement authority investigates the quality of the building. The lower the quality of the constructed building, the higher the probability of the authority detecting corner-cutting. If $q_i = 1$, that is, if the contractor does not cut corners, then the probability of detection is zero. Conversely, if $q_i = 0$, that is, if the contractor does not spend cost for construction at all, the probability of detection is one. For simplicity, we assume that the probability that the authority detects corner-cutting is $1 - q_i = (d_i - c_i)/d_i$.

If the authority detects corner-cutting, it imposes a penalty on the contractor. The greater the scale of corner-cutting, the larger is the amount of penalty. For simplicity, we assume that the penalty is proportional to the scale of corner-cutting, and the penalty rate is given by $r > 1$. That is, if the scale of corner-cutting is $d_i - c_i$, the penalty is $r \cdot (d_i - c_i)$.

If the contractor who has cut corners and has been detected has enough cash balance to pay the penalty—that is, if penalty $r \cdot (d_i - c_i)$ is less than or equal to the contractor's cash balance, $w_i + b_i - c_i$, at that point of time—then he pays the penalty. Otherwise, the contractor goes bankrupt and pays only the cash balance $w_i + b_i - c_i$.

The contract procedure in the public sectors can be summarized as follows.

Stage 1 (Auction Stage): Each firm submits bid b_i to the authority. The firm with the minimum bid wins and is chosen as the contractor. The contract price is the winning bid.

Stage 2 (Construction Stage): The contractor determined in Stage 1, say firm i, receives the contract price b_i and chooses spending c_i for construction.

Stage 3 (Investigation Stage): The procurement authority investigates if the contractor cuts corners in construction. The probability of corner-cutting being detected is $(d_i - c_i)/d_i$.

Stage 4 (Penalty Stage): If corner-cutting $d_i - c_i$ is detected in stage 3, a penalty $r \cdot (d_i - c_i)$ is imposed on the contractor. If $w_i + b_i - c_i \geq r \cdot (d_i - c_i)$, the contractor pays $r \cdot (d_i - c_i)$. Otherwise, he goes bankrupt and only pays $w_i + b_i - c_i$.

The profit of a firm is defined as its final cash balance minus its initial cash balance. It is computed as follows: Suppose firm i bids b_i. (i) If firm i does not win the auction, then its final cash balance is equal to its initial cash balance, and its profit is zero. (ii) If firm i wins the auction, spends c_i on construction, and corner-cutting is not detected, then its final cash balance is $w_i + b_i - c_i$, and its profit is $b_i - c_i$. (iii) If firm i wins, spends c_i on construction, and corner-cutting is detected but it does not go bankrupt, then the final cash balance is $w_i + b_i - c_i - r \cdot (d_i - c_i)$, and the profit is $b_i - c_i - r \cdot (d_i - c_i)$. (iv) If firm i wins, spends c_i on construction, and corner-cutting is detected and it goes bankrupt, then the final cash balance is 0 and its profit is $-w_i$.

3. Theoretical Analysis

We analyze firms' behavior backward. In other words, we first analyze their behavior in Stage 2 and then in Stage 1.

3.1. Contractor's choice of spending

Firms enter Stage 2 only if they win the auction in Stage 1. Thus, the firms in Stage 2 are already contractors. We analyze how much a contractor spends for construction given its initial cash balance w_i and contract price b_i. In this subsection, since we focus on the behavior of one contracting firm and ignore the others, we omit appending subscripts to w_i, d_i, b_i, and c_i for simpler notation.

When corner-cutting is detected, and the deficit is greater than the limit, i.e., $c + r \cdot (d - c) - b > w$, the contractor becomes bankrupt. Thus, if corner-cutting is detected, the constructor's payoff is $\max\{b - c - r \cdot (d - c), -w\}$.

When the contractor spends the cost c, since the probability of the detection is $1 - d/c$, his expected payoff is

$$\pi = \frac{c}{d} \cdot (b - c) + \frac{d - c}{d} \cdot \max\{b - c - r \cdot (d - c), -w\}.$$

We assume that the firms are risk-neutral and seek to maximize the expected profit π as defined above. Note that

$$b - c - r \cdot (d - c) \lesseqgtr -w \Leftrightarrow c \lesseqgtr [r \cdot d - (b + w)]/(r - 1).$$

Thus, a contractor goes bankrupt when corner-cutting is detected, if and only if its spending c is less than $\bar{c} \equiv [r \cdot d - (b + w)]/(r - 1)$.

Given w, d, and b, let $c^*(w, d, b)$ be the optimal spending for w and b, i.e., the spending that maximizes the expected profit, and let $\Pi(w, d, b) = \pi(c^*(w, d, b))$.

Proposition 1 below characterizes the optimal cost and maximal expected profit given b and w.

