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A STRATEGY-PROOF MECHANISM SHOULD BE ANNOUNCED TO BE STRATEGY-PROOF: AN EXPERIMENT FOR THE VICKREY AUCTION

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A strategy-proof mechanism should be announced to be strategy-proof: An experiment for the Vickrey auction*

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Abstract

We conduct laboratory experiments for the Vickrey auction *with* and *without* an announcement on strategy-proofness to subjects. Although the rate of truth-telling among the subjects stays at 20% without the announcement, it increases to 47% with the announcement. Moreover, by conducting experiments for the pay-your-bid auction, which is not strategy-proof, with and without advice, we find that our experimental results are not attributed to so-called experimenter demand effects. Strategy-proof mechanisms are sometimes criticized because players often fail to find the benefit of truth-telling, but our observations tell that introducing an educative announcement helps them behave "correctly."

Keywords: advice effect; strategy-proofness; Vickrey auction; pay-your-bid auction; market design

JEL codes: D44; D71; D61; D82

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1 Introduction

1.1 Motivation

The technology of designing economic mechanisms has been rapidly grown in the last few decades. Its real-life applications now include spectrum auctions, school choice, and kidney exchange among many others. A particularly preferred property of mechanisms is *strategy-proofness*, which ensures that truthfully reporting his own type is always a dominant strategy for every participant. As long as a strategy-proof mechanism is employed, no participant is supposed to mis-report his type, so that a social optimum is realized through gathered true information.

On the other hand, it has been very often observed in laboratory experiments that the percentage of truth-reporting subjects is not high, or even low. These observations have been considered as an anomaly to the theory, giving a skepticism to real-life performance of strategy-proof mechanisms. A prominent example is the Vickrey auction, under which many experimental studies have observed overbidding behavior. However, this does not imply that strategy-proofness of the Vickrey auction is not useful in reality. Simply, it shows the necessity of developing some device that puts strategy-proofness to work, making the Vickrey auction useful in real-life applications.

Indeed, the proof of strategy-proofness of the Vickrey auction is non-trivial so that the usual person on the street would not be able to understand it. A simple idea to overcome this difficulty is to announce strategy-proofness of the Vickrey auction to subjects, which is what we shall try in this experimental research. In our experiment, we announce strategy-proofness of the Vickrey auction and examine its effect. A main observation is that such an announcement drastically improves the rate of truth-telling.

Our experiment deals with the case that multiple units of an item are to be sold under the Vickrey auction. There, we investigate the effect of our announcement to bidding behavior and efficiency of outcomes. Note that the Vickrey auction is in fact strategy-proof, and hence saying such an announcement involves no ethical problem on deception. One may say that our approach is an intervention to freedom of choice or free play, but we consider that saying so is an overreaction. Suppose you purchase a new electronic device and someone from the maker of the device tells you how to nicely use it, and you still have freedom of choice of not following the advice. Then we do not say that the person is intervening your freedom of choice.

What we would like to do for economic mechanisms is exactly like this. It is a kind of consumer protections rather than any intervention. Or, one might consider that it is an education rather than an intervention. Anyway, in our experiment, even after players are given an advice, they are fully allowed not to follow, and some of them in fact did so.

1.2 Related literature

The rate of truth-telling. Several experimental studies report that most subjects do not reveal true type in the Vickrey auction even in the single-unit case. Kagel and Levin (1993) find that the rate of sincere bidding is about 27% of all bids. Garratt et al. (2012) report that even though the subjects are familiar with bidding in eBay auctions, about four out of five subjects failed to bid sincerely.

Efficiency loss. Ausubel et al. (2014) point out that, under the uniform price auction, bidders have strong incentives to underbid, causing a serious loss of efficiency; that is, the so called "demand reduction" phenomenon happens. List and Lucking-Reiley (2000) observe that the Vickrey auction also mitigates demand reduction. On the other hand, Kagel and Levin (2001) observe that it is not the case for the Ausubel auction, which is a dynamic counterpart of the Vickrey auction (Ausubel, 2004; Okamoto, 2018). Manelli et al. (2006) and Kagel and Levin (2009) observe that subjects in a Vickrey auction experiment tend to overbid, compared with subjects in the dynamic counterpart. Engelmann and Grimm (2009) find that the Vickrey auction yields lower efficiency than the pay-your-bid and the uniform price auctions do, especially at the beginning periods.

Overcoming the unawareness of strategy-proofness by strengthening it. Saijo et al. (2007) point out that even if a mechanism is strategy-proof, it often admits the presence of an inefficient Nash equilibrium consisting of mis-reporting. They propose to strengthen strategy-proofness to "secure implementability" requiring that no Nash equilibrium realizes an outcome that is not the "true" outcome. An experimental study by Cason et al. (2006) compares bidding behavior of securely implementable (and so strategy-proof) mechanism and that of other strategy-proof mechanisms, and observe that the rate of truth-telling in the former is higher than that in the latter.

Li (2017) proposes a stronger version of strategy-proofness, called "obvious strategy-

proofness," that can be applied for dynamic mechanisms such as the ascending auction or matching algorithms. In the problem of auctioning a single item, the ascending auction is obviously strategy-proof, but the Vickrey auction is not so. In an experiment of auctioning a single item, Li observes that the ratio of dominant strategies played by subjects is significantly higher that under the ascending clock auction than under the Vickrey auction.

