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AN EXPERIMENTAL STUDY OF JAPANESE PROCUREMENT AUCTIONS WITH ENDOGENOUS MINIMUM PRICES

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An Experimental Study of Japanese Procurement Auctions with Endogenous Minimum Prices

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Abstract

Several Japanese local governments started to add endogenous minimum prices to first-price auctions in their public procurements. Any bid less than the endogenous minimum price is referred to as abnormally low and is excluded from the procurement procedure. The endogenous minimum price is generally calculated as 80% to 90% of the average of some of the lowest bids or all bids. Therefore, producers who join this new institution have incentives to raise their bids and pull the endogenous minimum price to exclude others. We experimentally evaluate the performance of this new institution relative to the standard first-price auction which do not have any minimum price. We find that winning prices of this new institution (i) coincide with the ones of the standard first-price auction and are close to the production cost under our identical cost condition, and (ii) are higher than the ones of the standard first-price auction and diverge from the lowest production cost under our different cost condition when subjects' identifications and all their bids are revealed.

JEL classification: C92; D44; L15

Key words: Public procurement; First-price auction; Experiment; Abnormally low tender; Endogenous minimum price

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1. Introduction

First-price auctions are widely employed in public procurements for constructing roads, bridges, buildings, etc. But they have a risk that winning prices become much lower than standard production costs and that the quality of public works becomes low for governments and taxpayers. The European Commission (1999) refers to such bids as "*abnormally low tenders*". Ganuza (2007) lists examples of procurement projects whose costs overran winning prices and huge delay occurred in Europe and the US. Cox et al. (1996) found that cost overruns resulted from too-low bids of the first-price auction in procurement auction experiments with post-auction cost uncertainty.

According to the European Commission (1999), Belgium, Italy, Portugal, Spain and Greece *"recognize (and/or suspect) a tender as being abnormally low, the price offered is less by a certain percentage than the average of the tenders submitted or discounts granted, with various differences in the percentage and/or calculation of the average"*[1].

Japan also has employed the first-price auction in public procurements and has suffered from the abnormally low tenders, particularly local governments have[2]. Since many local governments do not have specialists who investigate the quality of public works, the law of the local government procurements allows local governments to set minimum prices which automatically exclude any bids less than the minimum price in procurement procedures to exclude abnormally low bids[3].

Since Japanese local governments have traditionally thought that the minimum price should be a benchmark to engage for the quality of public work, they have traditionally set the minimum price as 80% to 90% of the reservation price. The reservation price is estimated as standard costs by the governments[4].

Many Japanese local governments have announced the reservation price and/or the minimum price in advance to avoid a corruption that civil servants leak these prices to some construction companies by bribery[5]. An announcement of the minimum price in advance, however, leads to a problem that all producers who join the auction bid the minimum price, and a winner is selected by a lottery regardless of their real costs and qualities[6]. Even if they do not announce the minimum price but only announce the reservation price in advance, same problem occurs because the minimum price is set traditionally 80% to 90% of the reservation price, which makes producers estimate the minimum price easily.

To avoid deciding the winner by a lottery and exclude abnormally low bids, several

[1] Calveras, Ganuza, and Hauk (2004) point out the possibility of the failure of this type of minimum prices briefly.

[2] In Japan, this problem is generally called "dumping".

[3] Since the central government has the specialist who investigates the quality of products, it does not employ the minimum price.

[4] In Japan, the law of local government procurement requires reservation prices to avoid a situation that winning prices are over their budgets.

[5] According to the Ministry of Land, Infrastructure, Transport and Tourism's survey (2007) covered 1,874 local governments, 64% of all local governments announced the reservation price in advance, and 65% of all local governments employed the minimum price. 20% of local governments which employed the minimum price announced the minimum price in advance.

[6] According to the Ministry of Land, Infrastructure, Transport and Tourism's survey (2006) covered 1,826 local governments which employed the minimum price on April in 2003 to July in 2004 (this frequency is about 56% of 3,228 local governments existing at that time), 145 local governments decided the winner by a lottery during that period. This frequency is 61% of 236 local governments which announced the minimum price in advance.

Japanese local governments started to determine minimum prices endogenously like European countries. For example, Nagano Prefecture set the minimum price as 80% of average of the lowest five bids, and Yokosuka city set the minimum price as 90% of the lowest ten bids[7]. We refer to these new minimum prices as endogenous minimum prices.

Similar types of endogenous minimum prices have become popular in the past several years, and now the Ministry of Internal Affairs and Communications in Japan (2006) recommends endogenous minimum prices. Total contract prices of the public works from 2005 to 2007 for all local governments are about 24 trillion yen (229 billion US dollars)[8]; the ones for the central government are about 7 trillion yen (67 billion US dollars)[9]. In the future, the first-price auction with endogenous minimum price is likely to become one of major institutions to transfer large amounts of money from local governments to construction companies.

This new institution, however, has a feature that producers who join this procurement institution raise their bids and pull the minimum price to exclude others, so that winning prices are likely to be higher than their real cost. It implies that taxpayers waste their money. To confirm this feature, first we theoretically analyze Nash equilibria in this new institution.

Then we employ an experimental method to evaluate the theoretical result. Experimental studies had been used to evaluate the performance of markets with price controls such as price ceilings and floors. Smith and Williams (1981), Isaac and Plott (1981), Coursey and Smith (1983), and Gode and Sunder (2004) find that even theoretically nonbinding price controls affect trading prices in the laboratory. Not only for evaluating price controls but for evaluating new auction institutions, the experimental method had been used widely. Cason (1995) and Cason and Plott (1996) use it to evaluate emission permit auctions in the US. Olson et al. (2003), Plott and Salmon (2004), Banks et al. (2005) and Salmon and Iachini (2007) use it for spectrum auctions in the UK and US. Abbink et al. (2006) use it for government security auctions in Spain.

Our experiment features three treatment variables – minimum prices (the endogenous minimum price vs. no-minimum price), production costs (identical vs. different), and the information of subjects' identifications and all their bids (disclosure vs. nondisclosure). In the previous procurement auction experiments, Saijo et al. (1996) find that winning prices are close to the cost regardless winning prices are revealed or not, but Dufwenberg and Gneezy (2002) find that winning prices diverge from the cost when all bids are revealed. But they do not disclose subjects' identifications. We disclose of the seating chart of subjects and all their bids for all subjects to see who bids what price and examine this information effect.

In the theoretical analysis, we find that the most efficient type of minimum price for governments and taxpayers to minimize their expenditures is the certain percents of the average of the some of the lowest bids. The winning price of the first-price auction with this type of minimum price coincides with the cost (lowest cost) in the identical (different) cost condition.

In the laboratory, we find that winning prices of the first-price auction with this

[7] They are first local governments which employ the endogenous minimum price. They employed these minimum prices in 2005.

[8] 1 US dollar = 105 yen.

[9] Original data are from websites of East Japan Construction Surety Co.,Ltd, Hokkaido Construction Surety Co.,Ltd, and West Japan Construction Surety Co.,Ltd.

minimum price (i) coincide with the ones of the standard first-price auction which does not have any minimum prices and close to the cost in the identical cost condition, and (ii) are higher than the ones of the standard first-price auction and diverge from the lowest cost in the different cost condition when subjects' identifications and their all bids are revealed.

The paper is organized as follows. Section 2 develops the theoretical model and hypotheses. Section 3 details the experimental design and procedures. Section 4 analyzes the results. Section 5 summarizes the concluding remarks.

2. Theoretical model and hypotheses

In Section 2.1, we classify the endogenous minimum prices into four types and analyze Nash equilibria in the first-price auction (FPA) with each type of the minimum price. We also consider the most efficient type of the minimum price for the governments and taxpayers to minimize their expenditures. In section 2.2, we provide testable hypotheses in the parameter values used in the experiment.

2.1 Theoretical model

A rule of the FPA with endogenous minimum price is simply described as follows. Consider n producers who join this procurement auction. Let $\overline{p}$ be the reservation price determined by a government in advance. Denote producer i's bid by $b_i \in [0, \overline{p}]$ and this bid function is continuous. A bid profile is a n-tuple $b = (b_1, \ldots, b_n) \in [0, \overline{p}]^n$. Given a bid profile $b = (b_1, \ldots, b_n)$, denote the first lowest bid by b^1, the second lowest bid by b^2, and so on. Given a bid profile b, $2 \leq m \leq n$, and $k \in (0, 1]$, denote the average bid $a_m(b) = [b^1 + \cdots + b^m]/m$ of the m lowest bids and the minimum price $d(b) = k \cdot a_m(b)$[10]. When a bid profile is b, a winner is a producer whose bid is the lowest one between $d(b)$ and $\overline{p}$ inclusively, and a winning price is her bid. In case of tie, such producers win with equal probability.

We classify endogenous minimum prices $d(b) = k \cdot a_m(b)$ into four types below.

Type 1: average of the lowest m bids ($k = 1$ and $m < n$)

Type 2: average of the all bids ($k = 1$ and $m = n$)

Type 3: $k \times$ average of the lowest m bids ($k < 1$ and $m < n$)

Type 4: $k \times$ average of the all bids ($k < 1$ and $m = n$)

In Japan, *Type 3* minimum price is the most popular and *Type 4* minimum price is the second popular. Nobody employs *Type 1* and *Type 2* minimum prices. Procurement auctions for Japanese local governments are held with the same set of producers who work in the same cities or prefectures. Since wages and rental costs are not so varied in local areas, we assume that every producer has identical cost, c, to produce a homogenous good, and the cost is common knowledge among producers[11].

In the following, we divide Nash equilibria of the FPA with endogenous minimum prices into two cases to compare with Nash equilibria of the standard FPA which does not have any minimum prices (simply we call it standard FPA). In Case I, we show Nash equilibria such that all bids are not less than the cost, that is, $b_i \geq c$, for every i. This condition is satisfying if the bid profile is a Nash equilibrium in the standard FPA because

[10] In 2005, m was determined in advance. Since n is uncertaintiy, several local goverments have started to set m as rougly 60% of n. Genearally, they do not use the endogneous minimum price if $n < 5$.

[11] We have two other projects. One is that we assume costs are common value among producers, and the other is that producer can decide the quality of the good. We may leave the detail to the other paper.

any producer bidding less than the cost obtains negative payoffs. In Case II, we show Nash equilibria such that some bids are less than the cost, that is, $b_i < c$, for some i. Although there is no Nash equilibrium satisfying this condition in the standard FPA, there are many Nash equilibria satisfying this condition in the FPA with endogenous minimum prices as described in Case II.

Case I: Nash equilibria such that $b_i \geq c$, for every i.

First we analyze Nash equilibria in the FPA with *Type 1* minimum price and the ones in the FPA with *Type 2* minimum price in Propositions 1 and 2 below, respectively, with technical details and proofs contained in Appendix A.

Proposition 1. In the FPA with *Type 1* minimum price ($k = 1$ and $m < n$), a bid profile b is a Nash equilibrium if and only if (i) there is $b^* \in [c, \overline{p}]$ such that $b_1 = \cdots = b_n = b^*$, or (ii) there is $N' \subseteq N$ such that $\#N' \geq m + 1$ and $b_i = c$ for all $i \in N'$.

In the FPA with *Type 1* minimum price, since the winning price is more than or equal to the cost, governments and taxpayers have a risk to pay more than the cost and waste their money.

Proposition 2. In the FPA with *Type 2* minimum price ($k = 1$ and $m = n$), only the bid profile b such that $b_1 = \cdots = b_n = \overline{p}$ is a Nash equilibrium.

In the FPA with *Type 2* minimum price, since the winning price coincides with the reservation price, governments and taxpayers need to pay more than the cost and waste their money.

Next we analyze Nash equilibria in the FPA with *Type 3* minimum price ($k < 1$ and $m < n$) and FPA with *Type 4* minimum price ($k < 1$ and $m = n$). Since there are many Nash equilibria, it is complicated to describe all of them in each institution. First we analyze the winning price in the Nash equilibrium in each institution in Proposition 3 below, with this proof contained in Appendix A. Then we present an example of the Nash equilibrium in each institution. For general case, see Appendix B.

Proposition 3. Both in the FPA with *Type 3* minimum price ($k < 1$ and $m < n$) and FPA with *Type 4* minimum price ($k < 1$ and $m = n$), if a bid profile b is a Nash equilibrium, the winning price is the cost.

Example 1 (*Type 3*). Let $n = 5$, $k = 0.8$, $m = 3$, $\overline{p} = 243$, and $c = 97$. Consider a bid profile $b = (97, 97, 130, 150, 160)$. The minimum price is $d(b) = 0.8 \cdot (97+97+130)/3 = 86.4$, and the winner is one of producers bidding 97. If one of the producers bidding 97 raises her bid to 130, then since the minimum price becomes $d(b) = 0.8 \cdot (130+97+130)/3 = 95.2$ and still remains less than 97, she cannot exclude the other producer bidding 97. If she raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (150+97+130)/3 = 100.5$ and still remains less than 130, she cannot exclude producers bidding prices less than 130. She cannot affect the minimum price by raising her bid to a price more than 150. If the producer bidding 130 raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (97 + 97 + 150)/3 = 91.7$ and still remains less than 97, she cannot exclude producers bidding 97. In this bid profile, nobody has an incentive to raise her bid and exclude others. Hence, this bid profile is a Nash equilibrium, and the winning price coincides with the cost.

Next consider a bid profile $b = (97, 97, 130, 220, 230)$. Since $b^4 = 220$ is much higher than $b^3 = 130$, the producer bidding $b^3 = 130$ can pull the minimum price above 97 and exclude producers bidding 97 by raising her bid to $b^4 = 220$. Thus, this bid profile is not a Nash equilibrium. In this institution, since b^4 is the same as a price ceiling for producers bidding prices less than b^4, b^4 needs to be not so high that producers bidding prices less than b^4 cannot exclude others if a bid profile is a Nash equilibrium.

In the FPA with *Type 3* minimum price, the winning price coincides with the cost. This minimum price is the most efficient for the government and taxpayers to minimize their expenditures.

EXAMPLE 2 (*Type 4*). Let $n = 5$, $k = 0.8$, $\overline{p} = 243$, and $c = 97$. Consider a bid profile $b = (97, 97, 100, 130, 150)$. The minimum price is $d(b) = 0.8 \cdot (97+97+100+130+150)/5 = 91.8$, and the winner is one of the producers bidding 97. If one of the producers bidding 97 raises her bid to 100, then since the minimum price becomes $d(b) = 0.8 \cdot (100+97+100+130+150)/5 = 92.3$, she cannot exclude the other producer bidding 97. If she raises her bid to 130, then since the minimum price becomes $d(b) = 0.8 \cdot (130+97+100+130+150)/5 = 97.1$, she cannot exclude the producer bidding 100. If she raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (150+97+100+130+150)/5 = 100.3$, she cannot exclude the producer bidding 130. If she raises her bid to 243, then since the minimum price becomes $d(b) = 0.8 \cdot (243 + 97 + 100 + 130 + 150)/5 = 115.2$, she cannot exclude producers bidding prices less than 243.

If the producer bidding 100 raises her bid to 130, then since the minimum price becomes $d(b) = 0.8 \cdot (97+97+130+130+150)/5 = 96.6$, she cannot exclude the producer bidding 97. If the producer bidding 130 raises her bid to 130, then since the minimum price becomes $d(b) = 0.8 \cdot (97 + 97 + 100 + 150 + 150)/5 = 99.8$, she cannot exclude the producer bidding 100. If the producer bidding 150 raises her bid to 243, then since the minimum price becomes $d(b) = 0.8 \cdot (97 + 97 + 100 + 130 + 243)/5 = 106.7$, she cannot exclude the producer bidding 130. In this bid profile, nobody has an incentive to raise her bid and exclude others[12]. Hence, this bid profile is a Nash equilibrium, and the winning price coincides with the cost.

Next consider a bid profile $b = (97, 97, 99, 100, 150)$. If the producer bidding 150 raises her bid to $\overline{p} = 243$, then since the minimum price becomes $d(b) = 0.8 \cdot (97 + 97 + 99 + 100 + 243)/5 = 101.7$, she can exclude others and be the winner. Thus, this bid profile is not a Nash equilibrium. In this institution, since all producers affect the minimum price, $\overline{p}$ needs to be not so high that all producers cannot excludes others if a bid profile is a Nash equilibrium.

REMARK. Let $\overline{p} = 600$ in Example 2. Since everybody has an incentive to raise her bid to $\overline{p} = 600$, there is no pure Nash equilibrium (see Claim and Proof in Appendix

[12] Let $d(b) \leq 97 = b^1 = b^2$. A bid profile b is a NE if and only if $(1)\frac{k}{5}(b^3 + b^2 + b^3 + b^4 + b^5) \leq b^2$, $(2)\frac{k}{5}(b^4 + b^2 + b^3 + b^4 + b^5) \leq b^3$, $(3)\frac{k}{5}(b^5 + b^2 + b^3 + b^4 + b^5) \leq b^4$, $(4)\frac{k}{5}(\overline{p} + b^2 + b^3 + b^4 + b^5) \leq b^5$, $(5)\frac{k}{5}(b^1 + b^2 + b^4 + b^4 + b^5) \leq b^2$, $(6)\frac{k}{5}(b^1 + b^2 + b^5 + b^4 + b^5) \leq b^4$, $(7)\frac{k}{5}(b^1 + b^2 + \overline{p} + b^4 + b^5) \leq b^5$, $(8)\frac{k}{5}(b^1 + b^2 + b^3 + b^5 + b^5) \leq b^2$, $(9)\frac{k}{5}(b^1 + b^2 + b^5 + \overline{p} + b^5) \leq b^5$, $(10)\frac{k}{5}(b^1 + b^2 + b^3 + b^4 + \overline{p}) \leq b^4$. Notice that (4) implies (7) and (9) and (3) implies (6).