Proposition 1: Let $\overline{b} = 2d - w - d/\sqrt{r}$. Then,

$$c^*(w,d,b) = \begin{cases} (b+w)/2 & \text{if } b \leq \overline{b} \\ (1 - 1/2r) \cdot d & \text{otherwise,} \end{cases}$$

$$\Pi(w,d,b) = \begin{cases} \left[(b+w)^2 - 4dw\right]/4d & \text{if } b \leq \overline{b} \\ b - d + d/4r & \text{otherwise.} \end{cases}$$

The proof is provided in Appendix. Proposition 1 states the following: (i) If the contract price b is smaller than threshold level $\overline{b}$, then the contractor's optimal choice c^* does not depend on its proper cost d. (ii) On the other hand, if the contract price b is greater than $\overline{b}$, then the contractor's optimal choice c^* does not depend on its initial cash balance w or contract price b. A contractor chooses to go bankrupt when detected, if and only if $b < \overline{b}$.

Note that at $b = \overline{b} = 2d - w - \frac{d}{\sqrt{r}}$,

$$\frac{1}{4d} \cdot \left[(b+w)^2 - 4dw\right] = b - d + \frac{d}{4r}, \text{ and } \frac{b+w}{2} < (1 - \frac{1}{2r}) \cdot d.$$

That is, the contractor's maximized expected profit $\Pi(w,d,b)$ is continuous with respect to b, but the optimal spending $c^*(w,b)$ is not.

We consider a firm's bid b_0 such that if the firm wins the auction by bidding b_0, his expected profit will be zero in Stage 2. That is, b_0 is a bid such that $\Pi(w,d,b_0) = 0$. We term such a bid b_0 a "zero-profit bid." If $d - d/4r \geq \overline{b}$, then $b_0 = d - d/4r$, and if $d - d/4r < \overline{b}$, then by $(b_0 + w)^2 - 4dw = 0$, $b_0 = 2\sqrt{dw} - w$. Note that

$$d - d/4r \gtreqless \overline{b} \quad \Leftrightarrow \quad w \gtreqless d \cdot \left(2\sqrt{r} - 1\right)^2 / 4r.$$

Since $\Pi(w,d,b)$ is increasing in b, $\Pi(w,d,b) \gtreqless 0 \Leftrightarrow b \gtreqless b_0$. Therefore, we have Lemma 1 below.

Lemma 1: (i) If $w \geq d \cdot \left(2\sqrt{r} - 1\right)^2/4r$, then $b_0 = d - d/4r$, and if $w < d \cdot \left(2\sqrt{r} - 1\right)^2/4r$, then $b_0 = 2\sqrt{d \cdot w} - w$. (ii) $\Pi(w,d,b) \gtreqless 0 \Leftrightarrow b \gtreqless b_0$.

In an ordinal auction model for public construction, i.e., a model in which firms have no option of corner-cutting, once a firm wins the auction in Stage 1, it is required to spend its proper cost in Stage 2; hence, the distinction between a firm's proper cost and the cost it actually spends is meaningless. In the ordinal model, the expected profit of a firm is positive if and only if it wins the auction by bidding greater than its cost. (ii) of Lemma 1 implies that zero profit bids have similar properties in our model where firms have the option of corner-cutting. This fact plays an important role in analyzing the equilibria of the auction in Stage 1.

3.2. Equilibria

In this subsection, we analyze firms' bidding behavior in Stage 1 by employing the results of subsection 3.1. We assume that firms know only their own initial cash balances and proper costs, but not those of the others. We analyze firms' bidding behavior in Stage 1 in the framework of incomplete information games.

Since initial cash balances and proper costs vary, we depict firms' bidding behaviors as bidding functions. A *bidding function of firm i* is a function $b_i(\cdot,\cdot)$ of its initial cash balance w_i and its proper cost d_i. $b_i(w_i, b_i)$ denotes firm i's bid in Stage 1 when its initial cash balance is w_i and its proper cost is d_i.

We denote the initial cash balance profile by $w = (w_1, \ldots, w_n)$, the proper cost profile by $d = (d_1, \ldots, d_n)$, and the bid function profile by $b(\cdot,\cdot) = (b_1(\cdot,\cdot), \ldots, b_n(\cdot,\cdot))$. Further, W denotes the class of initial cash balance profiles, and D the class of proper cost profiles. For each firm i, let W_i be the projection of W on the ith coordinate, D_i be the projection of D on the ith coordinate, and let $W_{-i} = \prod_{j \neq i} W_j$ and $D_{-i} = \prod_{j \neq i} D_j$.

