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

Takehito Masuda
Toyotaka Sakai
Shigehiro Serizawa
Takuma Wakayama

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The Institute of Social and Economic Research
Osaka University
6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

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

Takehito Masuda† Toyotaka Sakai‡
Shigehiro Serizawa§ Takuma Wakayama¶

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Abstract

We conduct laboratory experiments for the multi-unit Vickrey auction *with* and *without* providing advice to subjects on strategy-proofness. Although the rate of truth-telling among the subjects stays at 20% without advice, the rate increases to 47% with advice. By conducting similar experiments for the pay-your-bid auction, which is not strategy-proof, we confirm that our results are not due to so-called experimenter demand effects. Moreover, advice improves efficiency in the Vickrey auction, particularly in early periods in which subjects are less experienced. It is well known that subjects tend to overbid in several Vickrey auction experiments. Our results indicate the possibility that simple advice decreases such overbidding by promoting better understanding of the strategy-proofness property in the Vickrey auction. Strategy-proof mechanisms are sometimes criticized because players often fail to find the benefit of truth-telling, but our observations show that introducing advice on the property of strategy-proofness helps them to 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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†Institute of Social and Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan. E-mail: tmasuda@iser.osaka-u.ac.jp

‡Department of Economics, Keio University, 2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan. E-mail: tsakai@z5.keio.jp

§Institute of Social and Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan. E-mail: serizawa@iser.osaka-u.ac.jp

¶Faculty of Economics, Ryukoku University, 67 Tsukamoto-cho, Fukakusa, Fushimi-ku, Kyoto 612-8577, Japan. E-mail: wakayama@econ.ryukoku.ac.jp

1 Introduction

The technology for the design of economic mechanisms has grown rapidly in the last few decades. Practical applications of economic mechanisms now include spectrum auctions (Milgrom, 2000), school choice (Abdulkadiroğlu and Sönmez, 2003), and kidney exchange (Roth et al., 2004), among many others. A 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 the collection of accurate information.

On the other hand, laboratory experiments often exhibit that the percentage of truth-reporting subjects is not high or is even low (e.g., Attiyeh et al. (2000), Kawagoe and Mori (2001), Cason et al. (2006), and Chen and Sönmez (2006)).[1] These observations have been considered as an anomaly to the theory, encouraging skepticism concerning the practical performance of strategy-proof mechanisms. A prominent example is the Vickrey auction, under which many experimental studies have observed overbidding behavior.[2] 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.

The fact that the Vickrey auction is strategy-proof is not so trivial that the average person would not notice it.[3] This means that the Vickrey auction does not exhibit the expected performance if the explanation on the rule is merely given to participants. A simple idea to overcome this difficulty is to announce strategy-proofness of the Vickrey auction to users, which is what we shall attempt in this experimental research. In our experiment, we provide advice on the strategy-proofness of the Vickrey auction to the

[1]Velez and Brown (2019) study the phenomenon of strategy-proof mechanism experiments from a different angle. They identify the condition under which the untruthful behavior is "empirically" plausible.

[2]Several experimental auction studies report that most subjects do not reveal their true type in the Vickrey auction even in the single-unit case. Kagel and Levin (1993) find that the rate of sincere bidding is approximately 27% of all bids. Garratt et al. (2012) report that even though the subjects are familiar with bidding in eBay auctions, approximately four out of five subjects failed to bid sincerely. 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 Ausubel auction, which is a dynamic counterpart of the Vickrey auction (Ausubel, 2004; Okamoto, 2018). See Kagel and Levin (2016) for a survey on experimental results of the Vickrey auction.

[3]Hassidim et al. (2017) provide possible explanations as to why individuals do not report their true preferences under the deferred acceptance mechanism, which is a well-known strategy-proof mechanism in the context of two-sided matching both in the field and in the lab. They cite "failure to identify the dominant strategy" as one of the explanations

subjects and examine its effect on subject behavior.

Our experiment deals with a case where multiple units of an item are to be sold under the Vickrey auction. We investigate the effect of providing advice on bidding behavior and the efficiency of outcomes. Since the Vickrey auction is truly strategy-proof, providing such advice involves no ethical problem concerning deception.[4,5] In our experiment, even after subjects were given advice, they were not required to follow the advice, and some of them in fact did not.

We observe that although the rate of sincere bidding is approximately 20% without advice, it increases to 46.9% once subjects are advised as to the strategy-proofness of the Vickrey auction. One might suspect that this increase stems from a so-called experimenter demand effect (Zizzo, 2009). To detect a "net effect" of advice in the Vickrey auction, we conduct similar experiments for a pay-your-bid auction, which is not strategy-proof.[6] We used the same advice across auction mechanisms to avoid deception. Then, we find that the advice effect in the Vickrey auction is much greater than the experimenter demand effect. Moreover, for the Vickrey auction, the impact of the advice is stronger for subjects who well understand the auction rule than for other subjects.

In the literature of auction theory, overbidding in the Vickrey/second price auction has been attributed to the joy of winning (Cooper and Fang, 2008), a cognitive limit on contingent reasoning (Li, 2017), and so on. Our results, however, show the possibility that simple advice decreases overbidding by promoting better understanding of the strategy-proofness property in the Vickrey auction. Our experimental results suggest that before operating strategy-proof mechanisms, explaining the property of strategy-proofness helps those who are unaware of its property to behave "correctly."

Related literature. The effect of providing advice on strategy-proof mechanisms has recently been studied by several authors (Guillen and Hing, 2014; Ding and Schot-

[4]Our approach sounds an intervention of freedom of choice or free play, but we consider that saying so is an overreaction. Suppose a consumer purchases a new electronic device and the maker of the device kindly explains how the consumer should use it. The consumer still has the freedom of choice to not follow the advice. Then, we do not say that the person giving the advice is intervening in the consumer's freedom of choice. What we would like to do for economic mechanisms is exactly like this. This scenario represents a type of consumer protection rather than an intervention. Or, we could describe the situation as an opportunity for education rather than an intervention.

[5]Even in practical auctions, this type of advice is sometimes given to bidders. For example, the eBay auction provides bidders with "Tips for winning actions" (`https://www.ebay.com/help/buying/bidding/tips-winning-auctions?id=4015`).

[6]The pay-your-bid auction is used by many countries in practical Treasury bonds allocation. See Brenner et al. (2009) and Marszalec (2017) for more details.

ter, 2017b). These studies use a two-sided matching model 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 announcing the strategy-proofness of strategy-proof matching mechanisms raises the rate of truth-telling, although giving a detailed explanation of the definition of a mechanism rather decreases it.[7] These results suggest that advice helps participants to confirm 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.[8]

To enhance that people understand incentive properties, Saijo et al. (2007) and Li (2017) attempt to strengthen strategy-proofness. Saijo et al. (2007) emphasize that even if a mechanism is strategy-proof, it often admits the presence of an inefficient Nash equilibrium composed of mis-reporting. They strengthen strategy-proofness to "secure implementability" by additionally 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 under a securely implementable (and so strategy-proof) mechanism and that of other strategy-proof mechanisms. They 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 to dynamic mechanisms such as ascending auctions or matching algorithms. In a problem where a single item is auctioned, the ascending auction is obviously strategy-proof, but the Vickrey auction is not so. In an experiment where a single item is auctioned, Li observes that the ratio of dominant strategies played by subjects is significantly higher under the ascending clock auction than under the Vickrey auction. 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 advice can be applied to any strategy-proof mechanism in any environment. The Vickrey auc-

[7]Guillen and Hakimov (2018) consider top-down advice (e.g., advice given by the mechanism administrator). Several studies examine whether the source of advice affects 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 such as websites (Guillen and Hing, 2014).

[8]Shogren et al. (2001) conduct a Vickrey auction experiment under the condition that subjects are informed of the strategy-proofness of the Vickrey auction. However, they do not test the effect of the advice because they do not conduct a Vickrey auction experiment without advice. In addition, in some experimental studies that aim to elicit real values for items through incentive-compatible mechanisms such as the Vickrey auction, the experimental instructions explicitly inform subjects that truth-telling is the best strategy (e.g., Grether and Plott (1979) and List (2001)). However, these studies are not interested in testing whether or not providing such information will affect the rate of truth-telling.

tion is neither securely implementable nor obviously strategy-proof, but giving advice drastically improves its performance on truth-telling.

The remainder of the paper is organized as follows. Section 2 describes the theoretical background and our experimental design. Section 3 presents our experimental results. Section 4 provides concluding remarks.

2 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 the 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

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

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 the seller collects all bidders' bids, the seller ranks them from the highest to the lowest bid and allocates the two units to the two highest bids. If bidder i wins one (or two, respectively) unit, then the bidder has to pay the highest bids (or the sum of the highest and the second-highest bids, respectively) from among the other bidders' losing bids.

- **Pay-your-bid auction:** Each bidder simultaneously submits a bid vector $b_i = (b_i^1, b_i^2) \in V$. After the seller collects all bidders' bids, the seller ranks them from the highest to the lowest bid and allocates the two units to the two highest bids. If bidder i wins one (or two, respectively) unit, then the bidder has to pay b_i^1 (or $b_i^1 + b_i^2$, respectively).

The most important feature of the Vickrey auction is 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 not so. However, in contrast to the Vickrey auction, the pay-your-bid auction violates strategy-proofness.

2.2 Experimental procedures

We conducted an experiment to test the effect of advice for the Vickrey auction. We used between-subjects design. To distinguish between whether subjects follow the advice because they understand it or 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 to 1,000 with increments of 10. Then, the larger (smaller) integer is assigned the value of the first (second) unit. All values are displayed in Japanese yen (JPY).

Each of VA, PA, and PN had three experimental sessions, whereas VN had two sessions. We conducted these 11 sessions at Osaka University in March of 2015 and

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.

July of 2016. We recruited student subjects from Osaka University through campus-wide advertisements. None of the students were experienced in this particular type of experiment. No subject attended more than one session. Our experiment was 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 assigned by a lottery. All terminals were separated by partitions. No communication among subjects was allowed. Each subject had a set of printed instructions and a recording sheet.[9] The experimenter read aloud the instructions. Then, subjects answered a 17-question quiz that tested whether they understood the auction rule that they had been informed of a short time ago. Every correct answer was worth \$0.30 (\$1 = JPY 100). The experimenter read aloud the answers to the quiz. Subsequently, only in VA and PA, the experimenter distributed a paper with written advice and also 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.*"

Note that the advice involves no deception problem for VA and PA. The subjects were given time to ask questions before proceeding to two practice periods and to the 25 successive payment periods under the random matching protocol. At the beginning of each period, all subjects were separated into groups of three. At the bidding stage, each subject was asked to enter his/her two bids as nonnegative integers—such that

[9] The full set of experimental instructions (including screen shots, the quiz, and the questionnaire) is provided in Appendices C–H.

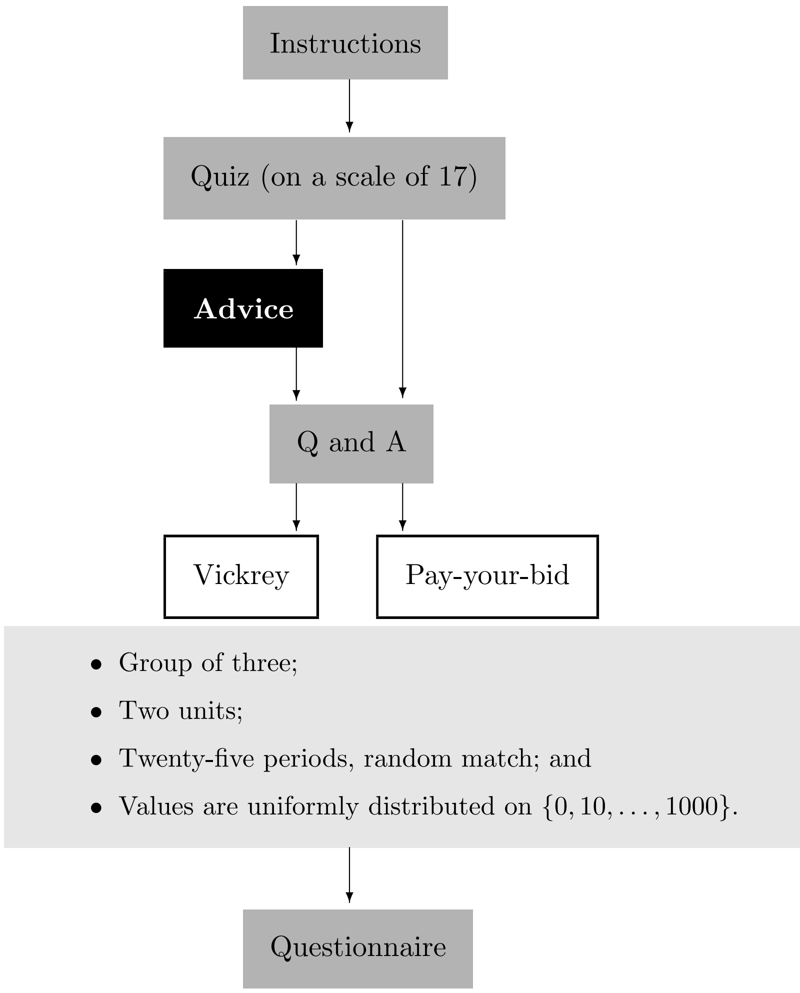

Figure 1: Timeline of one session.

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 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 \$5.90 to \$70.30.

3 Experimental results

3.1 Level of understanding of auction rules

Figure 2 displays the distributions of quiz scores. The scores range from 0 to 17. A first look at Figure 2 shows clear evidence that over 60% of the subjects received a perfect score in the Vickrey auction while over 80% did so in the pay-your-bid auction. Given

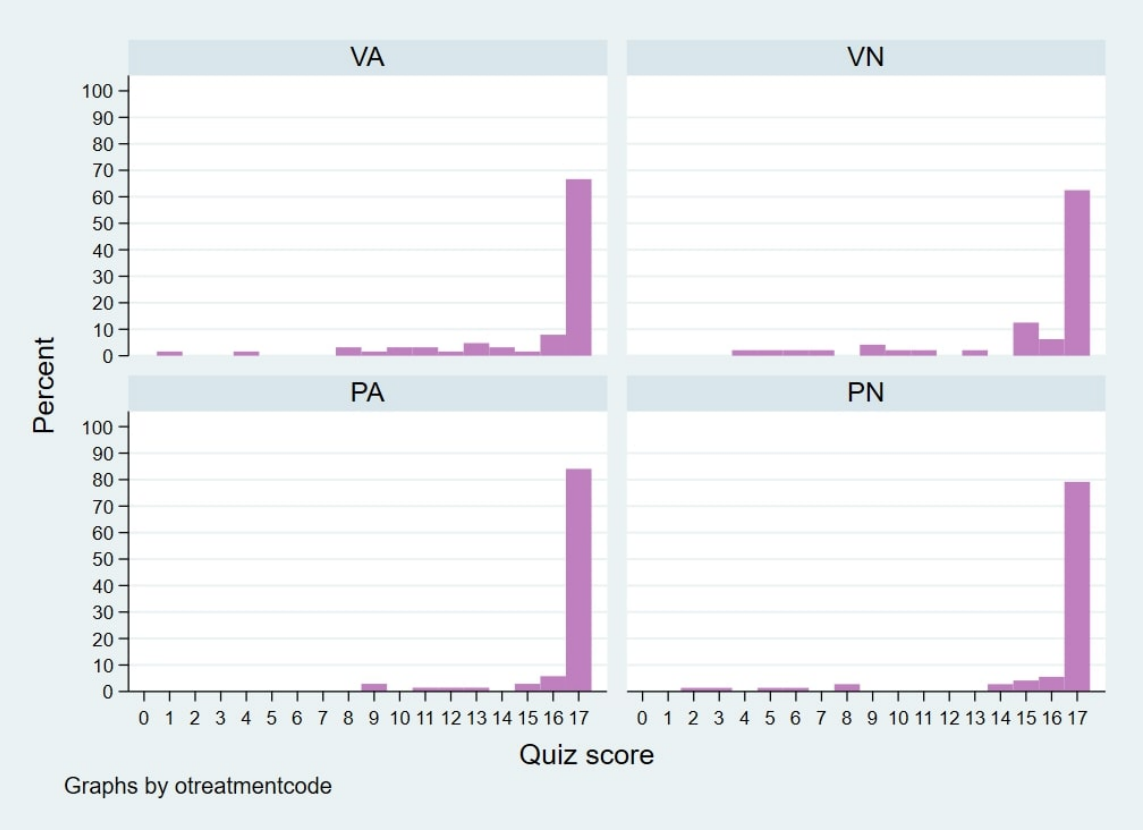

Figure 2: Distribution of quiz scores for each treatment prior to the auctions.

an auction rule, we found no statistical difference in the score distributions with and without advice.[10] Similarly, we found no statistical evidence to support the different levels of understanding between the two auctions regardless of the presence of advice.[11] In summary, we have the following result.

Result 1 (Level of understanding auction rules). *The majority of subjects had a thorough understanding of the auction rules prior to playing regardless of whether they participated in the Vickrey or the pay-your-bid auction.*

[10] 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. The same conclusions hold under a chi-square test also.

[11] The K-S test had a p-value > 0.10 for all pairwise comparisons of (i) VA vs. PA, (ii) VA vs. PN, (iii) VN vs. PA, and (iv) VN vs. PN.

3.2 Bidding behavior

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 overbid is bidder 1's first unit, while the remaining two bids are underbids. Hence, the overall average sincere bid rate is 0.5 (i.e., we divide the number of sincere bids by 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 shows the scatter plots for values and bids in each treatment. Initially, the Vickrey treatments graphs suggest that, for unit 1, bidders with higher values more likely to overbid. When values are close to the maximum, 1,000, bids jump as high as 2,000. For unit 2, bidding behavior is polarized with an increase in underbidding: overbidding is prevalent regardless of the realized values. At the same time, we also observe a cluster of zero bidding when unit 2 values are no more than 500. Table 2 summarizes the classification of bids into three categories by treatment and unit by unit.[12]

As Panel (a) of Table 2 (VA−VN column) shows, sincere bidding increased by 26.3% with the statement of strategy-proofness in the Vickrey auction. Notice that overbidding is prevalent in the Vickrey auction without advice (VN), which amounts to 63.29% of all bids. This observation is consistent with findings in experiments of the multi-unit Vickrey auction by Manelli et al. (2006), Engelmann and Grimm (2009), and Kagel and Levin (2009). With an explicit statement on the strategy-proofness of the Vickrey auction (VA), 45.3% of the case was overbidding; that is, this means that our advice decreased overbidding by 17.99%. Moreover, we found that underbidding also decreases when the advice is given. Specifically, our advice decreased underbidding by 8.31%. In order to compare the impact of advice on overbids and underbids, we calculate the ratio of the reduction rate of overbidding to the rate of overbidding in VN as well as the ratio of the reduction rate of underbidding to the rate of underbidding in VN. As a result, we find the advice has more impact on underbids (8.31/16.08) than overbids (17.99/63.29). When we break down the data into each unit (Panels (b) and (c) of Table 2), the same tendency holds. In contrast, approximately 90% of the subjects in PA and PN are likely to underbid. We also observe a 3%-increase of sincere

[12]See Appendix B for individual-oriented analysis.