B). In this institution, if the reservation price is much higher than the cost, then since everybody has an incentive to bid the reservation price and exclude others, there is no pure Nash equilibrium.

By the remark above, since it is not ensured that the winning price coincides with the cost, governments and taxpayers have a risk to waste their money.

CASE II: Nash equilibria such that $b_i < c$, for some i.

In this case, in each type of minimum price, there are many Nash equilibria such that some bids are less than the cost. We show such a Nash equilibrium in each type of the minimum price in the example below.

EXAMPLE 3. Let $n = 5$, $\overline{p} = 243$, $c = 97$, $k = 0.8$ if $k < 1$, and $m = 3$ if $m < n$.

Type 1 ($k = 1$ and $m = 3$). Consider a bid profile $b = (1, 97, 97, 97, 150)$. The minimum price is $d(b) = (1 + 97 + 97)/3 = 52$, and the winner is one of the producers bidding 97. If the producer bidding 1 raises her bid to 97, then since her payoffs still remain 0, she does not have an incentive to deviate from this bid profile. She can not affect the minimum price by raising her bid more than 97. The producer bidding 97 can not affect the minimum price by raising her bid more than 97, either. In this bid profile, nobody has an incentive to raise her bid. Hence, this bid profile is a Nash equilibrium, and the winning price coincides with the cost. Similarly, there are many Nash equilibria such that some bids are less than the cost.

Type 2 ($k = 1$ and $m = 5$). Consider a bid profile $b = (1, 1, 97, 97, 140)$. The minimum price is $d(b) = (1 + 1 + 97 + 97 + 140)/5 = 67.2$, and the winner is one of the producers bidding 97. If one of the producers bidding 1 raises her bid to 97, then since her payoffs still remain 0, she does not have an incentive to deviate from this bid profile. If she raises her bid to 140, then since the minimum price becomes $d(b) = (140+1+97+97+140)/5 = 95$ and still remains less than 97, she cannot exclude producers bidding 97. If she raises her bid to 243, then since the minimum price becomes $d(b) = (243+1+97+97+140)/5 = 115.6$ and still remains less than 140, she cannot exclude the producer bidding 140. Since one of the producers bidding 1 does not exclude producers bidding 97, nobody exclude producers bidding 97. In this bid profile, nobody has an incentive to raise her bid. Hence, this bid profile is a Nash equilibrium. Similarly, there are many Nash equilibria such that some bids are less than the cost.

Type 3 ($k = 0.8$ and $m = 3$). Consider a bid profile $b = (1, 97, 97, 150, 200)$. The minimum price is $d(b) = 0.8 \cdot (1+97+97)/3 = 52$, and the winner is one of the producers bidding 97. If the producer bidding 1 raises her bid to 97, then since her payoffs still remain 0, she does not have an incentive to deviate from this bid profile. If she raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (150 + 97 + 97)/3 = 91.7$ and still remains less than 97, she cannot exclude producers bidding 97. If the producer bidding 97 raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (1 + 97 + 150)/3 = 66.1$ and still remains less than 97, she cannot exclude the other producer bidding 97. Nobody can affect the minimum price if she raises her bid more than 150. In this bid profile, nobody has an incentive to raise her bid. Hence, this bid profile is a Nash equilibrium. Similarly, there are many Nash equilibria such that some bids are less than the cost.

Type 4 ($k = 0.8$ and $m = 5$). Consider a bid profile $b = (1, 97, 97, 130, 150)$. The minimum price is $d(b) = 0.8 \cdot (1 + 97 + 97 + 130 + 150)/5 = 76.0$, and the winner is one of the producers bidding 97. If the producer bidding 1 raises her bid to 97, then since her payoffs still remain 0, she does not have an incentive to deviate from this bid profile. If she raises her bid to 130, then since the minimum price becomes $d(b) = 0.8 \cdot (130+97+97+130+150)/5 = 96.6$ and still remains less than 97, she cannot exclude producers bidding 97. If she raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (150+97+97+130+150)/5 = 99.8$ and still remains less than 130, she cannot exclude producer bidding 130. If she raises her bid to 243, then since the minimum price becomes $d(b) = 0.8 \cdot (243+97+97+130+150)/5 = 114.7$ and still remains less than 130, she cannot exclude producer bidding 130. If the producer bidding 130 raises her bid to 150, then since the minimum price becomes $d(b) = 0.8 \cdot (1+97+97+150+150)/5 = 79.2$ and still remains less than 97, she cannot exclude producers bidding 97. If the producer bidding 150 raises her bid to 243, then since the minimum price becomes $d(b) = 0.8 \cdot (1+97+97+130+243)/5 = 90.8$ and still remains less than 97, she cannot exclude producers bidding prices less than 243. In this bid profile, nobody has an incentive to raise her bid[13]. Hence, this bid profile is a Nash equilibrium. Similarly, there are many similar Nash equilibria such that some bids are less than the cost.

In both cases of Nash equilibria, since winning prices of the FPA with *Type 3* minimum price coincide with the cost regardless of the value of the reservation price, this institution is best for the governments and taxpayers to minimize their expenditures. Therefore, we focus on this institution and evaluate this performance in the laboratory.

2.2 Hypotheses

In the experiment, we employ the FPA with *Type 3* minimum price. We set the minimum price as 0.8 $\times$ average of the lowest 5 bids ($k = 0.8$ and $m = 5$) out of 10 producers ($n = 10$)[14]. In the experiment, we allow subjects to bid only nonnegative integers. To evaluate the performance of the FPA with *Type 3* minimum price, we compare winning prices of this institution with the ones of the standard FPA in the identical cost condition and different cost condition.

First we propose hypotheses in the identical cost condition. In the identical cost condition, we set every producer's cost as 97 ($c = 97$). By Proposition 3, the winning price coincides with the cost of 97. Notice that since bids are only integers, a bid profile $b_1 = \cdots = b_{10} = 98$ is also a Nash equilibrium. Therefore, we obtain the hypothesis below.

Hypothesis 1. In the identical cost condition, the winning price is 97 or 98.

In the standard FPA, the winning price also coincides with the cost of 97. Additionally, since bids are only integers, a bid profile $b_1 = \cdots = b_{10} = 98$ is also a Nash equilibrium. Therefore, we obtain the hypothesis below.

Hypothesis 2. There is no difference in the winning prices between the FPA with *Type 3* minimum price and standard FPA.

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[13] Let $b^1 < d(b) \leq 97 = b^2 = b^3$. A bid profile b is a NE if and only if (1)$\frac{k}{5}(b^4 + b^2 + b^3 + b^4 + b^5) \leq b^3$, (2)$\frac{k}{5}(b^5 + b^2 + b^3 + b^4 + b^5) \leq b^4$, (3)$\frac{k}{5}(\overline{p} + b^2 + b^3 + b^4 + b^5) \leq b^5$, (4)$\frac{k}{5}(b^1 + b^2 + b^4 + b^4 + b^5) \leq b^2 = b^3$, (5)$\frac{k}{5}(b^1 + b^2 + b^5 + b^4 + b^5) \leq b^4$, (6)$\frac{k}{5}(b^1 + b^2 + \overline{p} + b^4 + b^5) \leq b^5$, (7)$\frac{k}{5}(b^1 + b^2 + b^3 + b^5 + b^5) \leq b^2 = b^3$, (8)$\frac{k}{5}(b^1 + b^2 + b^5 + \overline{p} + b^5) \leq b^5$, (9)$\frac{k}{5}(b^1 + b^2 + b^3 + b^4 + \overline{p}) \leq b^4$. Notice that (3) implies (6) and (8). (1) implies (4). (2) implies (5).

[14] This minimum price is the same as the first one of Nagano prefecture.

Next we propose hypotheses in the different cost condition. Although wages and rental costs are not so varied in the limited area, some huge nationwide companies who join procurement auctions for local governments have a power to cut wages and rental costs much more than small localized companies do. We capture this situation into the laboratory and set producer i's cost as 97 ($c_i = 97$, $i = 2, 5, 8$) and producer j's cost as 150 ($c_j = 150$, $j = 1, 3, 4, 6, 7, 9, 10$)[15].

Since there are many Nash equilibria in the different cost condition, and it is complicated to describe all of them. First we analyze the winning price in the Nash equilibrium in Proposition 4 below, with proofs in Appendix A. Then we present an example of the Nash equilibrium.

PROPOSITION 4. Let $c_1 = c_2 \leq \cdots \leq c_n$. In the FPA with *Type 3* minimum price ($k < 1$ and $m < n$), if a bid profile b is a Nash equilibrium, the winning price is the lowest cost, c_1.

FACT. In the different cost condition, there is no Case I Nash equilibrium such that $b_i \geq c_i$, for every i.

To explain the fact above intuitively (see Lemmas 1 to 4 and Fact in Appendix A), consider a bid profile b such that every producer whose cost is 97 bids 97 and every producer whose cost is 150 bids 150. If the producer bidding 97 raises her bid to 149, she can pull the minimum price above 97 and be the winner. So that producers whose costs are 97 have incentives to raise their bids more than 97 not to be excluded. But they also keep incentives to reduce their bids to win. Hence, they trade off raising and reducing their bids. Therefore, there is no Case I Nash equilibrium such that every producer bids a price more than or equal to the cost. There are only Case II Nash equilibria such that $b_i < c_i$, for some i in the example below.

EXAMPLE 4. Consider a bid profile b such that producers 2, 5, and 8 whose costs are 97 bid 97, producer 1 whose cost is 150 bids 1, and remaining producers whose costs are 150 bid 150, that is, $b = (1, 97, 150, 150, 97, 150, 150, 97, 150, 150)$. In this bid profile, the minimum price is $0.8 \cdot (97 + 97 + 97 + 1 + 150)/5 = 70.7$, and the winner is one of the producers bidding 97. Since nobody can pull the minimum price above 97, this bid profile is a Nash equilibrium. Similarly, there are many Case II Nash equilibria such that some bids are extremely low.

Notice that since bids are only integers in the experiment, there are Nash equilibria such that wining price is 98. For example, a bid profile b such that producers 2, 5, and 8 whose costs are 97 bid 98, producer 1 whose cost is 150 bids 1, and remaining producers whose costs are 150 bid 150, that is, $b = (1, 98, 150, 150, 98, 150, 150, 98, 150, 150)$ is a Nash equilibrium[16]. Therefore, we obtain the hypothesis below.

[15] Dufwenberg and Gneezy (2000) find that price competition does work well when the number of competitors is three. We follow their idea and allocate the lower cost to three producers.

[16] Since bids are only integers in the experiment, there are several nonessential Nash equilibria. For example, consider a bid profile b such that producer 2 bids 120, producer 5 bids 130, producer 8 bids 145, producer 1 bids 97, producer 3 bids 121, and remaining producers bid 145, that is, $b = (97, 120, 121, 145, 130, 145, 145, 145, 145, 145)$. The minimum price is $d(b) = 0.8 \cdot (97 + 120 + 121 + 130 + 145)/5 = 98.0$, and the winner is the producer bidding 121. If the producer bidding 97 raises her

Hypothesis 3. In the different cost condition, the winning price is 97 or 98.

In the standard FPA, the winning price also coincides with the lowest cost of 97. Additionally, since bids are only integers, a bid profile such that producers 2, 5 and 8 bid 98 ($b_2 = b_5 = b_8 = 98$) and others bid prices more than 98 is also a Nash equilibrium. Therefore, we obtain the hypothesis below.

Hypothesis 4. There is no difference in the winning prices between the FPA with *Type 3* minimum price and standard FPA.

From above hypotheses, there is no difference in winning prices between the FPA with *Type 3* minimum price and standard FPA in either cost condition.

3. Experimental design and procedures

3.1 Design

Each session proceeded through a sequence of 10 procurement periods. Each session consisted of 10 producers who had the same homogenous good. Each subject bid only one selling price per period, and the experimenter bought only one unit of good per period with the reservation price of 243 points of experimental cash. The winner produced a good and earned profits equal to her selling price less her cost; other producers did not produce a good and earned zero profits for that period[17].

Our experiment features three treatment variables – minimum prices, production costs, and the information of subjects' identifications and all their bids.

The minimum prices of our most interest have two conditions – the no-minimum price condition and *Type 3* minimum price condition. In the no-minimum price condition, we employed the standard FPA which does not have any minimum prices. In this condition, the winner was the producer whose bid was the lowest one among bids less than or equal to the reservation price, and the winning price was her bid. In case of tie, such producers won with equal probability. This was the benchmark control condition.

In the *Type 3* minimum price condition, we employed the FPA with *Type 3* minimum price. The minimum price was 80% of the average of the lowest five bids among 10 producers. The winner was the producer whose bid was the lowest one between the reservation price and *Type 3* minimum price inclusively, and the winning price was her bid. In case of tie, such producers won with equal probability.

The production costs have two conditions – the identical cost condition and different cost condition. In the identical cost condition, we announced that production costs for all producers were 97 points. In the different cost condition, we announced that production costs for three producers with identification numbers 2, 5 and 8 were 97 points, and the ones of the remaining producers were 150 points. In each condition, subjects were randomly assigned one of the identification numbers and remained in the same role throughout the session.

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bid to 120 and win, since her cost is 150, she obtains negative payoffs. If the producer bidding 121 reduces her bid to 120 and win, since her cost is 150, she obtains negative payoffs. If the producer bidding 130 reduces her bid to 120, since the minimum price $d(b) = (97 + 120 + 121 + 120 + 145)/5 = 120.6$, she cannot be the winner. Thus, nobody has an incentive to change her bid, so that this bid profile is a Nash equilibrium. But, essentially, the winning price in the FPA with *Type 3* minimum price coincides with the lowest cost of 97 in the Nash equilibrium.

[17] We avoid terms "winners" and "winning prices" in the instructions (see Appendix C for more detail).

The information of subjects' identifications and all their bids has two conditions – the disclosure condition and nondisclosure condition. Procurement auctions for Japanese local governments are held with the same set of producers. They work in the same cities or prefectures and know each other very well. We designed our experiments to capture this environment in the disclosure condition. To this end, in the disclosure condition, at the beginning of the session, we wrote the seating chart of all producers on a whiteboard for all subjects to see which producer had which seat[18].

After the winner was decided, we called each bid along with writing it in each seat of the seating chart[19]. After writing the all bids, in the no-minimum price condition, the winning price, winner's identification number, and her own profits were displayed on each subject's screen. In the *Type 3* minimum price condition, the winning price, winner's identification number, the average of the lowest five bids, the minimum price, and her own profits were displayed on each subject's screen.

Since we examined the effect of information of subjects' identifications and all their bids, we did not disclose the seating chart and all bids in the nondisclosure condition. After the winner was decided, the same kind of information provided in the disclosure condition were displayed in each subject's screen.

We used a full factorial design with 2 minimum price conditions × 2 production cost conditions × 2 information conditions of subjects' identifications and all their bids. Table 1 summarizes our 8 cells. Each cell included 2 sessions. The No- and T3- prefix in the session name indicate the no-minimum price condition and *Type 3* minimum price condition, respectively. The -I- and -D- at the middle of the session name indicate the identical cost condition and different cost condition, respectively. The -D- and -N- suffix indicate the disclosure condition and nondisclosure condition, respectively.

Table 1 is around here

3.2 Procedures

The experiments were conducted in the PC laboratory in Institute of Social and Economic Research at Osaka University. A computerized interface was programmed with the software z-Tree. (Fischbacher 2007). Subjects were undergraduate and graduate students at Osaka University[20]. They were invited to sign up at designated websites by flyers posted around campus and email solicitations sent to students who had signed up for other experiments before. No one participated in more than one session.

Upon arrival, the subjects were seated at separate computer terminals and no communication was permitted throughout the session. Appendix C contains the instructions and PC operation manuals. Subjects listened to prerecorded instructions, while they followed along on their own copies. Then, they privately read questions and answers about instruc-

[18] In our laboratory, subjects seating rearward can see backs of subjects seating fore.

[19] Yokosuka city discloses all bids along with companies' names. We capture this information disclosure rule into the laboratory.

[20] Subjects were a mixture of economics majors and noneconomics majors.

tions in 10 minutes to confirm the rules of the experiment[21]. After that, they listened to prerecorded PC operation manuals, while they followed along on their own copies.

After above procedures, the producers' identification numbers 1 to 10 were determined by a lottery, and each subject received a record sheet. Then, we provided 10 minutes for subjects to consider the strategy of subsequent auctions.

After that, period 1 started, and all subjects entered their selling price[22] on the computer and their record sheets within 3 minutes in each period. As soon as all subjects bid, the auction was automatically closed and the winner was decided even if 3 minutes did not elapse.

In the disclosure condition, we called each bid with the identification number and wrote it in each seat of the seating chart on the whiteboard. In the nondisclosure condition, we did not announce that information. In the no-minimum price condition, subjects entered the winning price, winner's identification number, and their own profits on their record sheets. In the *Type 3* minimum price condition, all subjects entered the winning price, winner's identification number, the average of the lowest five bids, the minimum price, and their own profits on their record sheets.

After period 10 was completed, record sheets were collected, and their total profits were calculated. Subjects were paid their experimental points in cash under the conversion rate of 1 point equal to 30 yen (29 cents)[23]. All sessions lasted roughly 1.5 hour, and earnings of the subjects ranged from 900 yen ($8.57) to 5,070 yen ($48.29), with a mean of approximately 1,710 yen ($16.29).

4. Results

We divide the results into two subsections. Section 4.1 presents results in the identical cost condition, and Section 4.2 presents the ones in the different cost condition. The raw data from the entire experiment are available on the supplementary materials.