Let $\Pr(\cdot)$ be a probability distribution on $W \times D$. That is, $\Pr(W \times D) = 1$, and further, for an event $X \subset W \times D$, $\Pr(X)$ is the probability of the event, i.e., the probability that $(w, d) \in X$. For firm i, given its initial cash balance w_i and proper cost d_i, $\Pr_{-i}(\cdot; w_i, d_i)$ is the conditional probability on $W_{-i} \times D_{-i}$. That is, $\Pr(W_{-i} \times D_{-i}) = 1$, and further, for an event $X_{-i} \subset W_{-i} \times D_{-i}$, $\Pr_{-i}(X_{-i}; w_i, d_i)$ is the probability of the event of X_{-i} under the condition that firm i's initial cash balance is w_i and its proper cost is d_i. The conditional expected payoff of firm i is $E(b_i, b_{-i}(\cdot,\cdot); w_i, d_i)$ when firm i bids b_i, the other firms follow $b_{-i}(\cdot,\cdot)$, and firm i's initial cash balance and proper cost are w_i and d_i, respectively.

The Bayesian Nash equilibrium defined below is a standard equilibrium concept of incomplete information games.

DEFINITION: A bid function profile $b(\cdot,\cdot) = (b_1(\cdot,\cdot), \ldots, b_n(\cdot,\cdot))$ is a *Bayesian Nash equilibrium* if for all firm i, all its cash balance w_i, all its proper cost d_i, and all its bid $\widehat{b}_i$,

$$E(b_i(w_i, d_i), b_{-i}(\cdot,\cdot); w_i, d_i) \geq E(\widehat{b}_i, b_{-i}(\cdot,\cdot); w_i, d_i)$$

In this paper, we pay a special attention to the event that *there are at least two firms whose initial cash balances are zero.* This event is formally defined as $W^* \times D$,

$$\text{where } W^* = \{w \in W : \exists i \ \ \& \ \ \exists j \text{ such that } i \neq j \text{ and } w_i = w_j = 0\}.$$

In Proposition 2 below, we assume that the probability of this event is one, that is, $\Pr(W^* \times D) = 1$.

To state Proposition 2, we introduce a *zero winning-bid profile.* This is a bid function profile $b^*(\cdot,\cdot) = (b_1^*(\cdot,\cdot), \ldots, b_n^*(\cdot,\cdot))$ such that for all firm i, all initial cash balances w_i, and all proper costs d_i, if $w_i = 0$, $b_i^*(0, d_i) = 0$, and if $w_i > 0$, $b_i^*(0, d_i) > 0$. Note that if the above assumption holds and firms follow a zero winning-bid profile, then with probability one, the winner is a firm with a zero initial cash balance and the winning bid is zero. Further, note that if the winner is a firm with a zero initial cash balance and the winning bid is zero, then it follows that in Stage 2, the winner spends nothing for construction, and so the quality of the constructed building is zero.

PROPOSITION 2: *Assume that there are at least two firms whose initial cash balances are zero with probability one. Then, a zero winning-bid profile is a Bayesian Nash equilibrium. At this equilibrium, the winner is a firm with a zero initial cash balance, and the winning bid and the quality of the building constructed by the winner are both zero.*

The proof is simple. By Lemma 1, the zero-profit bids of firms with zero initial cash balance are zero, and those of others are positive. At a zero winning-bid profile, the conditional expected profits of all firms are zero. A firm with a zero initial cash balance cannot win by a positive bid since another firm else bids zero. Thus, firms with zero initial cash balance cannot obtain a greater conditional expected profit by deviating from the zero winning-bid profile. If a firm with a positive initial cash balance bids zero, then it wins with positive probability, but winning by zero bid makes its expected payoff negative. Thus, firms with positive initial cash balances do not deviate either from the zero winning-bid profile.

It is worthwhile to remark the robustness of the equilibria of Proposition 2. Typically, Bayesian Nash equilibria of the first price auction of Bayesian models depend on the details of the prior probability distribution of private information. In addition, the symmetry of the prior distribution is often assumed to derive symmetric equilibria. On the other hand, the equilibria of Proposition 2 do not depend on such details. In this sense, the equilibria of Proposition 2 are more robust than Bayesian Nash equilibria. This robustness is rather similar to that of ex-post Nash equilibrium, another equilibrium concept of incomplete information games.

DEFINITION: A bid function profile $b(\cdot,\cdot) = (b_1(\cdot,\cdot), \ldots, b_n(\cdot,\cdot))$ is an *ex-post Nash equilibrium* if for all initial cash balance profile $w = (w_1, \ldots, w_n)$, all proper cost profile $d = (d_1, \ldots, d_n)$, for all firm i, and all its bid $\widehat{b}_i$,

$$u_i(b(w,d); w_i, d_i) \geq u_i(\widehat{b}_i, b_{-i}(w_{-i}, d_{-i}); w_i, d_i).$$

The concept of ex-post Nash equilibrium is independent of the probability distribution of private information such as initial cash balances and proper costs. In other words, ex-post Nash equilibria are Bayesian Nash equilibria for any probability distribution of private information. Similarly, although Proposition 4 requires the assumption of a probability of one for the event that there are at least two firms whose initial cash balances are zero, the zero winning-bid profiles are the Bayesian Nash equilibria for any probability distribution of private information that satisfy these assumptions. In the next section, we provide experimental procedures to examine Proposition 2.

