Auctions and Leaks:
A Theoretical and Experimental Investigation[☆]

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Abstract

In first- and second-price private value auctions with sequential bidding, second movers may discover the first movers' bid. Equilibrium behavior in the first-price auction is mostly unaffected but there are multiple equilibria in the second-price auction. Consequently, comparative statics across price rules are equivocal. Experimentally, leaks in the first-price auction favor second movers but harm first movers and sellers, as theoretically predicted. Low to medium leak probabilities eliminate the usual revenue dominance of first- over second-price auctions. With a high leak probability, second-price auctions generate significantly more revenue.

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1. Introduction

Most theoretical and experimental studies of sealed-bid auctions assume simultaneous bidding (Kagel, 1995; Kaplan & Zamir, 2014). Nonetheless, in government procurement or when selling a privately owned company (such as an NBA franchise), the auctioneer may approach bidders separately, or bidding firms/groups go through a protracted procedure of authorizing the bid – what may imply a sequential timing of decisions (cf. Bulow & Klemperer, 2009).[1] This paper studies situations in which bidding is sequential and information leaks about earlier bids are possible.

Consider independently and identically distributed private value auctions with two bidders and an exogenously given and commonly known probability of the first bid being leaked to the second bidder before her bidding. We

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[1] We acknowledge that the auctioneer may ask a bidder for an updated bid. It may, however, be prohibitively expensive and time consuming for a bidder to generate a new bid. Government procurement auctions often employ *best and final offer* procedures meaning that, after initial bids are collected, bidders are requested to submit a final price bid. In such cases, our theoretical model and experiment can be viewed as reflecting this (commonly known) final bidding stage.

derive how the equilibria of the first- and second-price sequential auction depends on leak probability and how they are affected by risk aversion.[2] For power function distributions of valuations like the uniform distribution, the unique equilibrium in first-price auctions is invariant with leak probability (Arozamena & Weinschelbaum, 2009). In second-price auctions, multiple equilibria exist, differing in how the second bidder reacts when learning that the first bid exceeds the own value—a case in which the second bidder's decision essentially allocates the surplus between first bidder and seller. We refer to all second bidders who in this situation make a bid below the first bid as *rational losers*, as losing the auction is rational given that a winning bid would result in a negative payoff.[3] While there is a continuum of rational loser bids, one can distinguish three focal bids resulting in very different equilibria of the second-price auction: (a) truthful bidding of the rational loser—equivalent to the equilibrium of the simultaneous auction—in which the rational loser bids his true value; (b) spiteful bidding according to which the rational loser slightly underbids the first bid; and (c) cooperative bidding, where the bid equals the reserve price of the seller.

In the field, the probability of a leak can be manipulated in various ways. Early movers can actively leak information; late movers can engage in industrial espionage, whereas auctioneers may try to prevent leaks through legal action or by imposing strict simultaneity of bids. Leaks can also result from corruption, if one bidder bribes the agent running the auction for revealing the other bidders' bids and allowing her to revise her own.[4] As a first step in studying these environments, we assume exogenously given leak probabilities and analyze the effects on bidding behavior and outcomes.

According to the equilibrium of the first-price auction, leaks favor the second bidder who, after observing a first bid below her value, can win the auction at the price equal to the first bid. Thus, compared to simultaneous bidding, second bidders with the higher value pay a lower price. If the equilibrium bid of the first bidder is below her own value, second movers may win even when their value is the smaller of the two. Thus, an increase in leak probability increases the expected revenue of the second bidder while reducing that of the first bidder, as well as seller surplus and efficiency.

In the second-price auction, outcomes strongly depend on the selected equilibrium. With truthful bidding, leaked information is ignored, and hence buyer surplus, seller revenue, and efficiency are not affected. In all other equilibria, efficiency decreases with increasing leak probability, with the cooperative equilibrium performing worst in terms of seller revenue and efficiency. In the cooperative equilibrium, first bidders earn more and second bidders less than in the truthful bidding equilibrium, whereas the opposite holds for the spiteful bidding equilibrium. These differences with respect to truthful bidding increase with leak probability.

Whether the parties or a social planner should prefer the first– or second-price rule depends not only on equilibrium selection in the second-price auction but, in some cases, also on leak probability. For example, when bidders coordinate on the cooperative equilibrium in the second-price auction, seller revenue is higher in the first-price auction, irrespective of leak probability. Efficiency is only higher in the first-price auction if leak probability exceeds one half, and is otherwise higher in the second-price auction. This illustrates why, despite the ubiquity of first-price auctions in the field and their revenue dominance in simple experimental settings, the use of the second-price rule should be reconsidered when leaks are possible.[5]

Our experiments primarily test these theoretical predictions. The experimental design allows to explore equilibrium selection in the second-price auction with leaks, and to test the effects of auction mechanism and leak probabilities on bidders surplus, seller revenue, and efficiency. The empirical investigation of equilibrium selection is important because, ex ante, it is not clear which equilibrium will be favored as all equilibria have desirable features from the point of view of the bidders. Truthful bidding is simple and frugal as well as ex-ante egalitarian. The cooperative equilibrium maximizes what bidders jointly earn. The spiteful bidding equilibrium is best for the second bidder who eventually selects the equilibrium as a rational loser, while materially being indifferent across the entire equilibrium set. Our experimental design manipulates the leak probability within each price rule while keeping roles fixed. Two

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[2] The analysis for second-price auctions extends to English, or ascending bid, auctions, under the assumption that the bidding strategy is determined 'in the office', before the bidding process commences. This predetermination renders the risk of leaks very relevant.