4.1 The identical cost condition

First we test Hypothesis 1. Figure 1 presents all bids in sessions 1 and 2 in cell No-I-N. The horizontal axis represents the number of periods, and vertical axis represents the price of bids. Diamonds with numbers 1 to 10 represent bids of producers 1 to 10, respectively. Winning prices are connected by a straight line, and these values are presented right next to the winning prices. Figure 2 presents all bids in sessions 1 and 2 in cell T3-I-N. Squares connected by a straight line represent the minimum prices. Figure 3 presents all bids in sessions 1 and 2 in cell No-I-D. Figure 4 presents all bids in sessions 1 and 2 in cell T3-I-D.

Figures 1, 2, 3 and 4 are around here

[21] Subjects sometimes ask the detailed strategy of experiments, which has a possibility to give a bias to their decision makings in the subsequent auction periods. Since we prohibited any questions and excluded any biases, we prepared questions and answers about instructions and distributed them to each subject.

[22] We used the term "selling price" instead of "bid".

[23] In cells No-I-N and T3-I-N, although conversion rate of 1 point was 30 yen (29 cents), we did not inform of it. We announced that their initial experimental points were zero and that the higher their experimental points were, the higher their earnings of the experiments were in the instructions. We ensured minimum payments even if final experimental points were less than or equal to zero in the questions and answers. The minimum payments were 1500 yen ($14.28), which was equal to 50 points × 30 yen (29 cents).

Table 2 reports the summary statistics across the sessions in each cell. The median of pooled winning prices across sessions is 97 in both cells No-I-N and T3-I-N. Wilcoxon signed-rank tests do not reject the null hypothesis that the median of pooled winning prices across sessions coincides with the theoretical prediction of 97 in both cells No-I-N and T3-I-N (two-tailed p-values are 1.00 and 0.146, respectively). On the other hand, the median of pooled winning prices across sessions is 98 in both cells No-I-D and T3-I-D. Wilcoxon signed-rank tests do not reject the null hypothesis that the median of pooled winning prices across sessions coincide with the theoretical prediction of 98 in both cells No-I-D and T3-I-D (two-tailed p-values are 1.00 and 0.453, respectively). These results support Hypothesis 1. Hence, we obtain the result below.

RESULT 1. In the identical cost condition, wining prices of each institution coincide with the theoretical prediction of 97 or 98, regardless of the information condition.

Table 2 is around here

Next we test Hypothesis 2. Wilcoxon rank sum tests do not reject the null hypothesis of no difference in medians of pooled winning prices across sessions between cells No-I-N and T3-I-N (z-value=-1.25, two-tailed p-value=0.209) and do not reject the null hypothesis of no difference in medians of pooled winning prices across sessions between cells No-I-D and T3-I-D (z-value=1.12, two-tailed p-value=0.264). These results support Hypothesis 2. Hence, we obtain the result below.

RESULT 2. In the identical cost condition, winning prices of the FPA with *Type 3* minimum price coincide with the ones of the standard FPA, regardless of the information condition.

Next we focus on the information effect of subjects' identifications and all their bids within the same institution. Wilcoxon rank sum tests do not reject the null hypothesis of no difference in medians of pooled winning prices across sessions between cells T3-I-N and T3-I-D (z-value=1.52, two-tailed p-value=0.128) but reject the null hypothesis of no difference in medians of pooled winning prices across sessions between cells No-I-N and No-I-D (z-value=3.67, two-tailed p-value=0.002). Hence, we obtain the result below.

RESULT 3. In the identical cost condition, winning prices of the FPA with *Type 3* minimum price in the disclosure condition coincide with the ones in the nondisclosure condition, but winning prices of the standard FPA in the disclosure condition are slightly higher than the ones in the nondisclosure condition.

Dufwenberg and Gneeze (2002) find, in their FPA experiment, that although winning prices converge to the theoretical prediction when they disclose only winning prices, winning prices diverge from the theoretical prediction when they disclose all bids. In contrast, winning prices of our standard FPA coincides with the theoretical prediction, and the differences of winning prices between two information conditions are very small.

These slightly differences seem to due to the different information of payments scheme. In cells No-I-N and T3-I-N, we did not provide a calculation formula from experimental points to cash rewards. It was likelihood that some subjects misunderstood their rewards when they sold the good than when they did not sell it even if their profits were negative. This misunderstanding motivates some subjects to bid prices less than or equal to the cost of 97 to win.

In cells No-I-D and T3-I-D, on the other hand, we provide the calculation formula of their rewards. It was clearer for subjects to understand that negative payoffs would reduce their rewards, so that they tried to earn profits to bid prices more than the cost of 97.

Since the number of the bids less than or equal to 97 in cell No-I-N is more than the ones in cell No-I-D, the different information on the payment scheme seem to induce the difference of winning prices between these cells. But we do not have such differences between cells T3-I-N and T3-I-D. This is an issue in the future.

4.2 The different cost condition

First we test Hypothesis 3. Figure 5 presents all bids in sessions 1 and 2 in cell No-D-N. Diamonds with 2 (97), 5 (97), and 8 (97) represent bids of producers 2, 5 and 8 whose costs are 97, respectively. Triangles with identification numbers 1, 3, 4, 6, 7, 9, and 10 represent bids of each producer whose cost is 150. Figure 6 presents all bids in sessions 1 and 2 in cell T3-D-N. Figure 7 presents all bids in sessions 1 and 2 in cell No-D-D. Figure 8 presents all bids in sessions 1 and 2 in cell T3-D-D.

Figures 5, 6, 7 and 8 are around here

Medians of pooled winning prices across sessions in cells No-D-N and T3-D-N are 106 and 102, respectively. On the other hand, medians of pooled winning prices across sessions in cells No-D-D and T3-D-D are 100 and 119.5, respectively. By Table 2, Wilcoxon rank-sum tests reject the null hypothesis that the median of pooled winning prices across sessions coincides with 97 or 98 at 1% significance level in each cell..

But winning prices in the nondisclosure condition appear to converge toward the theoretical prediction of 98; the ones in the disclosure condition do not. We test whether winning prices converge to the theoretical prediction of 98. We define that winning prices converge to the theoretical prediction if the slopes of the OLS regression of winning prices on the number of periods are negative and winning prices in last five periods coincide with the theoretical prediction.

Table 3 presents results of the OLS regression of winning prices on the number of periods in each session in cells No-D-N, T3-D-N, No-D-D, and T3-D-D:

$$Winning\ prices = a + b \cdot Period + \varepsilon$$

In cells No-D-N and T3-D-N, slopes are negative and constants are positive in each session. They are significant at 1% level, and joint F-statistic tests of slopes and constants are also significant at 1% level.

Table 3 is around here

Medians of pooled winning prices in the last five periods across the sessions are 100.5 and 98 in cells No-D-N and T3-D-N, respectively. Wilcoxon signed-rank tests do not reject the null hypothesis that the median of pooled winning prices in the last five periods across the sessions coincide with 98 in both cells No-D-N and T3-D-N (two-tailed p-values are 0.062 and 1.000, respectively). These results support that winning prices converge to 98.

In cells No-D-D and T3-D-D, however, slopes are not significant at 1% level, and joint F-statistic tests of slopes and constants are significant at 1% level. Medians of pooled winning prices in the last five periods across the sessions are 100 and 116 in cells No-D-D and T3-D-D, respectively. Wilcoxon signed-rank tests reject the null hypothesis that the median of pooled winning prices in the last five periods across sessions coincide with 98 in both cells No-D-D and T3-D-D (two-tailed p-values are 0.015 and 0.002, respectively). These results does not support that winning prices converge to 98. Therefore, Hypothesis 3 is supported in the nondisclosure condition; it is not supported in the disclosure condition. Hence, we obtain the result below.

RESULT 4. In the different cost condition, winning prices in each institution converge to the theoretical prediction of 98 in the nondisclosure condition but do not converge to the theoretical prediction in the disclosure condition.

Next we test Hypothesis 4. Wilcoxon signed-rank tests do not reject the null hypothesis of no difference in medians of winning prices between cells No-D-N and T3-D-N (z-value=0.733, two-tailed p-value=0.463) but reject the null hypothesis of no difference in medians of winning prices between cells No-D-D and T3-D-D (z-value=-4.67, two-tailed p-value=0.000). Therefore, Hypothesis 4 is supported in the nondisclosure condition; it is not supported in the disclosure condition. Hence, we obtain the result below.

RESULT 5. In the different cost condition, winning prices of the FPA with *Type 3* minimum price coincide with the ones of the standard FPA in the nondisclosure condition, but winning prices of the FPA with *Type 3* minimum price are higher than the ones of the standard FPA in the disclosure condition.

The result above implies that the information of subjects' identifications and all their bids affects the winning prices. Next we focus on this information effect within the same institution. Wilcoxon rank sum tests do not reject the null hypothesis of no difference in medians of pooled winning prices between cells No-D-N and No-D-D (z-value=-1.28, two-tailed p-value=0.199) but reject the null hypothesis of no difference in medians of pooled winning prices between cells T3-D-N and T3-D-D (z-value=3.88, two-tailed p-value=0.000). Thus, we obtain the result below.

RESULT 6. In the different cost condition, winning prices of the FPA with *Type 3* minimum price in the disclosure condition are higher than the ones in the nondisclosure condition, but winning prices of the standard FPA in the nondisclosure condition coincide with the ones in the disclosure condition.

Although winning prices in cell No-D-D do not converge to nor coincide with the theoretical prediction, since winning prices ranged from 98 to 100 and from 99 to 119 in sessions 1 and 2, respectively, apart from period 9 in session 1, they are not so far from the theoretical prediction. Winning prices in cell T3-D-D, however, are higher than the ones in cells T3-D-N and No-D-D and diverge from the theoretical prediction. Next, comparing T3-D-N and T3-D-D, we consider why winning prices in cell T3-D-N diverge from the theoretical prediction.

As described in Fact in Section 2.1, in the FPA with *Type 3* minimum price, there is no Case I Nash equilibrium such that $b_i \geq c_i$, for any i. If all producers bid prices more than their costs, producers whose costs are 97 have incentives to bid prices more than their cost not to be excluded. But, as described in Example 4 in Section 2.2, there are many Case II Nash equilibria such that $b_i < c_i$, for some i. Specifically, if a producer bids extremely low price such as 1, then since the minimum price becomes low, there is very little possibility that producers whose costs are 97 are excluded when they bid prices close to their cost.

Comparing cells T3-D-N and T3-D-D, although there are three 1 point bids in cell T3-D-D, there are many 1 point bids in cell T3-D-N. Specifically, in cell T3-D-N, producers 7, 9 and 10 in session 1 and producer 4 in session 2 repeated bidding 1, and the minimum prices became less than 80 from period 5, apart from period 10 in session 1. In cell T3-D-D, however, nobody repeated bidding 1 from period 5, and the minimum prices were higher than 105, apart from periods 6, 9 and 10 in session 1.

According to the questionnaire sheets we distributed after the experiment, producers 4 and 10 who repeated bidding 1 in cell T3-D-N changed their strategies, along the way of the experiment, to reduce payoffs of the producers whose cost are 97 by bidding extremely low prices. Their motivations seem to be similar to spiteful strategies defined by Cason et al. (2004) in the non-excludable public good experiments. They define the spiteful strategy *"if she selects a strategy reducing both her own payoff and the other subject's payoff in comparison to the payoffs when she takes an own payoff-maximizing strategy, given an expected strategy of the other subject"*[24].

We expand this definition in the meaning of the expected payoffs and apply to our result of repeated bidding 1. Since bidding a price less than the cost has a risk to obtain negative payoffs, expected payoffs of the producer whose cost is 150 are smaller when she bids 1 than when she bids 151, given any bid profiles. Her strategy of bidding 1, however, reduces not only her own expected payoffs but the ones of the producer whose cost is 97.

Given bidding prices more than 150 of producers whose costs are 150, if producers whose costs are 97 bid prices more than 97 and less than 150, they can win and the winner's payoffs ranged from 1/3 to 52[25]. On the other hand, given bidding 1 of producers whose costs are 150, the expected payoff-maximizing strategies of the producers whose costs are

[24] Cason et al. (2004), p.89, l.4-6.

[25] The minimum expected payoffs are 1/3 if three producers whose costs are 97 bid 98 and the maximum ones are 52 if only one producer whose cost is 97 bid 149 and win.

97 are bidding 98, and their expected payoffs are 1/3 at maximize. Thus, bidding 1 of producers whose costs are 150 is the spiteful strategy in the meaning of expected payoffs.

Since the disclosure of subjects' identifications and all their bids erases repeated 1 bids as the spiteful strategy, it seems to be easier for subjects to play the spiteful strategy when their identifications and actions are hidden than when this information is revealed. Thus, the nondisclosure condition leads the spiteful strategy which motivates producers whose costs are 97 to bid prices close to their costs, so that winning prices converge to the theoretical prediction of 98. The disclosure condition, however, does not lead the spiteful strategy, which motivates producers whose costs are 97 to raise their bids more than 97 not to be excluded, so that wining prices diverge from the lowest cost.

Finally, we consider the market efficiency defined by total surplus of the local government and producers. In the view of the market efficiency, the most efficient case is that the producer whose cost is 97 produces the good and sells it to the government. In cell T3-D-D, producer 10 whose cost is 150 won at her bid of 151 at period 10 in session 1, and producer 7 whose cost is 150 won at her bid of 155 at period 8 in session 2. These observations imply that the FPA with *Type 3* minimum price has a risk to lose the market efficiency when the production costs are different if governments disclose producers' identifications and all their bids. We compare the frequency of achieving the most efficient case between cells No-D-D and T3-D-D. The proportion test does not reject the null hypothesis of no difference in frequencies of achieving the most efficient case between cells No-D-D and T3-D-D (two-tailed p-value=0.146). Hence, we obtain the result below.

RESULT 7. In the different cost condition, there is no difference in market efficiencies between the FPA with *Type 3* minimum price and standard FPA.

5. CONCLUDING REMARKS

In this paper, we evaluate the performance of the FPA with endogenous minimum prices relative to the standard FPA. Theoretically, the minimum price calculated as the certain percents of the average of some of the lowest bids is the most efficient for governments and taxpayers to minimize their expenditures. Winning prices in the FPA with this type of minimum price coincide with the cost.

In the laboratory, winning prices of the FPA with the most efficient type of minimum price (i) coincide with the ones of the standard FPA and close to the cost in the identical cost condition, but (ii) are higher than the ones of the standard FPA and diverge from the lowest cost in the different cost condition when subjects' identifications and their all bids are revealed.

Higher winning prices of the FPA with endogenous minimum price due to the information condition. The nondisclosure of subjects' identifications and their all bids leads bidding 1 point as the spiteful strategy which motivates producers with the lowest costs to bid prices close to their costs, so that winning prices converge toward the lowest cost. The disclosure condition, however, does not lead bidding 1 point as the spiteful strategy, which motivates producers with the lowest costs to raise their bids not to be excluded, so that wining prices diverge from the lowest cost. These results suggests for local governments to pay attention to the information control of producers' identifications and their bids when they employ the endogenous minimum price.

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APPENDIX A.

When a bid profile is b, producer i's probability $X_i(b)$ of selling the good is : $X_i(b) = 0$ if $b_i > \min\{b_j : b_j \geq d(b)\}$, and $X_i(b) = 1/n'$ if $b_i = \min\{b_j : b_j \geq d(b)\}$, where n' is the number of bids of $\arg\min\{b_j : b_j \geq d(b)\}$. When a bid profile is b, producer i's (expected) payoff is $u_i(b) = (b_i - c_i) \cdot X_i(b)$, where c_i is producer i's cost for the good considered.

PROOF OF PROPOSITION 1. Part I: "if". Let b be a bid profile such that there is $b^* \in [c, \overline{p}]$ and $b_1 = \cdots = b_n = b^*$. We show that b is a Nash equilibrium. Let $i \in N$, and $\widehat{b}_i \in [c, \overline{p}]$. We need to show $u_i(b) \geq u_i(\widehat{b}_i, b_{-i})$. Note that $u_i(b) = (b^* - c)/n \geq 0$. If $\widehat{b}_i < b_i$, then since $2 \leq m$, together with $k = 1$, implies $\widehat{b}_i < d(\widehat{b}_i, b_{-i})$, we have $u_i(\widehat{b}_i, b_{-i}) = 0 \leq u_i(b)$. If $\widehat{b}_i > b_i$, then since $m < n$ implies $\widehat{b}_i > d(\widehat{b}_i, b_{-i})$, and there is $j \in N \backslash \{i\}$ such that $b_j = d(\widehat{b}_i, b_{-i})$, we have $u_i(\widehat{b}_i, b_{-i}) = 0 \leq u_i(b)$. Thus, b is a Nash equilibrium.

Let b be a bid profile such that there is $N' \subseteq N$ such that $\#N' \geq m + 1$ and $b_i = c$ for all $i \in N'$. Note that $u_i(b) = 0$ for all $i \in N$. Also note that for all $i \in N$ and all $\widehat{b}_i \in [c, \overline{p}]$, since $\#N' \geq m + 1$ and $b_j = c$ for all $j \in N'$, whether $i \in N'$ or $i \notin N'$, $d(\widehat{b}_i, b_{-i}) = c$ and $u_i(\widehat{b}_i, b_{-i}) = 0$. Thus, b is a Nash equilibrium.

Part II: " only if". Let b be a Nash equilibrium. We show that (1) there is $b^* \in [c, \overline{p}]$ such that $b_1 = \cdots = b_n = b^*$, or (2) there is $N' \subseteq N$ such that $\#N' \geq m + 1$ and $b_i = c$ for all $i \in N'$. Suppose that neither (1) nor (2) holds. Let $i \in N$ be such that $b_i = b^1(b)$. Since (2) does not hold, $\#\{j \in N : b_j = c\} < m$ or $\#\{j \in N : b_j = c\} = m$. We derive a contradiction in each of the following cases.