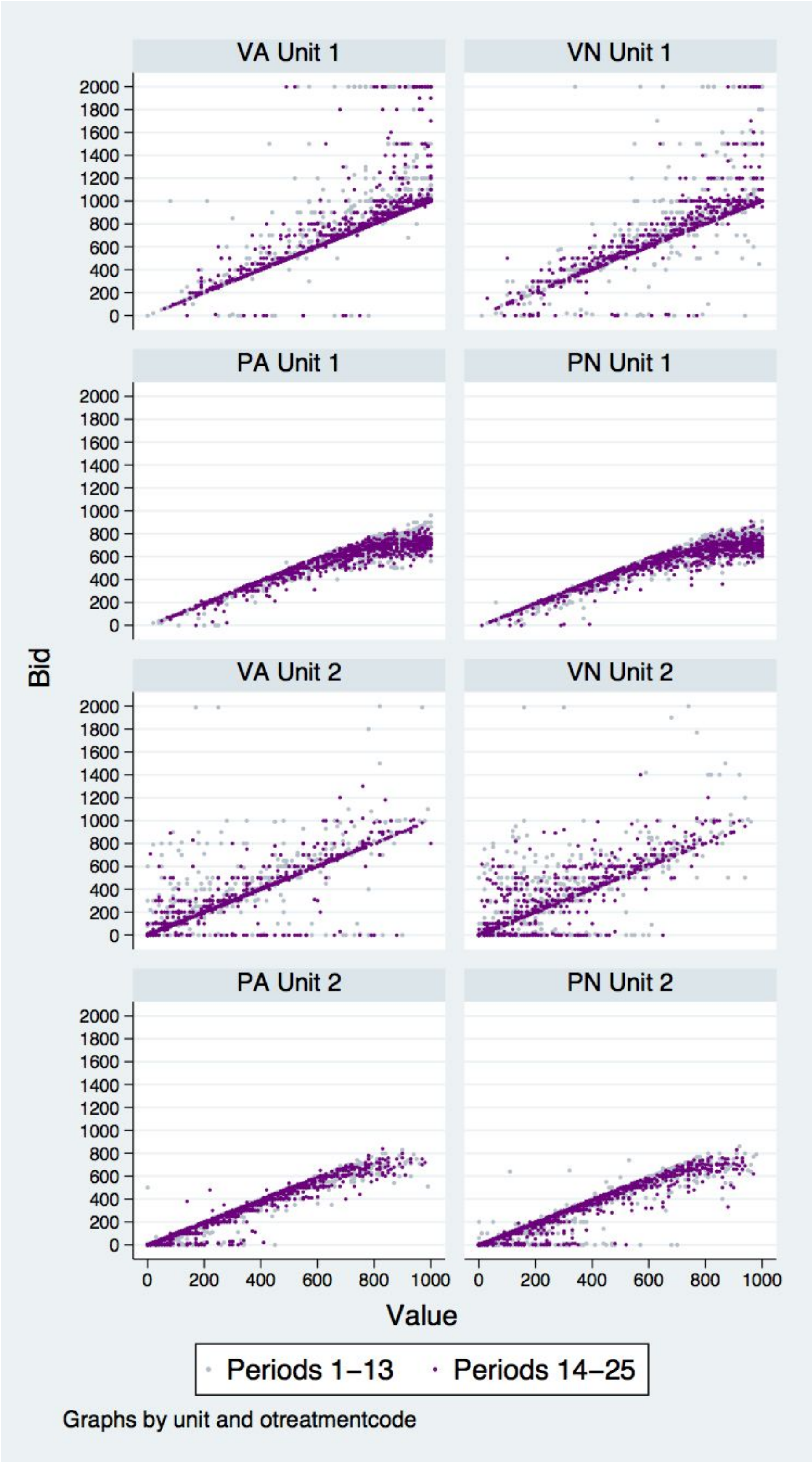

Figure 3: Scatter plots of bids. Blue and red plots indicate bids for unit one and two, respectively.

bidding although the advice is not true in this case.[13]

Table 3 summarizes the frequencies of sincere bidding by treatment, whether the quiz score is perfect or not, and by unit. In what follows, we apply a normal approximation to examine whether the following three factors affect sincere bidding behavior: auction rule, advice, and unit.[14] Suppose that sincere bidding behavior in treatment $j \in \{\mathsf{VA}, \mathsf{VN}, \mathsf{PA}, \mathsf{PN}\}$ is a realization of a random variable X_j with the Bernoulli distribution that takes 1 (= sincere bidding) with the success rate of p_j.[15] That is,

$$X_j = \begin{cases} 1 & \text{with prob.}\, p_j, \\ 0 & \text{with prob.}\, 1 - p_j. \end{cases}$$

Let $\overline{X}_j$ denote the sample mean for n_j realizations of X_j and let

$$S_j = \frac{\overline{X}_j(1 - \overline{X}_j)}{n_j}.$$

Table 3 summarizes the observed sincere bidding. Superscripts a, p, and i correspond to all subjects, the subjects whose quiz scores are perfect, and the subjects whose quiz scores are imperfect, respectively. Hereafter, capital letters indicate random variables while small letters do realized values.

3.2.1 Advice effects and experimenter demand effects

Using mainly both units' data shown in Panel (a) of Table 3, we first test whether or not the advice increases sincere bidding in each auction rule. We summarize our findings as follows:

Result 2.

(i) *The advice increases sincere bidding in each auction rule when using all data. The mean increases are 26.3% (95% confidence interval, 23.9% to 28.7%) and 2.5% (95% confidence interval, 1.3% to 3.7%) in the Vickrey auction and in the pay-your-bid auction, respectively.*

[13] A simple regression of all bids to values strongly shows the coefficients are 0.8032 for PA and 0.7927 for PN. For the theory of multi-unit, pay-your-bid auctions, see Lebrun and Tremblay (2003).

[14] See Jacquemet and L'Haridon (2018, p. 255) for the construction of our test statistics.

[15] It is plausible to assume independence among subjects and periods since the values are independent and identically distributed draws from the uniform distribution, and we employed random matching. On the other hand, two bids in a given period and subject can depend on each other.

(a) Both unit

	Vickrey					Pay-your-bid				
Bid category	VA		VN		VA−VN	PA		PN		PA−PN
Over	1,427	(45.3%)	1,519	(63.29%)	−17.99%	19	(0.55%)	33	(0.92%)	−0.37%
Sincere	1,478	(46.92%)	495	(20.63%)	26.30%	287	(8.32%)	209	(5.81%)	2.51%
Under	245	(7.78%)	386	(16.08%)	−8.31%	3,144	(91.13%)	3,358	(93.28%)	−2.15%
Total	3,150		2,400			3,450		3,600		

(b) Unit 1

	Vickrey					Pay-your-bid				
Bid category	VA		VN		VA−VN	PA		PN		PA−PN
Over	875	(55.56%)	876	(73%)	−17.44%	2	(0.12%)	2	(0.11%)	0.00%
Sincere	655	(41.59%)	210	(17.5%)	24.09%	35	(2.03%)	11	(0.61%)	1.42%
Under	45	(2.86%)	114	(9.5%)	−6.64%	1,688	(97.86%)	1,787	(99.28%)	−1.42%
Total	1,575		1,200			1,725		1,800		

(c) Unit 2

	Vickrey					Pay-your-bid				
Bid category	VA		VN		VA−VN	PA		PN		PA−PN
Over	552	(35.05%)	643	(53.58%)	−18.54%	17	(0.99%)	31	(1.72%)	−0.74%
Sincere	823	(52.25%)	285	(23.75%)	28.50%	252	(14.61%)	198	(11%)	3.61%
Under	200	(12.7%)	272	(22.67%)	−9.97%	1,456	(84.41%)	1,571	(87.28%)	−2.87%
Total	1,575		1,200			1,725		1,800		

Table 2: Bid category by treatment and unit.

(a) Both unit

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.469	0.206	0.263***	0.083	0.058	0.025***	0.238***
	s^a_j	(7.91×10^{-5})	(6.82×10^{-5})		(2.21×10^{-5})	(1.52×10^{-5})		
Perfect	$\overline{x}^p_j$	0.523	0.211	0.312***	0.079	0.046	0.033***	0.279***
	s^p_j	(1.19×10^{-4})	(1.11×10^{-4})		(2.51×10^{-5})	(1.54×10^{-5})		
Imperfect	$\overline{x}^i_j$	0.361	0.199	0.162***	0.104	0.105	−0.001	0.163***
	s^i_j	(2.20×10^{-4})	(1.77×10^{-4})		(1.69×10^{-4})	(1.25×10^{-4})		

(b) Unit 1

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.416	0.175	0.241***	0.02	0.006	0.014***	0.227***
	s^a_j	(1.54×10^{-4})	(1.20×10^{-4})		(1.14×10^{-5})	(3.31×10^{-6})		
Perfect	$\overline{x}^p_j$	0.463	0.176	0.287***	0.018	0.004	0.014***	0.273***
	s^p_j	(2.37×10^{-4})	(1.93×10^{-4})		(1.22×10^{-5})	(2.80×10^{-6})		
Imperfect	$\overline{x}^i_j$	0.322	0.173	0.149***	0.033	0.013	0.020*	0.129***
	s^i_j	(4.16×10^{-4})	(3.18×10^{-4})		(1.16×10^{-4})	(3.42×10^{-5})		

(c) Unit 2

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.523	0.237	0.286***	0.146	0.110	0.036***	0.250***
	s^a_j	(1.58×10^{-4})	(1.51×10^{-4})		(7.23×10^{-5})	(5.44×10^{-5})		
Perfect	$\overline{x}^p_j$	0.584	0.245	0.339***	0.141	0.087	0.054*	0.285***
	s^p_j	(2.31×10^{-4})	(2.47×10^{-4})		(8.35×10^{-5})	(5.57×10^{-5})		
Imperfect	$\overline{x}^i_j$	0.400	0.224	0.176***	0.175	0.197	−0.022	0.198***
	s^i_j	(4.57×10^{-4})	(3.86×10^{-4})		(5.25×10^{-4})	(4.22×10^{-4})		

Notes: * denotes significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 3: Frequency of sincere bidding, by treatment, quiz score and unit.

(ii) *The advice is effective in the Vickrey auction even when focusing on the data of the subjects with perfect quiz scores only or of those with imperfect quiz scores only.*

(iii) *The same advice is effective in the pay-your-bid auction for the subjects with perfect quiz scores rather than those with imperfect quiz scores.*

Support. Given $\bullet \in \{\mathsf{V}, \mathsf{P}\}$, let $Y^a_\bullet \equiv \left(\overline{X}_{\bullet\mathsf{A}} - \overline{X}_{\bullet\mathsf{N}}\right)$. The test statistic is

$$\widetilde{Y}^a_\bullet \equiv \frac{Y^a_\bullet - \mathbb{E}(Y^a_\bullet)}{\sqrt{S^a_{\bullet\mathsf{A}} + S^a_{\bullet\mathsf{N}}}},$$

where $\mathbb{E}$ is the expectation operator. By the central limit theorem and reproducibility of normal distributions, $Y^a_\bullet$ follows a standardized normal distribution. Hence, in what follows, we evaluate probabilities by a standardized normal distribution unless noted otherwise. The following null hypotheses state that advice does not increase sincere bidding within an auction rule.

Null hypothesis ($\boldsymbol{H_0^1}$): $\mathbb{E}(Y^a_\mathsf{V}) = 0$.

Null hypothesis ($\boldsymbol{H_0^2}$): $\mathbb{E}(Y^a_\mathsf{P}) = 0$.

By a direct calculation,

$$\widetilde{y}^a_\mathsf{V} = \frac{0.263}{\sqrt{7.91 \times 10^{-5} + 6.82 \times 10^{-5}}} = 21.68.$$

This yields $\text{Prob}(\widetilde{Y}^a_\mathsf{V} \geq \widetilde{y}^a_\mathsf{V}) < 0.0001$. Hence, advice significantly increased sincere bidding in the Vickrey auction. Moreover, the 95% confidence interval of $\mathbb{E}(Y^a_\mathsf{V})$ is [0.239, 0.287]. To establish (ii), we break the data into two: the subjects with perfect quiz scores or those with imperfect quiz scores. Then, we obtain

$$\widetilde{y}^p_\mathsf{V} = \frac{0.312}{\sqrt{1.19 \times 10^{-4} + 1.11 \times 10^{-4}}} = 20.58;$$
$$\widetilde{y}^i_\mathsf{V} = \frac{0.162}{\sqrt{2.20 \times 10^{-4} + 1.77 \times 10^{-4}}} = 8.132,$$

yielding $\text{Prob}(\widetilde{Y}^p_\mathsf{V} \geq \widetilde{y}^p_\mathsf{V}) < 0.0001$ and $\text{Prob}(\widetilde{Y}^i_\mathsf{V} \geq \widetilde{y}^i_\mathsf{V}) < 0.001$ respectively. Hence, both $\mathbb{E}(Y^p_\mathsf{V}) = 0$ and $\mathbb{E}(Y^i_\mathsf{V}) = 0$ are rejected.

By a direct calculation,

$$\widetilde{y}^a_\mathsf{P} = \frac{0.025}{\sqrt{2.21 \times 10^{-5} + 1.52 \times 10^{-5}}} = 29.50.$$

This yields $\text{Prob}(\widetilde{Y}^a_{\mathsf{P}} \geq \widetilde{y}^a_{\mathsf{P}}) < 0.0001$. Hence, advice significantly increased sincere bidding in the pay-your-bid auction although the advice is false. Therefore, this result supports a so-called experimenter demand effect (Zizzo, 2009). Moreover, the 95% confidence interval of $\mathbb{E}(Y^a_{\mathsf{P}})$ is [0.013, 0.037]. Nevertheless, when breaking the data into the subjects with perfect quiz scores and those with imperfect quiz scores,

$$\widetilde{y}^p_{\mathsf{P}} = \frac{0.033}{\sqrt{2.51 \times 10^{-5} + 1.54 \times 10^{-5}}} = 5.186;$$
$$\widetilde{y}^i_{\mathsf{P}} = \frac{-0.001}{\sqrt{1.69 \times 10^{-4} + 1.25 \times 10^{-4}}} = -0.058,$$

yielding $\text{Prob}(\widetilde{Y}^p_{\mathsf{P}} \geq \widetilde{y}^p_{\mathsf{P}}) < 0.0001$ and $\text{Prob}(\widetilde{Y}^i_{\mathsf{P}} \geq \widetilde{y}^i_{\mathsf{P}}) = 0.523$ respectively. Hence, $\mathbb{E}(Y^p_{\mathsf{P}}) = 0$ is rejected, while $\mathbb{E}(Y^i_{\mathsf{P}}) = 0$ is accepted. Thus, we establish (iii). □

3.2.2 Net effect of advice

Result 2 reports the advice effect on the pay-your-bid auction. The effect should be considered as an experimenter demand effect since the advice is false in that auction. Thus, there is a possibility that the advice effect in the Vickrey auction might also be an experimenter demand effect. However, Result 2 also reports that the advice effect in the Vickrey auction is much higher than that in the pay-your-bid auction. An excess of effect over the experimenter demand effect is considered as a "net effect" of advice to promote sincere bidding in the Vickrey auction. We test whether the advice in the Vickrey auction has a net effect.

Since the advice given in both auctions is identical, the experimenter demand effects would also be similar in both auctions. Moreover, since the advice is false in the pay-your-bid auction, its advice effect is an all experimenter demand effect. Thus, we assume that the net effect of advice in the Vickrey auction can be measured by the difference in advice effects on the two auctions. We test the net effect of advice in the Vickrey auction under this assumption.

Result 3. *The advice increases sincere bidding much more in the Vickrey auction compared to the pay-your-bid auction, with the mean increase of 23.8% (95% confidence interval, 21.1% to 26.5%).*

Support. We follow a difference-in-difference type argument. Let $Z^a = (Y^a_{\mathsf{V}} - Y^a_{\mathsf{P}})$. The test statistic is

$$\widetilde{Z}^a \equiv \frac{Z^a - \mathbb{E}(Z^a)}{\sqrt{S^a_{\mathsf{VA}} + S^a_{\mathsf{VN}} + S^a_{\mathsf{PA}} + S^a_{\mathsf{PN}}}}.$$

We formulate the null hypothesis as follows:

Null hypothesis ($\boldsymbol{H_0^3}$): $\mathbb{E}(Z^a) = 0$.

By a direct calculation,

$$\widetilde{z}^a = \frac{0.263 - 0.025}{\sqrt{7.91 \times 10^{-5} + 6.82 \times 10^{-5} + 2.21 \times 10^{-5} + 1.52 \times 10^{-5}}} = 17.52.$$

This yields $\text{Prob}(\widetilde{Z}^a \geq \widetilde{z}^a) < 0.0001$. Moreover, the 95% confidence interval of $\mathbb{E}(Z^a)$ is [0.211, 0.265]. □

The difference, 21.1%, of the advice effects in the two auctions is considered as a net effect of advice on the Vickrey auction. Many authors investigate why subjects do not bid sincerely in the Vickrey auction by proposing alternative explanations. Result 3 suggests that a considerable amount of such behavior might be mitigated by providing advice that helps to understand the strategy-proofness property of the Vickrey auction.

3.2.3 Relationship between quiz scores and advice effects

We finally test whether quiz scores affect the responsiveness to advice in the Vickrey auction. The following result demonstrates that the responsiveness to advice depends on the quiz scores in the Vickrey auction.

Result 4. *Within the Vickrey auction, the subjects with perfect quiz scores are more responsive to advice than the subjects with imperfect quiz scores. The mean difference between the two groups in terms of an increase in the sincere bidding rate is 15.0% (95% confidence interval, 10.1% to 20.0%).*

Support. Given $\bullet \in \{p, i\}$, let $Y_{\mathsf{V}}^{\bullet} = \left(\overline{X}_{\mathsf{VA}} - \overline{X}_{\mathsf{VN}}\right)$ and let $W_{\mathsf{V}} = (Y_{\mathsf{V}}^p - Y_{\mathsf{V}}^i)$. The test statistic is

$$\widetilde{W}_{\mathsf{V}} \equiv \frac{W_{\mathsf{V}} - \mathbb{E}(W_{\mathsf{V}})}{\sqrt{S_{\mathsf{VA}}^p + S_{\mathsf{VN}}^p + S_{\mathsf{VA}}^i + S_{\mathsf{VN}}^i}}.$$

We formulate the null hypothesis as follows:

Null hypothesis ($\boldsymbol{H_0^4}$): $\mathbb{E}(W_{\mathsf{V}}) = 0$.

By a direct calculation,

$$\widetilde{w}_{\mathsf{V}} = \frac{0.312 - 0.162}{\sqrt{1.19 \times 10^{-4} + 1.11 \times 10^{-4} + 2.20 \times 10^{-4} + 1.77 \times 10^{-4}}} = 5.992.$$

This yields $\text{Prob}(\widetilde{W}_{\mathsf{V}} \geq \widetilde{w}^a_{\mathsf{V}}) < 0.0001$. Moreover, the 95% confidence interval of $\mathbb{E}(W_{\mathsf{V}})$ is [0.101, 0.200]. □

Result 4 suggests that subjects who well understand the rule of the Vickrey auction tend to bid sincerely under the advice than others who do not so.

3.2.4 Robustness

We comment on the robustness of our results regarding bidding behaviors.

1. When we restrict attention to unit-by-unit data in Table 3, almost all results carry over: H_0^1, H_0^2, and H_0^3 are again rejected at the 1% significance level except for the cases including imperfectly scored subjects in the pay-your-bid auction. Additionally, H_0^4 is rejected at the 1% significance level for both units.

2. When we restrict our attention to the first period only and use both units' data, as shown in Table 5 in Appendix A, H_0^1, H_0^2, and H_0^3 are again rejected at the 10% significance level except for the cases including imperfectly scored subjects in the pay-your-bid auction where the sample size is smaller than 30 while H_0^4 is accepted.

3. We also examined whether the subjects' bidding behaviors change over time. All observations stated in this subsection held even when we focus on the former periods (periods 1–13) or the latter periods (periods 14–25). See Table 6 in Appendix A for more details.

3.3 Efficiency

Our efficiency measure is due to Kagel and Levine (2009).[16] 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 observed efficiency ratio r 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 $(v_1^1, v_1^2, v_2^1, v_2^2, v_3^1, v_3^2)$. The efficiency ratio of the full or part of a treatment is the average of the efficiency ratios in the games in the full treatment or part of the treatment.

As in Section 3.2, we again normally approximated to examine the effect of auction rules, advice, and experience on efficiency. Suppose the efficiency ratio r in treatment

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

$j \in \{\mathsf{VA}, \mathsf{VN}, \mathsf{PA}, \mathsf{PN}\}$ is a realization of a random variable R_j with mean $\mathbb{E}(R_j) \in [0,1]$ and variance $\mathrm{Var}(R_j)$. Let $\overline{R}_j$ denote the sample mean for n'_j realizations of R_j. Let

$$V_j \equiv \frac{\sum_{k=1}^{n_j}(R_{jk} - \overline{R}_j)^2}{n'_j - 1} \quad \text{and} \quad T_j \equiv \frac{V_j}{n'_j}.$$

Superscripts a, f, and ℓ correspond to all periods, the former periods (periods 1–13), and the latter periods (periods 14–25), respectively. Table 4 summarizes the results on efficiency with a focus on experience. In Table 4, the upper (resp., middle, bottom) panel collects the results obtained for all periods (resp., periods 1–13, periods 14–25).

Result 5. *Advice improves efficiency in the Vickrey auction, particularly in the former 13 periods.*

Support. Given $\bullet \in \{a, f, \ell\}$, let $U^{\bullet}_{\mathsf{V}} = \left(\overline{R}^{\bullet}_{\mathsf{VA}} - \overline{R}^{\bullet}_{\mathsf{VN}}\right)$. The test statistic is

$$\widetilde{U}^{\bullet}_{\mathsf{V}} \equiv \frac{U^{\bullet}_{\mathsf{V}} - \mathbb{E}(U^{\bullet}_{\mathsf{V}})}{\sqrt{T^{\bullet}_{\mathsf{VN}} + T^{\bullet}_{\mathsf{VN}}}}.$$

The following hypothesis states that advice does not increase efficiency within the Vickrey auction.