4. Experimental Procedures

The experiment was consisted of two sessions. It was programmed and conducted with the software z-Tree (Fischbacher, 2007). The subjects were undergraduate and graduate students from Osaka University. They were invited to sign up at the designated websites through flyers posted around campus and email solicitations sent to those students who had signed up for other experiments before. None of the subjects participated in more than one session.

Upon arrival, the subjects were seated at separate computer terminals, and no communication was permitted throughout the session. The subjects listened to prerecorded instructions, while simultaneously following the same from their own copies.[2] In the instructions, they were told that their roles were those of producers producing a good each and selling them to the experimenter[3]. The subjects were prohibited from asking any questions in verifying their understanding of the procedures in an examination.

The top twenty subjects who passed the examination participated in the subsequent proceedings[4]. After we announced the correct answers of the examination to the subjects, the identification numbers of producers were determined through a lottery.

Each session consisted of 16 periods. At the beginning of each period, the subjects are automatically assigned into five groups, each comprising four subjects[5]. Each subject received his ready reckoner of the all payoffs with respect to all his bid and costs. Each subject knew only his own initial cash balances and proper costs from that reckoner. We

[2] Instructions are available from the authors upon requests.

[3] We use "producers" instead of firms in the experiment.

[4] In each session, we invited more than 20 subjects including a few extra subjects in order to ensure the necessary number.

[5] The instructions are available from the authors upon request.

set initial cash balances, w_i, as 0, 0, 50, and 100, and the proper cost d_i, as 24, 30, 36, and 42 for each group. Throughout the 16 periods, every subject was assigned to all combinations of 4 initial cash balances and 4 proper costs, but this fact was not informed to the subjects. The subjects entered their proper costs and initial cash balances into their record sheets distributed along with the instructions. Apart from their own initial cash balances and proper costs, they are informed that each group has at least two producers whose initial cash balances were zero in the instruction.

In each group, the first-price auction was implemented. Subjects were allowed to enter their actual costs and bids into the interface and calculate their profits and probabilities of corner-cutting being detected as many times as desired before they made their final decisions. They, however, decided their costs and bids simultaneously within 6 minutes. The subjects were not allowed to change their costs after the winner was decided. It was mandated that their bids would be no more than the ceiling price of 58 set by us, and that their actual costs would be no more than their proper costs. Further, the costs were mandated to be no more than the sum of the bids and initial cash balances so as to avoid bankruptcy before the experimenter investigated the quality of the produced good.

The penalty ratio, r, is 2. When the winner was detected to have cut corners, his final cash balance was equal to his initial cash balance plus bid minus his cost and penalty if he was able to pay the all amounts of penalty, and it was zero if he was not. Winner's profits were his final cash balance minus initial cash balance; those of others were zero.

After the winner was decided, each subject's computer screen displayed whether or not he won along with his own profits. The subjects enter these results into their record sheets.

The subjects were paid in cash in accordance with their total experimental points under the conversion rate of 7 yen (8 cents)[6] for each point. To cover the loss of the subjects, we added 40 points at the end of each period. Each session lasted roughly 3 hours. The average payments to subjects were 4,554 yen ($50.6). No one had negative total experimental points.

5. Experimental Results

First, we focus on the market outcomes and examine Proposition 2. Table 1 summarizes the means and standard errors of qualities of produced goods, winning bids, winners' cost spending, and the ratio of the winning of producers with zero initial cash balance. On average, the quality of produced goods is less than 0.4. the ratio of the winning of producers with zero initial cash balance is more than 0.9. These results suggest that producers with zero initial cash balance win and cut corners in large scale. Both of the qualities of produced goods and winning prices are not significantly different between sessions in both t-tests (two-tailed p-values are 0.20 and 0.35, respectively) and Wilcoxon rank-sum tests (two-tailed p-values are 0.17 and 0.52, respectively).

Table 1 is around here.

[6] $1 = 90 yen at that time.

Both the qualities of produced goods and winning prices, however, are higher than the theoretical prediction of zero. Next, we focus on the dynamics of these values and examine whether the learnings of subjects in the laboratory induce the theoretical prediction.

Figure 1 presents all the qualities of the produced goods and the OLS regression lines of the qualities of the produced goods for the periods in each session and for the two sessions taken together. In each figure, circles and diamonds represent the qualities of the goods produced by producers with zero initial cash balance and those with positive initial cash balances, respectively. The quality of produced goods, however, are censored variables between 0 and 1, inclusively; hence, we employ a Tobit regression of all qualities of the produced goods on periods. Table 2 summarizes the results of this regression. The coefficient on period is negative and significant at the 1% level in both sessions and for the two sessions taken together. According to F-tests of the hypothesis of no changes in the intercepts and the coefficients of periods across the two sessions, both of them are not significantly different (two-tailed p-values are 0.212). Therefore, we conclude that the qualities of the produced goods tend toward the theoretical prediction of zero as subjects learn more.