Case 1: producer i is not a winner. Note that $u_i(b) = 0$, and by $b_i = b^1(b)$, $b_i < d(b) \leq b^m(b) \leq b^{m+1}(b)$. Since $\overline{p} \geq d(\overline{p}, b_{-i})$ and $d(\cdot, b_{-i})$ is continuous in b_i, there is $\widehat{b}_i \in (b_i, \overline{p}]$ such that $\widehat{b}_i = d(\widehat{b}_i, b_{-i})$. Since $b_i < b^{m+1}(b)$, $d(\cdot, b_{-i})$ is increasing in b_i up to $b_i = b^{m+1}(b)$. Thus, $d(\widehat{b}_i, b_{-i}) > d(b) \geq c$. Therefore, $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c)/n' > 0 = u_i(b)$, where n' is the number of producers whose bids are equal to $d(\widehat{b}_i, b_{-i})$. Since b is a Nash equilibrium, this is a contradiction.

Case 2: producer i is a winner and $\#\{j \in N : b_j = c\} < m$. Since producer i is a winner, $d(b) \leq b_i$. Since (1) does not hold, there is $j \in N \backslash \{i\}$ such that $b_j > b_i$. Note $u_j(b) = 0$.

If $\#\{j' \in N : b_{j'} = c\} < m - 1$, since $c \leq d(c, b_{-j})$ and $d(\cdot, b_{-j})$ is continuous in b_j, there is $\widehat{b}_j \in (c, b_j)$ such that $\widehat{b}_j = d(\widehat{b}_j, b_{-j})$. Then, $u_j(\widehat{b}_j, b_{-j}) = (\widehat{b}_j - c)/n' > 0 = u_j(b)$, where n' is the number of producers whose bids are equal to $d(\widehat{b}_j, b_{-j})$. Since b is a Nash equilibrium, this is a contradiction.

If $\#\{j' \in N : b_{j'} = c\} = m - 1$, let $\widehat{b}_j \in (c, b^m(b))$. Then, $c < d(\widehat{b}_j, b_{-j}) < \widehat{b}_j$, and so producer j can be a single winner by bidding $\widehat{b}_j$. Thus, $u_j(\widehat{b}_j, b_{-j}) = (\widehat{b}_j - c) > 0 = u_j(b)$. Since b is a Nash equilibrium, this is also a contradiction.

Case 3: producer i is a winner and $\#\{j \in N : b_j = c\} = m$. Note that $d(b) = b_i = c$, and $u_i(b) = 0$. Also note $\#\{j \in N : b_j = c\} = m$ implies $b^{m+1}(b) > c$. Let $\widehat{b}_i \in (c, b^{m+1}(b))$. Then, $c < d(\widehat{b}_i, b_{-i}) < \widehat{b}_i$, and so producer i can be a single winner by bidding $\widehat{b}_i$. Thus, $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c) > 0 = u_i(b)$. Since b is a Nash equilibrium, this is a contradiction. QED

PROOF OF PROPOSITION 2. Let b be a Nash equilibrium. Similarly to Part II of the proof of Proposition 1, we can show that there is $b^* \in [c, \overline{p}]$ such that $b_1 = \cdots = b_n = b^*$

because (ii) cannot happen by $m = n$. Suppose $b^* < \overline{p}$. Note that $u_i(b) = (b^* - c)/n$. Let $\widehat{b}_i = \overline{p}$. Since by $m = n$ and $k = 1$, $b^* < d(\widehat{b}_i, b_{-i})$. Thus, the bids of all producers other than i are excluded, and so $u_i(\widehat{b}_i, b_{-i}) = (\overline{p} - c) > (b^* - c)/n = u_i(b)$. This is a contradiction.

Finally, we show that the bid profile b such that $b_1 = \cdots = b_n = \overline{p}$ is a Nash equilibrium. Let $i \in N$, and $\widehat{b}_i < b_i = \overline{p}$. Note that $u_i(b) = (\overline{p} - c)/n > 0$. By $m = n$ and $k = 1$, $\widehat{b}_i < d(\widehat{b}_i, b_{-i}) < \overline{p}$. Since $\widehat{b}_i$ is excluded, $u_i(\widehat{b}_i, b_{-i}) = 0 < (\overline{p} - c)/n = u_i(b)$. Thus, b is a Nash equilibrium. QED

Proof of proposition 3.

Step 1: More than one producers bid b^*. Suppose that only one producer bids b^*. This winner can raise her bid to the price slightly less than the second lowest bid, $b^* + \varepsilon < b^2$, and increase her payoffs. This is a contradiction.

Step 2: $b^* = c$. Suppose $b^* > c$.

Case 1: $d(b) < b^*$. The producer bidding b^* has an incentive to reduce her bid to $b^* - \varepsilon$ and increase her payoffs. This is a contradiction.

Case2: $d(b) = b^*$. If the producer bidding b^* raises her bid to the price slightly less than the second highest bid, $b^2 - \varepsilon$, then since she can pull the minimum price above b^* and exclude other producers bidding b^*, she can increase her payoffs. This is a contradiction.

Proof of proposition 4.

Step 1: More than one producers bid b^*. Suppose that only one producer bids b^*. This winner can raise her bid to the price slightly less than the second lowest bid, $b^* + \varepsilon < b^2$, and increase her payoffs. This is a contradiction.

Step 2: The winner is a producer whose cost is c_1. Suppose that the winner is a producer whose cost is more than or equal to c_3. Since $b^* > c_3$, the producer whose cost is c_1 can raise her bid to b^* and increase her payoffs. This is a contradiction.

Step 3: $c_1 \leq b^* < c_3$. Suppose $b^* < c_1$. Since the winner is the producer whose cost is c_1 and her payoffs are less than zero, she has an incentive to raise her bid to c_1 and increase her payoffs. This is a contradiction. Suppose $b^* \geq c_3$. **Case 1:** $d(b) < b^*$. The producer whose cost is c_1 has an incentive to reduce her bid to $b^* - \varepsilon$, and increase her payoffs. This is a contradiction. **Case2:** $d(b) = b^*$. If the producer whose cost is c_1 raises her bid to the price slightly less than the second highest bid, $b^2 - \varepsilon$, then since she can pull the minimum price above b^* and exclude other producers bidding b^*, she can increase her payoffs. This is a contradiction.

Step 4: $b^* = c_1$. Suppose $b^* > c_1$. **Case 1:** $d(b) < b^*$. The producer whose cost is c_1 has an incentive to reduce her bid to $b^* - \varepsilon$ and increase her payoffs. This is a contradiction. **Case2:** $d(b) = b^*$. If the producer whose cost is c_1 raises her bid to the price slightly less than the second highest bid, $b^2 - \varepsilon$, then since she can pull the minimum price above b^* and exclude other producers bidding b^*, she can increase her payoffs. This is a contradiction.

In the following, we assume that bids are nonnegative integers and that producer 1 has the lowest cost, producer 2 has the second lowest cost, and so on, that is, $c_1 \leq c_2 \leq \cdots \leq c_n$. Given a bid profile b, let $b^*(b)$ be the winning bid of b, that is, $b^*(b) = \min\{b_i : i \in N$ and $b_i \geq d(b)\}$.

Lemma 1: In a Nash equilibrium b such that $b_i \geq c_i$ for every i, no bid is excluded by $d(b)$, that is, $b^1(b) \geq d(b)$.

PROOF. Suppose that there is a bid b_i excluded by $d(b)$, that is, $b_i < d(b)$. Note that $u_i(b) = 0$. Let $\widehat{b}_i = b^*(b)$. If producer i can be a winner by bidding $\widehat{b}_i$, that is, $\widehat{b}_i = \min\{b_j : j \in N \text{ and } b_j \geq d(\widehat{b}_i, b_{-i})\}$, then since $\widehat{b}_i = b^*(b) \geq d(b) > b_i > c_i$, and $X_i(\widehat{b}_i, b_{-i}) > 0$, it follows that $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c_i) \cdot X_i(\widehat{b}_i, b_{-i}) > 0 = u_i(b)$. This is a contradiction to Nash equilibrium. Let $\widetilde{b}_i = b^m(b)$, that is, $\widetilde{b}_i$ is equal to the $m-$th lowest bid among $\{b_1, \ldots, b_n\}$. Note that $\widetilde{b}_i > d(\widetilde{b}_i, b_{-i}) \geq d(\widehat{b}_i, b_{-i}) \geq d(b)$. Thus, if producer i cannot be a winner by bidding $\widehat{b}_i$, then producer i can be a winner by bidding some $\overline{b}_i \in [b^*(b), b^m(b)]$, and similarly he can obtain a positive $u_i(\overline{b}_i, b_{-i})$. This is also a contradiction to Nash equilibrium. QED

REMARK: In the Nash equilibrium b such that $b_i \geq c_i$ for all i, $b^*(b) = \min\{b_i : i \in N\}$.

LEMMA 2: Let $b_i \geq c_i$ for all i. In the Nash equilibrium b, for all $i \in N$, if $b^*(b) > c_i$, $b_i = b^*(b)$.

PROOF. Suppose that $b^*(b) > c_i$, and $b_i \neq b^*(b)$ for some $i \in N$. By Lemma 1, for all $i \in N$, $b_i \geq b^*(b) \geq d(b)$. Thus, $b_i > b^*(b) > c_i$. By $b_i > b^*(b)$, $u_i(b) = 0$. Let $\widehat{b}_i = b^*(b)$. Note that $d(\widehat{b}_i, b_{-i}) \leq d(b) \leq b^*(b) = \widehat{b}_i$. By Lemma 1, for all $j \in N$, $b_j \geq b^*(b) = \widehat{b}_i$. Thus, producer i can be a winner by bidding $\widehat{b}_i$, that is, $\widehat{b}_i = \min\{b_j : j \in N \text{ and } b_j \geq d(\widehat{b}_j, b_{-1})\}$. Since $\widehat{b}_i = b^*(b) > c_i$, and $X_i(\widehat{b}_i, b_{-i}) > 0$, it follows that $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c_i) \cdot X_i(\widehat{b}_i, b_{-i}) > 0 = u_i(b)$. This is a contradiction to Nash equilibrium. Thus, for all $i \in N$, if $b^*(b) > c_i$, $b_i = b^*(b)$. QED

LEMMA 3: In the Nash equilibrium b such that $b_i \geq c_i$ for all i, if $b^*(b) > \max\{c_1 + 2, c_2\}$, then $d(b) \in (b^*(b) - 1, b^*(b)]$.

PROOF. Suppose $b^*(b) > \max\{c_1 + 2, c_2\}$ and $d(b) \leq b^*(b) - 1$. Since Lemma 2 implies $b_1 = b_2 = b^*(b)$, $X_1(b) \leq 1/2$. Thus, $u_1(b) = (b_1 - c_1) \cdot X_1(b) \leq (b_1 - c_1)/2$. Note

$$\begin{aligned} b^*(b) > c_1 + 2 \quad &\Rightarrow \quad 2 \cdot \{b^*(b) - c_1\} - 2 > b^*(b) - c_1 \\ &\Rightarrow \quad \{b^*(b) - 1 - c_1\} > (b_1 - c_1)/2. \end{aligned}$$

By bidding $b^*(b) - 1$, producer 1 can be a single winner and can obtain the payoff $(b^*(b) - 1 - c_1) > (b_1 - c_1)/2 = u_1(b)$. This is a contradiction to Nash equilibrium. Thus, $d(b) \in (b^*(b) - 1, b^*(b)]$. QED

LEMMA 4: In the Nash equilibrium b such that $b_i \geq c_i$ for all i, $b^1(b) = b^*(b) \leq b^2(b) \leq b^*(b) + 1$.

PROOF. By Lemma 1, $b^1(b) = b^*(b) \geq d(b)$. By definition, $b^1(b) \leq b^2(b)$. Thus, we show $b^2(b) \leq b^*(b) + 1$. Suppose $b^2(b) > b^*(b) + 1$. Let $i \in N$ be such that $b_i = b^1(b)$. Let $\widehat{b}_i = b^*(b) + 1$. Then, $u_i(\widehat{b}_i, u_{-i}) = b^*(b) + 1 - c_i > b^*(b) - c_i = u_i(b)$. This is a contradiction to Nash equilibrium. QED

CLAIM: Let $n = 10, m = 5, k = 4/5, c_1 = c_2 = c_3 = 97, c_4 = \cdots = c_{10} = 150$. There is no Nash equilibrium such that every producer bids a price more than or equal to her cost.

PROOF. Suppose there is a Nash equilibrium b such that $b_i \geq c_i$ for all i. Since $b_i \geq c_i$ for all i, it follows that for all $i \in N$, $c_i < b_i$ and $c_i < b^i(b)$. Note that $b^*(b) \geq b^1(b) \geq c_1 = 98$. We derive a contradiction in each of the following cases.

Case 1. $b^*(b) \geq 151$. $(b^*(b) \geq c_5 + 1.)$

By Lemma 2 and $b^*(b) > c_5$, $b_1 = \cdots = b_5 = b^*(b)$. Thus, by Lemma 1, $b^1(b) = \cdots = b^5(b) = b^*(b)$, and so $d(b) = (4/5) \cdot b^*(b)$. By Lemma 3, $(4/5) \cdot b^*(b) > b^*(b) - 1$. This inequality implies $b^*(b) < 5$. This is a contradiction to $b^*(b) \geq 151$.

Case 2. $98 \leq b^*(b) \leq 150$. $(c_3 + 1 \leq b^*(b) \leq c_4.)$

By Lemma 2 and $b^*(b) > c_3$, $b_1 = b_2 = b_3 = b^*(b)$. Thus, by Lemma 1, $b^1(b) = b^2(b) = b^3(b) = b^*(b)$, and so $d(b) = (4/5) \cdot [3 \cdot b^*(b) + b^4(b) + b^5(b)]/5$. Since $b_i \geq c_i$, $b^4(b) \geq 151$ and $b^5(b) \geq 151$. Note that $u_3(b) = [b^*(b) - 97]/3 \leq [150 - 97]/3$.

By Lemma 3, $b^*(b) - 1 < (4/5) \cdot [3 \cdot b^*(b) + b^4(b) + b^5(b)]/5$. Thus, $[13 \cdot b^*(b) - 25]/4 < b^4(b) + b^5(b)$. Let $\widehat{b}_3 = b^4(b)$.

We show $d(\widehat{b}_3, b_{-3}) > b^*(b) = b_1 = b_2$. Suppose $d(\widehat{b}_3, b_{-3}) \leq b^*(b)$. Since $[13 \cdot b^*(b) - 25]/4 < b^4(b) + b^5(b)$, $[13 \cdot b^*(b) - 25]/4 - b^5(b) < b^4(b)$. Thus,

$$\begin{aligned}
& b^*(b) \\
\geq\ & d(\widehat{b}_3, b_{-3}) \\
=\ & \frac{4}{5} \cdot \frac{2 \cdot b^*(b) + b^4(b) + b^4(b) + b^5(b)}{5} \\
=\ & \frac{4}{25} \cdot \left[2 \cdot b^*(b) + 2 \cdot b^4(b) + b^5(b)\right] \\
>\ & \frac{4}{25} \cdot \left[2 \cdot b^*(b) + 2 \cdot \frac{13 \cdot b^*(b) - 25}{4} - 2 \cdot b^5(b) + b^5(b)\right] \quad \text{by } b^4(b) > \frac{13 \cdot b^*(b) - 25}{4} - b^5(b) \\
=\ & \frac{1}{25} \cdot \left[8 \cdot b^*(b) + 2 \cdot \{13 \cdot b^*(b) - 25\} - 4 \cdot b^5(b)\right] \\
=\ & \frac{1}{25} \cdot \left[34 \cdot b^*(b) - 50 - 4 \cdot b^5(b)\right].
\end{aligned}$$

Therefore,

$$\begin{aligned}
b^*(b) &> \frac{1}{25} \cdot \left[34 \cdot b^*(b) - 50 - 4 \cdot b^5(b)\right] \\
25 \cdot b^*(b) &> 34 \cdot b^*(b) - 50 - 4 \cdot b^5(b) \\
4 \cdot b^5(b) &> 9 \cdot b^*(b) - 50 \\
b^5(b) &> [9 \cdot b^*(b) - 50]/4.
\end{aligned}$$

Let $\widehat{b}_4 = b_5$. Then,

$$\begin{aligned}
d(\widehat{b}_4, b_{-4}) &= \frac{4}{5} \cdot \frac{3 \cdot b^*(b) + 2 \cdot b^5(b)}{5} \\
&> \frac{4}{25} \cdot \left[3 \cdot b^*(b) + 2 \cdot \frac{9 \cdot b^*(b) - 50}{4}\right] \quad \text{by } b^5(b) > \frac{9 \cdot b^*(b) - 50}{4} \\
&= \frac{1}{25} \cdot [30 \cdot b^*(b) - 100].
\end{aligned}$$

Thus, if $d(\widehat{b}_4, b_{-4}) \leq b^*(b)$, then $\frac{1}{25} \cdot [30 \cdot b^*(b) - 100] < b^*(b)$. This inequality implies $b^*(b) < 20$. This is a contradiction to $b^*(b) \geq 98$. Thus, $d(\widehat{b}_4, b_{-4}) > b^*(b) = b_1 = b_2 = b_3$. Since $d(\widehat{b}_4, b_{-4}) \leq b^5(b) = \widehat{b}_4$, $X_4(\widehat{b}_4, b_{-4}) \geq 1/2$, and so

$$u_4(\widehat{b}_4, b_{-4}) \geq [b^5(b) - c_4]/2 \geq [151 - 150]/2 > 0 = u_3(b).$$

Since b is a Nash equilibrium, this is a contradiction. Therefore, $d(\widehat{b}_3, b_{-3}) > b^*(b) = b_1 = b_2$.