Null hypothesis ($\boldsymbol{H_0^5}$): $\mathbb{E}(U^a_{\mathsf{V}}) = 0$.

By a direct calculation,

$$\widetilde{u}^a_{\mathsf{V}} = \frac{0.010}{\sqrt{8.95 \times 10^{-6} + 1.62 \times 10^{-5}}} = 2.054.$$

This yields $\mathrm{Prob}(\widetilde{U}^a_{\mathsf{V}} \geq \widetilde{u}^a_{\mathsf{V}}) = 0.020$. Therefore, advice significantly increased efficiency in the Vickrey auction.

To obtain further insights, we break the data into two: periods 1–13 and 14–25. Then, we obtain

$$\widetilde{u}^f_{\mathsf{V}} = \frac{0.015}{\sqrt{2.32 \times 10^{-5} + 4.59 \times 10^{-5}}} = 1.769;$$
$$\widetilde{u}^\ell_{\mathsf{V}} = \frac{0.006}{\sqrt{1.13 \times 10^{-5} + 1.53 \times 10^{-5}}} = 1.066,$$

yielding $\mathrm{Prob}(\widetilde{U}^f_{\mathsf{V}} \geq \widetilde{u}^f_{\mathsf{V}}) = 0.038$ and $\mathrm{Prob}(\widetilde{U}^\ell_{\mathsf{V}} \geq \widetilde{u}^\ell_{\mathsf{V}}) = 0.143$, respectively. Hence, $\mathbb{E}(U^f_{\mathsf{V}}) = 0$ is rejected, while $\mathbb{E}(U^\ell_{\mathsf{V}}) = 0$ is not rejected. $\square$

		Vickrey		$u_{\mathsf{V}}^{\bullet}$	Pay-your-bid		$u_{\mathsf{P}}^{\bullet}$	$q^{\bullet}$
Data		VA	VN	VA−VN	PA	PN	PA−PN	
All	$\overline{r}_j^a$	0.977	0.967	0.010**	0.990	0.988	0.002	0.009*
	t_j^a	(8.95×10^{-6})	(1.62×10^{-5})		(1.36×10^{-6})	(1.35×10^{-6})		
Periods 1–13	$\overline{r}_j^f$	0.970	0.956	0.015**	0.991	0.989	0.002	0.013*
	t_j^f	(2.32×10^{-5})	(4.59×10^{-5})		(2.27×10^{-6})	(2.60×10^{-6})		
Periods 14–25	$\overline{r}_j^\ell$	0.984	0.978	0.006	0.989	0.988	0.001	0.004
	t_j^ℓ	(1.13×10^{-5})	(1.53×10^{-5})		(3.26×10^{-6})	(2.75×10^{-6})		

Notes: * denotes significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 4: Efficiency by treatment and period.

Result 5 suggests that improvements in the efficiency of the Vickrey auction occurs mainly when subjects are less experienced.

Result 6. *The relative impact of the advice of strategy-proofness on the efficiency of the Vickrey auction compared with the pay-your-bid auction exists, particularly in early periods.*

Support. We again apply the difference-in-difference technique analogously to Result 4. Let $Q^a = (U^a_{\mathsf{V}} - U^a_{\mathsf{P}})$. The test statistic is

$$\widetilde{Q}^a \equiv \frac{Q^a - \mathbb{E}(Q^a)}{\sqrt{T^a_{\mathsf{VA}} + T^a_{\mathsf{VN}} + T^a_{\mathsf{PA}} + T^a_{\mathsf{PN}}}}.$$

We formulate the null hypothesis as follows:

Null hypothesis ($\boldsymbol{H^6_0}$): $\mathbb{E}(Q^a) = 0$.

By a direct calculation,

$$\widetilde{q}^a = \frac{0.009}{\sqrt{8.95 \times 10^{-6} + 1.62 \times 10^{-5} + 1.36 \times 10^{-6} + 1.35 \times 10^{-6}}} = 1.629.$$

This yields $\text{Prob}(\widetilde{Q}^a \geq \widetilde{q}^a) = 0.052$.

Again, we break the data into two: periods 1–13 and 14–25. Then, we obtain

$$\widetilde{q}^f = \frac{0.013}{\sqrt{2.32 \times 10^{-5} + 4.59 \times 10^{-5} + 2.27 \times 10^{-6} + 2.60 \times 10^{-6}}} = 1.454;$$
$$\widetilde{q}^\ell = \frac{0.0044}{\sqrt{1.13 \times 10^{-5} + 1.53 \times 10^{-5} + 3.26 \times 10^{-6} + 2.75 \times 10^{-6}}} = 0.770,$$

yielding $\text{Prob}(\widetilde{Q}^f \geq \widetilde{q}^f) = 0.073$ and $\text{Prob}(\widetilde{Q}^\ell \geq \widetilde{q}^\ell) = 0.221$, respectively. Hence, $\mathbb{E}(Q^f) = 0$ is rejected at the 10% significance level while $\mathbb{E}(Q^\ell) = 0$ is not rejected. $\square$

Result 6 suggests that a relative improvement in the efficiency of the Vickrey auction compared to the pay-your-bid auction occurs mainly when subjects are less experienced. Result 6 and Table 4 show that the pay-your-bid auction is not necessarily superior to the Vickrey auction with our advice.[17] In Table 7 in Appendix A, we also tested the same hypotheses using an alternative way of defining efficiency where we care only whether efficient allocation is realized in a group observation. Then, we found a

[17] Englemann and Grimm (2009) compare the Vickrey auction and the pay-your-bid auction in an experiment where two units of an item are auctioned to two bidders with flat demand. They find observations similar to ours regarding the comparison of the efficiency ratios in two auctions.

significant increase in the efficiency of the Vickrey auction but no significance in the difference-in-difference test.

4 Conclusion

We experimentally showed that introducing advice on strategy-proofness leads to a higher sincere bidding rate in a multi-unit static Vickrey auction. Without this advice, the rate of sincere bidding in our experiment is similar to rates observed in previous studies. The same advice has effects on the Vickrey auction but also on the pay-your-bid auction. The latter effect is considered as a so-called experimenter demand effect (Zizzo, 2009). To test whether the advice has an excess effect over the experimenter demand effect in the Vickrey auction, we compared the effects of the advice on the two auctions and found that the advice has a large excess effect in the Vickrey auction.

Since overbidding in the Vickrey auction has been widely observed in the literature (Kagel and Levin, 1993; Garratt et al., 2012; Engelmann and Grimm, 2009; Porter and Vragov, 2006), researchers have attempted to identify factors that drive overbidding, such as the anticipation of regret, the joy of winning (Cooper and Fang, 2008), and cognitive limits on contingent reasoning (Li, 2017). Our results suggest that one of the key drivers of overbidding is the subjects' failure to be aware of the strategy-proofness property of the Vickrey auction, even for those who perfectly understand the rule of the Vickrey auction.

Note that our statement of advice is quite simple so that the same advice can be used in the two auctions. We emphasize that even such a simple advice has a considerable excess effect in the Vickrey auction. Much detailed advice would make the subjects bid more sincerely.

Our results show that simple advice improves efficiency in the Vickrey auction, and this improvement is higher in early periods in which subjects are less experienced. Thus, our results show that advice improves efficiency in the Vickrey auction by promoting better understanding of the strategy-proofness property in the Vickrey auction.

To focus on the advice effect on bidding behavior, we conducted experiments in a "symmetric" environment; that is, an environment where each bidder in the same auction has the same distribution function of valuations. In the pay-your-bid auction in such an environment, there is a symmetric equilibrium bidding strategy whose outcomes are efficient. As discussed in Section 3.3, the pay-your-bid auction as well as the Vickrey auction generated almost perfectly efficient outcomes. Thus, even without advice, there is little room to improve efficiency in both auctions. Thus, in our experiment, the effects of advice on efficiency are limited in both auctions. We conjecture that experiments in an "asymmetric" environment would make the advice effect on efficiency clearer.

Appendices

A Appendix: Additional analysis

- Table 5 summarizes the sincere bidding rates in the first period only in the same manner as Table 3.
- Table 6 summarizes the sincere bidding rates in the former 13 periods and the latter 12 period.
- Table 7 summarizes the frequencies of realization of efficient allocation by treatment. In what follows, we apply normal approximation as we do in Section 3.2. Suppose achievement of efficient allocation in treatment $j \in \{\mathsf{VA}, \mathsf{VN}, \mathsf{PA}, \mathsf{PN}\}$ is a realization of a random variable E_j with the Bernoulli distribution that takes 1 (= efficient) with the success rate of q_j.[18] That is,

$$E_j = \begin{cases} 1 & \text{with prob. } q_j, \\ 0 & \text{with prob. } 1 - q_j. \end{cases}$$

Let $\overline{E}_j$ denote the sample mean for n'_j realizations of E_j and let

$$F_j = \frac{\overline{E}_j(1 - \overline{E}_j)}{n'_j}.$$

[18]It is plausible to assume independence among subjects and periods since the values are independent and identically distributed draws from the uniform distribution, and we employed random matching. On the other hand, two bids in a given period and subject can depend on each other.

(a) Both unit

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.468	0.188	0.280^{***}	0.123	0.021	0.102^{***}	0.178^{***}
	s^a_j	(1.98×10^{-3})	(1.59×10^{-3})		(7.82×10^{-4})	(1.43×10^{-4})		
Perfect	$\overline{x}^p_j$	0.512	0.233	0.279^{***}	0.138	0.026	0.112^{***}	0.167^{**}
	s^p_j	(2.97×10^{-3})	(2.98×10^{-3})		(1.03×10^{-3})	(2.22×10^{-4})		
Imperfect	$\overline{x}^i_j$	0.381	0.111	0.270^{***}	$0.045^{b)}$	0	0.045	0.225^{**}
	s^i_j	(5.62×10^{-3})	(2.74×10^{-3})		(1.95×10^{-3})	(0)		

(b) Unit 1

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.429	0.167	0.262^{***}	0.043	0	0.043^{**}	0.219^{***}
	s^a_j	(3.89×10^{-3})	(2.90×10^{-3})		(5.96×10^{-4})	(0)		
Perfect	$\overline{x}^p_j$	0.476	0.2	0.276^{***}	0.052	0	0.052^{**}	0.224^{**}
	s^p_j	$(5.94{\times}10^{-3})$	(5.33×10^{-3})		(8.50×10^{-4})	(0)		
Imperfect	$\overline{x}^i_j$	0.333	0.111	0.222^{**}	$0^{b)}$	$0^{b)}$	0	0.222^{**}
	s^i_j	(1.06×10^{-2})	(5.48×10^{-3})		(0)	(0)		

(c) Unit 2

Data		Vickrey VA	Vickrey VN	$y^\bullet_{\mathsf{V}}$ VA−VN	Pay-your-bid PA	Pay-your-bid PN	$y^\bullet_{\mathsf{P}}$ PA−PN	$z^\bullet$
All	$\overline{x}^a_j$	0.508	0.208	0.300^{***}	0.203	0.042	0.161^{***}	0.139^{*}
	s^a_j	(3.97×10^{-3})	(3.43×10^{-3})		(2.34×10^{-3})	(5.59×10^{-4})		
Perfect	$\overline{x}^p_j$	0.548	0.267	0.281^{***}	0.224	0.053	0.171^{***}	0.11
	s^p_j	(5.90×10^{-3})	(6.52×10^{-3})		(3.00×10^{-3})	(8.81×10^{-4})		
Imperfect	$\overline{x}^i_j$	0.429	0.111	0.318^{***}	0.091	0	0.091	0.227^{*}
	s^i_j	(1.17×10^{-2})	(5.48×10^{-3})		$(7.52 \times 10^{-3})^{b)}$	$(0)^{b)}$		

Notes: a) * denotes significant at the 10% level, ** at the 5% level, and *** at the 1% level and b) The number of observations is no more than 30.

Table 5: Frequency of sincere bidding in period one, by treatment, quiz score and unit.

(a) Former 13 periods

Data		Vickrey		$y^{\bullet}_{\mathsf{V}}$	Pay-your-bid		$y^{\bullet}_{\mathsf{P}}$	$z^{\bullet}$
		VA	VN	VA−VN	PA	PN	PA−PN	
All	$\overline{x}^a_j$	0.467	0.186	0.281***	0.093	0.058	0.034***	0.246***
	s^a_j	(1.52×10^{-4})	(1.21×10^{-4})		(4.68×10^{-5})	(2.93×10^{-5})		
Perfect	$\overline{x}^p_j$	0.510	0.182	0.329***	0.088	0.045	0.043***	0.286***
	s^p_j	(2.29×10^{-4})	(1.91×10^{-4})		(5.34×10^{-5})	(2.92×10^{-5})		
Imperfect	$\overline{x}^i_j$	0.379	0.192	0.187***	0.115	0.108	0.008	0.179***
	s^i_j	(4.32×10^{-4})	(3.33×10^{-4})		(3.58×10^{-4})	(2.47×10^{-4})		

(b) Latter 12 periods

Data		Vickrey		$y^{\bullet}_{\mathsf{V}}$	Pay-your-bid		$y^{\bullet}_{\mathsf{P}}$	$z^{\bullet}$
		VA	VN	VA−VN	PA	PN	PA−PN	
All	$\overline{x}^a_j$	0.472	0.228	0.243***	0.073	0.058	0.015**	0.228***
	s^a_j	(1.65×10^{-4})	(1.53×10^{-4})		(4.09×10^{-5})	(3.16×10^{-5})		
Perfect	$\overline{x}^p_j$	0.537	0.242	0.295***	0.070	0.046	0.024***	0.271***
	s^p_j	(2.47×10^{-4})	(2.55×10^{-4})		(4.66×10^{-5})	(3.21×10^{-5})		
Imperfect	$\overline{x}^i_j$	0.341	0.206	0.135***	0.090	0.103	−0.012	0.147***
	s^i_j	(4.47×10^{-4})	(3.80×10^{-4})		(3.14×10^{-4})	(2.57×10^{-4})		

Notes: * denotes significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 6: Frequency of sincere bidding in the former 13 periods and the latter 12 periods.

Data		Vickrey VA	Vickrey VN	(1) VA−VN	Pay-your-bid PA	Pay-your-bid PN	(2) PA−PN	(1)−(2)
All	$\overline{e}_j$	0.779	0.705	0.074***	0.823	0.783	0.039*	0.035
	f_j	(3.28×10^{-4})	(5.20×10^{-4})		(2.54×10^{-4})	(2.83×10^{-4})		
Periods 1–13	$\overline{e}_j$	0.744	0.644	0.099***	0.823	0.782	0.041	0.059
	f_j	(6.98×10^{-4})	(1.10×10^{-3})		(4.88×10^{-4})	(5.46×10^{-4})		
Periods 14–25	$\overline{e}_j$	0.817	0.771	0.047	0.822	0.785	0.038	0.009
	f_j	(5.92×10^{-4})	(9.20×10^{-4})		(5.29×10^{-4})	(5.87×10^{-4})		

Notes: * denotes significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 7: Binary efficiency by treatment and period.

B Appendix: Individual-oriented analysis

B.1 VA1

Sixteen subjects (ID numbers 1–3, 6, 7, 9–16, 18, 19, 21) received a perfect score on the quiz.

Unit 1

- **Sincere bidding.** Four subjects (ID numbers 3, 11, 20, 21) bid sincerely in all periods. Two subjects (ID numbers 1, 10) bid sincerely in most periods (the frequency that each of these subjects bid sincerely was at least 88% (= 22/25)).
- **Overbidding.** Three subjects (ID numbers 12, 15, 17) overbid in all periods. Six subjects (ID numbers 4, 5, 6, 8, 13, 18) overbid in most periods (the frequency that each of these subjects overbid was at least 80% (= 20/25)).
- **Other patterns.**
    - One subject (ID number 2) overbid until period 11 and bid sincerely in most of the remaining periods.
    - One subject (ID number 7) bid any one of 0, 1,000, and 2,000.
    - Four subjects (ID numbers 9, 14, 16, 19) fluctuated between sincere bidding and overbidding in most or all periods.

Unit 2

- **Sincere bidding.** Four subjects (ID numbers 10, 11, 20, 21) bid sincerely in all periods. Two subjects (ID numbers 3, 19) bid sincerely in most periods (the frequency that each of these subjects bid sincerely was at least 92% (= 23/25)).
- **Overbidding.** One subject (ID number 12) overbid in all periods. Five subjects (ID numbers 1, 4, 5, 15, 17) overbid in most periods (the frequency that each of these subjects overbid was at least 76% (= 19/25)).
- **Underbidding.** One subject (ID number 7) bid 0 in all but one period.
- **Other patterns.**
    - One subject (ID number 2) overbid until period 11 and bid sincerely in the remaining periods.

- Three subjects (ID numbers 6, 8, 9) fluctuated between sincere bidding and overbidding in most or all periods.
- One subject (ID number 13) fluctuated between underbidding and overbidding in most periods.
- One subject (ID number 14) fluctuated between sincere bidding and underbidding in most periods.
- One subject (ID number 16) fluctuated between underbidding and overbidding until period 7, switched to sincere bidding for 12 periods, and fluctuated between sincere bidding and overbidding in the last 6 periods.
- One subject (ID number 18) fluctuated between sincere bidding and underbidding in most of the first 8 periods, switched to overbidding for 8 periods, and sincere bidding for the next five periods, then chose underbidding in the last 4 periods.

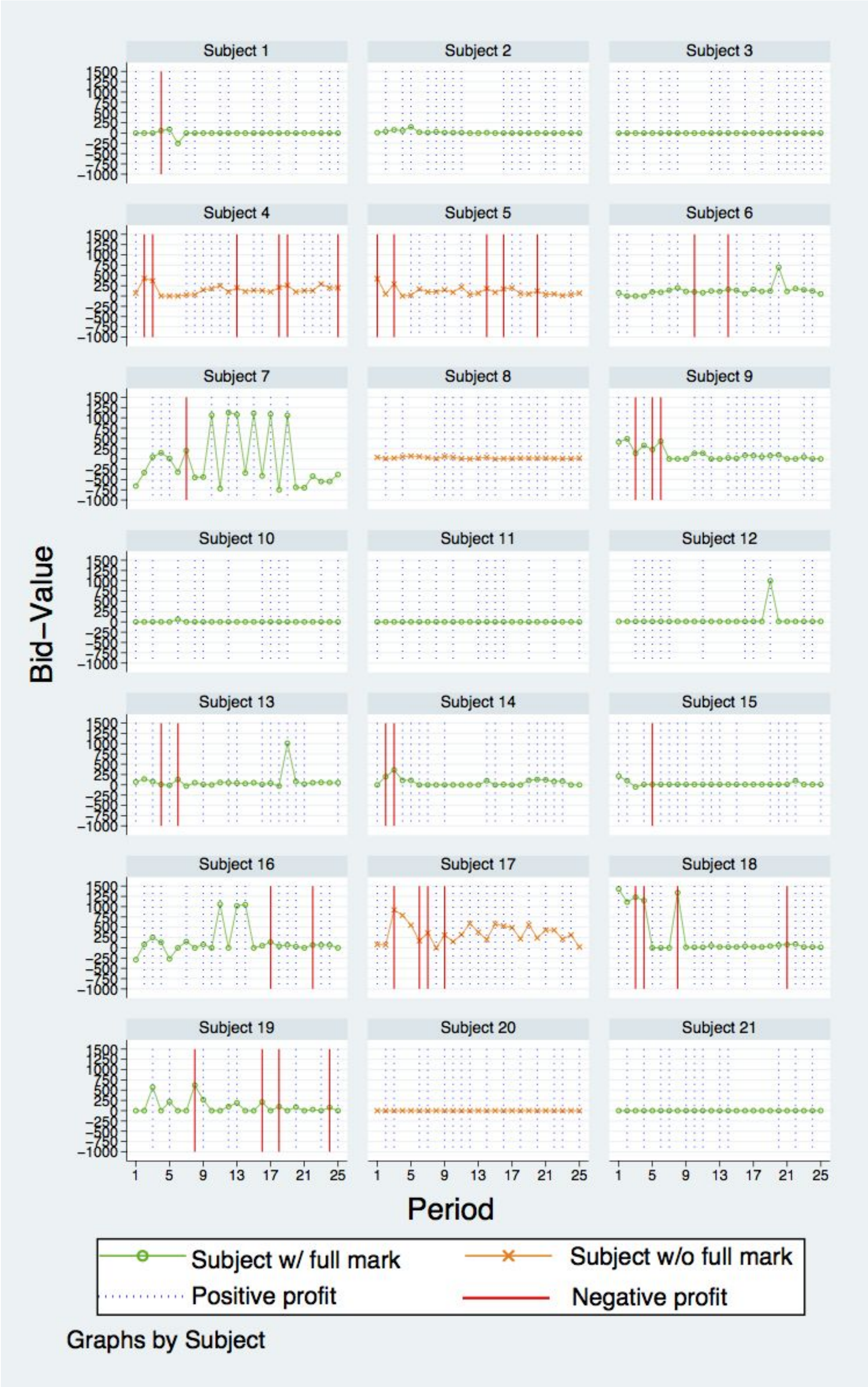

Figure 4: Time evolution of the gap between bid and value for unit 1 in VA1.