Figure 1 and Table 2 are around here.

Figure 2, on the other hand, presents all the winning prices and the OLS regression lines of the winning prices on the periods in each session and the two sessions taken together. All winning prices are less than 30. Winning prices are also censored variables between 0 and 58 of the ceiling price, inclusively, and hence, we employ a Tobit regression of all winning prices on periods. Table 3 summarizes the results of this regression. The coefficient on period is negative and significant at the 1% level in both sessions and in both taken together. According to the F-tests of the hypothesis of no changes in the intercepts and the coefficient of period across sessions, both sessions are not significantly different (two-tailed p-values are 0.246). Therefore, we conclude that the winning prices tend toward the theoretical prediction of zero as subjects learn more.

Figure 2 and Table 3 are around here.

Proposition 2 also suggests that the proper costs of producers with zero initial cash balance do not affect both the winning prices and the qualities of the produced goods. In order to examine this suggestion, we add the proper cost as a variable to the above Tobit regression of winning prices and that of qualities of the produced goods and conduct separate Tobit regressions. Table 4 summarizes the results of these regressions. Since there are no significant differences in the winning prices and the qualities of the produced goods between sessions as described in the F-tests above, we use pooled data across sessions in each regression. In these regressions, the coefficients on proper cost are not significant in the winning prices, but are negative and significant at the 1% level in the qualities of the produced goods. These findings suggest that the proper costs of producers with zero initial cash balance do not affect the winning prices but affect the qualities of the produced goods in the laboratory.

Table 4 is around here.

The average of the qualities of produced goods for the proper costs of 24, 30, 36, and 42 are 0.41, 0.37, 0.27, and 0.24, respectively. In the experiment, the subjects must choose integer costs, so that producers with zero initial cash balance and with higher proper costs have more choices with regard to their cost spending. Since the quality is inversely related to proper cost, the higher the proper cost, the lesser is the quality. Our results suggest that theoretically non-binding proper costs may affect the qualities of the produced goods. It is similar to the results of the market experiments in Smith and Williams (1981), Isaac and Plott (1981), Coursey and Smith (1983), and Gode and Sunder (2004), who discover that theoretically non-binding price controls also affect trading prices.

Next, we focus on individual behaviors and examine the relation between bids and costs as described in Proposition 1. Table 5 summarizes the results of OLS regression of costs on bids for each proper costs in the region $b_i < \overline{b}$. Since there are only data of producers with zero initial cash balance on this region, we set $w_i = 0$. The coefficients on price are more than 0.5 and significant at the 5% level for each proper cost. According to the F-test of the hypothesis that $c_i = b_i/2$, the experimental results are significantly different from the risk-neutral theoretical prediction for each proper cost. This result suggests that subjects spend more than the theoretical risk-neutral level relative to the bid if $b_i < \overline{b}$.

Table 5 is around here.

Table 6 summarizes, on the other hand, the results of the OLS regression of costs on bids for each proper costs on the region $b_i \geq \overline{b}$. The coefficient on price is more than 0 and significant at the 5% level for the proper costs 24 and 42. According to the F-test of the hypothesis that $c_i = 3d_i/4$, the experimental results are significantly different from the risk-neutral theoretical prediction for each proper cost. In this region, however, the adjusted R^2 is very low. Therefore, we need more experiments to obtain a precise conclusion with regard to whether or not the subjects are risk averse.

Table 6 is around here.

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6. Conclusions

In this paper, we analyzed corner-cutting by firms who participate in procurement auctions. Theoretically, in the first-price auction, if there are at least two firms with zero initial cash balance, the winning bids and the qualities of the constructed buildings in the Bayesian Nash equilibria are both zero. In the laboratory, we find that (i) the winners are firms with zero initial cash balance, (ii) the qualities of the constructed buildings are considerably less than 1 and decrease as periods proceed, (iii) winning prices are considerably less than their proper costs and decrease as periods proceed, (iv) the proper costs of firms with zero initial cash balance do not affect the winning prices but affect the qualities of the constructed buildings, and (v) cost spendings relative to bids are higher than the risk-neutral predictions.

The decreasing qualities of the constructed buildings and winning prices are consistent with Dufwenberg and Gneezy (2002), who find that winning prices converge to the Nash outcomes when they inform the subjects of which participant wins without uncertainty of the cost. Our results, however, do not reach the Bayesian Nash outcome of zero in both the qualities of the constructed buildings and winning prices. Upon examining the relation between cost spendings and bids in Proposition 1, the risk attitudes of subjects is likely to cause cost spending to diverge from theoretical level. Although more experiments are needed to investigate why subjects spend and bid higher than the risk-neutral predictions, we can conclude that firms with zero initial cash balance win and cut corner in considerable scale.