[3] It may be still rational to win the auction if the bidder enjoys a *joy of winning*. Joy of winning, however, does not provide a good description of behavior in experimental auctions (Levin et al., 2016).

[4] Several theoretical papers consider revisions of bids due to corruption. Menezes & Monteiro (2006) and Lengwiler & Wolfstetter (2010) assume that corrupt auctioneers offer the auction winner to revise their bid. Arozamena & Weinschelbaum (2009) analyze the effect of corruption on bidding in first-price auctions in an environment similar to ours under different value distributions. These studies neglect the multiplicity of equilibria arising in second-price auctions and the empirical behavior that are the focus of this paper.

[5] One clearly needs to take other issues into account, such as the risk of internally or externally stable ring formation as detailed in Fehl & Güth (1987) and Güth & Peleg (1996).

additional treatments manipulate ex-ante symmetry in bidder roles while keeping leak probability fixed at one, to explore how role inequality affects equilibrium selection in second-price auctions.

In line with equilibrium predictions, first mover bids in first-price treatments do not vary systematically with leak probabilities. Informed second bidders generally behave rationally, winning the auction if and only if they can gain by doing so. Overall, leaks increase the second bidder's payoff and reduce the first bidder's payoff, seller revenue, and efficiency.

In the second-price auction experiments, rational losers employ different strategies—mostly similar to one of our three focal equilibria—with about one third of participants behaving consistently across all rounds. On average, efficiency decreases with leak probability while all other outcomes are not sensitive to it. Without leaks the first-price rule enhances seller revenue due to bid shading, as is often observed in experimental auctions (see, e.g. Kagel & Levin, 2016). Conversely, when leaks are certain, seller revenue is higher in the second-price auction. Efficiency is slightly higher in the second-price treatments for all leak-probabilities. A secondary hypothesis about how ex-ante equality affects coordination is not supported.

The sequential protocol in auctions has been studied, theoretically and experimentally, in the context of contests (Fonseca, 2009; Hoffmann & Rota-Graziosi, 2012; Segev & Sela, 2014) and asymmetric bidders (Cohensius & Segev, 2014). Although no previous study looked at the effect of equilibrium selection in second-price auctions with sequential moves, this topic has been indirectly addressed in ascending bid auctions. Cassady (1967) suggests, based on anecdotal evidence, that placing a high initial bid can deter other bidders from entry, what may be rational when participation or information acquisition is costly (Fishman, 1988; Daniel & Hirshleifer, 1998).[6] In our setup, bidding costs would eliminate all but the cooperative equilibrium in the second-price auction and not affect the equilibrium in the first-price auction when bidding costs are very small.

Our study is also related to the literature on information revelation in auctions (Milgrom & Weber, 1982; Persico, 2000; Kaplan, 2012; Gershkov, 2009). Several papers study revelation of information about bidders' valuations by the auctioneer (Kaplan & Zamir, 2000; Landsberger et al., 2001; Bergemann & Pesendorfer, 2007; Eső & Szentes, 2007). As in our study, Fang & Morris (2006) and Kim & Che (2004) compare first- and second-price mechanisms but focus on value revelation rather than on leaked bids. The predictions of Kim & Che (2004) are experimentally tested and corroborated by Andreoni et al. (2007).

We describe and analyze the bidding contests in Section 2. The experimental design is described in Section 3, the findings are discussed in Section 4, and section 5 concludes.

2. The Auction Game and Benchmark Solutions

Two bidders $i = 1, 2$, compete via bidding to buy a single indivisible good over two time periods. Each bidder i has private value v_i drawn independently from the continuous distribution F on $[0, 1]$, with 0 denoting the exogenously given reservation price of the seller. At time 1 bidder 1, the first mover, submits an unconditional bid $b_1(v_1)$. At time 2 bidder 2, the second mover, observes b_1 with probability p, and submits a conditional bid $b_2(b_1, v_2)$, and with the complementary probability $1 - p$ does not see b_1 and submits an unconditional bid $b_2(\emptyset, v_2)$. In case of a tie, it's assumed throughout that bidder 2 wins. The allocation and payments are determined either by the first-price (FPA) or second-price auction (SPA).