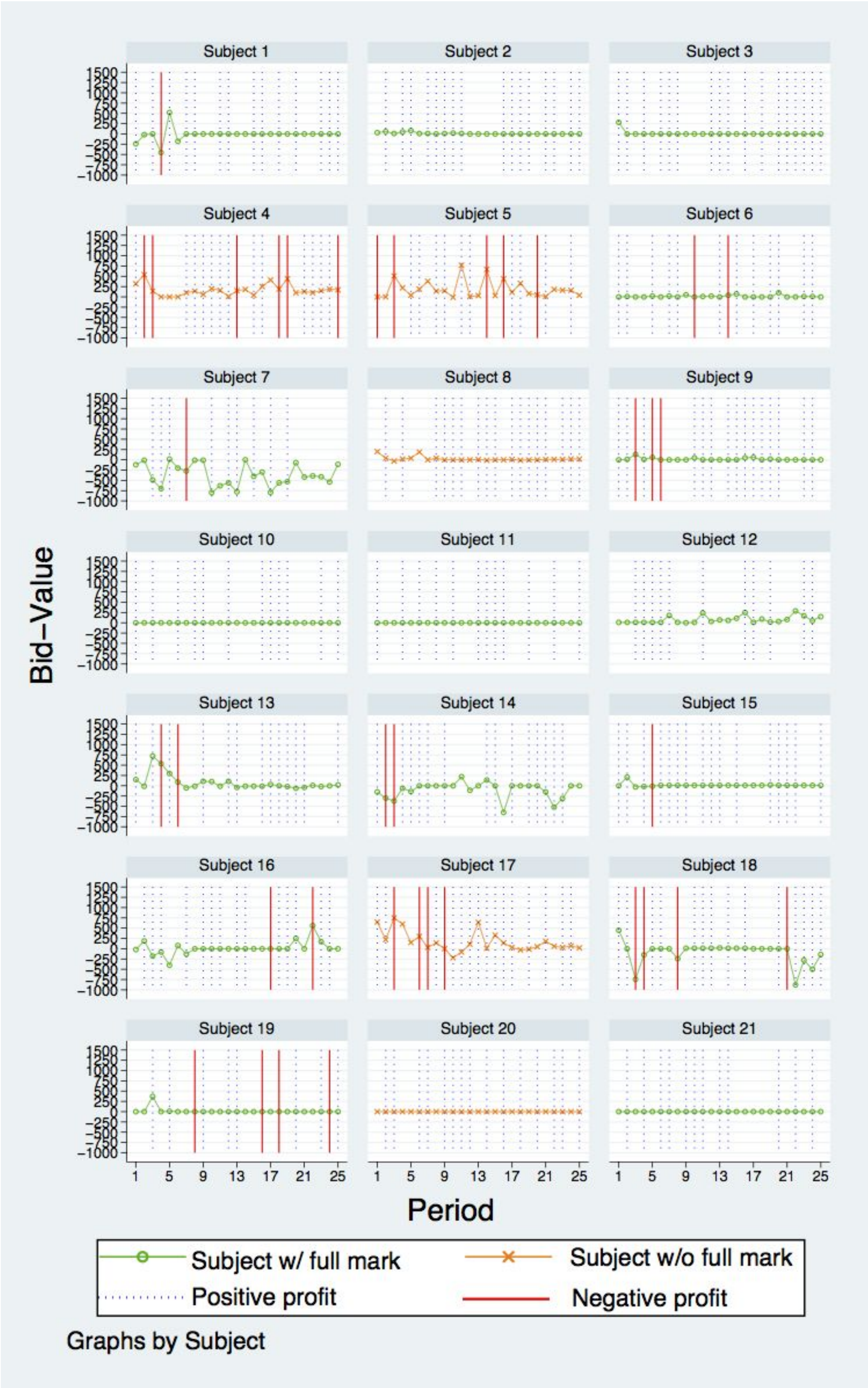

Figure 5: Time evolution of the gap between bid and value for unit 2 in VA1.

B.2 VA2

Thirteen subjects (ID numbers 2–4, 7, 8, 11, 13, 15–20) received a perfect score on the quiz.

Unit 1

- **Sincere bidding.** Three subjects (ID numbers 8, 10, 15) bid sincerely in all periods.
- **Overbidding.** One subject (ID number 7) overbid in all periods. Eleven subjects (ID numbers 1–4, 9, 12, 14, 16–18, 20) overbid in most periods (the frequency that each of these subjects overbid was at least 76% (= 19/25)).
- **Other patterns.**
    - One subject (ID number 5) fluctuated among overbidding, underbidding, and sincere bidding.
    - One subject (ID number 6) fluctuated between sincere bidding and overbidding in the former 13 periods and bid sincerely in most of the latter 12 periods.
    - Four subjects (ID numbers 11, 13, 19, 21) fluctuated between sincere bidding and overbidding in most or all periods.

Unit 2

- **Sincere bidding.** Three subjects (ID numbers 8, 10, 15) bid sincerely in all periods. Three subjects (ID numbers 6, 11, 13) bid sincerely in most periods (the frequency that each of these subjects bid sincerely was at least 76% (= 19/25)).
- **Overbidding.** Six subjects (ID numbers 2, 4, 7, 12, 18, 20) overbid in most periods (the frequency that each of these subjects overbid was at least 76% (= 19/25)).
- **Underbidding.** Two subjects (ID numbers 5, 21) underbid in most periods (the frequency that each of these subjects underbid was at least 76% (= 19/25)).
- **Other patterns.**
    - Two subjects (ID numbers 1, 16) fluctuated between underbidding and overbidding in most periods.

- One subject (ID number 3) underbid in the first 4 periods and overbid in most of the remaining periods.
- Two subjects (ID numbers 9, 17) fluctuated among overbidding, underbidding, and sincere bidding.
- One subject (ID number 14) basically fluctuated between underbidding and overbidding until period 16 and underbid in the remaining periods.
- One subject (ID number 19) fluctuated between sincere bidding and overbidding in most periods.

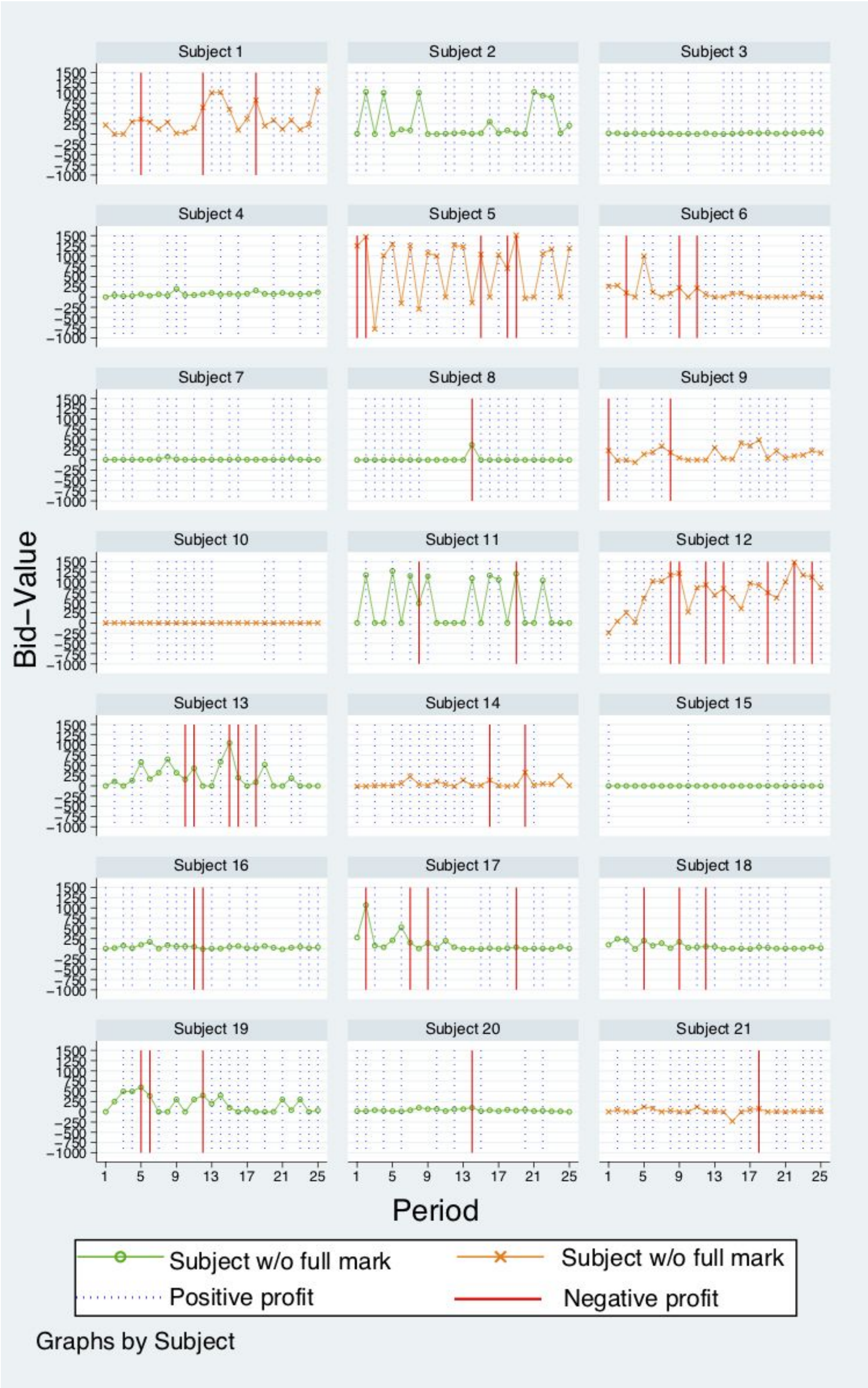

Figure 6: Time evolution of the gap between bid and value for unit 1 in VA2.

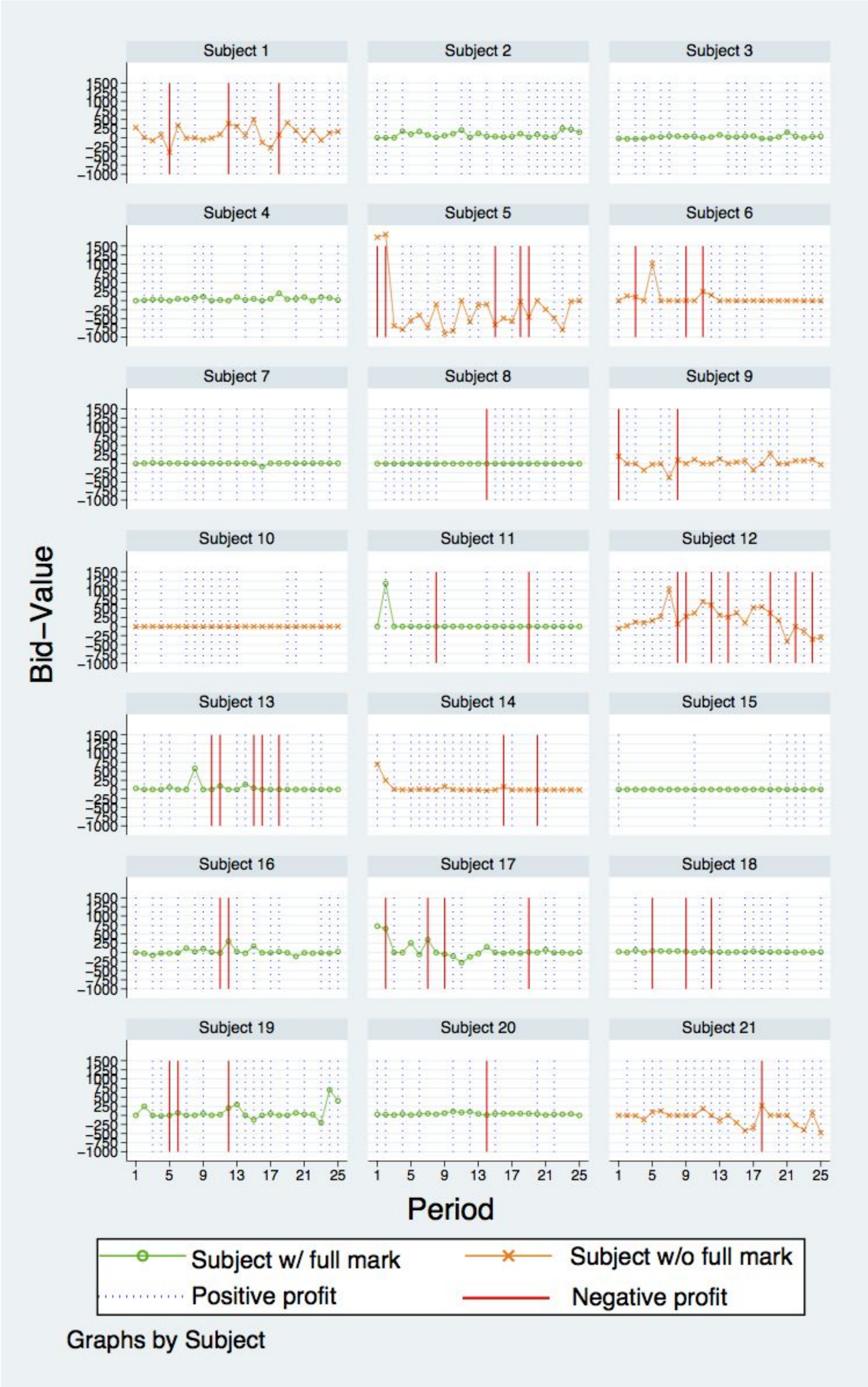

Figure 7: Time evolution of the gap between bid and value for unit 2 in VA2.

B.3 VA3

Thirteen subjects (ID numbers 2, 4–6, 10–12, 14–16, 18, 19, 21) received a perfect score on the quiz.

Unit 1

- **Sincere bidding.** Four subjects (ID numbers 4, 13, 15, 18) bid sincerely in all periods. Five subjects (ID numbers 6, 8, 11, 14, 16) bid sincerely in most periods (the frequency that each of these subjects bid sincerely was at least 76% (= 19/25)).
- **Overbidding.** One subject (ID number 17) overbid in all periods. Seven subjects (ID numbers 2, 3, 7, 9, 12, 19, 21) overbid in most periods (the frequency that each of these subjects overbid was at least 76% (= 23/25)).
- **Other patterns.**
  - One subject (ID number 1) overbid in most of the former 13 periods and fluctuated between sincere bidding and overbidding in the latter 12 periods.
  - Two subjects (ID numbers 5, 10) fluctuated between sincere bidding and overbidding.
  - One subject (ID number 20) bid sincerely in most of the former 13 periods and fluctuated between sincere bidding and overbidding in the latter 12 periods.

Unit 2

- **Sincere bidding.** Seven subjects (ID numbers 4, 6, 10, 13, 15, 16, 18) bid sincerely in all periods. Six subjects (ID numbers 5, 7, 8, 11, 12, 14) bid sincerely in most periods (the frequency that each of these subjects bid sincerely was at least 72% (= 18/25)).
- **Overbidding.** Three subjects (ID numbers 2, 3, 9) overbid in most periods (the frequency that each of these subjects overbid was at least 80% (= 20/25)).
- **Other patterns.**
  - One subject (ID number 1) fluctuated among overbidding, underbidding, and sincere bidding.

- One subject (ID number 17) overbid until period 12 and fluctuated among overbidding, underbidding, and sincere bidding in the remaining periods.
- One subject (ID number 19) bid sincerely until period 7 and fluctuated between sincere bidding and overbidding in the remaining periods.
- Two subjects (ID numbers 20, 21) fluctuated between sincere bidding and overbidding in most periods.

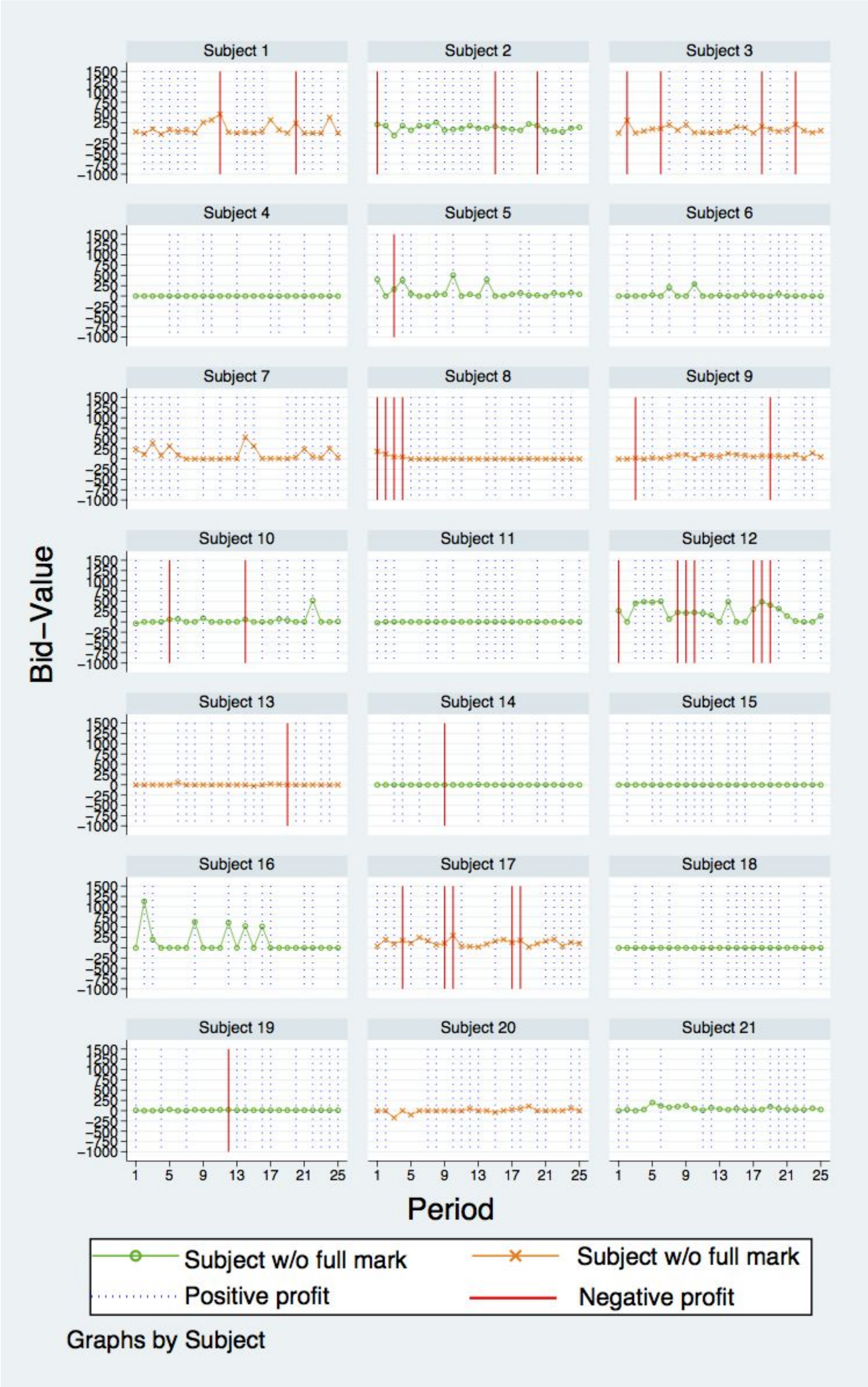

Figure 8: Time evolution of the gap between bid and value for unit 1 in VA3.