To make people understand incentive properties, the aforementioned studies try to strengthen strategy-proofness. However, given that the class of strategy-proof mechanisms is already narrow (e.g., Holmström (1979)), strengthening strategy-proofness severely restricts the admissible class of mechanisms. On the other hand, our approach of providing an advice can be applied to any strategy-proof mechanism in any environment. Indeed, the Vickrey auction is neither securely implementable nor obviously strategy-proof, but giving an advice drastically improves its performance on truth-telling.

The role of advice in strategy-proof environments. As mentioned in the previous section, providing advice to participants in a mechanism is one of the most important factor in implementing the mechanism in the real world. The effect of providing advice on strategy-proof mechanisms has recently been studied by several authors (Guillen and Hing, 2014; Ding and Schotter, 2017b; Guillen and Hakimov, 2018). These studies use the model of two-sided matching to test whether or not providing advice will affect the rate of truth-telling. A closely related work by Guillen and Hakimov (2018) finds that giving an announcement of strategy-proofness of strategy-proof matching mechanisms raises the rate of truth-telling.[1] They also find that giving only a detailed explanation of the definition of a mechanism decreases the rate of truth-telling. These results suggest that an advice well helps participants be confirmed of individual optimality of truth-telling. To the best of our knowledge, this study is the first one that tests the role of advice in the literature of auction studies.

[1]Guillen and Hakimov (2018) consider top-down advice (e.g., advice given by the mechanism administrator). Several studies examine whether the source of advice affect the truth-telling behavior: advice given to children by their parents (Ding and Schotter, 2017b); peer information sharing in networks (Ding and Schotter, 2017a); and third-party advice like website (Guillen and Hing, 2014).

2 The experimental design

2.1 Theoretical considerations

There are three bidders, $\{1,2,3\}$, and two indivisible identical objects to be auctioned. Each bidder is admitted to demand two units. Bidder i's *valuation* for the objects is denoted by $v_i = (v_i^1, v_i^2)$, where v_i^j denotes the value that bidder i assigns to j-th unit. Bidder i's valuation is drawn independently from the uniform distribution on $V \equiv \{(v_i^1, v_i^2) \in [0,\overline{v}]^2 \colon v_i^1 \geq v_i^2\}$, where $\overline{v} > 0$. Given any $v_i \in V$, bidder i's utility of obtaining k units of objects and paying $p_i \in \mathbb{R}$ units of money is

$$U(k, p_i; v_i) \equiv \begin{cases} v_i^1 + v_i^2 - p_i & \text{if } k = 2 \\ v_i^1 - p_i & \text{if } k = 1 \\ -t_i & \text{if } k = 0. \end{cases}$$

A list $v = (v_1, v_2, v_3) \in V^3$ is a *valuation profile*. An *assignment function* is a function $d \colon V^3 \to \{0,1,2\}^3$ that satisfies the following resource constraint: for each $v \in V^3$, $d_1(v) + d_2(v) + d_3(v) = 2$. A *payment function* is a function $p \colon V^3 \to \mathbb{R}^3$. A *rule* is a pair of assignment and payment functions, $f = (d, p)$. Given any $v \in V^3$, the projection of $f(v) = (d(v), p(v))$ on $i \in \{1,2,3\}$ is denoted by $f_i(v) = (d_i(v), p_i(v))$; that is, $d_i(v) \in \{0,1,2\}$ is the number of the objects i obtains and $p_i(v) \in \mathbb{R}$ is the amount of money i pays.

We are interested in rules in which sincere bidding is a weakly dominant strategy for everyone. Formally:

Strategy-proofness: For each $v \in V^3$, each $i \in \{1,2,3\}$, and each $v_i' \in V$, $U(f_i(v); v_i) \geq U(f_i(v_i', v_{-i}); v_i)$.

The following rules are central in the literature on auction theory.

- **Vickrey auction:** Each bidder simultaneously submits a bid vector $b_i = (b_i^1, b_i^2) \in V$. After seller collects all bidders' bids, she ranks them from the highest to the lowest bid and allocates the two units to the two highest bids. If bidder i wins $k \in \{1,2\}$ units, then he has to pay the sum of k highest losing bids of other bidders.

- **Pay-your-bid auction:** Each bidder simultaneously submits a bid vector $b_i = (b_i^1, b_i^2) \in V$. After seller collects all bidders' bids, she ranks them from

the highest to the lowest bid and allocates the two units to the two highest bids. If bidder i wins two (resp. one) units, then he has to pay $b_i^1 + b_i^2$ (resp. b_i^1).

One of the most important features of the Vickrey auction is the fact that it satisfies strategy-proofness. However, many previous experimental studies report that bidders tend to overbid in Vickrey auctions. The pay-your-bid auction is widely used in real-life, while the Vickrey auction is rare. However, in contrast to the Vickrey auction, the pay-your-bid auction violates strategy-proofness.