This paper is a first step of analyzing corner-cutting. As we pointed out in the introduction, auction authorities prescribe special rules to prevent corner-cutting, such as setting minimum prices in order to exclude the abnormally low bids and stipulating the necessary levels of initial cash balances for firms. Although our findings suggest that firms cut corners in considerable scale if no such regulation exists, the effects of these regulations are yet to be assessed. Thus, a next step is to evaluate those regulations. Our goal is to design best regulation to maximize social benefits in models where firms cut corners.

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Appendix

PROOF OF PROPOSITION 1: First, we compute the maximizer c^* of π on the two subdomains, Subdomain 1: $\{c \geq \overline{c}\}$ and Subdomain 2: $\{c \leq \overline{c}\}$.

Subdomain 1: On this subdomain, since $b - c - r \cdot (d - c) \geq -w$,

$$\begin{aligned} \pi(c) &= \frac{c}{d} \cdot (b - c) + \frac{d - c}{d} \cdot \{b - c - r \cdot (d - c)\} \\ &= -\frac{r}{d} \cdot [c - \frac{2r - 1}{2r} \cdot d]^2 + b - d + \frac{d}{4r} \end{aligned}$$

At the singular point $c_1 = \frac{2r-1}{2r} \cdot d$ of this quadratic function, we have: $\pi(c_1) = b - d + \frac{d}{4r}$. Note

$$c_1 \gtreqless \overline{c} \Leftrightarrow \frac{2r - 1}{2r} \cdot d - (\frac{r}{r - 1} \cdot d - \frac{b + w}{r - 1}) \gtreqless 0 \Leftrightarrow b \gtreqless \frac{3r - 1}{2r} \cdot d - w.$$

Therefore, by letting $b_1 \equiv \frac{3r-1}{2r} \cdot d - w$, we have:

$$\arg\max\{\pi(c) : c \geq \overline{c}\} = \begin{cases} c_1 = \frac{2r-1}{2r} \cdot d & \text{if } b \geq b_1 \\ \overline{c} & \text{otherwise,} \end{cases}$$

$$\max\{\pi(c) : c \geq \overline{c}\} = \begin{cases} b - d + \frac{d}{4r} & \text{if } b \geq b_1 \\ -\frac{r}{d} \cdot [\overline{c} - \frac{2r-1}{2r} \cdot d]^2 + b - d + \frac{d}{4r} & \text{otherwise.} \end{cases}$$

Subdomain 2: On this subdomain, since $b - c - r \cdot (d - c) \leq -w$,

$$\begin{aligned} \pi(c) &= \frac{c}{d} \cdot (b - c) - \frac{d - c}{d} \cdot w \\ &= -\frac{1}{d}\left[c - \frac{b + w}{2}\right]^2 + \frac{1}{4d} \cdot \left[(b + w)^2 - 4dw\right]. \end{aligned}$$

At the singular point $c_2 = \frac{b+w}{2}$ of this quadratic function, we have: $\pi(c_2) = \frac{1}{4d} \cdot [(b + w)^2 - 4dw]$. Note

$$c_2 \gtreqless \overline{c} \Leftrightarrow \frac{b + w}{2} - (\frac{r}{r - 1} \cdot d - \frac{b + w}{r - 1}) \gtreqless 0 \Leftrightarrow b \gtreqless \frac{2r}{r + 1} \cdot d - w.$$

Therefore, by letting $b_2 \equiv \frac{2r}{r+1} \cdot d - w$, we have:

$$\arg\max\{\pi(c) : c \leq \overline{c}\} = \begin{cases} c_2 & \text{if } b \leq b_2 \\ \overline{c} & \text{otherwise,} \end{cases}$$

$$\max\{\pi(c) : c \le \overline{c}\} = \begin{cases} \frac{1}{4d} \cdot [(b+w)^2 - 4dw] & \text{if } b \le b_2 \\ \frac{\overline{c}}{d} \cdot (b-c) - \frac{d-\overline{c}}{d} \cdot w & \text{otherwise.} \end{cases}$$

Note:

$$b_2 - b_1 = (\frac{2r}{r+1} \cdot d - w) - (\frac{3r-1}{2r} \cdot d - w) = \frac{(r-1)^2}{2r(r+1)} \cdot d.$$

Thus, by $r > 1$ and $d > 0$, $b_2 > b_1$. This implies that we have, Case A: $b \le b_1 < b_2$, Case B: $b_1 < b < b_2$, or Case C: $b_1 < b_2 \le b$. In the following, we compute the maximizer of π in each case.

Case A: Since $c_1 < \overline{c}$ and $c_2 \le \overline{c}$ holds, $\max \pi(c) = \pi(c_2) = \frac{1}{4d} \cdot [(b+w)^2 - 4dw]$.

Case B: Since $c_2 < \overline{c} < c_1$ holds, $\max \pi(c) = \pi(c_1) = b - d + \frac{d}{4r}$ or $\max \pi(c) = \pi(c_2) = \frac{1}{4d} \cdot [(b+w)^2 - 4dw]$.