2.1. First-Price Auction

Our analysis builds on Arozamena & Weinschelbaum (2009) and adds risk aversion, captured by utility function $u_i(v_i - b_i)$ being concave and differentiable. To solve the first-price auction, first look at bidder 2's optimal bid $b_2(b_1, v_2)$ after seeing b_1, bidder 1's bid.[7] If $b_1 \leq v_2$, bidding $b_2(b_1, v_2) = b_1$ would let bidder 2 win at the lowest possible price. For $b_1 > v_2$, bidder 2 underbids b_1 (by how much does not affect the outcome). Thus, in equilibrium

$$b_2(b_1, v_2) \begin{cases} = b_1 & \text{if } b_1 \leq v_2, \\ < b_1 & \text{otherwise.} \end{cases} \tag{1}$$

[6] See Avery (1998) for an analysis of jump bidding with affiliated values. See also Ariely et al. (2005); Ockenfels & Roth (2006); Roth & Ockenfels (2002) for an analysis of second-price auctions with endogenous timing.

[7] Whenever we speak of "optimal" or "rational" behavior, we assume opportunistic preferences, either in combination with risk neutrality or risk aversion.

When chance prevents an information leak, assume $b_1(v_1)$ and $b_2(\emptyset, v_2)$ to be monotonically increasing in the own value v_1 and v_2, with inverse functions $v_1(b_1)$ and $v_2(b_2)$, respectively. Without loss of generality, assume that $u_1(0) = u_2(0) = 0$. Expected optimality requires for bidder 2

$$\pi_2(v_2) = \max_{b_2} F(v_1(b_2))\, u_2(v_2 - b_2). \tag{2}$$

Similarly, bidder 1 tries to maximize

$$\pi_1(v_1) = \max_{b_1}[pF(b_1) + (1-p)F(v_2(b_1))]u_1(v_1 - b_1). \tag{3}$$

The first-order conditions from (2) and (3) are

$$F'(v_1(b_2))v_1'(b_2)u_2(v_2(b_2) - b_2) = u_2'(v_2(b_2) - b_2)F(v_1(b_2)),$$

$$[(1-p)F'(v_2(b_1))v_2'(b_1) + pF'(b_1)]u_1(v_1(b_1) - b_1) = u_1'(v_1(b_1) - b_1)[(1-p)F(v_2(b_1)) + pF(b_1)].$$

Proposition 1. *For F uniform and CRRA utility with Arrow-Pratt risk aversion parameter of r satisfying $0 \leq r < 1$, the unique equilibrium is $(v_1(b_1) = (2-r)b_1; v_2(b_2) = (2-r)b_2)$.*[8]

Proof. For F uniform and CRRA utility, the first-order conditions reduce to

$$v_1'(b_2)(v_2(b_2) - b_2) = (1-r)v_1(b_2),$$

$$[(1-p)v_2'(b_1) + p](v_1(b_1) - b_1) = (1-r)[(1-p)v_2(b_1) + pb_1],$$

with the unique solution $v_1(b_1) = (2-r)b_1$ and $v_2(b_2) = (2-r)b_2$. □

The CRRA results mirror those of Cox et al. (1985, 1988).

In equilibrium neither first nor conditional or unconditional second bids are affected by leak probability, but leaks can affect who wins and how much bidders earn (see Appendix Appendix A).

Corollary 1. *For F uniform, risk neutrality ($r = 0$), and the first-price auction, bidder 1 ex ante expects to earn $\frac{1}{6} - \frac{p}{12}$, and bidder 2 the amount $\frac{1}{6} + \frac{p}{8}$. Expected seller revenue is $\frac{1}{3} - \frac{p}{12}$, what implies an efficiency loss of $\frac{p}{24}$.*

2.2. *Second-Price Auction*

The second-price auction has multiple equilibria in weakly undominated strategies when $p > 0$. When bidder 2 does not see 1's bid, it is weakly dominant to bid truthfully (Vickrey, 1961):

$$b_2(\emptyset, v_2) = v_2 \text{ for all } v_2. \tag{4}$$

If bidder 2 observes that b_1 exceeds v_2, she will underbid b_1. We refer to such bidder 2 as "*rational loser*" and denote the associated bid $b_2(b_1, v_2)$ by $g(b_1, v_2)$ as follows.

Property (P1): . $g(b_1, v_2) < b_1$ for all $v_2 < b_1$.

If bidder 2 observes $b_1 < v_2$, she will overbid b_1, with truthful bidding (v_2) being focal. Altogether the equilibrium bid of an informed bidder 2 is given by

$$b_2(b_1, v_2) = \begin{cases} v_2 & \text{if } b_1 \leq v_2, \\ g(b_1, v_2) & \text{otherwise.} \end{cases} \tag{5}$$

Anticipating this, bidder 1 maximizes

$$p\int_0^{b_1} u(v_1 - g(b_1, v_2))dF(v_2) + (1-p)\int_0^{b_1} u(v_1 - v_2)dF(v_2) + \int_{b_1}^{1} u(0)dF(v_2).$$

[8] In line with much of the auction literature we assume the same r for both bidders.

where $u(\bullet)$ is bidder 1's differentiable and strictly increasing utility function.