2.2 Experimental procedures

2.2.1 Design

We conducted an experiment to test the effect of an advice for the Vickrey auction. We used between-subjects design. To distinguish if subjects follow the advice because they understand it and if they obey the advice without understanding it, we also conducted corresponding experiments for the pay-your-bid auction. We have four types of treatments in total:

1. **Treatment VA**: the Vickrey auction with advice
2. **Treatment VN**: the Vickrey auction without advice
3. **Treatment PA**: the pay-your-bid auction with advice
4. **Treatment PN**: the pay-your-bid auction without advice

In each treatment, three bidders compete for two units of an item. For each bidder, two integer values are drawn from the uniform distribution with the interval $[0, \overline{v}] = [0, 1000]$. Then, the larger (smaller) integer is assigned the value of the first (second) unit. All values are displayed in Japanese yen (JPY).

2.2.2 Subjects pool and procedure

Each of VA, PA, and PN had three experimental sessions, whereas VN had two sessions. We conducted these 11 sessions at the Osaka University in March of 2015 and July of 2016. We recruited student subjects from Osaka University through campus-wide advertisements. None of them were experienced in this particular type of experiment. No subject attended more than one session. Our experiment was

Treatment	Auction rule	Advice	Date	# of Sessions	# of Subjects (Groups)
VA	Vickrey	Yes	Mar-15	3	63 (21)
VN	Vickrey	No	Mar-15	2	48 (16)
PA	Pay-your-bid	Yes	Jul-16	3	69 (23)
PN	Pay-your-bid	No	Jul-16	3	72 (24)

Table 1: Summary of treatments.

computerized using the experimental software z-Tree (Fischbacher, 2007). Twenty-one or twenty-four subjects participated in each session. Table 1 summarizes the number of observations. Figure 1 illustrates the timeline of one session.

Each subject was seated at a computer terminal that was assigned by lottery. All terminals were separated by partitions. No communication among subjects was allowed. Each subject had a set of printed instructions and a record sheet. The experimenter read aloud the instructions. Then, subjects took a 17-question quiz that tests if they understand the auction rule which they were instructed a short time ago. Every correct answer was worth \$0.3 (\$1 = JPY 100). The experimenter read aloud the answers to the quiz. Subsequently, only in VA and PA, the experimenter distributed a piece of papers writing an advice and read it aloud. The text of the advice is as below:

> "The following advice is about the auction in which you are participating. Please consider carefully whether this advice is true or false. It is completely up to you whether you follow the advice or not. *You can maximize your earnings by bidding your values as they are, regardless of what others bid.*"

The subjects were given time to ask questions, proceeded to two practice periods and to the 25 successive payment periods under the random matching protocol. At the beginning of each period, all subjects are separated into groups of three members. At the bidding stage, each subject was asked to enter his/her two bids as nonnegative integers—such that the first unit bid is weakly greater than that of the second unit bid—into a box on the display screen. We set the maximum feasible first unit bid to be 2,000.

After the 25 payment periods, the subjects completed a questionnaire and were immediately paid in cash. Each subject was privately paid the sum of his/her earnings over the 25 periods. The value of the individual payments ranged from \$5.9 to \$70.3.

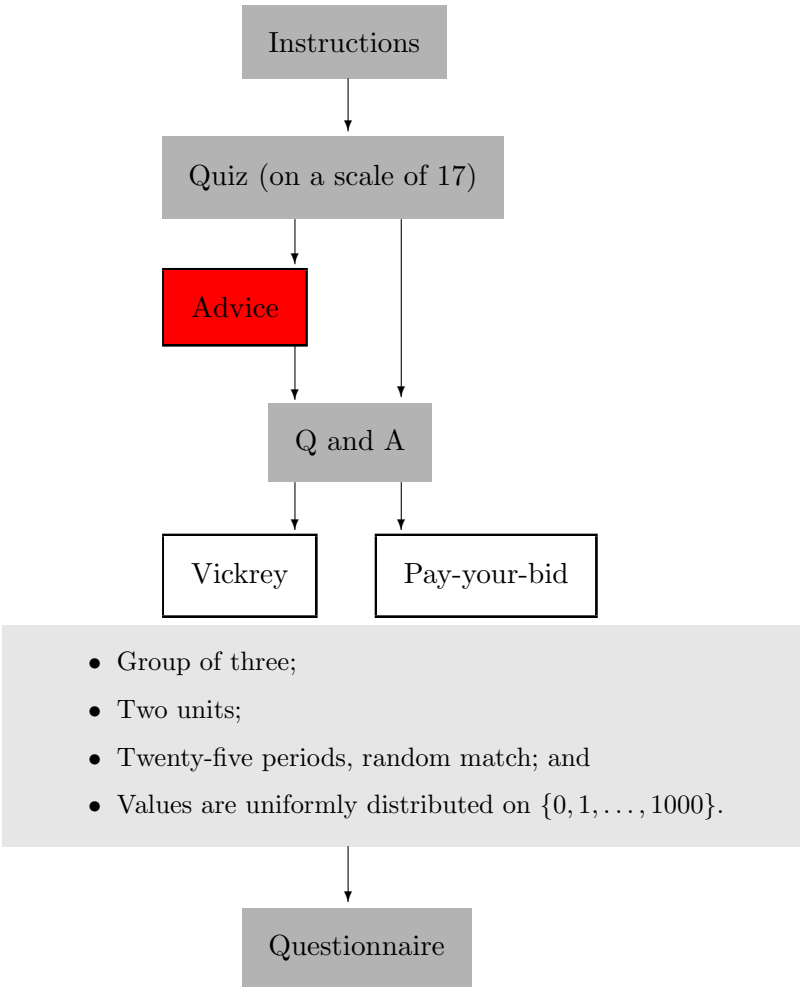


Figure 1: Timeline of one session.