We need to compute which of $\pi(c_1)$ or $\pi(c_2)$ is bigger. Note

$$\pi(c_1) - \pi(c_2) = \frac{1}{4} d^{-1} \cdot \left(4bd - 2bw + 4dw - b^2 - 4d^2 - w^2 + \frac{d^2}{r} \right).$$

Thus, by $d > 0$,

$$\pi(c_1) \gtreqless \pi(c_2) \Leftrightarrow 4bd - 2bw + 4dw - b^2 - 4d^2 - w^2 + \frac{d^2}{r} \gtreqless 0.$$

Also note

$$4bd - 2bw + 4dw - b^2 - 4d^2 - w^2 + \frac{d^2}{r} = -\left(b - (2d-w)\right)^2 + \frac{d^2}{r}.$$

The solutions of the equation $-\left(b - (2d-w)\right)^2 + \frac{d^2}{r} = 0$ are $b = (2d - w) \pm \frac{d}{\sqrt{r}}$. Thus,

$$4bd - 2bw + 4dw - b^2 - 4d^2 - w^2 + \frac{d^2}{r} \ge 0 \Leftrightarrow 2d - w - \frac{d}{\sqrt{r}} \le b \le 2d - w + \frac{d}{\sqrt{r}}.$$

Therefore, we have:

$$\pi(c_1) \ge \pi(c_2) \Leftrightarrow 2d - w - \frac{d}{\sqrt{r}} \le b \le 2d - w + \frac{d}{\sqrt{r}}.$$

Note that

$$\left(2 \cdot d - w + \frac{d}{\sqrt{r}}\right) - b_2 = d \cdot \left(\frac{1}{\sqrt{r}} - 2\frac{r}{r+1} + 2\right).$$

By $d > 0$,

$$2 \cdot d - w + \frac{d}{\sqrt{r}} \ge b_2 \Leftrightarrow \frac{1}{\sqrt{r}} - 2\frac{r}{r+1} + 2 \ge 0.$$

By $r > 1$, $\frac{1}{\sqrt{r}} - 2\frac{r}{r+1} + 2 > 0$, and so $b_2 < 2d - w + \frac{d}{\sqrt{r}}$ holds. Also note

$$\left(2d - w - \frac{d}{\sqrt{r}}\right) - b_1 = \frac{d}{2r} \cdot (\sqrt{r} - 1)^2 > 0.$$

Thus, $2d - w - \frac{d}{\sqrt{r}} \ge b_1$. Also note

$$b_2 - \left(2d - w - \frac{d}{\sqrt{r}}\right) = \frac{d}{(r+1)\sqrt{r}} \cdot (r - 2\sqrt{r} + 1).$$

By $d > 0$ and $r > 1$,

$$b_2 \geq 2d - w - \frac{d}{\sqrt{r}} \Leftrightarrow r - 2\sqrt{r} + 1 \geq 0.$$

By $r > 1$, $\frac{d}{dr}(r - 2\sqrt{r} + 1) = 1 - \frac{1}{\sqrt{r}} > 0$. Thus, since, $r - 2\sqrt{r} + 1 = 0$ at $r = 1$, $b_2 > 2d - w - \frac{d}{\sqrt{r}}$. Accordingly, we have:

$$b_1 < 2d - w - \frac{d}{\sqrt{r}} < b_2 < 2d - w + \frac{d}{\sqrt{r}}.$$

This implies that in Case B, we have:

$$\pi(c_1) \geq \pi(c_2) \Leftrightarrow 2d - w - \frac{d}{\sqrt{r}} \leq b.$$

Therefore,

$$\max \pi(c) = \begin{cases} \pi(c_2) = \frac{1}{4d} \cdot [(b+w)^2 - 4dw] & \text{if } b \leq 2d - w - \frac{d}{\sqrt{r}} \\ \pi(c_1) = b - d + \frac{d}{4r} & \text{otherwise.} \end{cases}$$

Case C: Since $c_2 \geq \bar{c}$ and $c_1 > \bar{c}$ holds, $\max \pi(c) = \pi(c^*) = b - d + \frac{d}{4r}$.

QED

Table 1. Market overviews

Session	Qualities of the produced goods	Winning price	Winner's cost	Ratio. (producers without initial cash balance win)	No. of obs.
1	0.37 (0.02)	16.20 (0.49)	10.45 (0.45)	0.94	80
2	0.33 (0.02)	16.84 (0.47)	9.93 (0.52)	0.96	80
total	0.35 (0.01)	16.52 (0.34)	10.19 (0.34)	0.95	160

Table 2. Tobit regression of winners' qualities on periods

Session	Intercept	Period	Adjusted R^2	No. of obs.	# Left-censored	# Right-censored
1	0.51*** (0.03)	–0.02*** (0.00)	0.22	80	0	0
2	0.43*** (0.04)	–0.01*** (0.00)	0.09	80	0	0
total	0.47*** (0.03)	–0.01*** (0.00)	0.15	160	0	0