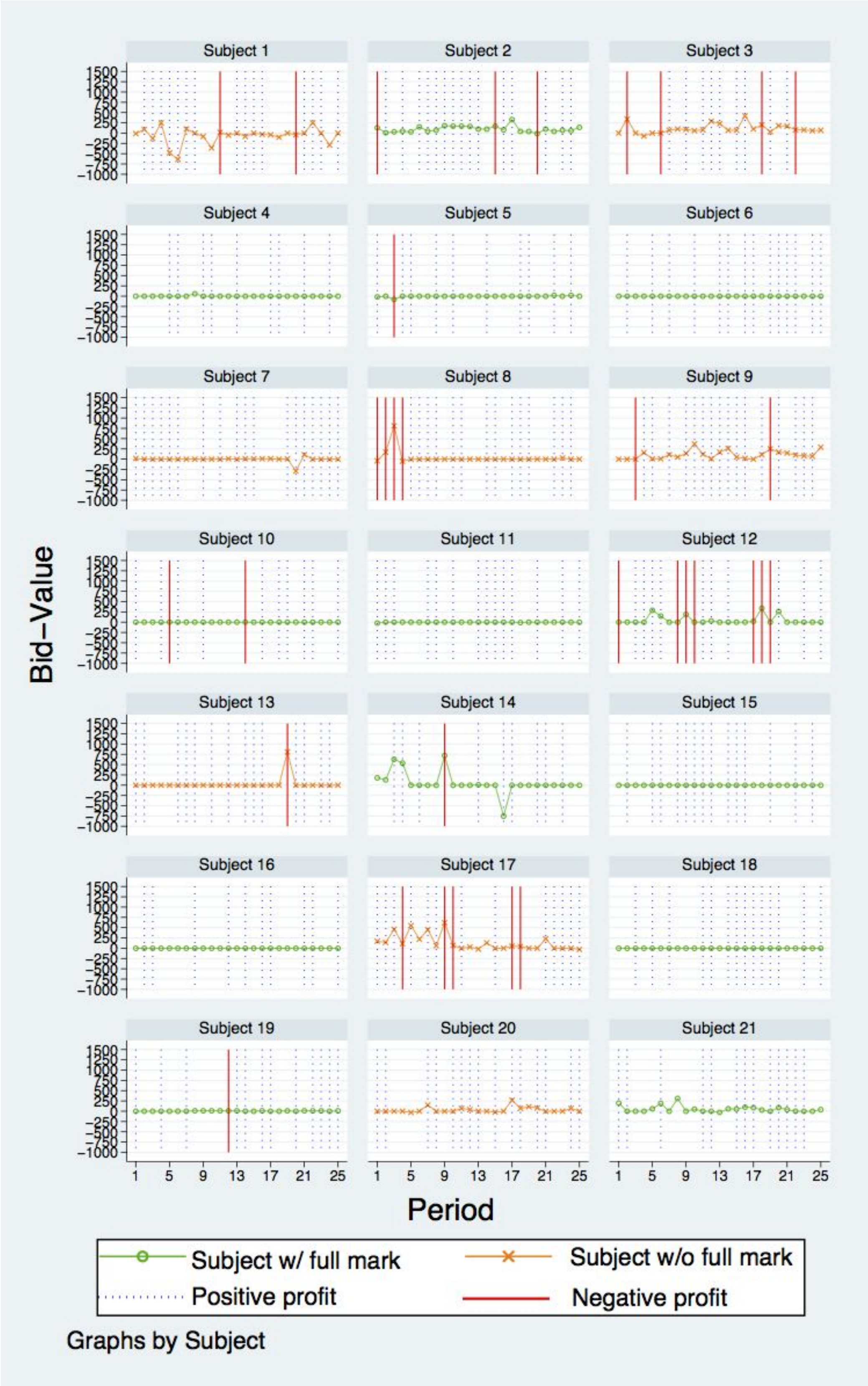

Figure 9: Time evolution of the gap between bid and value for unit 2 in VA3.

B.4 VN1

Sixteen subjects (ID numbers 1, 2, 4, 5, 8, 9, 11–15, 17–20, 24) received a perfect score on the quiz.

Unit 1

- **Sincere bidding.** One subject (ID number 18) bid sincerely in all periods.
- **Overbidding.** Six subjects (ID numbers 3, 9, 12, 13, 15, 20) overbid in all periods. Nine subjects (ID numbers 1, 4, 14, 16, 17, 19, 21, 22, 24) overbid in most periods (the frequency that each of these subjects overbid was at least 76% (= 19/25)).
- **Underbidding.** One subject (ID number 10) underbid in most periods (the frequency that the subject underbid was 72% (= 18/25)).
- **Other patterns.**
  - One subject (ID number 2) overbid until period 12 and fluctuated between sincere bidding and overbidding in the remaining periods.
  - One subject (ID number 5) overbid in most of the former 13 periods and fluctuated between sincere bidding and overbidding in the latter 12 periods.
  - One subject (ID number 6) bid either 0 or 1,000 in the former 13 periods and bid sincerely in most of the latter 12 periods.
  - One subject (ID number 7) bid 1,000 in most of the former 13 periods and bid either 0 or 1,000 in the latter 12 periods.
  - One subject (ID number 8) fluctuated between underbidding and overbidding in most periods.
  - One subject (ID number 11) fluctuated between sincere bidding and underbidding in most periods.
  - One subject (ID number 23) fluctuated between sincere bidding and overbidding in most periods.

Unit 2

- **Sincere bidding.** Two subjects (ID numbers 15, 18) bid sincerely in all periods. One subject (ID number 23) bid sincerely in most periods (the frequency that the subject bid sincerely was 80% (= 20/25)).

- **Overbidding.** One subject (ID number 3) overbid in all periods. Six subjects (ID numbers 9, 12, 13, 17, 19, 22) overbid in most periods (the frequency that each of these subjects overbid was at least 72% (= 18/25)).
- **Underbidding.** Three subjects (ID numbers 1, 6, 20) underbid in most periods (the frequency that each of these subjects underbid was at least 76% (= 19/25)).
- **Other patterns.**
  - Two subjects (ID numbers 2, 21) fluctuated between sincere bidding and overbidding in most or all periods.
  - One subject (ID number 4) overbid in most of the former 13 periods and bid sincerely in most of latter 12 periods.
  - One subject (ID number 5) fluctuated between sincere bidding and overbidding in most of the first 14 periods and bid sincerely in the remaining periods.
  - Two subjects (ID numbers 7, 16) fluctuated between underbidding and overbidding in most or all periods.
  - One subject (ID number 8) fluctuated among overbidding, underbidding, and sincere bidding.
  - Two subjects (ID numbers 10, 24) fluctuated between overbidding and underbidding in the former 13 periods and overbid in most of the latter 12 periods.
  - One subject (ID number 11) fluctuated between sincere bidding and underbidding.
  - One subject (ID number 14) fluctuated between overbidding and underbidding in the former 13 periods and underbid in most of the latter 12 periods.

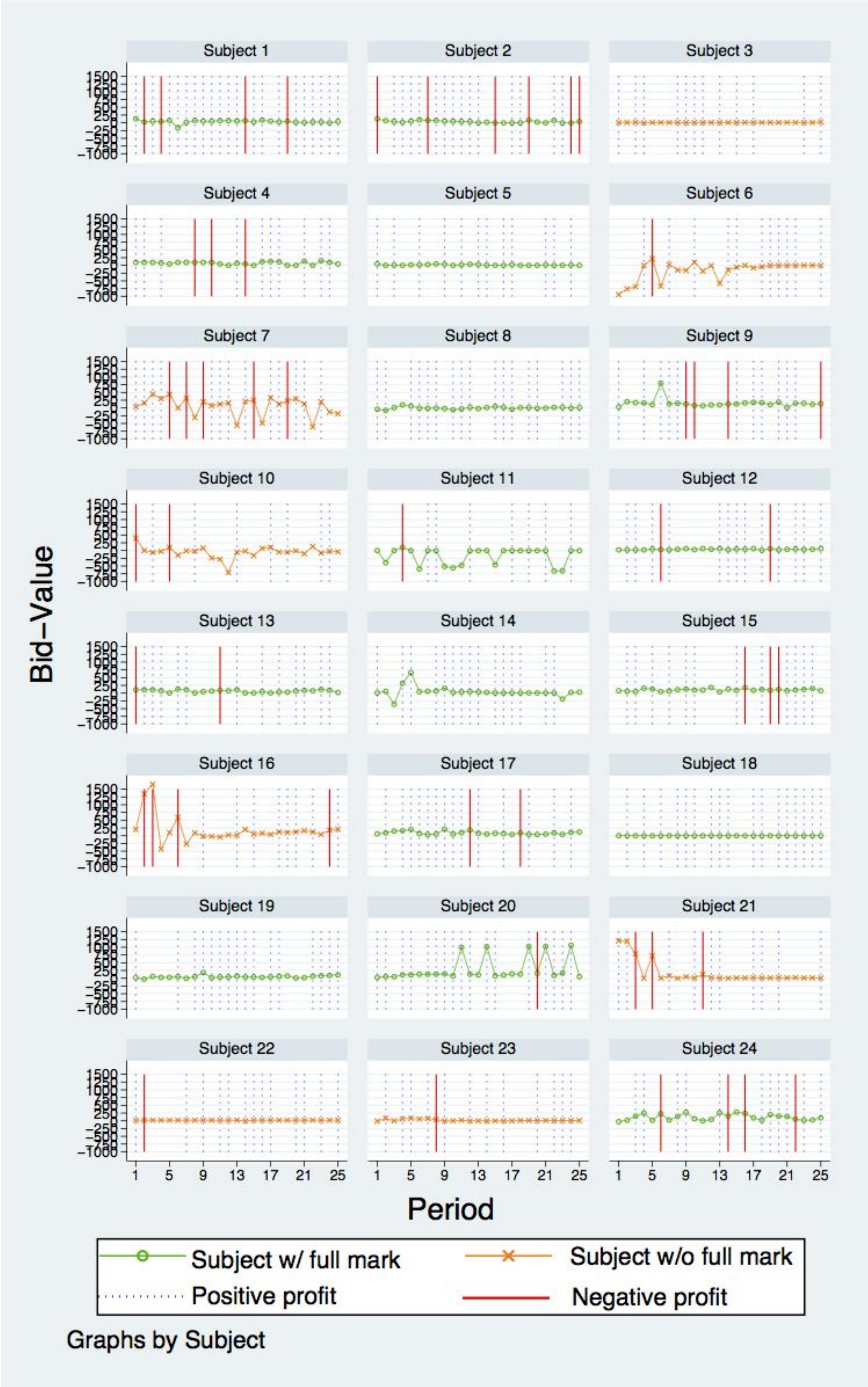

Figure 10: Time evolution of the gap between bid and value for unit 1 in VN1.

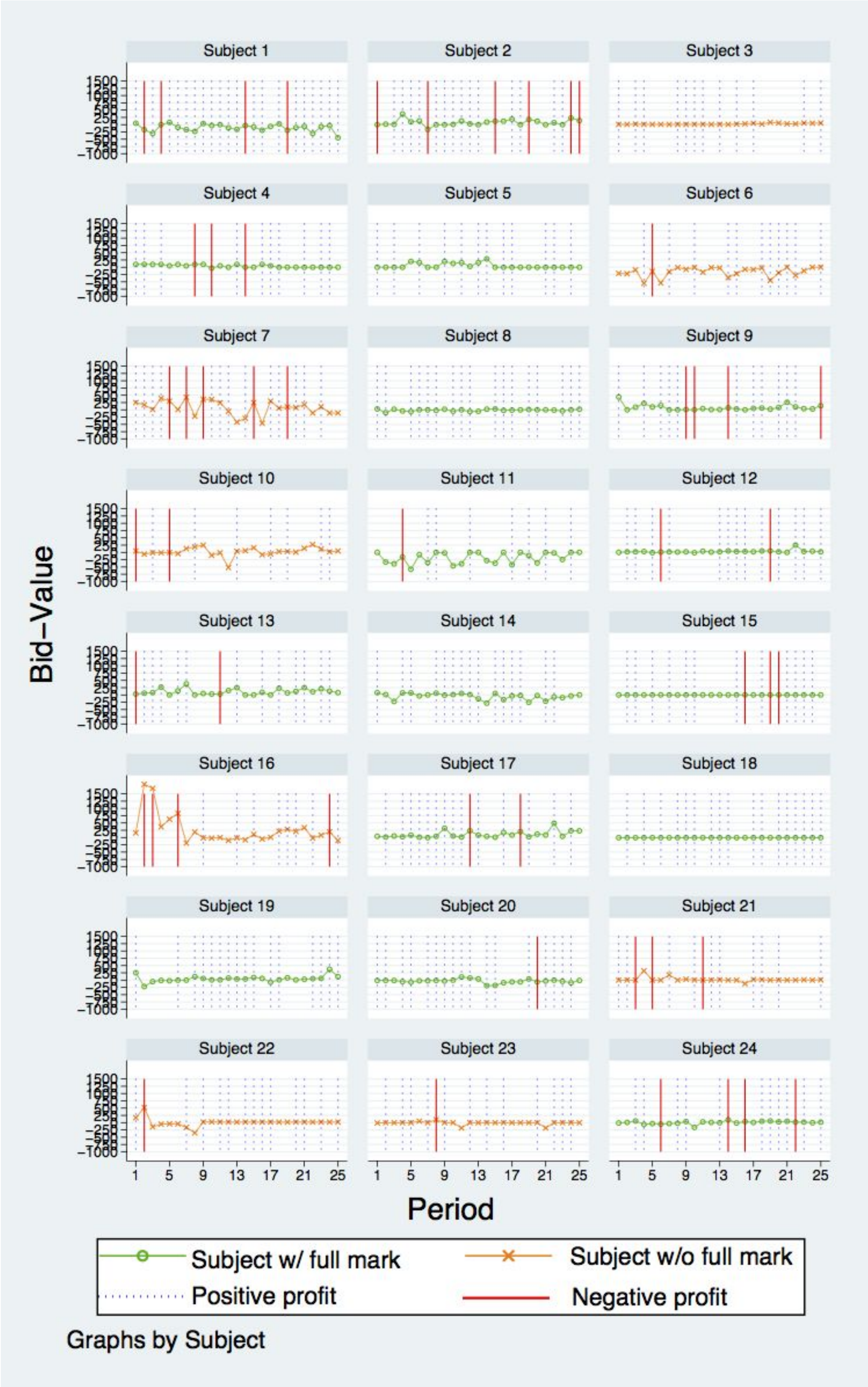

Figure 11: Time evolution of the gap between bid and value for unit 2 in VN1.

B.5 VN2

Fourteen subjects (ID numbers 2–6, 8, 11, 12, 14, 15, 18–21) received a perfect score on the quiz.

Unit 1

- **Sincere bidding.** Two subjects (ID numbers 1, 5) bid sincerely in all periods. One subject (ID number 15) bid sincerely in most periods (the frequency that the subject bid sincerely was 72% (= 18/25)).
- **Overbidding.** Six subjects (ID numbers 2, 4, 6, 9, 21, 22) overbid in all periods. Ten subjects (ID numbers 3, 7, 10, 11, 12, 14, 16, 19, 20, 23) overbid in most periods (the frequency that each of these subjects overbid was at least 72% (= 18/25)).
- **Other patterns.**
  - One subject (ID number 8) fluctuated between overbidding and underbidding.
  - One subject (ID number 13) fluctuated between sincere bidding and overbidding until period 19 and bid sincerely in the remaining periods.
  - One subject (ID number 17) fluctuated between sincere bidding and overbidding.
  - One subject (ID number 18) fluctuated among overbidding, underbidding, and sincere bidding.
  - One subject (ID number 24) underbid until period 15 and overbid in the remaining periods.

Unit 2

- **Sincere bidding.** Two subjects (ID numbers 1, 5) bid sincerely in all periods.
- **Overbidding.** Three subjects (ID numbers 4, 6, 9) chose overbidding in all periods. Nine subjects (ID numbers 2, 7, 11, 12, 14, 19, 21, 22, 24) overbid in most periods (the frequency that each of these subjects overbid was at least 72% (= 18/25)).

- **Underbidding.** One subject (ID number 8) underbid in most periods (the frequency that the subject underbid was 80% (= 20/25)).
- **Other patterns.**
  - One subject (ID number 3) fluctuated between overbidding and underbidding in the former 13 periods and overbid in most of the latter 12 periods.
  - Two subjects (ID numbers 10, 18) fluctuated between overbidding and underbidding in most periods.
  - One subject (ID number 13) fluctuated between sincere bidding and overbidding until period 18 and bid sincerely in the remaining periods.
  - Two subjects (ID numbers 15, 17) fluctuated between sincere bidding and underbidding.
  - One subject (ID number 16) overbid until period 11 and fluctuated among overbidding, underbidding, and sincere bidding in the remaining periods.
  - One subject (ID number 20) fluctuated between sincere bidding and overbidding in most periods.
  - One subject (ID number 23) underbid in most of the former 13 periods and overbid in most of the latter 12 periods.

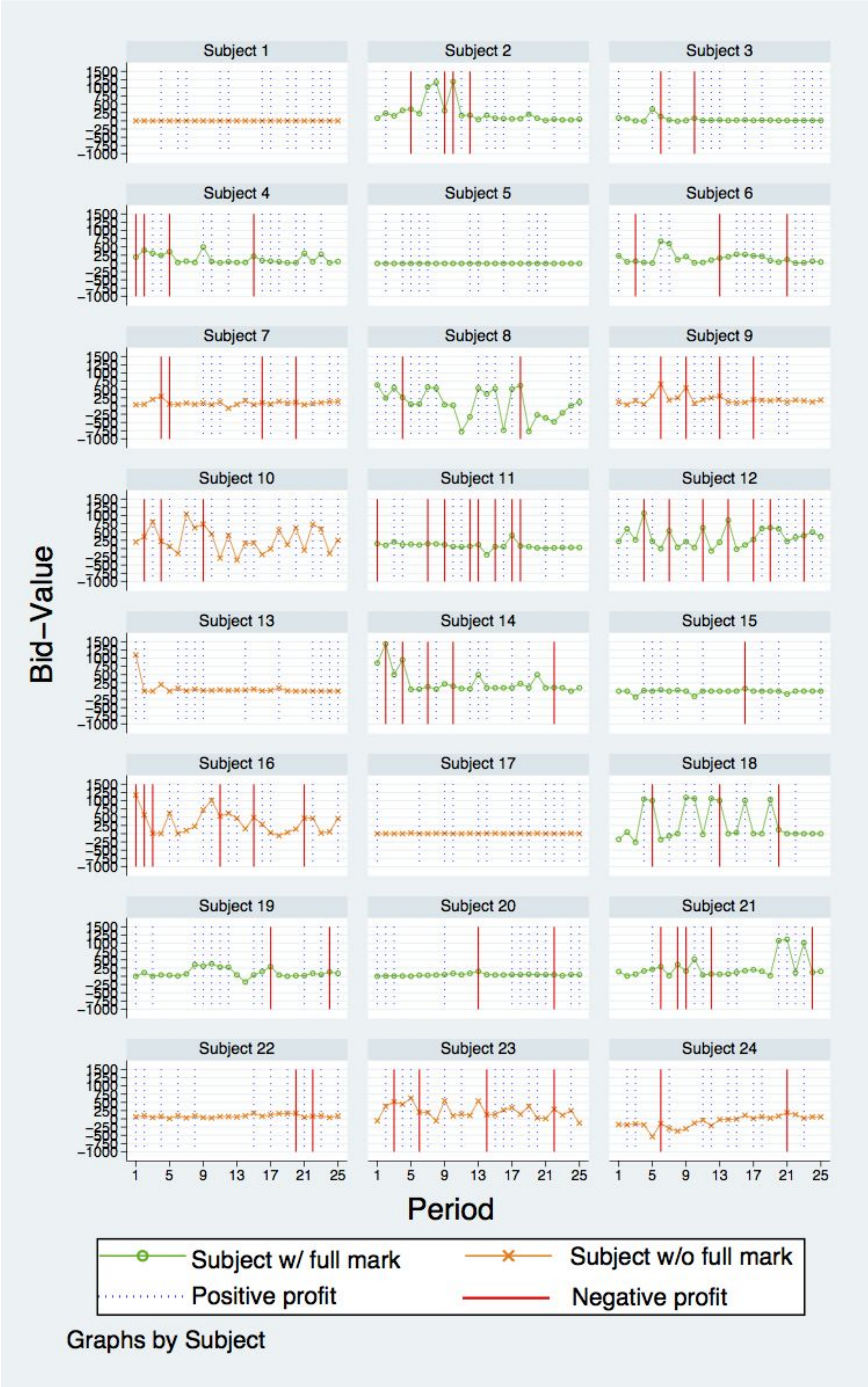

Figure 12: Time evolution of the gap between bid and value for unit 1 in VN2.