3 Experimental results

3.1 Level of understanding of auction rules

Figure 2 displays the distributions of quiz scores before the real stage. The score ranges from 0 to 17. A first look at Figure 2 shows clear evidence that over 60% of the subjects got a perfect score in the Vickrey auction while over 80% did so in the pay-your-bid auction. Given an auction rule, we found no statistical difference in score distributions between with and without advice (a two-sample Kolmogorov-Smirnov (K-S) test for the equality of two score distributions had a p-value > 0.90 for both VA vs. VN and PA vs. PN). Similarly, we found no statistical evidence to support the different understanding level between two auctions, irrelevant of the presence of an advice (the K-S test had a p-value > 0.10 for all pairwise comparison of VA vs. PA, VA vs. PN, VN vs. PA and VN vs. PN). In sum, we have:

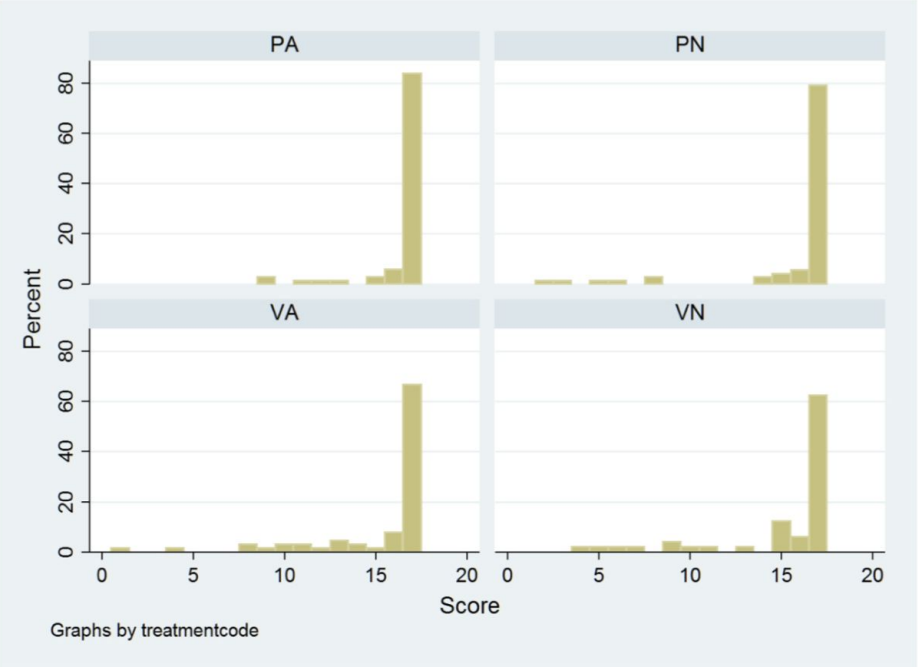


Figure 2: Distribution of quiz scores for each treatment prior to the auctions.

Result 1 (Level of understanding auction rules). *Subjects understood well the auction rules prior to playing auctions, regardless of whether they participated in the Vickrey or the pay-your-bid auction.*

3.2 Bidding behavior

Figure 3 shows scatter plots between values and bids in each treatment. In Figure 3, blue and red plots indicate bids for unit one and two, respectively. Table 2 summarizes the classification of bids into three categories, unit by unit.

For a given unit, we say that a bid is *sincere* if it matches exactly the value drawn for the unit. Similarly, we say that a bid is *over* (resp. *under*) if the bid is more (resp. less) than the value. For example, if values and bids are $v_1 = (800, 300)$, $v_2 = (600, 400)$, $v_3 = (900, 500)$, $b_1 = (850, 240)$, $b_2 = (600, 400)$ and $b_3 = (900, 0)$, then the sincere bids are the first and second units of bidder 2 and the first unit of bidder 3. The unique over bid is bidder 1's second unit, while the remaining two bids are under bids. Hence, the overall average sincere bid rate is 0.5 (i.e., we divide the number of sincere bids with the total number of bids by the three bidders), whereas the average sincere bid rate of bidder 1, 2, and 3 is 0, 1, and 0.5, respectively.