Note

$$\begin{aligned}
d(\widehat{b}_3, b_{-3}) &= \frac{4}{5} \cdot \frac{2 \cdot b^*(b) + b^4(b) + b^4(b) + b^5(b)}{5} \\
&= \frac{4}{25} \cdot \left[3 \cdot b^*(b) + \{b^4(b) - b^*(b)\} + b^4(b) + b^5(b)\right] \\
&= \frac{4}{25} \cdot \left[3 \cdot b^*(b) + b^4(b) + b^5(b)\right] + \frac{4}{25} \cdot \{b^4(b) - b^*(b)\} \\
&= d(b) + \frac{4}{25} \cdot \{b^4(b) - b^*(b)\} \\
&\leq b^*(b) + \frac{4}{25} \cdot \{b^4(b) - b^*(b)\} \\
&< b^*(b) + \{b^4(b) - b^*(b)\} = b^4(b).
\end{aligned}$$

Therefore, $d(\widehat{b}_3, b_{-3}) \leq b^4(b) = \widehat{b}_3$. Thus, $X_3(\widehat{b}_3, b_{-3}) \geq 1/2$, and so

$$u_3(\widehat{b}_3, b_{-3}) \geq [b^4(b) - c_3]/2 \geq [151 - 97]/2 > [150 - 97]/3 \geq u_3(b).$$

Since b is a Nash equilibrium, this is a contradiction.. QED

Appendix B.

Here, we show the Nash equilibrium in the FPA with *Type 3* minimum price ($k < 1$ and $m < n$) and the FPA with *Type 4* minimum price ($k < 1$ and $m = n$) in Propositions 1 and 2 below, respectively.

Proposition 1. In the FPA with *Type 3* minimum price ($k < 1$ and $m < n$), a bid profile b is a Nash equilibrium if and only if there is a set of positive integers $\{n_l\}_{l=1}^{m'}$ such that
(1) $b^1 = \cdots = b^{n_1} < b^{n_1+1} = \cdots = b^{n_1+n_2} < \cdots < b^{n_1+\cdots+n_{m'-1}+1} = \cdots = b^{n_1+\cdots+n_{m'}}$,
(2) $n_1 + \cdots + n_{m'-1} \leq m$, $n_1 + \cdots + n_{m'} \geq m+1$,
(3) $b^1 = c$,
(4) $d(b) \leq c$,
(5) $n_1 \geq 2$,
(6) for all $l \in \{1, 2, \ldots, m'\}$,

6-i) if $n_l = 1$, then
$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^m)/m \leq b^{n_1+\cdots+n_{l-1}}$,

6-ii) if $n_l \geq 2$, then
$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^m)/m \leq b^{n_1+\cdots+n_l}$,

and 6-iii) for all $l' \in \{l+1, \ldots, m'\}$,
$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_{l'}+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^m)/m \leq b^{n_1+\cdots+n_{l'}}$.

Proof. Part I: "if". Let b be a bid profile such that there is a set of positive integers $\{n_l\}_{l=1}^{m'}$ such that Conditions (1)-(6) hold. We show that b is a Nash equilibrium. Let $i \in N$, and $\widehat{b}_i \in [c, \overline{p}]$. We need to show $u_i(b) \geq u_i(\widehat{b}_i, b_{-i})$. Since (3) and (4) imply $b^1 = c$ is a winning bid, $u_i(b) = 0$. If $\widehat{b}_i < b_i$, then since $d(\widehat{b}_i, b_{-i}) \leq d(b) \leq c$, $b^1 = c$ is still a winning bid, and so we have $u_i(\widehat{b}_i, b_{-i}) = 0 = u_i(b)$. If $\widehat{b}_i > b_i$, then since (5) and (6) imply that when $\widehat{b}_i$ raises the minimum price, $\widehat{b}_i$ cannot be a winning bid, we have $u_i(\widehat{b}_i, b_{-i}) = 0 = u_i(b)$. Thus, b is a Nash equilibrium.

Part II: "only if". Let b be a Nash equilibrium. It is trivial to construct a set of positive integers $\{n_l\}_{l=1}^{m'}$ satisfying (1) and (2). We show that $\{n_l\}_{l=1}^{m'}$ satisfies (3)-(6).

Let $i \in N$ be such that $b_i = b^1(b)$. We show i is a winner. Suppose not. Then, $u_i(b) = 0$, and by $b_i = b^1(b)$, $c \leq b_i < d(b) \leq b^m(b) \leq b^{m+1}(b)$. Since $\overline{p} \geq d(\overline{p}, b_{-i})$ and $d(\cdot, b_{-i})$ is continuous in b_i, there is $\widehat{b}_i \in (b_i, \overline{p}]$ such that $\widehat{b}_i = d(\widehat{b}_i, b_{-i})$. Since $d(\widehat{b}_i, b_{-i}) \geq d(b) > c$, $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c)/n' > 0 = u_i(b)$, where n' is the number of producers whose bids are equal to $d(\widehat{b}_i, b_{-i})$. Since b is a Nash equilibrium, this is a contradiction.

We show (3). Suppose $b^1 > c$. First, consider the case that $b^1 = \cdots = b^n$. Note that $u_1(b) = (b^1 - c)/n > 0$. Since $k \in (0, 1)$, $d(b) < b^1$. Note that for all $\widehat{b}_1 \in (\max\{d(b), c\}, b^1)$, $d(\widehat{b}_1, b_{-1}) < d(b) < \widehat{b}_1$, and $u_1(\widehat{b}_1, b_{-1}) = (\widehat{b}_i - c)$. Thus since $(b^1 - c)/n > 0$, for $\widehat{b}_1$ close to b^1, $u_1(\widehat{b}_1, b_{-1}) = (\widehat{b}_1 - c) > (b^1 - c)/n = u_1(b)$. This is a contradiction. Next, consider the case that $b_j > b^1$ for some $j \in N$. Since j is not a winner, $u_j(b) = 0$. Since b^1 is a winning bid, by bidding $\widehat{b}_j = b^1$, j can be a winner, and obtain $u_j(\widehat{b}_j, b_{-j}) = (\widehat{b}_j - c)/(n_1 + 1) > 0 = u_j(b)$. Since b is a Nash equilibrium, this is a contradiction. Therefore, (3) holds.

Since b^1 is a winning bid, (3) implies (4).

We show (5) $n_1 \geq 2$. Suppose $n_1 = 1$. Then, $b^2 > b^1$. Note that (3) implies $u_i(b) = 0$. Let $\widehat{b}_i \in (c, b^2)$. Then, since (4) implies $d(\widehat{b}_i, b_{-i}) \leq \widehat{b}_i$, by bidding $\widehat{b}_i$, i is still a single winner and obtains $u_i(\widehat{b}_i, b_{-i}) = (\widehat{b}_i - c) > 0 = u_i(b)$. Since b is a Nash equilibrium, this is a contradiction. Therefore, (5) holds.

Let $l \in \{1, \ldots, m'\}$. We show 6-i). Suppose that $n_l = 1$, and

$$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^m)/m > b^{n_1+\cdots+n_{l-1}}.$$

Let $j = n_1 + \cdots + n_{l-1} + 1$. Note that by (3) and (4), $u_j(b) = 0$. If j bids $\widehat{b}_j = b^{n_1+\cdots+n_l+1}$, then since $k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^m)/m > b^{n_1+\cdots+n_{l-1}}$, all the producers whose bids are lower than or equal to $b^{n_1+\cdots+n_{l-1}}$ are excluded, and j can be a winner and obtain $u_j(\widehat{b}_j, b_{-i}) = (\widehat{b}_j - c)/(n_{l+1} + 1) > 0 = u_j(b)$. Since b is a Nash equilibrium, this is a contradiction. Therefore, 6-i) holds. Similarly, we can show 6-ii) and 6-iii). QED

PROPOSITION 2. In the FPA with *Type 4* minimum price ($k < 1$ and $m = n$), a bid profile b is a Nash equilibrium if and only if there is a set of positive integers $\{n_l\}_{l=1}^{m'}$ satisfying (1), (3), (4), (5) of Proposition 2, and (2$\prime$), (6$\prime$) below:

(2$\prime$) $n_1 + \cdots + n_{m'} = n$.

(6$\prime$) for all $l \in \{1, 2, \ldots, m' - 1\}$,

$6 - i\prime$) if $n_l = 1$, then

$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^n)/n \leq b^{n_1+\cdots+n_{l-1}}$,

$6 - ii\prime$) if $n_l \geq 2$, then

$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_l+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^n)/n \leq b^{n_1+\cdots+n_l}$,

$6 - iii\prime$) for all $l' \in \{l + 1, \ldots, m' - 1\}$,

$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + b^{n_1+\cdots+n_{l'}+1} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^n)/n \leq b^{n_1+\cdots+n_{l'}}$,

$6 - iv\prime$) $k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{l-1}} + \overline{p} + b^{n_1+\cdots+n_{l-1}+2} + \cdots + b^n)/n \leq b^n$,

$6 - v\prime$) if $n_{m'} = 1$, then

$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{m'-1}} + \overline{p})/n \leq b^{n-1}$,

and $6 - vi\prime$) if $n_{m'} \geq 2$, then

$k \cdot (b^1 + \cdots + b^{n_1+\cdots+n_{m'-1}} + \overline{p} + b^{n_1+\cdots+n_{m'-1}+2} + \cdots + b^n)/n \leq b^n$.

PROOF is similar to Proposition 2.

CLAIM. Let $n = 10$, $m = 5$, $k = 4/5$, $c = 97$, and $\overline{p} = 600$. There is no pure Nash equilibrium satisfied with Proposition 2.

PROOF. Let $n = 5$, $k = 8/10$, $c = 97$, and $\overline{p} = 600$. Suppose that for a bid profile b, a set of positive integers $\{n_l\}_{l=1}^{m'}$ satisfying (1), (2$\prime$), (3), (4), (5), (6$\prime$) exists. Without loss of generality, let $b_1 \leq b_2 \leq b_3 \leq b_4 \leq b_5$. By (3) and (5), $b_1 = b_2 = 97$. Thus, by (4), $d(b) = (97 + 97 + b_3 + b_4 + b_5) \cdot k/m \leq c$, that is, $b_3 + b_4 + b_5 \leq c \cdot m/k - 194 = 485/0.8 - 194 \simeq 412$. By $(6 - v\prime)$, $d(b) = (97 + 97 + b_3 + b_4 + \overline{p}) \cdot k/m \leq b_4$, that is, $b_4 \geq (194 + b_3 + \overline{p}) \cdot k/(m - k) = (194 + b_3 + 600) \cdot 0.8/(5 - 0.8)$. Since $97 \leq b_3$ and $b_4 \leq b_5$, $b_5 \geq b_4 \geq (194 + 97 + 600) \cdot 0.8/(5 - 0.8) \simeq 169$. Thus, $b_3 + b_4 + b_5 \geq 97 + 2 \cdot (194 + 97 + 600) \cdot 0.8/(5 - 0.8) \simeq 436$. This is a contradiction. Hence, for no bid profile, a set of positive integers $\{n_l\}_{l=1}^{m'}$ satisfying (1), (2$\prime$), (3), (4), (5), (6$\prime$) exists, and there is no Nash equilibrium. QED

Appendix C. Instructions and PC operation manuals

Instructions (of cell T3-I-D)

In this experiment, every subject makes a decision on selling the goods to the experimenter. Please understand the rules of the experiment well, make an appropriate decision, and earn as much rewards as possible.

Outline of the experiment

In this experiment, you will be assigned a role of a producer, and sell a “good” to the experimenter. The number of subjects participating in this experiment is 10 people in total. Each subject acts the role of the producer. The computer acts as the experimenter. The experiment will be repeated 10 periods. In each period, the experimenter purchases a good from a producer according to pre-determined certain rules. Following explains the rules of purchasing a good for the experimenter acted by the computer and the role of a producer every subject acts.

The purchasing rules of the experimenter

First, we explain the purchasing rules of the experimenter acted by the computer. The experimenter purchases one unit of “good” from one of 10 producers according to the rules below. The purchasing rules of the experimenter are as follows.

First of all, the experimenter asks all 10 producers to submit the selling prices for the good through computer display. Money used in this experiment is measured by “point” of a fictitious monetary unit. The experimenter purchases a good at the selling price less than or equal to 243 points. Therefore, the maximum selling price of you as the producer can submit to the experimenter is 243 pt. Note that selling prices you can submit are only integers. You have three minutes to input your selling price on your computer screen. Note that you cannot cancel the selling price once you have submitted it to the experimenter.

Next, the experimenter selects five producers in the order of the lowest selling prices. The experimenter calculates the average selling price of these five producers. Then, this average is multiplied by 0.8. The experimenter selects one producer whose selling price is the lowest among all the producers who have submitted the selling prices higher than or equal to “0.8 × (average selling price of lowest five producers)”. The experimenter purchases the good from that producer at the selling price he/she has submitted.

If there are two or more producers who have submitted that price, then the experimenter randomly selects one of them and purchases the goods from that producer.

Roles of producers

We explain the role of the producer you act. Before the beginning of the experiment, every subject will be assigned to a producer's identification number from 1 to 10 by a lottery. Once you receive a producer's number, that number will not change throughout the experiment.

Each producer can produce one unit of good at "production costs". The production cost of a good are common among all producers and it is 97 pt. The quality of the good any producers produce is same.

When a producer is selected by the experimenter, he/she is to produce a good and sell it to the experimenter to get "sales revenues". Since the unit of goods you can sell is one unit, the sales revenue is equal to the selling price to the experimenter, i.e. equal to the purchase price of the experimenter. The difference between the sales revenue and the production cost of the good is a "profit" the producer earns from the production and sales. That is, "profit = purchase price of the experimenter – production cost of the good."

However, producers who do not sell the good to the experimenter do not produce a good. In this case, these producers do not earn sales revenues but have no production cost incurred either, so his/her profit is 0 pt.

Purchasing rules of the experimenter and an example of the way to calculate producers' profits

This section explains the purchasing rules of the experimenter and the example of way to calculate producers' profits by using actual numbers. Although the experimenter do not purchase any goods with the selling price higher than 243 points in the experiment, here we assume that the experimenter can purchase a good at the price higher than 243 points, and explain the example.

For example, producers number 1 to 10 submit the following selling prices respectively as their selling prices: 3000 pt, 4000 pt, 5000 pt, 6000 pt, 7000 pt, 8000 pt, 5000 pt, 3000 pt, 4000 pt and 9000 pt. Five lowest prices are 3000 pt = 3000 pt < 4000 pt = 4000 pt < 5000 pt. The average of these prices is (3000 + 3000 + 4000 + 4000 + 5000) / 5 = 3800 pt. Multiplying this with 0.8, we get 3800 × 0.8 = 3040 pt. All the selling prices equal to or higher than this number are 4000 pt = 4000 pt < 5000 pt =

5000 pt < 6000 pt < 7000 pt < 8000 pt < 9000 pt. The lowest price is 4000 pt among them. However, there are two producers who have submitted 4000 pt of selling price. Therefore, one of them will be selected with the probability of 1/2, and that producer sells the good to the experimenter.

At this point, the producer selected by the experimenter is to produce a good at the production cost of 97 pt so that this producer's profit is 4000 – 97 = 3903 pt. All other producers' profits are 0 pt.

Let us repeat that, in the actual experiment, the experimenter purchases the good at the price lower than or equal to 243 pt. Every subject decide what selling price you are to submit to the experimenter, while taking account of what selling prices other producers submit, and try to earn as much rewards as possible.

Completion of the experiment and the calculation of rewards

Once all the producers submit their selling prices, the experimenter notify all producers from whom the experimenter purchases a good according to the rules as we explained earlier.

The experimenter discloses the following 4 types of information to all producers: "producer's identification number from whom the experimenter purchase a good", "the purchasing price of the experimenter", "average of five lowest selling prices", and "0.8 × (average of lowest five selling prices)". At this point, the first period finishes. Once the first period finishes, the second period will start with same procedures. At the time 10th period finishes this experiment is completed.

After the end of the experiment, the rewards each subject receives is calculated from total profits of the producer each subject acts. Specifically, the rewards to each subject after the end of the experiment are calculated as the following formula.

Rewards after the end of the experiment = (50 pt + Gross profit) × 30 Yen

We explain about this formula in detail. At the beginning of the experiment, each subject is given 50 pt only once. Total profits as the sum of the profits of producer you act for 10 periods are added to the 50 pts. However, profits can be minus in the experiment. If you submit the selling price below the production cost and the experimenter purchases the goods at that selling price, your profit will be minus. If the total profits as the sum of profits for 10 periods are minus, it will be subtracted from 50 pts given to you at the beginning of the experiment. Each subject receives the rewards in cash under the conversion rate of 1 pt = 30 yen. Please try to earn as much rewards as possible.

Above is the content of today's experiment. During the experiment, do not talk to others, and follow orders of the experimenter. You make a decision in the experiment by the software that operates on the personal computer assigned to each subject. The attached "PC Operation Manual" describes how to operate the PC. We will explain about this manual after the next reading period of "questions and answers on instructions".

Different production cost condition

Roles of producers

We explain roles of producers you act. Before the beginning of the experiment, every subject will be assigned to a producer identification number from 1 to 10 by a lottery. Once you receive a producer number, that number will not change throughout the experiment.

Each producer can produce one unit of good at "production cost". Production costs of a good are in the table below.

Producer No.	1	2	3	4	5	6	7	8	9	10
Cost	150 pt	97 pt	150 pt	150 pt	97 pt	150 pt	150 pt	97 pt	150 pt	150 pt

Producer number 1 has the production cost of 150 pt, No. 2 has 97 pt, No. 3 150 pt, No. 4 150 pt, No. 5 97 pt, No. 6 150 pt, No. 7 150 pt, No. 8 97 pt, No. 9 150 pt, and No. 10 150 pt. The quality of goods any producers produce is the same.