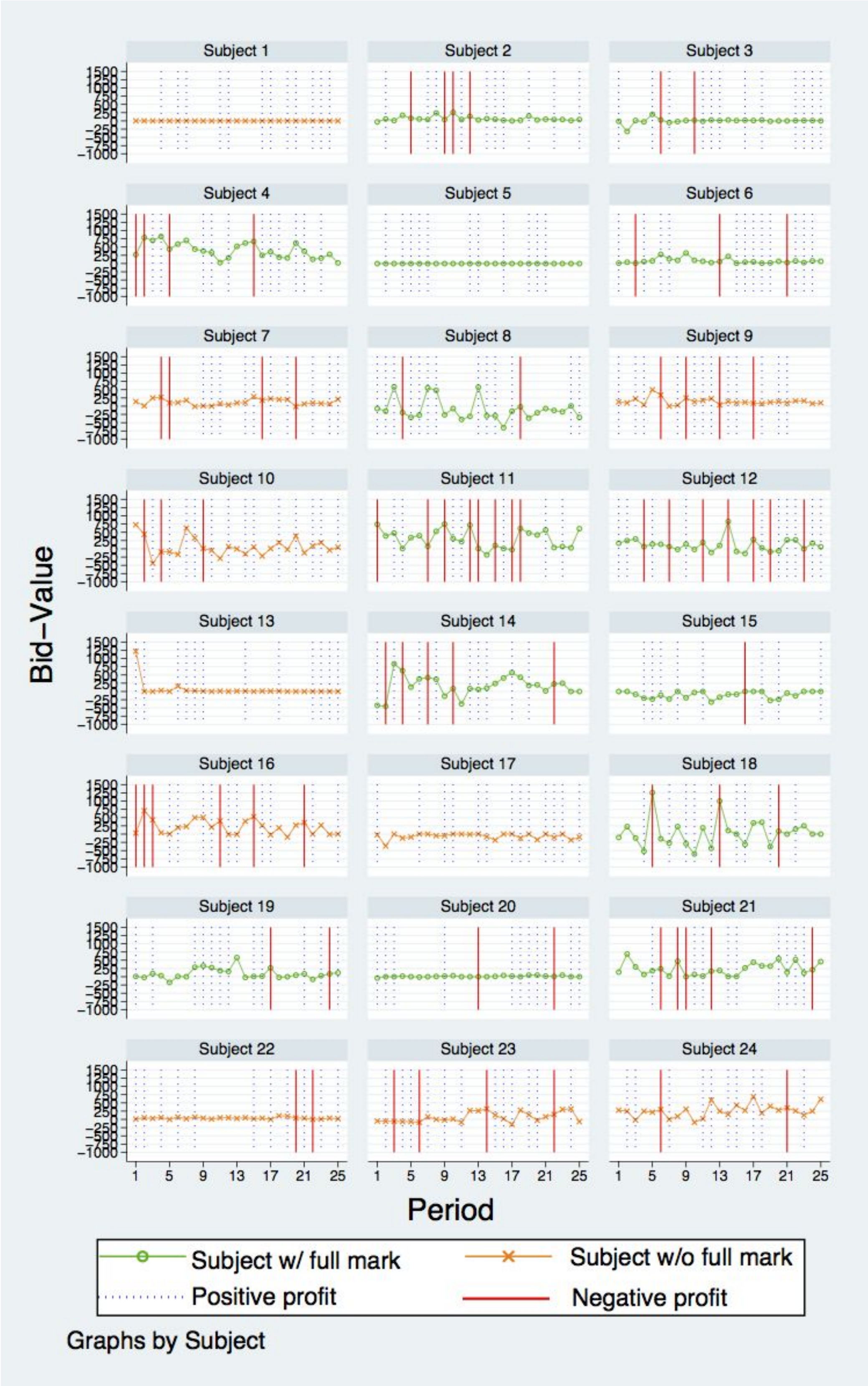

Figure 13: Time evolution of the gap between bid and value for unit 2 in VN2.

B.6 PA1

Twenty subjects (ID numbers 1, 3–21) received a perfect score on the quiz.

Unit 1

- **Underbidding.** Fifteen subjects (ID numbers 2, 4, 6, 8, 10–20) underbid in all periods. Six subjects (ID numbers 1, 3, 5, 7, 9, 21) underbid in most periods (the frequency that each of these subjects underbid was at least 92% (= 23/25)).

Unit 2

- **Underbidding.** Seven subjects (ID numbers 2, 4, 6, 8, 14, 15, 17) underbid in all periods. Eight subjects (ID numbers 5, 7, 10, 11, 13, 19–21) underbid in most periods (the frequency that each of these subjects underbid was at least 76% (= 19/25)). Two subjects (ID numbers 12, 18) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.

- **Other patterns.**
  - One subject (ID number 1) fluctuated between underbidding and sincere bidding in most periods.
  - One subject (ID number 3) fluctuated between underbidding and sincere bidding in most of the former 13 periods and underbid in most of the latter 12 periods.
  - One subject (ID number 9) underbid in most of the former 13 periods and fluctuated between underbidding and sincere bidding in the latter 12 periods.
  - One subject (ID number 16) bid sincerely until period 6 and underbid in most of the remaining periods.

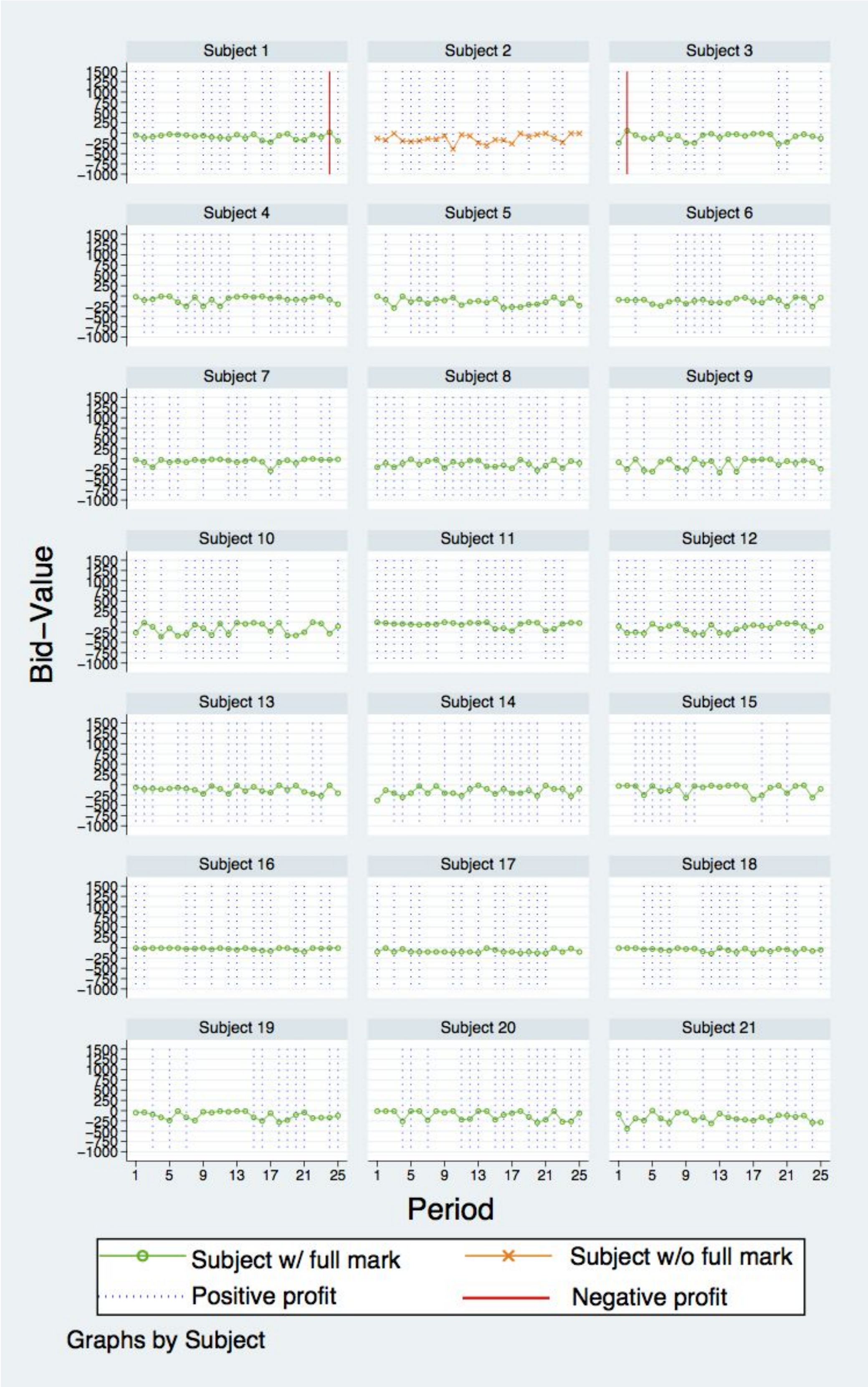

Figure 14: Time evolution of the gap between bid and value for unit 1 in PA1.

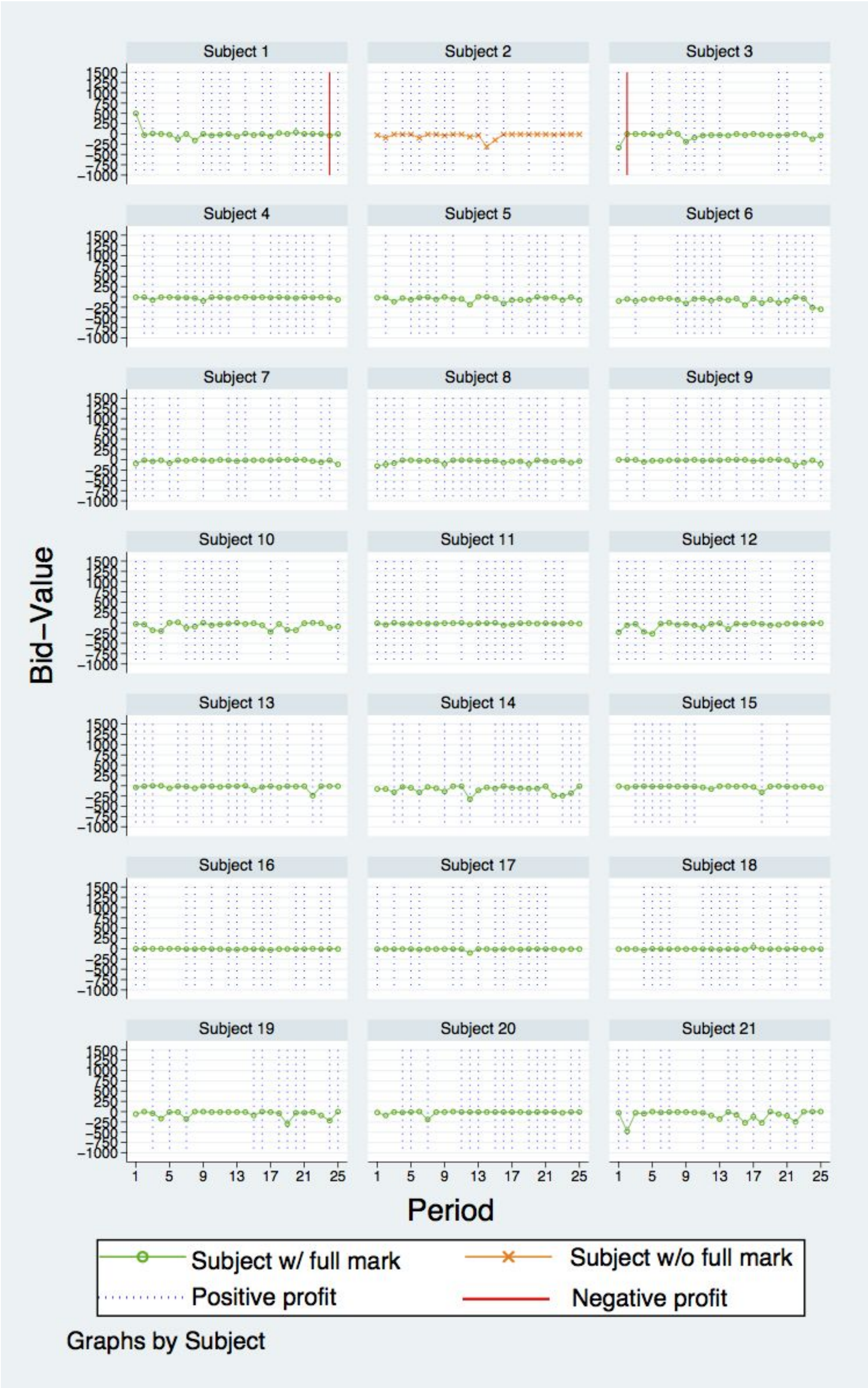

Figure 15: Time evolution of the gap between bid and value for unit 2 in PA1.

B.7 PA2

Eighteen subjects (ID numbers 1– 8, 10, 11, 15, 16, 18–22, 24) received a perfect score on the quiz.

Unit 1

- **Underbidding.** Eighteen subjects (ID numbers 2, 3, 5, 6, 8–13, 15–17, 19, 21–24) underbid in all periods. Six subjects (ID numbers 1, 4, 7, 14, 18, 20) underbid in most periods (the frequency that each of these subjects underbid was at least 92% (= 23/25)).

Unit 2

- **Underbidding.** Seven subjects (ID numbers 2, 3, 5, 8, 11, 15, 16) underbid in all periods. Thirteen subjects (ID numbers 1, 4, 7, 9, 10, 12–14, 17, 19, 20, 23, 24) underbid in most periods (the frequency that each of these subjects underbid was at least 76% (= 19/25)). Two subjects (ID numbers 6, 21) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.

- **Sincere bidding.** One subject (ID number 18) bid sincerely in most periods (the frequency that the subject bid sincerely was 88% (= 22/25)).

- **Overbidding.** One subject (ID number 22) overbid in most periods (the frequency that the subject overbid was 72% (= 18/25)).

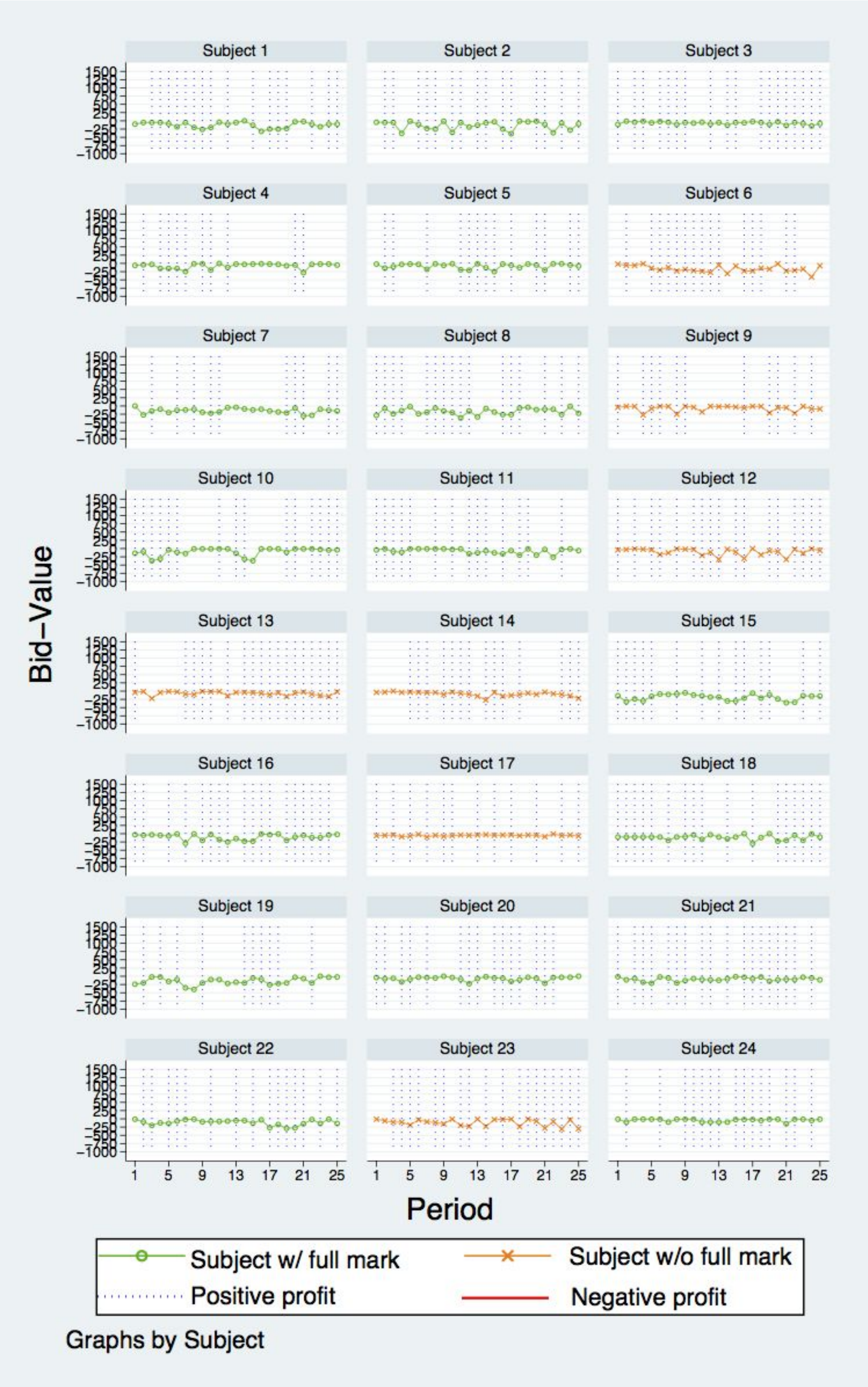

Figure 16: Time evolution of the gap between bid and value for unit 1 in PA2.

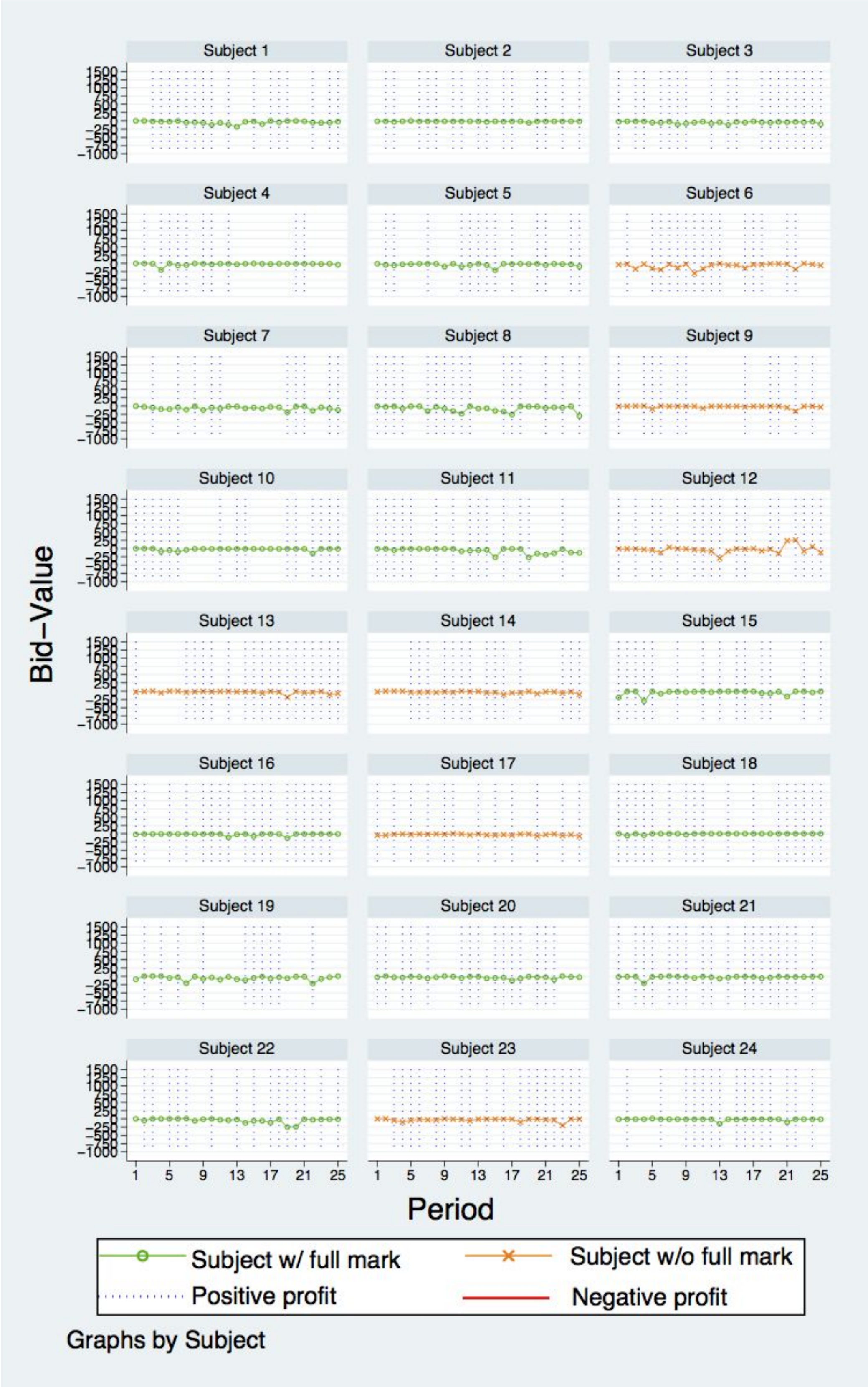

Figure 17: Time evolution of the gap between bid and value for unit 2 in PA2.