Figure 3 tells us that overbidding is prevalent in the Vickrey auction without

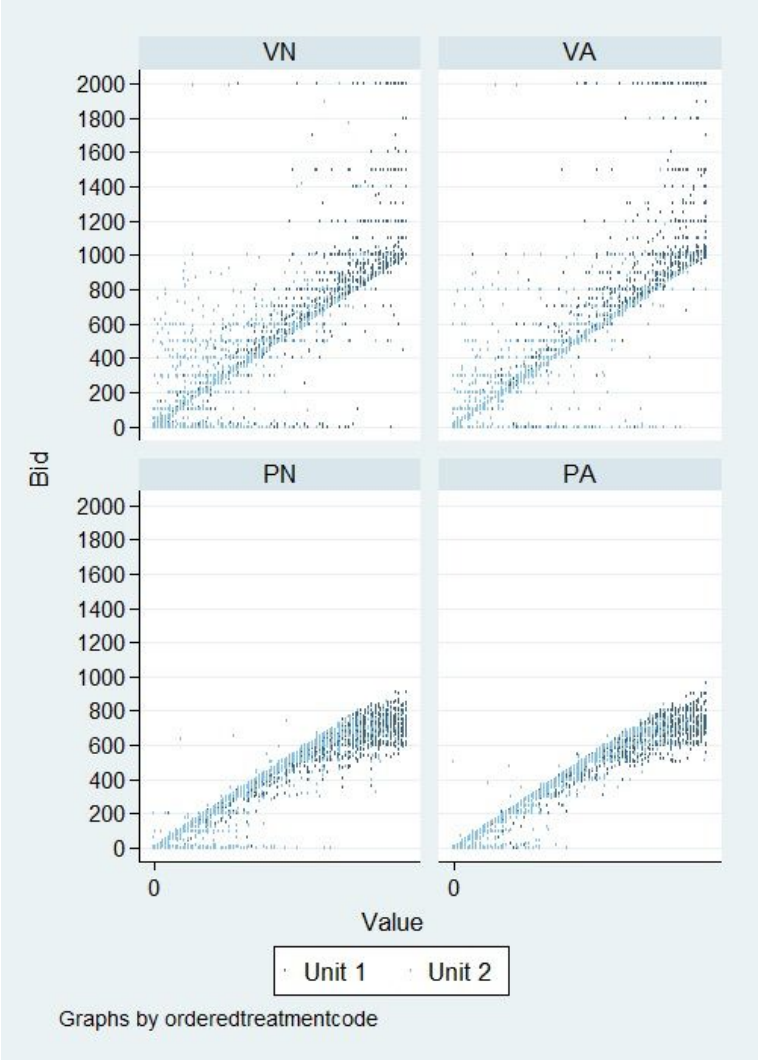


Figure 3: Scatter plots of bids.

advice (VN), which amounts to 63.29% of all bids. This observation is in consistent with previous findings in experiments of the multi-unit Vickrey auction by Engelmann and Grimm (2003), Manelli et al. (2006), and Kagel and Levin (2009). With an explicit statement of strategy-proofness of the Vickrey auction (VA), the subjects are less likely to overbid, which amounts to 45.3. Moreover, there is a shift from underbidding to sincere bidding when the advice is given. The underbids reduced from 16.08% to 7.78% by the advice, which means that the impact of the advice is more salient for underbids than overbids

In contrast, the subjects in PA and PN are likely to underbid, especially when

	Treatment							
Bid category	VA		VN		PA		PN	
Over	1,427	(45.3%)	1,519	(63.29%)	19	(0.55%)	33	(0.92%)
Sincere	1,478	(46.92%)	495	(20.63%)	287	(8.32%)	209	(5.81%)
Under	245	(7.78%)	386	(16.08%)	3,144	(91.13%)	3,358	(93.28%)
N	3,150		2,400		3,450		3,600	

Note: For each treatment, $N = 25$ (periods) $\times$ 2 (units) $\times$ (# of subjects).

Table 2: Frequency of bidding categories.

they have large values.[2]

We run the Wilcoxon rank sum test for the equality of mean sincere bidding rates, using one subject as a unit of observation. When we compare all the subjects in VA and VN, we get p-value < 0.001. In contrast, when we compare all subjects in PA and PN, we get p-value $= 0.066$. In sum:

Result 2 (Sincere bidding rates, an overview). *Telling strategy-proofness is statistically highly significant and increases the mean sincere bidding rate in the Vickrey auction, while the effect of the advise is marginal in the pay-your-bid auction.*

Together with the fact that the Vickrey auction is strategy-proof and the pay-your-bid auction is not, Result 2 suggests that there is no so-called experimenter demand effect (Zizzo, 2009); that is, our subjects actually checked whether the advice was true or false by themselves, rather than they thoughtlessly obey the advice. This result is in line with Guillen and Hakimov (2018), who reported that strategy-proof property of matching mechanisms increased sincere reporting of preferences.[3]

3.3 Efficiency

Our efficiency measure is due to Kagel and Levine (2009).[4] In one game, if i is the winner with the highest bid and if j is the winner with the second highest bid, then the efficiency ratio is given by $\dfrac{v_i^1 + v_j^1}{v[1] + v[2]}$ if $i \neq j$, and by $\dfrac{v_i^1 + v_i^2}{v[1] + v[2]}$ if $i = j$, where $v[1], v[2]$ denote the two highest units among six valuations $(v_1^1, v_1^2, v_2^1, v_2^2, v_3^1, v_3^2)$, respectively. The efficiency ratio of the full or a part of a treatment is the average of the efficiency ratios in the games in the full or the part of the treatment.