When a producer is selected by the experimenter, he/she is to produce a good and sell it to the experimenter to get "sales revenue". Since the unit of goods sold is one unit, the sales revenue is equal to the selling price to the experimenter, i.e. equal to the purchase price of the experimenter. The difference between the sales revenue and the production cost of the good is the "profit" the producer earns from the production and sales. In other words, "profit = purchase price of the experimenter – production cost of the good."

However, producers who do not sell the good to the experimenter do not produce a good. In this case, these producers do not earn sales revenue but have no production cost incurred either, so his/her profit is 0 pt.

Purchasing rules of the experimenter and an example of the way to calculate producers' profits

This section explains the purchasing rules of the experimenter and the example of way to calculate producers' profits by using actual numbers. Although the experimenter do not purchase any goods with the selling price higher than 243 points in the experiment, here we allow the experimenter to purchase a good at the price higher than 243 points and explain the example.

For example, producers number 1 to 10 submit the following selling prices respectively as their selling prices: 3000 pt, 4000 pt, 5000 pt, 6000 pt, 7000 pt, 8000 pt, 5000 pt, 3000 pt, 4000 pt and 9000 pt. Five lowest prices are 3000 pt = 3000 pt < 4000 pt = 4000 pt < 5000 pt. The average of these prices is (3000 + 3000 + 4000 + 4000 + 5000) / 5 = 3800 pt. Multiplying this with 0.8, we get: 3800 × 0.8 = 3040 pt. All the selling prices equal to or higher than this number are 4000 pt = 4000 pt < 5000 pt = 5000 pt < 6000 pt < 7000 pt < 8000 pt < 9000 pt. The lowest price is 4000 pt among them. However, there are two producers who have submitted 4000 pt of selling price. Therefore, one of them will be selected with the probability of 1/2, and that producer sells the good to the experimenter.

At this point, if the producer with production cost of 97 pt is selected, then he/she produces a good at 97pt, so his/her profit is 4000 – 97 = 3903 pt. If the selected producer has the production cost of 150 pt, then he/she manufactures goods at the cost of 150 pt, and his/her profit is 4000 – 150 = 3850 pt. All other producers' profits are 0 pt.

Let us repeat that, in the actual experiment, the experimenter purchases the good at the price lower than or equal to 243 pt. Every subject decide what selling price you are to submit to the experimenter, while taking account of what selling prices other producers submit, and try to earn as much rewards as possible.

Nondisclosure condition

Completion of the experiment and the calculation of rewards

Once all the producers submit their selling prices, the experimenter notify all producers from whom the experimenter purchases a good according to the rules as we explained earlier.

The experimenter discloses the following 4 types of information to all producers: "producer's identification number from whom the experimenter purchase a good", "the purchasing price of the experimenter", "average of five lowest selling prices", and "0.8 × (average of lowest five selling prices)". At this point, the first period finishes. Once the first period finishes, the second period will start with same procedures. At the time 10th period finishes this experiment is completed.

After the end of the experiment, the rewards each subject receives are calculated from total profits of the producer each subject acts. Specifically, the rewards to each subject after the end of the experiment are calculated as the following formula.

Rewards after the end of the experiment = (50 pt + Gross profit) × 30 Yen

We explain about this formula in detail. At the beginning of the experiment, each subject is given 50 pt only once. Total profits as the sum of the profits of producer you act for 10 periods are added to the 50 pt. However, profits can be minus in the experiment. If you submit the selling price below the production cost and the experimenter purchases the goods at that selling price, your profit will be minus. If the total profits as the sum of profits for 10 periods are minus, it will be subtracted from 50 pts given to you at the beginning of the experiment. Each subject receives the rewards in cash under the conversion rate of 1 pt = 30 yen.

The experimenter will not disclose to other subjects whom is assigned to which producer number during and after the experiment. Therefore, try to earn as much rewards as possible without concern for others. Please try to earn as much rewards as possible.

Cells T3-I-N and No-I-N

Completion of the experiment and the calculation of rewards

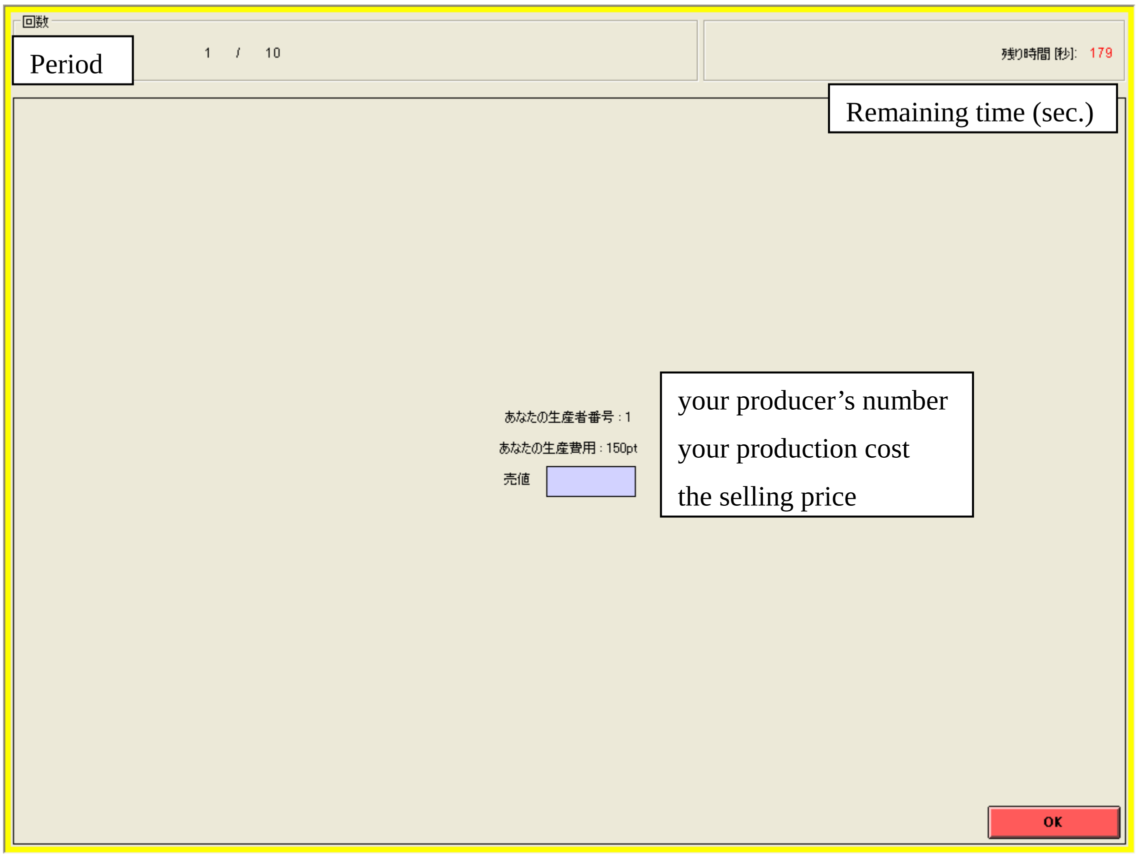
After the end of the experiment, the rewards for each subject are calculated from total profits of the producer each subject acts. Although every subject cannot know the formula to calculate the rewards, that formula is common among all subjects and have a feature that greater the total profit of the producer you act the greater the rewards.

At the beginning of the experiment, the profit of each producer is 0 pt. If you submit the selling price below the production cost and the experimenter purchases the goods at that selling price, your profit will be minus. Even if the total profits are 0 pt or minus, each subject is guaranteed to receive the minimum rewards. We cannot tell you how much the minimum rewards are. The rewards paid to the subject with the negative total profits are the same regardless of how big the negative profits are. Moreover, the subject with the negative total profits and the subject with 0 pt will receive the same minimum rewards.

The experimenter will not disclose to other subjects whom is assigned to which producer number during and after the experiment. Therefore, try to earn as much rewards as possible without concern for others.

PC operation manuals

In the experiment, each subject sells a good to the experimenter by using the PC assigned to each of them. We explain screens of the software we use in the experiment and how to manipulate it as follows.

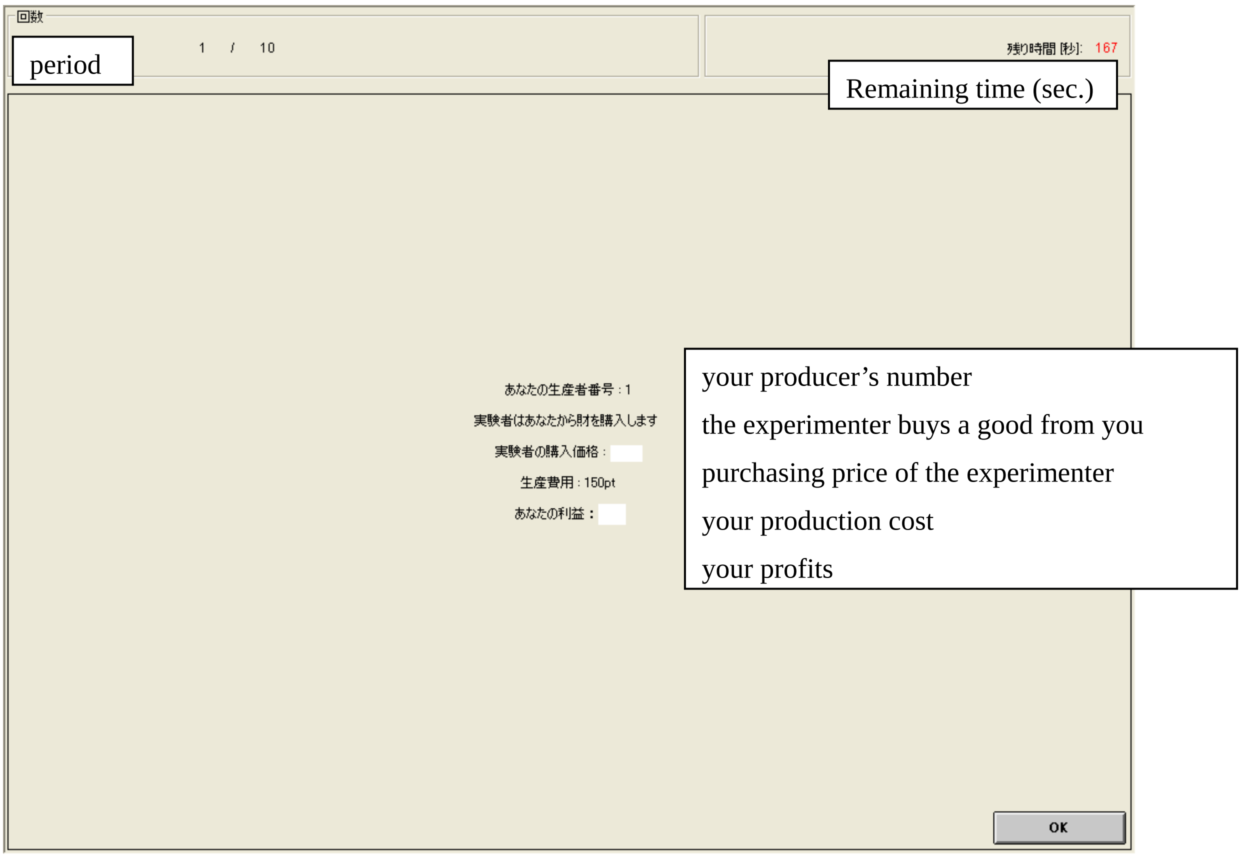


Screen 1

As soon as period 1 starts, the experimenter asks each producer to submit a selling price. Screen 1 is shown in the screen of the PC in front of every subject.

Please see screen 1. In the center of this screen, “your producer’s number”, “your production cost”, and a cell you submit a “selling price” are displayed. In this example, the cell of “your producer’s number” displays producer 1. Producer 1’s production cost is 150 pt so that the cell of “your production cost” displays 150 pt. **Any subjects submit integers between 1 pt and 243 pt (limits included). Every subject inputs the selling price and then writes that selling price in the cell in the record sheet. After you complete writing, click OK button in the upper-right corner of the screen. Note you can neither cancel nor correct once you click OK button. Please pay attention about it carefully.**

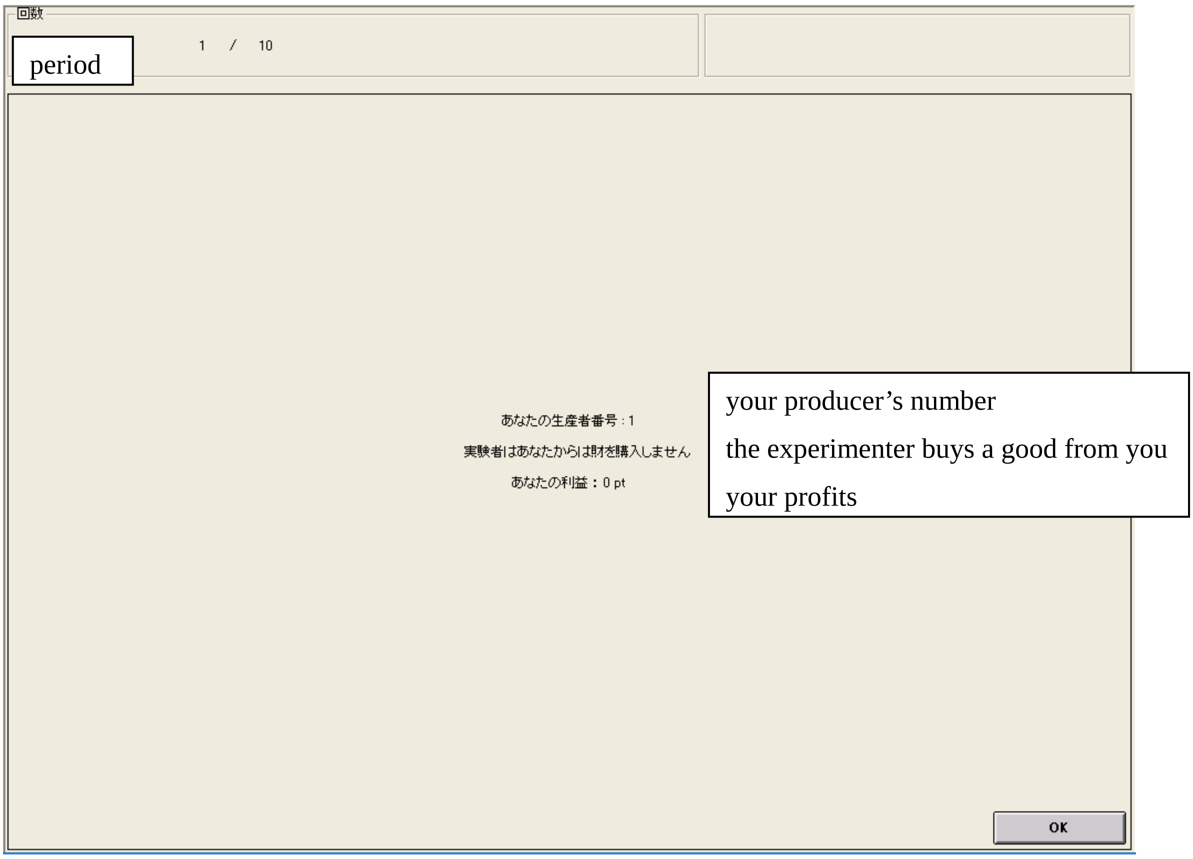
Additionally, “period” in the upper-left corner of the screen displays what period is in the experiment. In screen 1, it displays “1/10” as shown period 1. “Remaining period” in the upper-right corner of the screen displays how long you have left for submitting a selling price to the experimenter. Any subjects input the selling prices within 3 minutes (180 seconds). You necessarily input the selling price. The experimenter encourages subjects who do not input yet after the remaining time elapse 0 to input the selling price. Notice once all subjects click OK button, the experimenter start purchasing procedures even though 3 minutes do not elapse.



Screen 2

If the experimenter purchases the good from you, screen 2 is displayed. From the top of the display, “your producer’s number”, “the experimenter buys a good from you”, “purchasing price of the experimenter”, “production cost”, and “your profits” are displayed. In this example, the cell of “your producer’s number” displays producer 1. Producer 1’s production cost is 150 pt so that the cell of “your production cost” displays 150 pt. Numerical numbers are displayed in the white box cells of the right side of the “purchasing price of the experimenter” and “your profit”.