B.8 PA3

Twenty-one subjects (ID numbers 1–12, 14–17, 19–22, 24) received a perfect score on the quiz.

Unit 1

- **Underbidding.** Sixteen subjects (ID numbers 1, 4, 5, 7, 9–13, 15–18, 20–22) underbid in all periods. Seven subjects (ID numbers 2, 3, 6, 8, 14, 19, 23) underbid in most periods (the frequency that each of these subjects underbid was at least 80% (= 20/25)).
- **Other pattern.** One subject (ID number 24) fluctuated between sincere bidding and underbidding.

Unit 2

- **Underbidding.** Three subjects (ID numbers 1, 7, 17) underbid in all periods. Nine subjects (ID numbers 2–4, 6, 9, 10, 12, 14, 20) underbid in most periods (the frequency that each of these subjects underbid was at least 72% (= 18/25)). Six subjects (ID numbers 5, 15, 18, 19, 21, 22) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.
- **Other patterns.**
  - One subject (ID number 8) fluctuated between sincere bidding and underbidding in most periods.
  - One subject (ID number 11) fluctuated between sincere bidding and underbidding in the former 13 periods and underbid in most of the latter 12 periods.
  - Four subjects (ID numbers 13, 16, 23, 24) fluctuated between sincere bidding and underbidding.

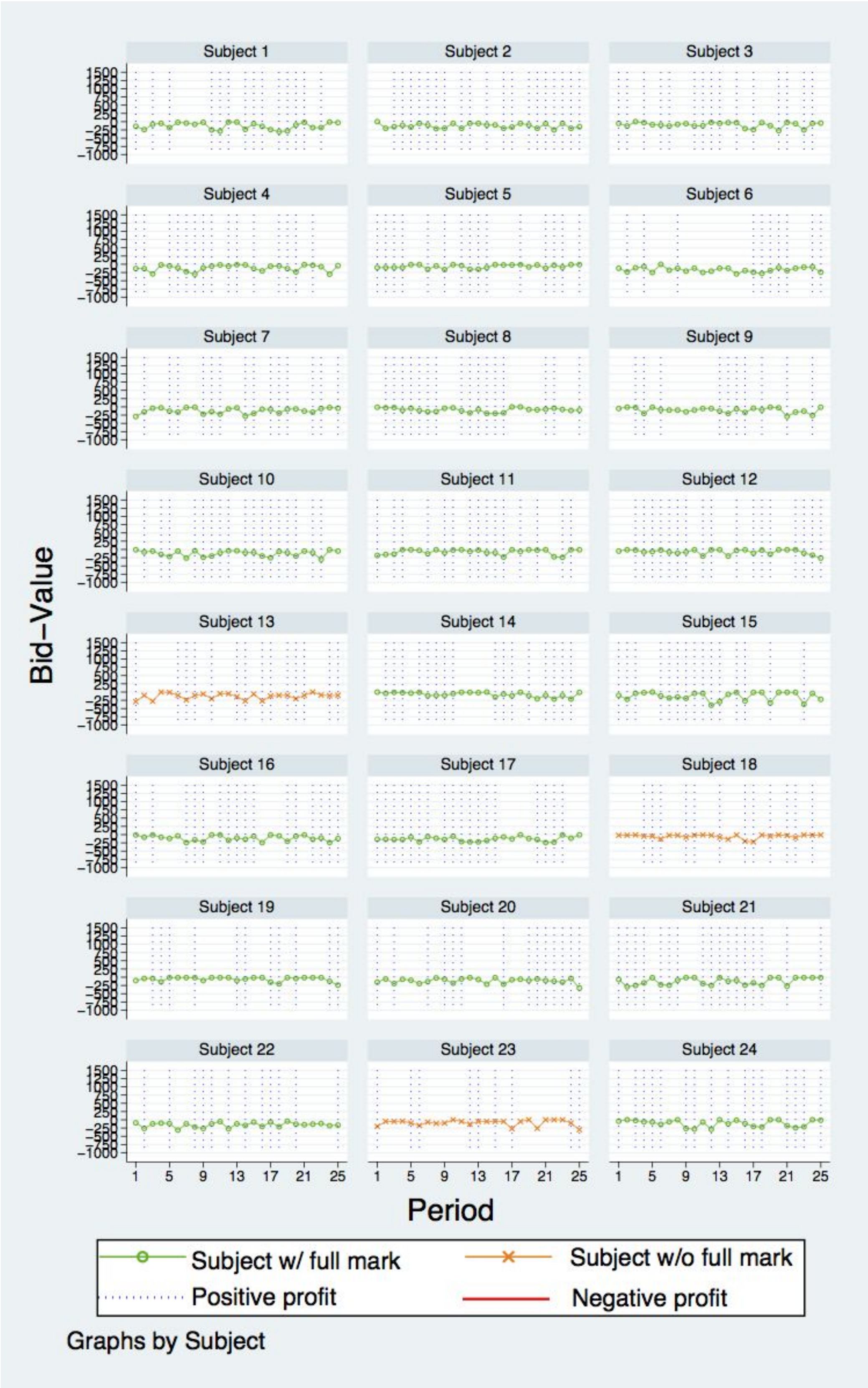

Figure 18: Time evolution of the gap between bid and value for unit 1 in PA3.

Figure 19: Time evolution of the gap between bid and value for unit 2 in PA3.

B.9 PN1

Twenty-one subjects (ID numbers 1–4, 6–8, 10–15, 17–24) received a perfect score on the quiz.

Unit 1

- **Underbidding.** Twenty subjects (ID numbers 3, 5–15, 17–24) underbid in all periods. Four subjects (ID numbers 1, 2, 4, 16) underbid in most periods (the frequency that each of these subjects underbid was at least 84% (= 21/25)).

Unit 2

- **Underbidding.** Twelve subjects (ID numbers 3, 5–10, 14, 17–19, 21) underbid in all periods. Six subjects (ID numbers 4, 11, 13, 15, 20, 23) underbid in most periods (the frequency that each of these subjects underbid was at least 80% (= 20/25)). Three subjects (ID numbers 12, 22, 24) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.

- **Other patterns.**
  - One subject (ID number 1) fluctuated between overbidding and other strategies in the former 13 periods and underbid in most of the latter 12 periods.
  - One subject (ID number 2) underbid in most of the former 13 periods and bid sincerely in most of the latter 12 periods.
  - One subject (ID number 16) fluctuated between sincere bidding and underbidding in the former 13 periods and underbid in most of the latter 12 periods.

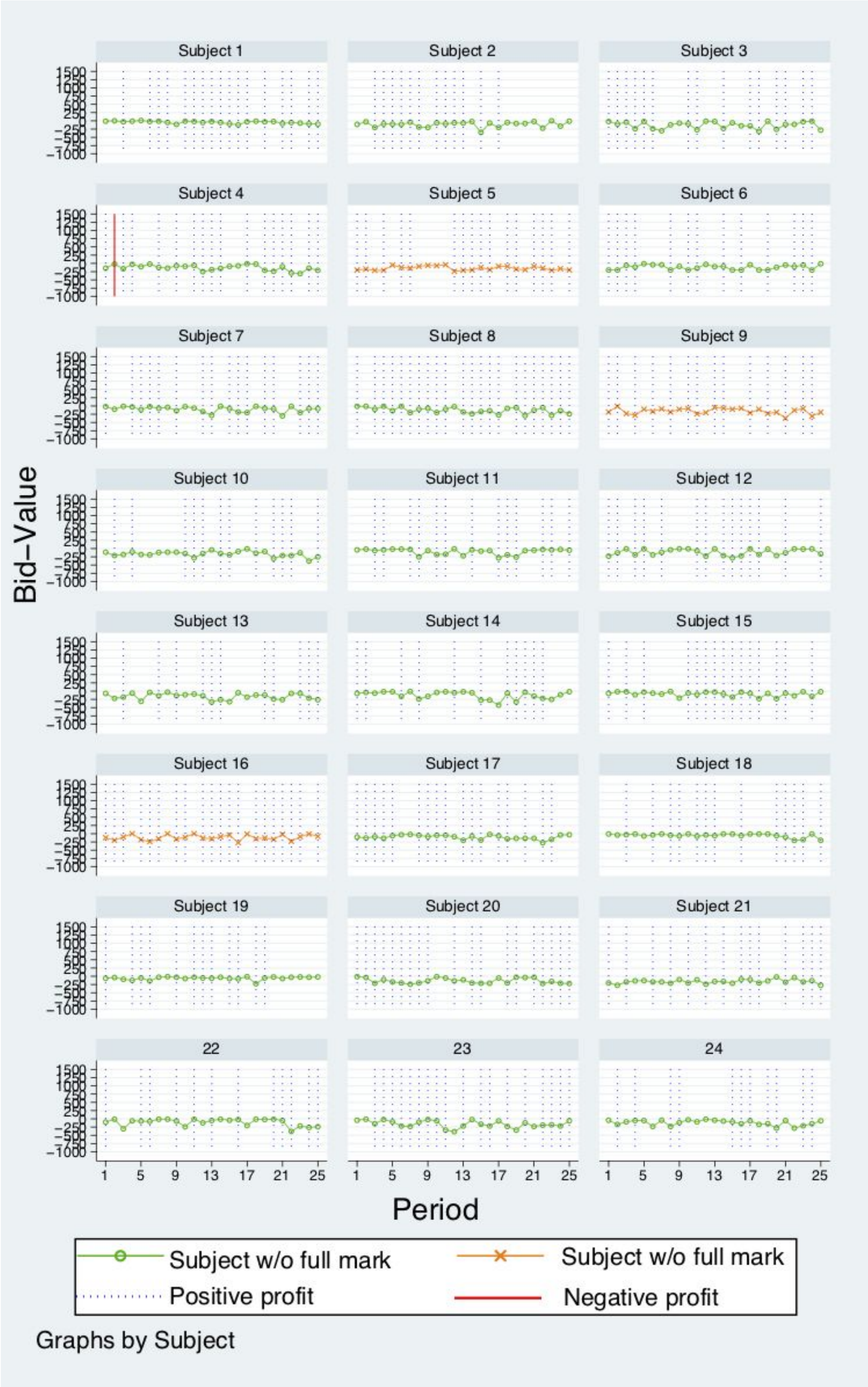

Figure 20: Time evolution of the gap between bid and value for unit 1 in PN1.

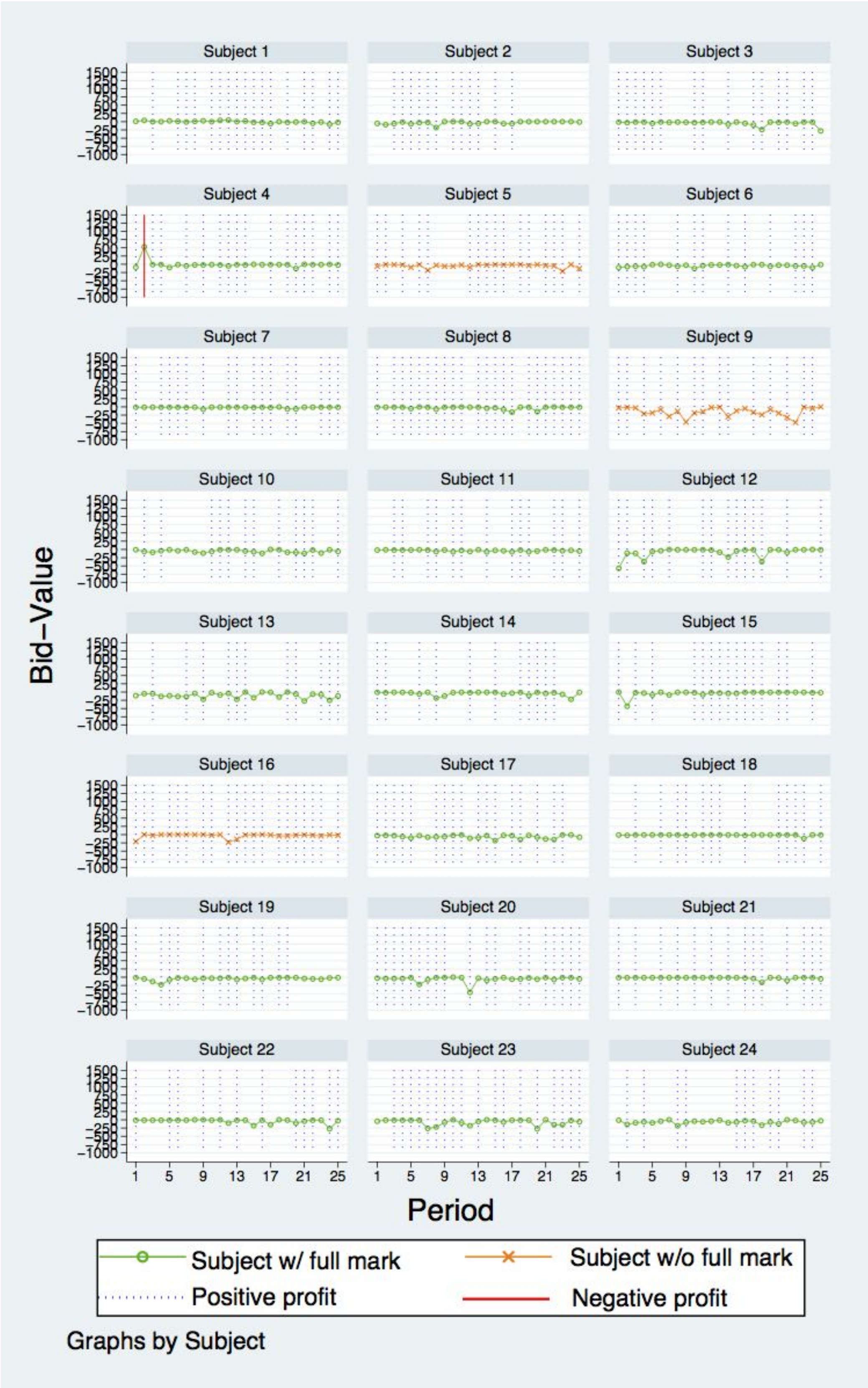

Figure 21: Time evolution of the gap between bid and value for unit 2 in PN1.

B.10 PN2

Eighteen subjects (ID numbers 2, 4, 5, 7–10, 12–14, 16–20, 22–24) received a perfect score on the quiz.

Unit 1

- **Underbidding.** All subjects underbid in all periods.

Unit 2

- **Underbidding.** Ten subjects (ID numbers 3, 6, 7, 9–12, 18, 19, 22) underbid in all periods. Six subjects (ID numbers 1, 2, 4, 13, 17, 23) underbid in most periods (the frequency that each of these subjects underbid was at least 84% (= 21/25)). Five subjects (ID numbers 5, 8, 14, 16, 20) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.

- **Other patterns.**
    - One subject (ID number 15) fluctuated between sincere bidding and underbidding.
    - One subject (ID number 21) underbid in most of the former 13 periods and fluctuated between sincere bidding and underbidding in the latter 12 periods.
    - One subject (ID number 24) fluctuated between underbidding and other strategies in the former 13 periods and underbid in most of the latter 12 periods.

Figure 22: Time evolution of the gap between bid and value for unit 1 in PN2.

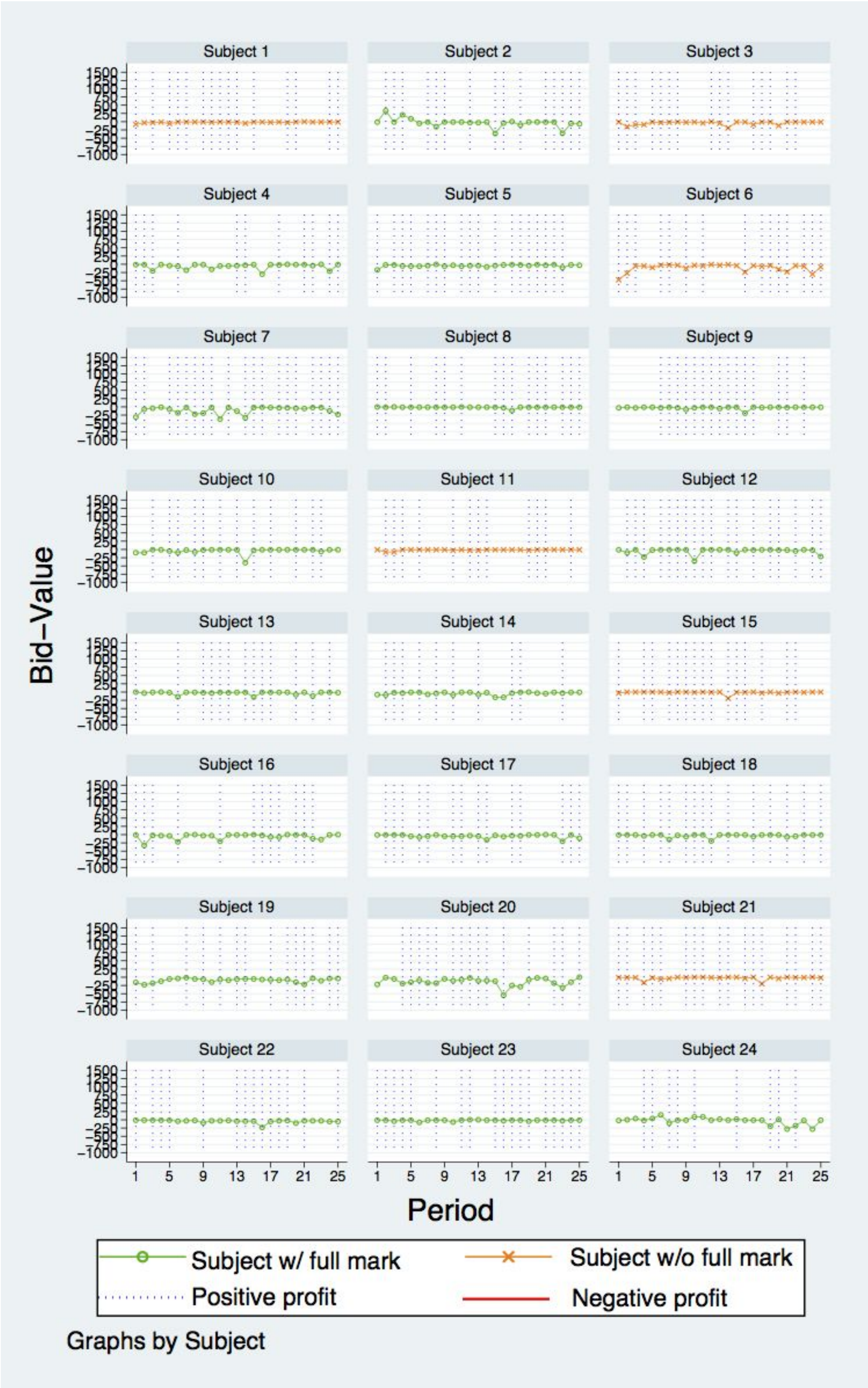

Figure 23: Time evolution of the gap between bid and value for unit 2 in PN2.

B.11 PN3

Eighteen subjects (ID numbers 1, 3–5, 7–14, 16–18, 20, 22, 23) received a perfect score on the quiz.

Unit 1

- **Underbidding.** Twenty subjects (ID numbers 1–7, 9, 11, 13, 14, 16–24) underbid in all periods. Four subjects (ID numbers 8, 10, 12, 15) underbid in most periods (the frequency that each of these subjects underbid was at least 88% (= 22/25)).