Note: Standard errors are in parentheses. Adjusted R^2 is the result of the OLS regression. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 3. Tobit regression of winning prices on periods

Session	Intercept	Period	Adjusted R^2	No. of obs.	# Left-censored	# Right-censored
1	20.77*** (0.84)	–0.46*** (0.09)	0.41	80	0	0
2	20.77*** (0.84)	–0.46*** (0.09)	0.25	80	0	0
total	21.06*** (0.57)	–0.53*** (0.06)	0.33	160	0	0

Note: Standard errors are in parentheses. Adjusted R^2 is the result of the OLS regression. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 4. Effect of proper cost

	Intercept	Period	Proper cost	Adjusted R^2	No. of obs.	# Left-censored	# Right-censored
Winning prices	20.86*** (1.36)	–0.53*** (0.06)	0.01 (0.04)	0.33	160	0	0
Qualities of the produced goods	0.74*** (0.05)	–0.01*** (0.00)	-0.01*** (0.00)	0.28	160	0	0

Note: Standard errors are in parentheses. Adjusted R^2 is the result of the OLS regression. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 5. Relation between costs and bids if $b < \overline{b}$

Proper cost	Intercept	Price	F-statistics (price=0.5, Intercept=0)	Adjusted R^2	No. of obs.	# Left-censored	# Right-censored
24	–0.78 (1.19)	0.62*** (0.07)	8.69***	0.49	78	0	0
30	–1.61 (1.55)	0.72*** (0.08)	26.87***	0.51	80	0	1
36	–0.74 (1.19)	0.71** (0.05)	54.62***	0.67	80	0	0
42	–4.27*** (1.30)	0.87*** (0.06)	58.00***	0.72	80	0	0

Note: Standard errors are in parentheses. Adjusted R^2 is the result of the OLS regression. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Relation between costs and bids if $b \geq \overline{b}$

Proper cost	Intercept	Price	F-statistics (price=0, Intercept=3*d*/4)	Adjusted R^2	No. of obs.	# Left-censored	# Right-censored
24	13.18***(1.84)	0.23***(0.07)	10.09***	0.08	82	0	10
30	19.25***(2.51)	0.15*(0.07)	6.05***	0.01	80	0	8
36	24.58***(3.57)	0.14*(0.09)	8.69***	0	80	0	11
42	24.28***(5.93)	0.28**(0.13)	17.26***	0.04	80	0	19

Note: Standard errors are in parentheses. Adjusted R^2 is the result of the OLS regression. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Figure 1. Qualities of the produced goods

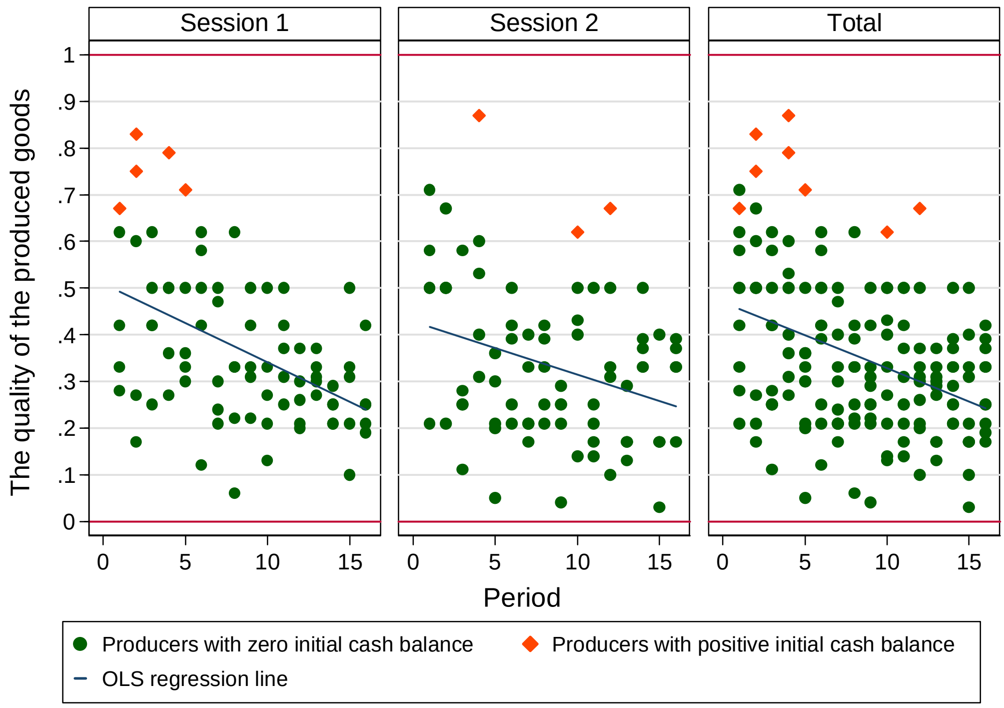

Figure 2. Winning prices