[2]This observation is consistent with the theory of multi-unit, pay-your-bid auctions. See, for example, Lebrun and Tremblay (2003).

[3]Guillen and Hing (2014) and Ding and Schotter (2017a) reported the opposite results—true advice of strategy-proofness decreased sincere reporting.

[4]See also Kwasnica and Sherstyuk (2013).

Table 3 summarizes results on efficiency with the focus on periods and size of values. In Table 3, the left panel collects results obtained for all value profiles, and the right panel collects results obtained for value profiles $v = (v_j^1, v_j^2)_{j\in\{1,2,3\}}$ such that $v[1] + v[2] \geq 1500$ where $v[k]$ denotes the k-th highest value among $(v_j^1, v_j^2)_{j\in\{1,2,3\}}$ and 1500 approximates the statistical median of $v[1], v[2]$ in our setting.

		Efficiency				Efficiency$^{\geq 1500}$			
Periods		VA	VN	PA	PN	VA	VN	PA	PN
All		0.977	0.967	0.990	0.988	0.983	0.970	0.987	0.985
	Difference		**−1.00%**	**1.30%**	**1.10%**		**−1.30%**	**0.40%**	**0.20%**
	vs. VA		**	*	N. Sig.		*	N. Sig.	N. Sig.
	vs. VN			***	***			*	N. Sig.
	vs. PA				N. Sig.				N. Sig.
1–13		0.970	0.956	0.991	0.989	0.980	0.955	0.989	0.986
	Difference		**−1.40%**	**2.10%**	**1.90%**		**−2.50%**	**0.90%**	**0.60%**
	vs. VA		*	***	N. Sig.		**	N. Sig.	N. Sig.
	vs. VN			***	***			***	**
	vs. PA				N. Sig.				N. Sig.
14–25		0.984	0.978	0.989	0.988	0.987	0.988	0.985	0.984
	Difference		**−0.60%**	**0.50%**	**0.40%**		**0.10%**	**−0.20%**	**−0.30%**
	vs. VA		N. Sig.	N. Sig.	N. Sig.		N. Sig.	N. Sig.	N. Sig.
	vs. VN			N. Sig.	N. Sig.			N. Sig.	N. Sig.
	vs. PA				N. Sig.				N. Sig.

Notes: $^*p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ by a Wilcoxon rank sum test for efficiency.Difference from VA are shown in bold. Efficiency$^{\geq 1500}$ denotes "efficiency when the sum of two highest values ≥ 1500."

Table 3: Comparison of efficiency.

When we combine outcomes of all 25 periods, efficiency of VN and VA are 96.7% and 97.7%, respectively. This increase may seem marginal, but it is statistically significant according to the Wilcoxon rank sum test ($p = 0.0068$ for VA vs. VN). This difference stems from the difference in early periods ($p = 0.0163$ for VA vs. VN in periods 1–13, $p = 0.1809$ in periods 14–25). Moreover, the right panel of Table 3 suggests that improvement of efficiency in the Vickrey auction occurs mainly when the sum of the two highest values are large, yielding 2.50% improvement compared to the Vickrey auction without advice in periods 1–13 ($p = 0.0336$ for VA vs. VN in all periods, $p = 0.0047$ for VA vs. VN in periods 1–13, $p = 0.8354$ for VA vs. VN in periods 14–25).

On the other hand, in the pay-your-bid auction, a corresponding advice does not cause any statistically significant change ($p = 0.0974$ for PA vs. PN in all periods, $p = 0.2031$ in periods 1–13, $p = 0.2799$ in periods 14–25). This tendency holds when we restrict attention to the data where the two highest values are large, as shown in the right panel of Table 3.

Result 3 (Efficiency). *Advice improves efficiency in the Vickrey auction, especially in the former 13 periods and when the two highest values are large.*

We also compare VA (or VN) and PN. First, the comparison between VA and PN yields $p = 0.5667$ for all periods, $p = 0.1275$ for periods 1–13, and $p = 0.4062$ for periods 14–15. Second, the comparison between VN and PN yields $p < 0.001$ for all periods, $p < 0.001$ for periods 1–13, and $p = 0.4682$ for periods 14–15.

Result 4 (Efficiency between auction rules). *The advice of strategy-proofness promotes the Vickrey auction outcome to be efficient as frequent as the pay-your-bid auction in early periods.*

Englemann and Grimm (2009) compare the Vickrey auction and the pay-your-bid auction in an experiment that two units of an item are auctioned to two bidders with flat demand. They observe that the efficiency ratio in the Vickrey auction is significantly lower than that in the pay-your-bid auction. In contrast, our Result 4 and Table 3 show that, the pay-your-bid auction is not necessarily superior to the Vickrey auction with our advice.

4 Conclusion

We experimentally showed that introducing an advice on strategy-proofness leads to a higher sincere bidding rate in the multi-unit static Vickrey auction. Without this announcement, the rate of sincere bidding is similar to the one observed in previous studies. Furthermore, we can conclude that our advice is influential only when the advice is true, because an advice does not change bidding behavior under the pay-as-bid auction. Advice improves efficiency of outcomes of the Vickrey auction, especially when subjects are less experienced. These results support the view that making a good advice to the participants should be counted as a part of designing a good mechanism.