Unit 2

- **Underbidding.** Five subjects (ID numbers 4, 9, 14, 18, 19) underbid in all periods. Nine subjects (ID numbers 1, 6–8, 13, 16, 17, 21, 24) underbid in most periods (the frequency that each of these subjects underbid was at least 80% (= 20/25)). One subject (ID number 20) bid sincerely in the first 6 periods and then switched to underbidding in the remaining periods. Four subjects (ID numbers 5, 11, 22, 23) bid 0 whenever his/her value for the second unit was 0 and underbid in other periods.
- **Other patterns.**
  - One subject (ID number 2) fluctuated between sincere bidding and other strategies in the former 13 periods and bid sincerely in most of the latter 12 periods.
  - Two subjects (ID numbers 3, 15) fluctuated between sincere bidding and underbidding.
  - Two subjects (ID numbers 10, 12) fluctuated between sincere bidding and underbidding in all but one period.

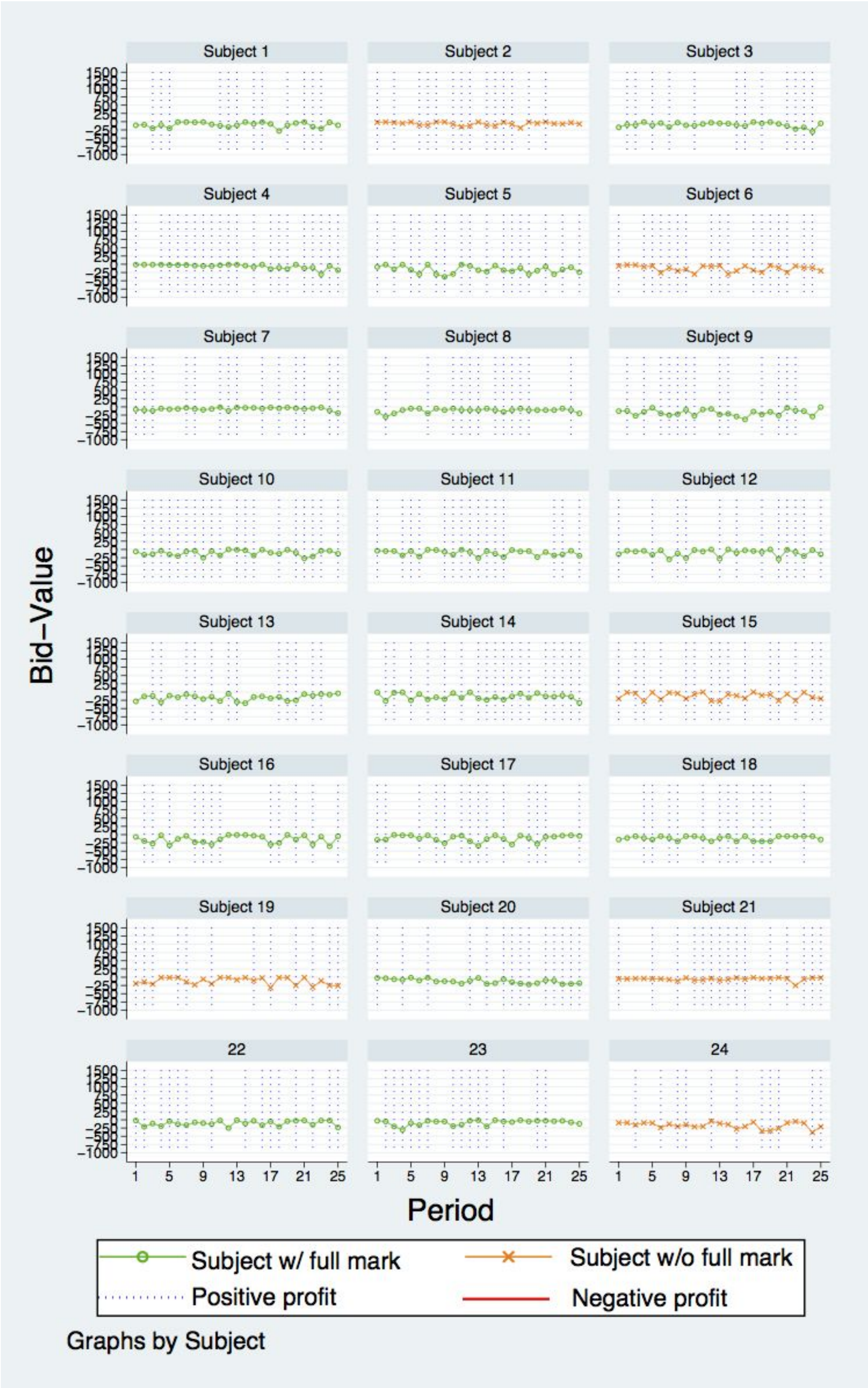

Figure 24: Time evolution of the gap between bid and value for unit 1 in PN3.

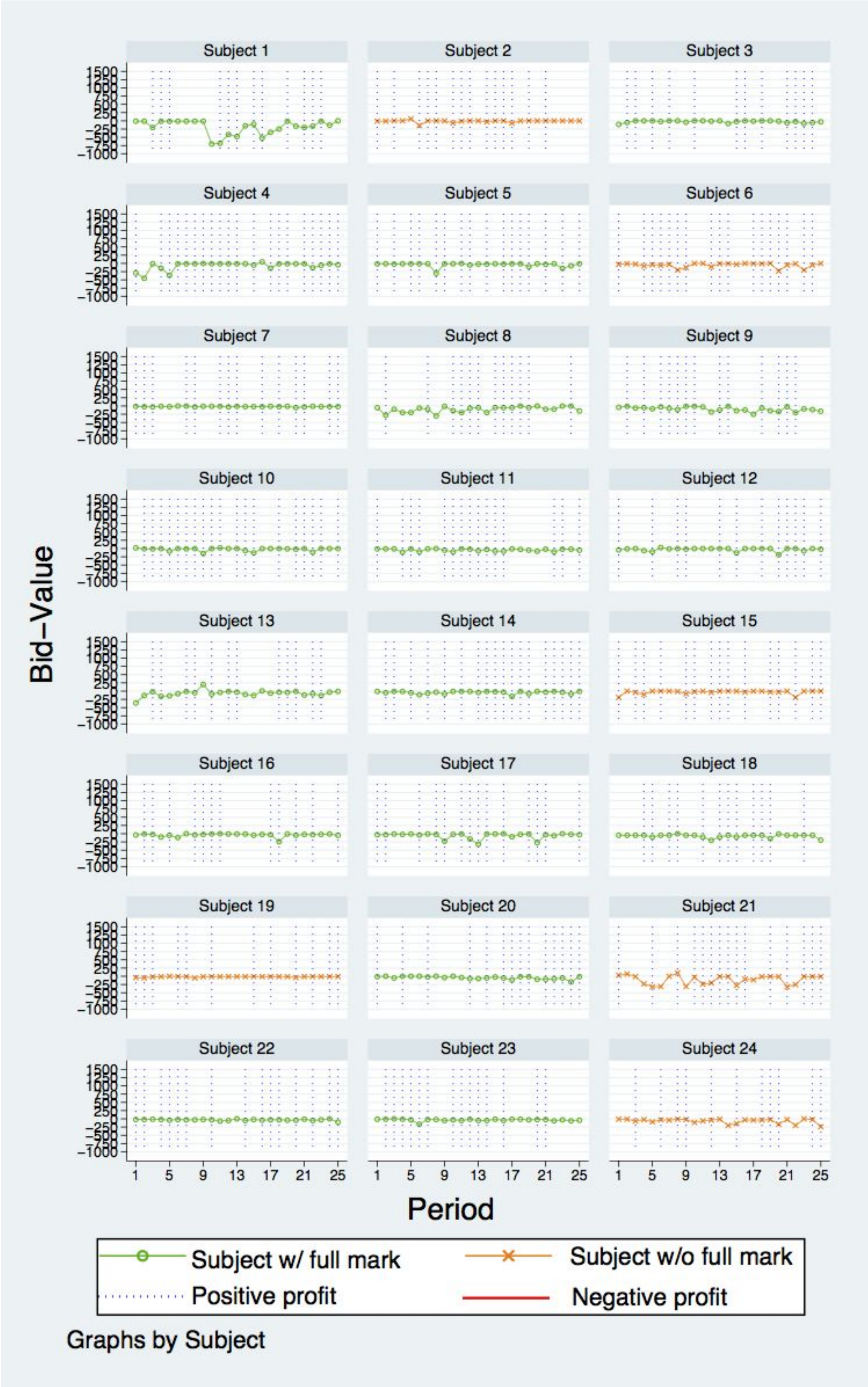

Figure 25: Time evolution of the gap between bid and value for unit 2 in PN3.

C 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
- Ballpoint pen, Pencil and Eraser
- Calculator

C.1 Overview

In this experiment, you will act as bidders in a sequence of auctions. Three bidders will participate in each auction. At the beginning of each period of auction, the experimenter randomly match you with two persons from the other subjects. The three of you will form a group. This experiment consists of 25 periods. The individuals you are matched with will change each period. You will not know who you are matched with either during or 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 will receive will be provided later in **C.3. Rewards**.

C.2 Auction

C.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 first unit ("1st unit's value") and another value for the second 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 will be 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 second unit's value will always be lower than the first 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 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 a tie among the high bids, the experimenter will randomly determine who earns an item. This described procedure determines the number of units earned by each bidder.
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.

C.2.2 Earnings calculation

We first explain how to calculate a bidder's earnings if the bidder earns an item using examples. There are three bidders, A, B, and C. Here, we 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 C.1. Suppose that A's value for the first unit is 680 and 480 for the second 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 C.2. Suppose that A's value for the first unit is 680 and 480 for the second 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. 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 C.3. Suppose that A's value for the first unit is 680 and 480 for the second 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 C.4. Suppose that A's value for the first unit is 680 and 480 for the second 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 third-highest bid is yours:

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

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

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

When your payment is higher than your first 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 first and second units' values, please note that your earnings will be negative.

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

C.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.

Recording Sheet

Seat Number ____________

Round	Value for 1st item	Value for 2nd item	Bid for 1st item	Bid for 2nd item	Payment (1st item)	Payment (2nd item)	Payment (Total)	Earnings
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

Recording Sheet

Seat Number ______________

Round	Value for 1st item	Value for 2nd item	Bid for 1st item	Bid for 2nd item	Payment (1st item)	Payment (2nd item)	Payment (Total)	Earnings
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								

D Appendix: Experimental instructions (PA)

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
- Ballpoint pen, Pencil and Eraser
- Calculator

D.1 Overview

In this experiment, you will act as bidders in a sequence of auctions. Three bidders will participate in each auction. At the beginning of each period of auction, the experimenter will randomly match you with two persons from the other subjects. The three of you 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 you are matched with either during or 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 **D.3. Rewards**.

D.2 Auction

D.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 first unit ("1st unit's value") and another value for the second 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 will be 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 second unit's value will always be lower than the first 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 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 a tie among the high bids, the experimenter will randomly determine who earns an item. The described procedure determines the number of units earned by each bidder.

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.

D.2.2 Earnings calculation

We first explain how to calculate a bidder's earnings if the bidder earns an item using examples. There are three bidders, A, B, and C. Here, we 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 his/her bid for first unit.

Example D.1. Suppose that A's value for the first unit is 680 and 480 for the second 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. Bidder A pays the amount of A's bid for the first unit, which is 600. Then, A's earnings are calculated as follows:

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

Example D.2. Suppose that A's value for the first unit is 680 and 480 for the second 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. A pays 800, which is A's bid for the first unit. A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} - 800 \text{ (payment)} = -120$$

(2) The case where a bidder earns two units A bidder who earns two units will pay the sum of his/her bid for the first unit and second unit.

Example D.3. Suppose that A's value for the first 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. Bidder A pays 1,150, the sum of the bid of 600 for the first unit and 550 for the second unit. A's earnings are calculated as follows:

$$680 \text{ (1st item's value)} + 480 \text{ (2nd item's value)} - 1150 \text{ (payment)} = 10$$

Example D.4. Suppose that A's value for the first unit is 680 and 480 for the second 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. Bidder A pays 1,750, the sum of the bid of 900 for the first unit and 850 for the second unit. A's earnings are calculated as follows:

$$680\text{ (1st item's value)} + 480\text{ (2nd item's value)} - 1750\text{ (payment)} = -590$$

The earnings calculation method may be summarized as follows:

- When you earn one unit:

$$\text{Earnings} = \text{1st item's value} - \text{ bid of 1st unit}$$

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

- When you earn two units:

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

  When your payment is higher than the sum of your first and second unit's values, please note that your earnings will be negative.

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

D.3 Rewards

We will explain the rewards you receive after the experiment. Your rewards are the sum of your earnings over all 25 periods and a participation fee of 1,000 yen plus you score in the quiz to check your understanding of each instruction.

For example, if the sum of your earnings is 2,580 yen and your score on the quiz is 420, your rewards will be 4,000 yen.

Recording Sheet Seat Number ____________

Round	Value for 1st item	Value for 2nd item	Bid for 1st item	Bid for 2nd item	Payment (1st item)	Payment (2nd item)	Payment (Total)	Earnings
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

Recording Sheet

Seat Number ____________

Round	Value for 1st item	Value for 2nd item	Bid for 1st item	Bid for 2nd item	Payment (1st item)	Payment (2nd item)	Payment (Total)	Earnings
13								
14								
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E Appendix: The text of advice

Advice on decision making

The following advice is about the auction in which you are participating. Please consider carefully whether this advice is true or not. It is completely up to you whether you follow the advice or not.

You can maximize your earnings by bidding at your values as they are, regardless of what others bid.

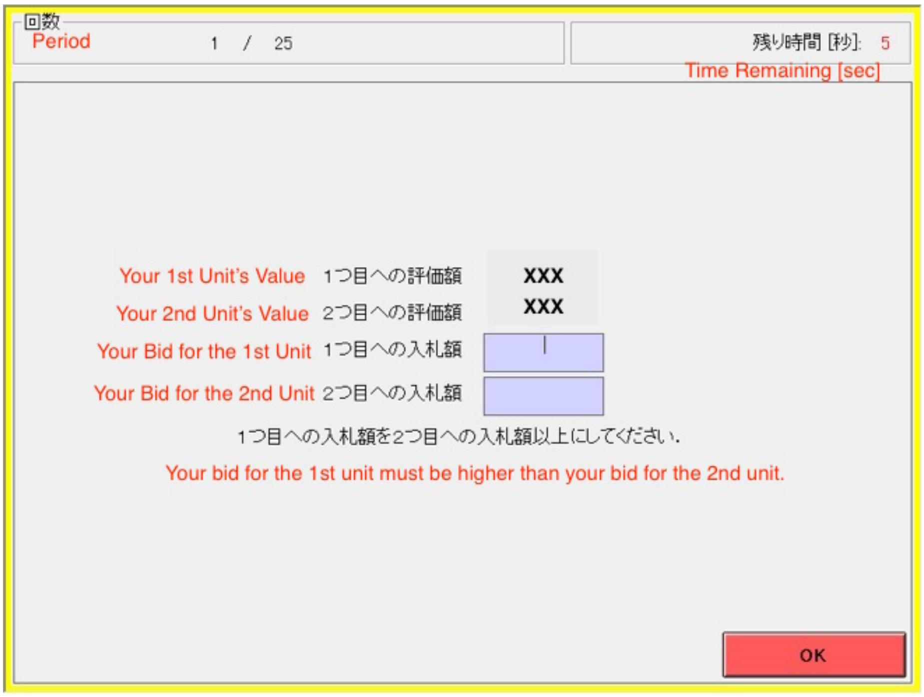
F Appendix: Auction screens and procedures

F.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 the experiment period. The following screen shows the first 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 this 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 first unit must be higher than your bid for the second unit.* After that, please transcribe your bids into the corresponding columns on the record sheet. After the transcription, click the "OK" button.

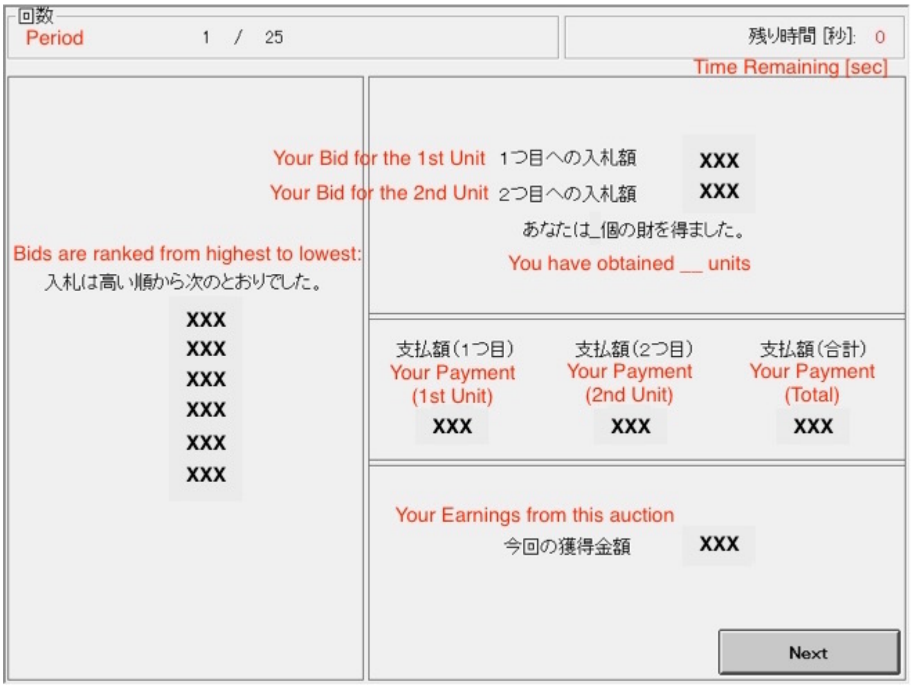
You will have 60 seconds to finalize your bid on this screen.



F.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 three 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 first unit, the amount you paid for the second unit, and the total amount you paid in this auction. Please transcribe this 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 into 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. This marks the end of one auction round. This experiment includes a series of 25 auctions.

G Appendix: Quiz

Please answer all questions below.

The bid from three bidders are shown in the following table. Suppose that B's value for the first unit is 900, and B's value for the second unit is 700. Suppose that C's value for the 1st unit is 600.

Bidder	Bid for 1st Unit	Bid for 2nd Unit
A	800	550
B	800	700
C	600	500

(1) Find (two) winning bids.

(2) Calculate B's payment.

(3) Calculate B's earnings.

(4) Calculate C's payment.

(5) Calculate C's earnings.

Suppose that B's bid for the first unit is 900; all other bids are shown in the table above.

(6) Find (two) winning bids.

(7) Calculate B's payment.

(8) Calculate B's earnings.

Suppose that B's bid for the first unit is 700 and 300 for the second unit; all other bids are shown in the table above.

(9) Find (two) winning bids.

(10) Calculate B's payment.

(11) Calculate B's earnings.

Suppose that C's bid for the first unit is 1,000; all other bids are shown in the table above.

(12) Find (two) winning bids.

(13) Calculate C's payment.

(14) Calculate C's earnings.

Suppose that C's bid for the 1st unit is 500; all other bids are shown in the table above.

(15) Find (two) winning bids.

(16) Calculate C's payment.

(17) Calculate C's earnings.

H Appendix: Post-experiment survey

Seat Number ____________

Faculty / Department____________ Age ________ Gender: Male / Female

1. Did you understand the auction rules (that is, how to calculate a bidder's earnings)?

   (a) I understood it after receiving the instructions.

   (b) I understood it after confirming the rules.

   (c) I understood it by following the practice, and before the first real round.

   (d) I understood it during the real rounds (from round ________)

   (e) I did not understand it.

2. Did you trust the decision-making advice?

   (a) I trusted it before the practice.

   (b) I trusted it after the practice, and before the first real round.

   (c) I began trusting it during the real rounds. (from round ________)

   (d) I did not trust it.

If you answer is (c) or (d), please write your reason(s) below.

3. How did you decide to bid? Please write specifically.

The number of times you bid your valuations: first unit (____times), second unit (____ times).

4. What did you think about others' bids? Please circle your selection and write specific details.

(Thought deeply, Didn't think much, Didn't think at all)

5. What do you think is the optimal bidding strategy? Please write your ideas and their reasoning.

6. If you had been aware of the others' valuations, would you have changed the way you decided to bid? If so, how would it have changed? Please write your ideas and reasons.

Thank you for your answers.

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