If $g(b_1, v_2)$ is continuous, differentiable, and weakly increasing in both arguments, the first-order condition (valid for $b_1 \in [0, 1)$) is

$$p \cdot u(v_1 - g(b_1, b_1)) + (1-p)u(v_1 - b_1) - u(0) = \frac{p}{F'(b_1)} \int_0^{b_1} u'(v_1 - g(b_1, v_2)) \frac{\partial g(b_1, v_2)}{\partial b_1} dF(v_2). \quad (6)$$

Proposition 2. *If $g(b_1, v_2)$ is continuous, differentiable, weakly increasing in both arguments, and satisfies P1, and $b_2(\emptyset, v_2)$ as well as $b_2(b_1, v_2)$ obey (4) and (5), respectively, then any interior equilibrium $b_1(v_1)$ must be consistent with (6).*

According to Proposition 2 multiple equilibria differ in $g(b_1, v_2)$, the conditional bid of a rational loser. In the following we distinguish three focal equilibria: in *SP-Truthful* a rational loser bids her true value $g(b_1, v_2) = v_2$ what induces bidder 1 to also bid her value. In *SP-Spiteful* a rational loser leaves as little for bidder 1 as possible by slightly underbidding him with $g(b_1, v_2) \nearrow b_1$. In case of a leak, the incentives to bidder 1 are similar to those in first-price auctions, implying more bid shading the larger leak probability p, but less so with increasing risk aversion. Finally, in *SP-Cooperative* a rational loser favors bidder 1 and harms the seller by $g(b_1, v_2) = 0$. In this case, bidder 1 gains his full value in case of a leak, incentivizing him to increase his bid above his value as p increases in order to enhance the chances for exploiting a leak. By doing so, bidder 1 is exposed to negative profits if there is no leak, hence bids decrease with risk aversion. These intuitions are formalized in the following proposition.

Proposition 3. *All SPA equilibria, where the expected strategy of the second bidder is given by (4) and (5), have the bid of bidder 1 depend upon $g(b_1, v_2)$ as follows:*

- *SP-Truthful: $g(b_1, v_2) = v_2$ and $b_1(v_1) = v_1$.*
- *SP-Spiteful:[9] $g(b_1, v_2) = b_1$. When u is concave, bidding is above that of risk neutrality. More specifically, with CRRA preferences it holds that $v_1 = b_1 + p \cdot (1-r)\frac{F(b_1)}{F'(b_1)}$.*
- *SP-Cooperative: $g(b_1, v_2) = 0$. When u is concave, bidding is below that under risk neutrality. With CARA preferences,[10] bidding decreases w.r.t. r. With risk-neutrality we have $b_1(v_1) = \frac{v_1}{1-p}$ for $v_1 \leq 1-p$ and $b_1(v_1) \geq 1$ otherwise.*

Proof. For SP-Truthful, since $g(b_1, v_2)$ is independent of b_1, the RHS of (6) equals 0. The LHS can only be 0 if $v_1 = b_1$. For SP-Spiteful, when $g(b_1, v_2) = b_1$, (6) becomes

$$\frac{u(v_1 - b_1) - u(0)}{u'(v_1 - b_1)} = p \cdot \frac{F(b_1)}{F'(b_1)}. \quad (7)$$

The derivative of the left hand side with respect to v_1 equals $1 - \frac{(u(v_1-b_1)-u(0))u''(v_1-b_1)}{u'(v_1-b_1)^2}$. When u is strictly concave, this is strictly greater than 1 for all $v_1 > b_1$. For risk neutrality, it is equal to 1. Hence, when finding the inverse bid function for the same bid, when utility is concave, $v_1 - b_1$ must be smaller. This implies that bids are higher with concavity than risk-neutrality. Substituting into (7) yields the CRRA result.

For SP-Cooperative, (6) becomes

$$pu(v_1) + (1-p)u(v_1 - b_1) = u(0). \quad (8)$$

This easily reduces to our result for risk neutrality. Note that $b_1 > v_1$ due to monotonicity.

Concavity of utility implies a decreasing slope so that:

$$\frac{u(v) - u(0)}{v} < \frac{u(0) - u(v-b)}{0 - (v-b)}. \quad (9)$$

[9] For the existence of a monotonic strategy by bidder 1 in SP-Spiteful, it is sufficient that the reverse hazard rate, $\frac{F'(v)}{F(v)}$, is decreasing.

[10] We follow Kagel & Levin (1993) in looking at CARA preferences since they are well defined in the negative range.

After rewriting this becomes

$$(u(v)-u(0))\,\frac{b-v}{v}<u(0)-u(v-b). \tag{10}$$

With risk neutrality (8) becomes:

$$pv_1+(1-p)(v_1-b_1^n)=0. \tag{11}$$

Combining yields

$$(u(v)-u(0))\,\frac{1-p}{p}<u(0)-u(v-b_1^n). \tag{12}$$

Since (8) implies $(u(v)-u(0))\,\frac{1-p}{p}=u(0)-u(v-b_1)$, we must have $b_1<b_1^n$.