A Appendix: Experimental instructions (VA)

Note: *In this experiment, please remember that you cannot communicate with other subjects. If there is communication, this experiment will be stopped at that point.*

First, please confirm the following items. If any of the items are missing, please contact the experimenter.

- Instructions (this handout)
- Record Sheet
- Pencil and Eraser
- Calculator

A.1 Overview

In this experiment, you will act as bidders in a sequence of auctions. Three bidders will participate in each of auctions. At the beginning of each period of auction, the experimenter will choose two persons you are matched with from the other subjects at random. You and these two persons will form a group. This experiment consists of 25 periods. The persons you are matched with will change each period. You will not know who are matched with you both during and after the experiment.

The rewards you receive after the experiment are determined based on the decisions you and others make in the experiment. Your rewards will be paid to you in cash at the end of the experiment. A detailed explanation of the rewards you receive will be provided later in **A.3. Earnings**.

A.2 Auction

A.2.1 Procedure in each period

1. Two units of an identical object will be auctioned off in every period. Three bidders, including yourself, will participate in an auction.

2. Each bidder will be assigned a value for the 1st unit ("1st unit's value") and another value for the 2nd unit ("2nd unit's value"). For each bidder, values will be randomly drawn from the interval JPY 0 to JPY 1,000 with increments of 10 yen. Any value within this interval has an equally likely chance of being

drawn and being assigned as a value. The higher of these two values will be the "1st unit's value", while the lower will be the "2nd unit's value". Each of the other two bidders is assigned values for two units in the same way that your values were assigned. The particular values assigned to the other two bidders will typically be different from yours. Please note that for each bidder, the 2nd unit's value will always be lower than the 1st unit's value. In addition, your "1st unit's value" and "2nd unit's value" are only for your private information. The other bidders will not be able to know your values.

3. You will submit your "bid for the 1st unit" and "bid for the 2nd unit" to the experimenter. Then, please note the following three points:

   - "Your bid for the 1st unit" must be higher than "your bid for the 2nd unit".
   - Your bid must exceed 0 yen.
   - Your bid must be increments of 10 yen.

4. Each of the three bidders will submit two bids. Therefore, there will be a total of six bids. The two highest bidders will each earn an item. In case of ties among the high bids, the experimenter will randomly determine who earns an item. From the above procedure, the number of units earned by each bidder can be determined.

5. The "earnings" for a bidder who earns an item are equal to his/her value of the item less his/her payment. The "earnings" for a bidder who has not earned any units are zero.

A.2.2 Earnings calculation

We first explain how to calculate a bidder's earnings if he/she earns an item by using examples. There are three bidders, A, B, and C. We here focus on bidder A. In the following examples, the numbers are displayed in Japanese yen.

(1) The case where a bidder earns one unit　A bidder who earns one unit will pay the amount of the highest bid from among the other bidders' losing bids.

Example 1. Suppose that A's value for the 1st unit is 680, and 480 for the 2nd unit. The bids from the three bidders are shown below.

Bidder	Bid for 1st Unit	Bid for 2nd Unit
A	600	450
B	500	300
C	400	250

Here, the winning bids are A's 600 and B's 500. The losing bids are A's 450, B's 300, C's 400, and C's 250. When A's 450 is excluded from the losing bids, B's 300, C's 400, and C's 250 are left. Bidder A pays the highest amount among these, which is 400. Please note that the payment differs from the winning bid. Then, A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} - 400 \text{ (payment)} = 280$$

Example 2. Suppose that A's value for the 1st unit is 680, and 480 for the 2nd unit. The bids from the three bidders are shown below.

Bidder	Bid for 1st Unit	Bid for 2nd Unit
A	800	350
B	750	300
C	700	250

Here, the winning bids are A's 800 and B's 750. Thus, bidder A earns one unit. Excluding A's other bid, the losing bids were B's 300, C's 700, and C's 250. Bidder A pays 700, the highest bid among these. Please note that the payment differs from the winning bid. Then, A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} - 700 \text{ (payment)} = -20$$

(2) The case where a bidder earns two units A bidder who earns two units will pay the sum of the highest and second highest bids from among the other bidders' losing bids.

Example 3. Suppose that A's value for the 1st unit is 680, and 480 for the 2nd unit. The bids from the three bidders are shown below.

Bidder	Bid for 1st Unit	Bid for 2nd Unit
A	600	550
B	500	300
C	400	250

Here, the winning bids are A's 600 and A's 550. The losing bids are B's 500, B's 300, C's 400, and C's 250. Thus, bidder A pays 900, the sum of the highest bid of 500 and the second highest bid of 400 from the losing bids. Here too, A's payment differs from A's own bids. A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} + 480 \text{ (2nd item's value)} - 900 \text{ (payment)} = 260$$

Example 4. Suppose that A's value for the 1st unit is 680, and 480 for the 2nd unit. The bids from the three bidders are shown below.