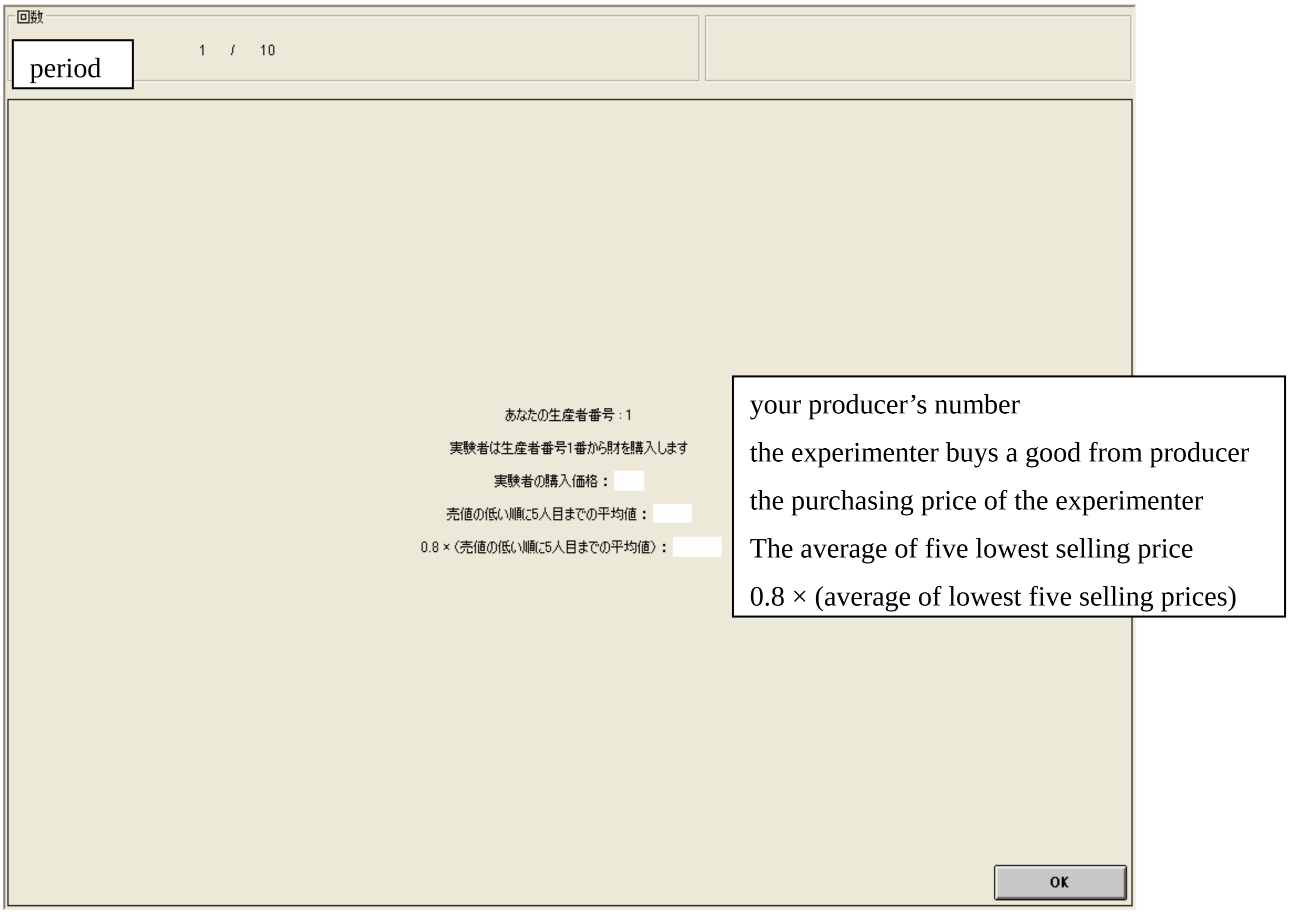
Every subject, in the actual experiment, transcribes the numerical number displayed at the right side of “your profit” on the record sheet. After the transcription, please click OK button in the lower-left corner of the screen.



Screen 3

If the experimenter does not purchase the good from you, screen 3 is displayed. From the top of the display, “your producer’s number”, “the experimenter does not buy a good from you”, “purchasing price of the experimenter”, “production cost”, and “your profits” are displayed. “Your profit” will be 0 pt.

Every subject, in the actual experiment, transcribes the numerical number displayed at the right side of “your profit” on the record sheet. After the transcription, please click OK button in the lower-left corner of the screen.



Screen 4

After the experimenter decides from whom he buy the good, he disclose "producer's identification number from whom the experimenter purchase a good", how much "the purchasing price of the experimenter" is, how much "average of five lowest selling prices" is, and how much "0.8 × (average of lowest five selling prices)" is. These information are displayed from the top of screen 4. Here we show the case where we purchase the good from producer 1 as an example. Numerical numbers are displayed in the white box cells of the right side of the "purchasing price of the experimenter", "average of five lowest selling prices", and "0.8 × (average of lowest five selling prices)".

Every subject transcribes these information from the top on the cells of "producer's number from whom the experimenter purchased the good", "the purchasing price of the experimenter", "average of five lowest selling prices", and "0.8 × (average of lowest five selling prices)" in the record sheet. After the transcription, please click OK button in the lower-left corner of the screen. Once everybody click OK button, period 1 is completed and period 2 will start. The operation after period 2 is the same as one in period 1. The experiment is completed at the time when period 10 is completed.

This is the end of explain the PC operation manuals.

Table 1. The environment of each cell

Cell	Number of sessions	Minimum price conditions	Production cost conditions	Information conditions of subjects' identifications and all their bids
No-I-N	2	No-minimum price	Identical	Nondisclosure
T3-I-N	2	*Type 3* minimum price	Identical	Nondisclosure
No-I-D	2	No-minimum price	Identical	Disclosure
T3-I-D	2	*Type 3* minimum price	Identical	Disclosure
No-D-N	2	No-minimum price	Different	Nondisclosure
T3-D-N	2	*Type 3* minimum price	Different	Nondisclosure
No-D-D	2	No-minimum price	Different	Disclosure
T3-D-D	2	*Type 3* minimum price	Different	Disclosure

Table 2. Summary of statistics in winning prices

(1) Treatment	(2) Periods	(3) Mini.	(4) Median	(5) Max.	(6) Wilcoxon signed-rank tests (two-tailed p-values)	
					H_0: (4) = 97	H_0: (4) = 98
No-I-N	1-5	96	97	98	0.625	0.016
	6-10	1	97	98	1.000	0.004
	all	1	97	98	1.000	0.000
T3-I-N	1-5	90	97	98	1.000	0.031
	6-10	97	97.5	98	0.063	0.063
	all	90	97	98	0.146	0.001
No-I-D	1-5	97	98	106	0.004	0.375
	6-10	76	98	99	0.070	0.625
	all	76	98	106	0.000	1.000
T3-I-D	1-5	78	98	100	0.754	0.688
	6-10	97	98	98	0.004	1.000
	all	78	98	100	0.019	0.453
No-D-N	1-5	99	121	136	0.002	0.002
	6-10	98	100.5	110	0.002	0.063
	all	98	106	136	0.000	0.000
T3-D-N	1-5	104	114	148	0.002	0.002
	6-10	98	98	100	0.002	1.000
	all	98	102	148	0.000	0.001
No-D-D	1-5	98	100	119	0.002	0.008
	6-10	98	100	147	0.002	0.016
	all	98	100	147	0.000	0.000
T3-D-D	1-5	119	123.5	151	0.002	0.002
	6-10	110	116	155	0.002	0.002
	all	110	119.5	155	0.000	0.000

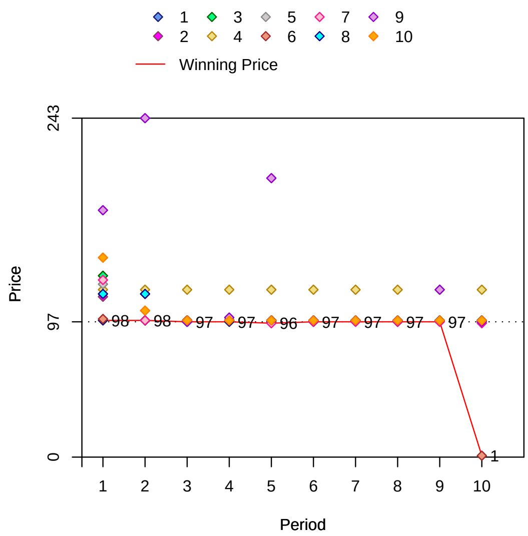
Mini. is the minimum value of winning prices.

Max. is the maximum value of winning prices.

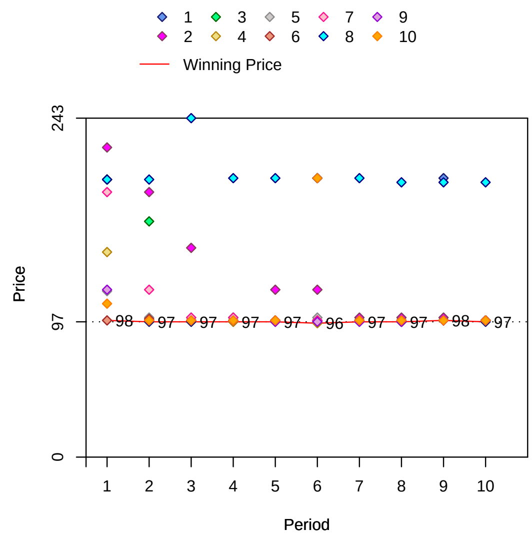
Table 3. Regression analysis

cell	session	coefficient		Probability	adjusted
		a	b	>F-statistic	R2
No-D-N	1	136***	-3.61***	0.00	0.90
	2	120***	-2.86***	0.00	0.61
T3-D-N	1	147***	-5.98***	0.00	0.83
	2	116***	-2.13***	0.00	0.85
No-D-D	1	113***	-1.19	0.06	0.29
	2	93***	1.99	0.26	0.05
T3-D-D	1	134***	-2.08	0.07	0.28
	2	129***	-0.99	0.55	-0.07

* denote that the parameters are different from zero at the 1% significance level