For CARA preferences (8) becomes $e^{r\cdot v_1}=p+(1-p)e^{r\cdot b_1}$. This implies $b_1>v_1$ since $e^{r\cdot x}>1$ for $r,x>0$ and is increasing in x. Solving for the inverse bid function yields

$$v_1=\frac{1}{r}Log(p+(1-p)e^{r\cdot b_1}).$$

The derivative w.r.t. to r is proportional to

$$\frac{be^{br}(1-p)r}{e^{br}(1-p)+p}-Log(p+e^{br}(1-p)).$$

This is 0 when r=0 and the derivative w.r.t. r is proportional to

$$b^2e^{br}(1-p)pr$$

which is strictly positive when p is interior and $r>0$. Hence v_1 is increasing in r and bidding is decreasing in r.

□

While in our analysis the support of F is $[0,1]$, in the the first price auction and SP-Spiteful a different support merely results in a shift of the equilibrium to that new support. For instance, in a first price auction with uniform distribution of valuations on [0,1], the equilibrium is to bid half one's value (under risk neutrality). If the distribution is uniform on [1,2], the equilibrium is to bid $\frac{v-1}{2}+1$. With SP-Truthful and SP-Cooperative, the equilibrium is not shifted with the support.

As p approaches 1 cooperative bidding has bidder 1 bidding equal to or above 1 (independently of v_2) and bidder 2 bidding 0. The resulting ex-ante expected outcomes are listed in Table 1 (see Appendix Appendix B for calculations).

While we have treated $g(b_1,v_2)$ as a representation of a pure strategy, it can also represent the expectation of a mixed strategy by bidder 2 or the expectation of several heterogeneous strategies used by different possible players. For instance, if fraction α play the strategy of *SP-Spiteful* and $1-\alpha$ use *SP-Cooperative*—or any strategy where the expectation of bidder 2's strategy is $\alpha\cdot b_1$—then any equilibrium will have the first bidder behave as if bidder 2 is playing $g(b_1,v_2)=\alpha\cdot b_1$.

Corollary 2. *With risk neutrality, in all equilibria of SPA where the expected strategy of the second bidder obeys (4) and (5) with $g(b_1,v_2)=\alpha\cdot b_1+\beta\cdot v_2$ (where $\alpha,\beta\geq 0$ and $\alpha+\beta\leq 1$), we have the first bidder choosing b_1 according to $v_1=(1-p+(\alpha+\beta)\cdot p)b_1+\alpha\cdot p\cdot\frac{F(b_1)}{F'(b_1)}$. In the uniform case, bidder 1's equilibrium strategy reduces to $b_1(v_1)=\frac{v_1}{1-p+(2\alpha+\beta)p}$.*

From Corollary 2, we see that in the uniform case $g(b_1,v_2)$ can be reduced to a linear function αb_1, where α incorporates the expected term $\mathbb{E}(\beta\cdot v_2)=\frac{\beta}{2}$. When $\alpha=1/2$, bidding by bidder 1 is truthful. With increasing α or β, bidding by bidder 1 becomes less aggressive. This is true not only when F is uniform, but for general F (under a decreasing reverse hazard rate). This is true more generally when comparing equilibria. Suppose there are two equilibria, k and l, based on equilibrium strategies $g^k(b_1,v_2)$ and $b_1^k(v_1)$ for equilibrium k and $g^l(b_1,v_2)$ and $b_1^l(v_1)$ for l, then the following proposition holds:

Proposition 4. *Under risk neutrality, if F is weakly concave and $\frac{\partial g^k(b_1,v_2)}{\partial b_1}>\frac{\partial g^l(b_1,v_2)}{\partial b_1}$ for all $b_1\geq 0$, $v_2\geq 0$, then $b_1^k(v_1)<b_1^l(v_1)$ for all $v_1>0$.*

Proof. The RHS of equation (6) is (i) equal to 0 for $b_1 = 0$, (ii) strictly increasing in b_1, and (iii) strictly larger for g^k than for g^l. Thus, for a particular $v_1 > 0$, the b_1 that equates both sides for g^k is strictly smaller than for g^l. Hence, we have $b_1^k(v_1) < b_1^l(v_1)$ for all $v_1 > 0$. □

Intuitively, Proposition 4 says that a more aggressive bidder 2 induces bidder 1 to bid less aggressively.

Table 1: Equilibria and Expected Outcomes for F Uniform on $[0, 1]$ and $r_1 = r_2 = 0$.