Bidder	Bid for 1st Unit	Bid for 2nd Unit
A	900	850
B	800	600
C	700	550

Here, the winning bids are A's 900 and A's 850. The losing bids are B's 800, B's 600, C's 700, and C's 550. Thus, bidder A pays 1,500, the sum of the highest bid of 800 and the second highest bid of 700 from the losing bids. Here too, A's payment differs from A's own bids. A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} + 480 \text{ (2nd item's value)} - 150 \text{ (payment)} = -340$$

The earnings calculation method may be summarized as follows:

- When you earn one unit and the 3rd highest bid is yours:

$$\text{Earnings} = \text{1st item's value} - \text{4th highest bid}$$

- When you earn one unit and the 3rd highest bid is not yours:

$$\text{Earnings} = \text{1st item's value} - \text{3rd highest bid}$$

When your payment is higher than your 1st item's value, please note that your earnings will be negative.

- When you earn two units:

$$\begin{aligned}\text{Earnings} = &(\text{1st unit's value} + \text{2nd unit's value}) \\ &- (\text{3rd highest bid} + \text{4th highest bid})\end{aligned}$$

When your payment is higher than the sum of your 1st unit's and 2nd unit's values, please note that your earnings will be negative.

- When you earn an item, your earnings will be zero.

A.3 Rewards

We will explain the rewards you receive after the experiment. Your rewards are the sum of your earnings over all 25 periods plus a participation fee of 1,000 yen.

For example, if the sum of your earnings is 2,580 yen, your rewards will be 3,580 yen. In other words, the more you earn from each period, the higher your rewards will be.

B Appendix: Auction screens and procedures

B.1 Bidding screen

When you are ready to submit your bid, the following screen will be displayed. The upper-left corner of the screen displays what period is in the experiment. The following screen shows the 1st period in a total of 25 periods. In the center of the screen, "Your 1st Unit's Value" and "Your 2nd Unit's Value" are displayed. First, please transcribe these information into the corresponding columns on the record sheet.

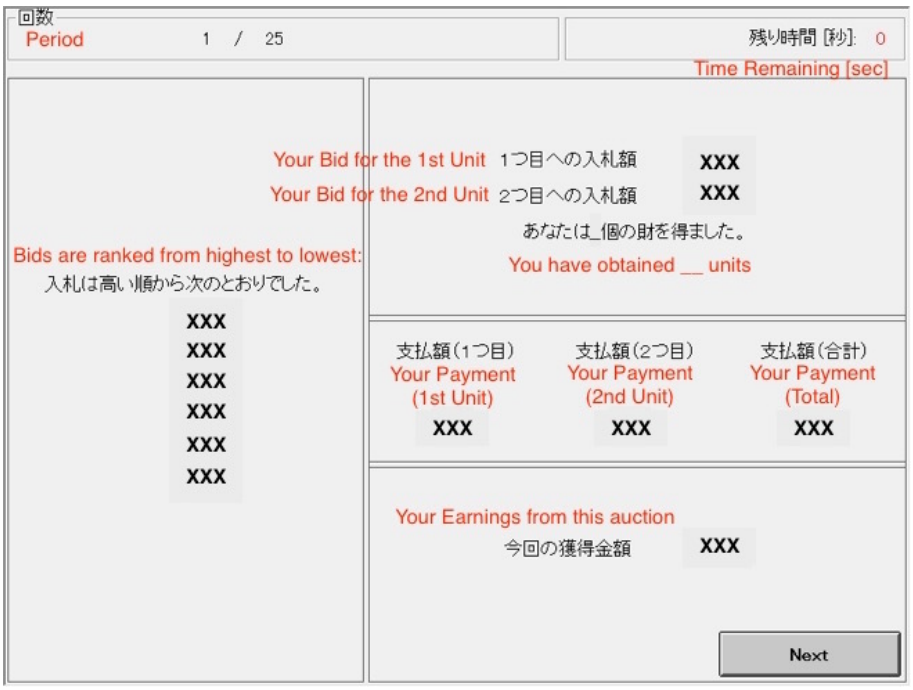
Next, you submit "Your Bid for the 1st Unit" and "Your Bid for the 2nd Unit", both in increments of 10 yen. Please input your bids into the corresponding cells on the screen. *Note that your bid for the 1st unit must be higher than your bid for the 2nd unit.* After that, please transcribe your bids into the corresponding columns on the record sheet. After the transcription, click the "OK" button.

You will have 60 seconds to finalize your bid on this screen.

B.2 Auction results screen

After all the subjects have clicked the "OK" button, the following screen will be displayed. On the left side of the screen, all the bids will be ranked from highest to

lowest. The right side will be divided into 3 sections. The top section will show "Your Bid for the 1st Unit","Your Bid for the 2nd Unit", and the number of units you have earned in this auction. In the middle section, your payment will be displayed in the following order: the amount you paid for the 1st unit, the amount you paid for the 2nd unit, and total amount you paid in this auction. Please transcribe these information into the corresponding columns on your record sheet. Finally, the bottom section will show the amount of "Your Earnings from this Auction". Please transcribe this information the corresponding column on your record sheet. After the transcription, click the "Next" button.



After all the subjects have clicked the "Next" button, the next auction will start. Now one round of auction has finished. A series of 25 auctions will be held in this experiment.

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