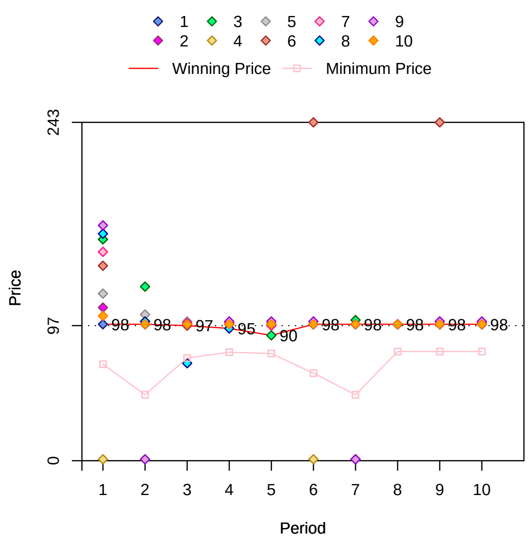


(a) Session 1

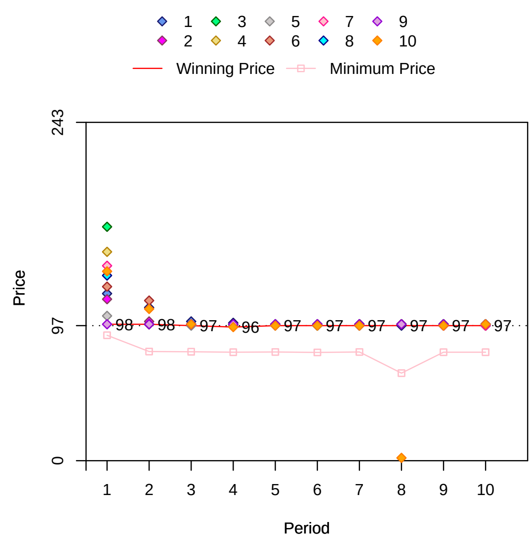


(b) Session 2

Figure 1. No-I-N

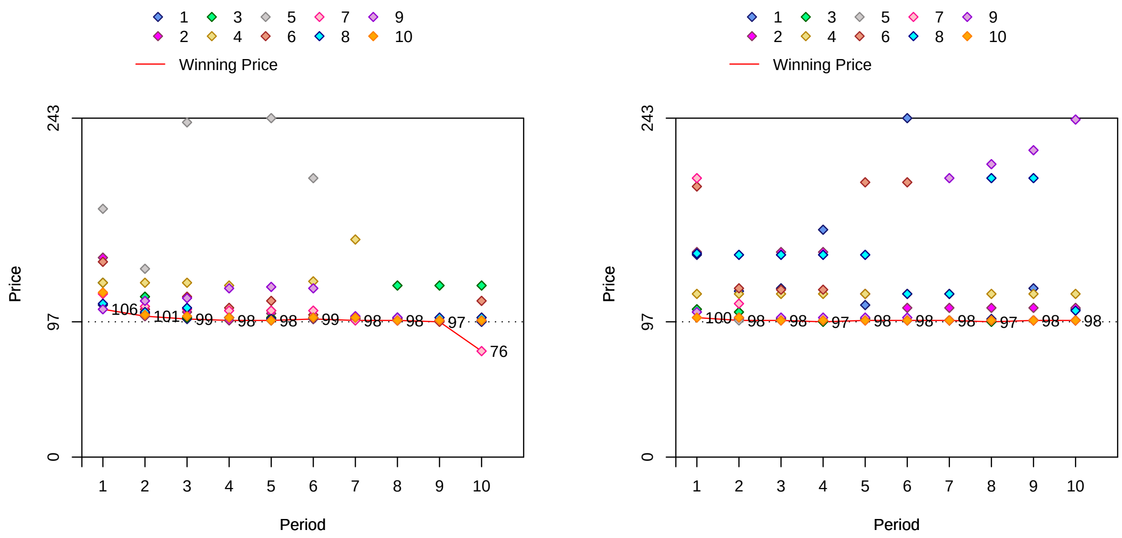


(a) Session 1



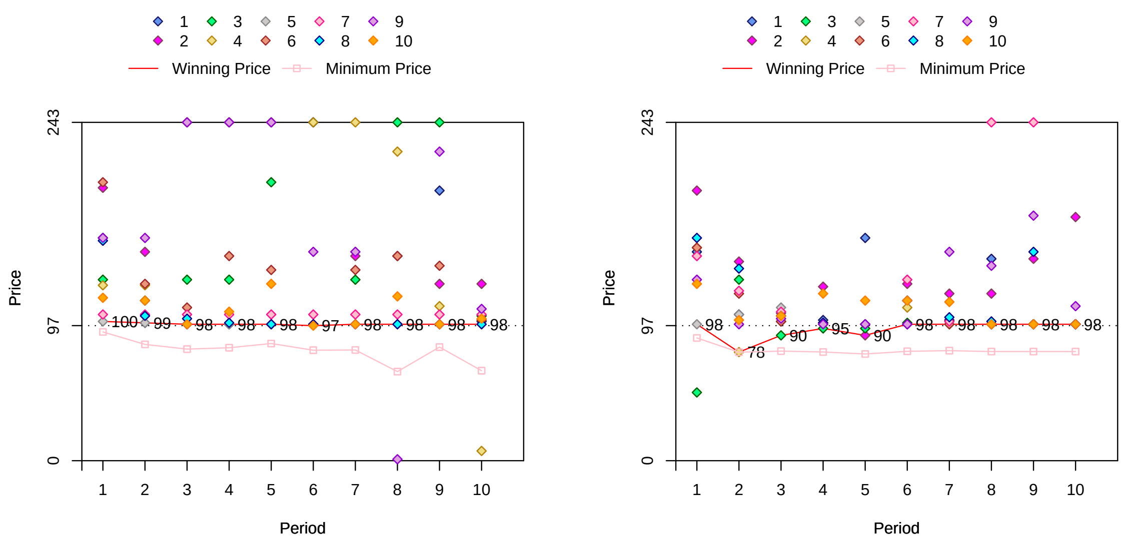
(b) Session 2

Figure 2. T3-I-N



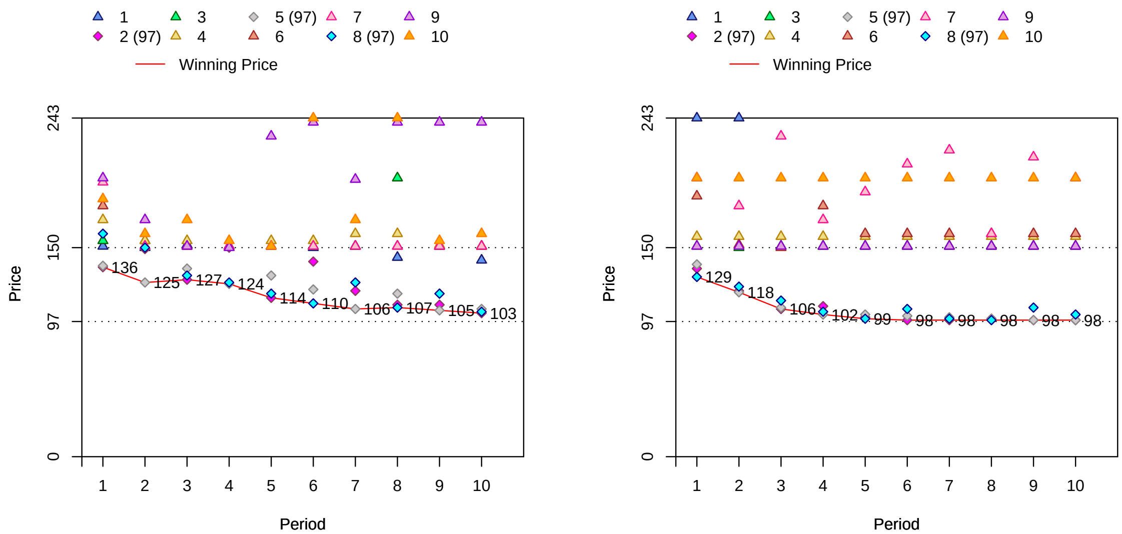
(a) Session 1 (b) Session 2

Figure 3. No-I-D



(a) Session 1 (b) Session 2

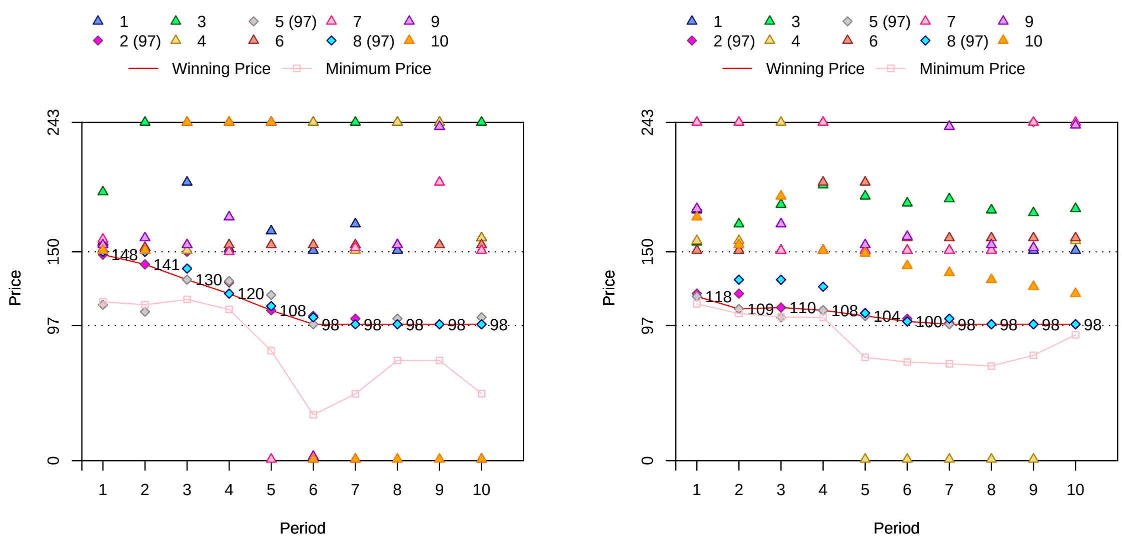
Figure 4. T3-I-D



(a) Session 1

(b) Session 2

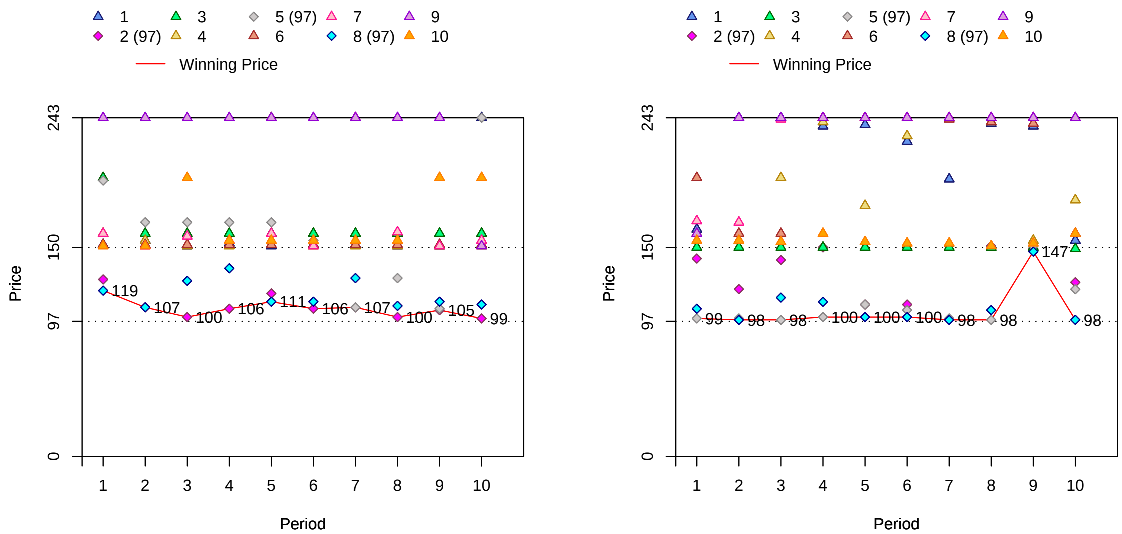
Figure 5. No-D-N



(a) Session 1

(b) Session 2

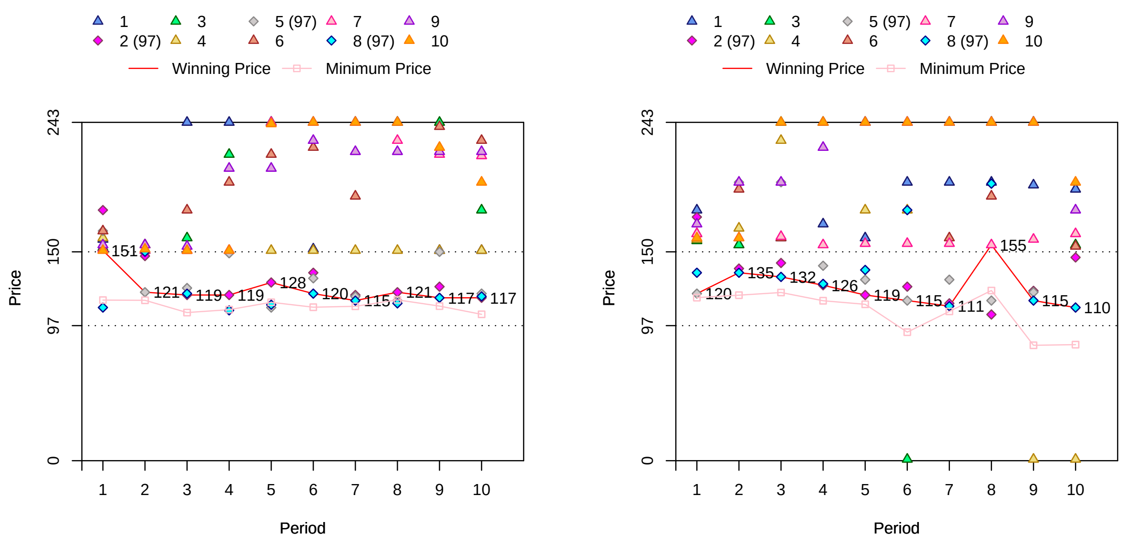
Figure 6. T3-D-N



(a) Session 1

(b) Session 2

Figure 7. No-D-D



(a) Session 1

(b) Session 2

Figure 8. T3-D-D

Supplementary materials

	Round									
producer's ID (cost)	1	2	3	4	5	6	7	8	9	10
T3-I-N: session 1										
1 (97)	98*	98	98	98	98	98	98	98	98	98
2 (97)	110	98	98	98	98	98	98	98	98	98
3 (97)	159	125	98	98	90*	98*	101	98	98*	98
4 (97)	1	1	98	98	98	1	98	98*	98	98
5 (97)	120	105	100	99	98	98	98*	98	100	98
6 (97)	140	98	97*	99	98	243	1	98	243	98
7 (97)	150	100	99	99	97	98	98	98	98	99
8 (97)	163	100	70	95*	98	98	98	98	98	98*
9 (97)	169	1	98	100	100	100	1	98	100	100
10 (97)	104	98*	98	98	98	98	98	98	98	98
endogenous minimu	69.3	47.4	73.8	77.9	77	62.9	47.4	78.4	78.4	78.4
T3-I-N: session 2										
1 (97)	120	110	100	99	98	97	97	97*	97*	97
2 (97)	116	100	98	98	98	98	98	98	98	98
3 (97)	168	98	98	98	98	97*	98	98	98	98
4 (97)	150	98	98	98	98	98	98	98	98	98
5 (97)	104	98*	97*	97	97*	97	98	98	98	98
6 (97)	125	115	98	98	98	98	98	98	98	97*
7 (97)	140	98	98	98	98	98	98	98	97	97
8 (97)	133	98	98	98	98	98	98	98	98	98
9 (97)	98*	98	98	98	98	98	98	98	98	98
10 (97)	136	109	98	96*	97	97	97*	2	97	98
endogenous minimu	90.1	78.4	78.2	77.9	78.1	77.8	78.1	62.9	77.9	77.9
T3-I-D: session 1										
1 (97)	160	99*	98	98*	98*	243	98	98*	194	100
2 (97)	196	150	243	243	243	243	147	147	127	127
3 (97)	130	115	130	130	200	243	130	243	243	104
4 (97)	126	126	243	243	243	243	243	222	111	7
5 (97)	100*	99	98	98	98	98	98	98	98	98
6 (97)	200	127	110	147	137	98	137	147	140	101
7 (97)	105	105	105	105	105	105	105	105	105	105
8 (97)	158	104	102	99	98	98	98	98	98	98*
9 (97)	160	160	243	243	243	150	150	1	222	109
10 (97)	117	115	98*	107	127	97*	98*	118	98*	102
endogenous minimu	92.5	83.5	80.2	81.1	84.2	79.4	79.5	64	81.6	64.6
T3-I-D: sesion 2										
1 (97)	150	105	100	101	160	115	101	145	98	98
2 (97)	194	143	106	125	90*	127	120	120	145	175
3 (97)	49	130	90*	95*	95	99	100	98	98*	98
4 (97)	153	78*	100	98	98	110	98	98*	98	98
5 (97)	98*	105	110	99	98	98	98*	98	98	98
6 (97)	153	120	100	99	98	98	98	98	98	98
7 (97)	147	122	107	98	98	130	100	243	243	98*
8 (97)	160	138	104	99	98	98*	103	100	150	98
9 (97)	130	98	102	98	98	98	150	140	176	111
10 (97)	127	101	104	120	115	115	114	98	98	98
endogenous minimu	88.2	77.9	78.7	78.1	76.6	78.6	79	78.4	78.4	78.4

* shows the winning price.

	Round									
producer's ID (cost)	1	2	3	4	5	6	7	8	9	10
T3-D-D: session 1										
1 (150)	157	153	200	152	165	151	170	151	240	160
2 (97)	148*	141*	150	128	108*	104	102	98*	98	98*
3 (150)	193	243	243	243	243	243	243	243	243	243
4 (150)	152	151	151	243	243	243	151	243	243	160
5 (97)	112	107	130*	129	119	98*	98	102	98*	103
6 (150)	156	153	155	155	155	155	155	155	155	155
7 (150)	159	151	155	150	1	1	153	155	200	151
8 (97)	150	150	138	120*	111	103	98*	98	98	98
9 (150)	155	160	155	175	243	3	1	155	240	1
10 (150)	151	151	243	243	243	1	1	1	1	1
endogenous minimu price	114	112	116	109	79	33	48	72	72	48.2
T3-D-N: session 2										
1 (150)	180	151	151	151	151	151	151	151	151	151
2 (97)	120	120	110*	108	104*	102	99	98	98*	98*
3 (150)	157	170	184	198	190	185	188	180	178	181
4 (150)	158	158	243	243	1	1	1	1	1	158
5 (97)	118*	109*	103	108*	104	100	98*	98	243	98
6 (150)	151	151	151	200	200	160	160	160	160	160
7 (150)	243	243	151	243	151	151	151	151	243	243
8 (97)	180	130	130	125	106	100*	102	98*	98	98
9 (150)	181	155	170	151	155	161	240	155	153	241
10 (150)	175	155	190	151	149	140	135	130	125	120
endogenous minimu price	113	106	103	103	74.2	70.9	69.6	68	75.7	90.4
T3-D-D: session 1										
1 (150)	159	151	243	243	243	152	243	243	151	151
2 (97)	180	147	119*	119*	128*	135	119	121*	125	117*
3 (150)	153	155	160	220	243	243	243	243	243	180
4 (150)	160	151	151	151	151	151	151	151	151	151
5 (97)	165	121*	124	149	110	131	118	115	150	120
6 (150)	165	155	180	200	220	225	190	243	240	230
7 (150)	152	151	151	151	243	243	243	230	220	219
8 (97)	110	150	120	108	112	120*	115*	113	117*	118
9 (150)	155	155	154	210	210	230	222	222	222	222
10 (150)	151*	152	151	151	242	243	243	243	225	200
endogenous minimu price	115	115	106	108	114	110	111	116	111	105
T3-D-D: session 2										
1 (150)	180	155	160	170	160	200	200	200	198	195
2 (97)	175	138	142	126*	119*	125	113	105	122	146
3 (150)	158	155	243	243	243	1	243	243	243	155
4 (150)	159	167	230	243	180	180	243	243	1	1
5 (97)	120*	200	200	140	130	115*	130	115	121	110
6 (150)	163	195	160	243	243	243	160	190	243	154
7 (150)	163	160	161	155	156	156	156	155*	159	163
8 (97)	135	135*	132*	127	137	180	111*	199	115*	110*
9 (150)	170	200	200	225	243	243	243	243	243	180
10 (150)	160	160	243	243	243	243	243	243	243	200
endogenous minimu price	117	119	121	115	112	92.3	107	122	82.9	83.4

* shows the winning price.

producer's ID (cost)	Round 1	2	3	4	5	6	7	8	9	10
No-I-N: session 1										
1 (97)	98*	98	97	97*	97	97*	98	97*	98	98
2 (97)	115	98*	98	98	98	98	98	98	98	98
3 (97)	130	98	98	98	98	98	98	98	98	98
4 (97)	120	120	120	120	120	120	120	120	120	120
5 (97)	124	98	98	98	98	98	98	98	98	98
6 (97)	99	98	98	98	98	98	98	98	98	1*
7 (97)	127	98	98	98	96*	97	97*	97	97*	96
8 (97)	117	117	98	98	98	98	98	98	98	98
9 (97)	177	243	97*	100	200	98	98	98	120	97
10 (97)	143	105	98	98	98	98	98	98	98	98
No-I-N: session 2										
1 (97)	199	97*	97*	98	98	200	98	97	200	97*
2 (97)	222	190	150	97*	120	120	100	100	100	98
3 (97)	199	169	98	100	98	98	98	98	98	98
4 (97)	147	98	98	97	97	96*	98	97*	98	98
5 (97)	119	100	100	100	98	100	98	98	98	98
6 (97)	98*	99	98	98	98	98	98	98	98	98
7 (97)	190	120	100	100	98	98	98	98	98*	98
8 (97)	199	199	243	200	200	200	200	197	197	197
9 (97)	120	98	98	98	97*	97	97*	97	98	98
10 (97)	110	98	98	98	98	200	98	98	98	98
No-I-D: session 1										
1 (97)	109	103	99*	100	98*	99*	99	98	98	97
2 (97)	143	101*	104	98*	103	99	99	98	98	98
3 (97)	125	115	100	100	100	100	100	123	123	123
4 (97)	125	125	125	123	105	126	156	99	98	100
5 (97)	178	135	240	100	243	200	98	98	98	98
6 (97)	140	106	115	107	112	102	99	99	97*	112
7 (97)	117	108	106	105	105	105	98*	98	98	76*
8 (97)	110	104	107	100	99	100	100	100	100	100
9 (97)	106*	112	114	121	122	121	101	100	98	98
10 (97)	118	102	101	100	98	100	100	98*	98	98
No-I-D: session 2										
1 (97)	145	119	121	163	109	243	98	99	121	106
2 (97)	147	99	147	147	117	107	107	107	107	107
3 (97)	106	104	99	97*	99	98	98*	97*	98	98
4 (97)	117	117	117	117	117	117	117	117	117	117
5 (97)	104	98*	98	98	98	98*	98	98	98	98
6 (97)	194	121	120	120	197	197	98	98	98	98
7 (97)	200	110	98	98	98	98	98	98	98	98
8 (97)	146	145	145	145	145	117	117	200	200	105
9 (97)	104	100	100	100	100	100	200	210	220	242
10 (97)	100*	100	98*	98	98*	98	98	98	98*	98*

* shows the winning price.

producer's ID (cost)	Round 1	2	3	4	5	6	7	8	9	10
No-D-N: session 1										
1 (150)	151	150	152	151	151	150	151	143	151	141
2 (97)	136*	149	127*	150	114*	140	119	109	109	103*
3 (150)	155	155	151	151	151	151	151	200	151	151
4 (150)	170	155	155	151	155	155	160	160	152	151
5 (97)	137	125*	135	124*	130	120	106*	117	105*	106
6 (150)	180	151	151	151	151	151	151	151	151	151
7 (150)	197	151	151	151	151	151	151	151	151	151
8 (97)	160	150	130	125	117	110*	125	107*	117	104
9 (150)	200	170	151	150	230	240	199	240	240	240
10 (150)	185	160	170	155	151	243	170	243	155	160
No-D-N: session 2										
1 (150)	243	243	151	151	151	151	151	151	151	151
2 (97)	135	119	106*	108	100	98*	98*	99	98*	98
3 (150)	151	150	151	151	151	151	151	151	151	151
4 (150)	158	158	158	158	158	158	158	158	158	158
5 (97)	138	118*	107	102*	102	101	100	99	98	98*
6 (150)	187	152	150	180	160	160	160	160	160	160
7 (150)	200	180	230	170	190	210	220	160	215	200
8 (97)	129*	122	112	104	99*	106	99	98*	107	102
9 (150)	151	151	151	151	151	151	151	151	151	151
10 (150)	200	200	200	200	200	200	200	200	200	200
No-D-D: session 1										
1 (150)	152	155	151	153	151	152	152	151	151	243
2 (97)	127	107*	100*	106*	117	106*	107	100*	105*	99*
3 (150)	200	160	160	160	160	160	160	160	160	160
4 (150)	160	155	151	151	243	151	151	151	151	151
5 (97)	198	168	168	168	168	155	107*	128	106	243
6 (150)	152	152	152	152	152	152	152	152	152	152
7 (150)	160	151	158	155	160	151	243	161	151	155
8 (97)	119*	107	126	135	111*	111	128	108	111	109
9 (150)	243	243	243	243	243	243	243	243	243	151
10 (150)	151	151	200	155	155	155	155	155	200	200
No-D-D: session 2										
1 (150)	163	243	243	237	238	226	199	239	237	155
2 (97)	142	120	141	150	109	109	151	151	149	125
3 (150)	150	150	150	150	150	150	150	150	150	149
4 (150)	160	155	200	240	180	230	243	240	155	184
5 (97)	99*	99	98*	100*	109	105	99	98*	151	120
6 (150)	200	160	160	243	243	243	242	240	239	160
7 (150)	169	168	242	243	243	243	243	243	243	243
8 (97)	106	98*	114	111	100*	100*	98*	105	147*	98*
9 (150)	160	243	243	243	243	243	243	243	243	243
10 (150)	155	155	154	160	154	153	153	151	153	160

* shows the winning price.