Environment/Eqm.	$b_1(v_1)$	$g(b_1, v_2)$	Bidder 1	Bidder 2	Seller	Eff. Loss
First Price	$\frac{v_1}{2}$	·	$\frac{1}{6} - \frac{p}{12}$	$\frac{1}{6} + \frac{p}{8}$	$\frac{1}{3} - \frac{p}{12}$	$\frac{p}{24}$
SP-Truthtful	v_1	v_2	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{3}$	0
SP-Spiteful	$\frac{v_1}{1+p}$	$\nearrow b_1$	$\frac{1}{6(1+p)}$	$\frac{1+3p(1+p)}{6(1+p)^2}$	$\frac{1+2p}{3(1+p)^2}$	$\frac{p^2}{6(1+p)^2}$
SP-Cooperative	$\frac{v_1}{1-p}$	0	$\frac{1+p+p^2}{6}$	$\frac{1-p}{6}$	$\frac{1-p^2}{3}$	$\frac{p^2}{6}$

3. Experimental Design

We ran six sessions, each with 32 student participants from universities in Jena recruited using ORSEE (Greiner, 2015).[11] The experiment was conducted using z-Tree (Fischbacher, 2007). Three sessions each implemented the first- and second price auction. In each of the six sessions participants were matched in pairs over 36 rounds using random stranger rematching. More specifically, the 32 participants were split up in four matching groups of 8 participants each. Participants were only informed about random rematching but not about matching groups. Unannounced to participants, half of them were assigned to role A, and the other half to role B. Roles remained fixed throughout the session.

We compared behavior in six different conditions. In *baseline*, the probability of a leak was zero. In three *one-sided* conditions, the role A participant was the first mover, and the role B participant the second mover. We compared three different leak probabilities of A's bid: 1/4, 1/2, and 3/4. In two further *two-sided* conditions, leak probability was 1, but roles were assigned randomly, with varying probabilities.

In every round, each participant $i = 1, 2$ was assigned a privately known value v_i, drawn independently from the uniform distribution on $[20.00, 120.00]$ in steps of 0.01. At the beginning of a round, the relevant probabilities were announced. Bidding then proceeded in two stages, corresponding to the unconditional and conditional bidding. To observe strategies irrespective of random information revelation or role assignment, we used the strategy method. First, both participants had to submit an *unconditional bid* between 0.00 and 140.00 in steps of 0.01.[12] Then, in cases where information revelation was possible, the potential second mover(s), was (were) informed about the unconditional bid of the other bidder and had to submit a conditional second bid $b_2(b_1, v_2)$. Finally, the random draw was realized (if applicable) to determine which of the bid(s) of each player would be used to determine the outcome. Note that using the conditional bid of one participant necessarily implies that the unconditional bid of the other participant was used. At the end of the round, participants received feedback about the outcome of the random draw (if applicable), the relevant bids, the winner of the auction and their own earnings for the round.

Table 2 lists all treatment conditions in detail. In *baseline*, participants submitted their unconditional bids simultaneously and there were no conditional bids. In the three *one-sided* treatments, both players submitted unconditional bids, i.e. $b_1(v_1)$ by role A, and $b_2(\emptyset, v_2)$ by role B simultaneously. The role B participant was then informed about A's bid and submitted the conditional bid $b_2(b_1, v_2)$, which was implemented with probabilities $1/4$, $1/2$, or $3/4$, depending on the treatment. In the *two-sided* treatments, both players first submitted an unconditional bid equivalent to $b_1(v_1)$ in the model. Next, each player was informed about the other bidder's unconditional bid, and submitted his

[11] The students were recruited from Friedrich Schiller University Jena and University of Applied Science Jena.

[12] We avoided using the positional order protocol (first bidder 1 bids, then bidder 2 without knowing b_1) as it is unclear how this may affect bidding. To the best of our knowledge the effect of the positional order protocol has not been studied for auctions.

Table 2: Probability treatments

Treatment	Leak Probability	1st mover	2nd mover	Prob. of role assignment
Baseline	0	A and B	–	1
one-sided-1/4	$1/4$	role A	role B	1
one-sided-1/2	$1/2$	role A	role B	1
one-sided-3/4	$3/4$	role A	role B	1
two-sym	1	role A	role B	$1/2$
		role B	role A	$1/2$
two-asym	1	role A	role B	$3/4$
		role B	role A	$1/4$

respective conditional bid $b_2(b_1, v_2)$. With probability 1/2 or 1/4, depending on the treatment, A's unconditional bid and B's conditional bid determined the payoff. With the complementary probability, B's unconditional bid and A's conditional bid were implemented.

The six conditions were varied within subjects across rounds. Participants rotated through six cycles, each consisting of one round per treatment, for a total of 36 rounds. The matching and order of rounds was independently randomized for each matching group and cycle in the FPA sessions, and repeated for the SPA sessions to facilitate comparison across auction mechanisms.[13] Participants did not know in advance the different probability combinations nor the cycle structure.

The instructions (see appendix) used non-technical and unloaded terminology. We first explained the experimental game in play method, followed by a set of computerized control questions, to test whether participants had understood the instructions. After everyone had successfully answered the control questions, we distributed a new set of instructions detailing the procedure, especially the strategy method. We randomly selected five of the 36 rounds for payment. If the sum in these rounds was negative, they were subtracted from a show-up fee of €2.50 and an additional payment of €2.50 for answering the control questionnaire. Participants with any remaining negative balance would be required to work it off, what however never occurred.[14] Experimental currency unit payoffs were converted to money at the end of the experiment at a conversion rate of 1 ECU = €0.13 (around 0.177 USD). Sessions lasted between 85 and 135 minutes (including admission and payment) and participants earned €15.41 on average.

3.1. Experimental Hypotheses

We first state experimental hypotheses for the main probability treatment conditions, the *baseline* and the three *one-sided* conditions.

Optimality in the last stage of the game implies Hypothesis 1 (see equations (1) and (5)).

Hypothesis 1. *Conditional bids $b_i(b_j, v_i)$ are optimal, i.e.,*

a) in FPA, $b_i(b_j, v_i) = b_j$ if $b_j \leq v_i$ and $b_i(b_j, v_i) < b_j$ otherwise.

b) in SPA, $b_i(b_j, v_i) \geq b_j$ if $b_j \leq v_i$ and $b_i(b_j, v_i) < b_j$ otherwise.

In FPA and irrespective of optimality in conditional bids, equilibrium unconditional bids b_1 remain unaffected by leak probability, as do unconditional bids of uninformed second movers, i.e., $b_2(\emptyset, v_2)$, in both FPA and SPA (see Proposition 1 and equation (5)). In SPA, unconditional bids of first movers $b_1(v_1)$ depend on leak probability and how rational losers behave. In *SP-Cooperative*, first movers bid above their valuation and in *SP-Spiteful* they bid below, with the expected deviations of bids from values increasing with leak-probability. It is therefore not possible to formulate a detailed hypothesis on $b_1(v_1)$.

Hypothesis 2. *In FPA, unconditional bids $b_1(v_1)$ and $b_2(\emptyset, v_2)$ are unaffected by changes in leak-probability.*

[13]Generally, learning in private value auctions is difficult due to random individual values. The probabilistic conditioning process exacerbates this problem. We reduced the number of fundamentally different tasks an individual faces, thus simplifying the experiment, by assigning the lower probability of revising a bid to role A.

[14] For this purpose we had a special program prepared in which a participant would have to count the letter "t" in the German constitution, with each paragraph reducing the debt by €0.50.

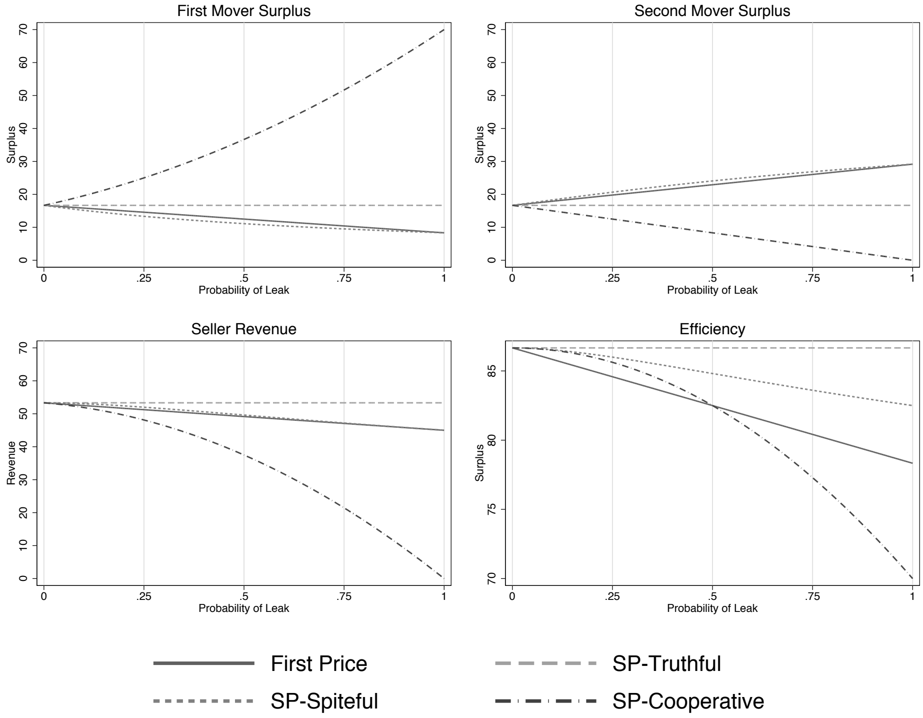

Figure 1: Theoretical Predictions

Hypothesis 3. *In SPA, unconditional bids of second movers ($b_2(\emptyset, v_2)$) are unaffected by changes in leak-probability.*

Figure 1 plots the equilibrium expected surplus of first mover (FM) and second mover (SM), the revenue, and efficiency as a function of leak probability, separately by mechanism and (in SPA) type of equilibrium (cf. Table 1). Outcomes for FPA and SP-Spiteful are highly similar throughout.

Hypothesis 4. *In FPA, the second-mover surplus increases and the first-mover surplus, seller revenue, and efficiency decrease with increasing leak probability.*

SP-Truthful is fully efficient, and neither bidder surplus nor revenue are affected by leaks. In SP-Cooperative, leaks have the strongest effects on outcomes (efficiency, revenue, and bidder surplus), including differences in inequality in bidders' earnings. In case of a leak and a low value v_2, the first mover collects his entire value such that the second mover and seller earn nothing. This is the most unequal and undesirable outcome when assuming pure inequality concerns (see, e.g., Bolton & Ockenfels 2000 and Charness & Rabin 2002). With increasing leak probability, ex-ante payoff expectations of bidders increasingly differ.[15]

Bolton et al. (2005) and Krawczyk & LeLec (2010) show that ex-post unequal outcomes become more acceptable when ex-ante expected outcomes are more equal. Applied to our setup, this suggests that unequal outcomes in SP-Cooperative are more acceptable in *one-sided* the less likely they are. Thus, in *one-sided*, participants would less likely coordinate on SP-Cooperative with increasing leak probability. However, since with increasing leak probability also strategic aspects and outcomes change considerably, it is difficult to predict how such concerns interact in shaping bidding behavior. The *two-sided* conditions induce two strategically identical conditions which only differ in ex-ante symmetry, allowing to test whether and how ex-ante symmetry or "procedural" fairness favors on one of the SPA equilibria.

Hypothesis 5. *In SPA more rational losers select SP-Cooperative in* two-sym *than in* two-asym.

[15] Since the sellers are not participants we assume only inequality of bidders matters.

If Hypothesis 5 holds, according to Corollary 3 and Proposition 4 equilibrium bids by Bidder 1 are larger in *two-sym* than *two-asym*.

4. Results

Our main research questions pertain to comparisons of aggregate outcomes – buyers' surplus, seller revenue, and efficiency – across auction mechanisms. Since these strongly depend on the equilibrium selection in SPA, we begin by describing the strategies used by participants, with special attention to rational losers in SPA, before turning to aggregate outcomes. When reporting results of mixed effects regressions, these are based on maximum likelihood estimations of models of the general form

$$y_{git} = \mathbf{x}_{git}\beta + u_g + e_i + \epsilon_{git}$$

with $\mathbf{x}$ being the vector of regressors, g indicating the matching group, i the participant, and t the experimental round (period). Error term e_i is nested in u_g and all error terms, including ϵ, are assumed to be orthogonal to each other and the regressors. In other words, u_g and e_i are random group and individual effects, respectively.

4.1. Individual Behavior

We analyze individual behavior backwards, starting with conditional bids of informed second bidders, separately for first and second-price auctions. Figure 2 summarizes types of conditional bids. The left panel shows the proportions of (sub-)optimal and non-optimal bids for both auction mechanisms. The right panel shows the distributions of types of conditional bids of rational losers in SPA, separately for the one- and two-sided treatments. The figure reveals that (a) clearly non-optimal behavior – placing a losing bid or losing when winning with profit is possible – is very rare; and (b) conditional bids of most rational losers resemble on of the three focal strategies, analyzed in Section 2. These results are described in detail below.

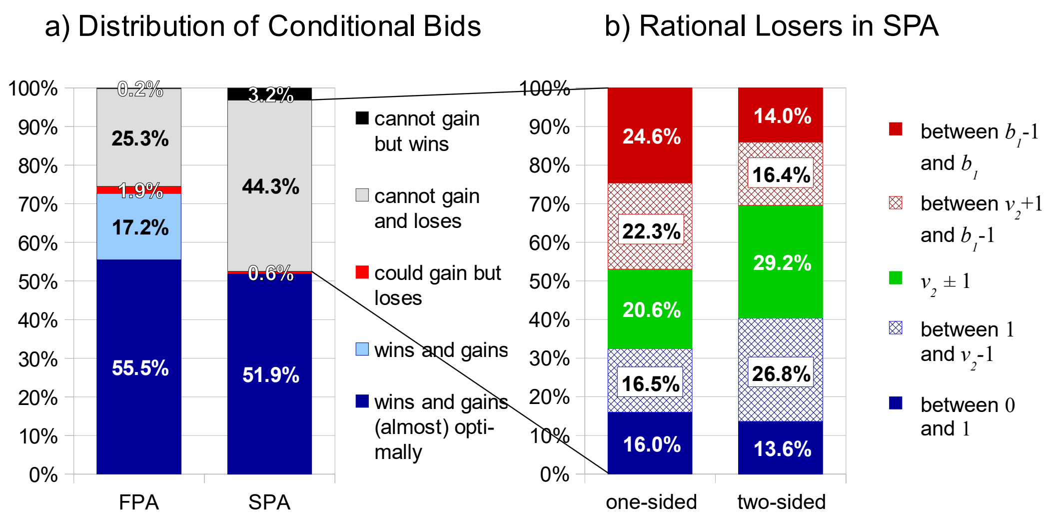

Figure 2: Conditional Bids

Notes: (almost) optimal win in FPA is defined as $b_1 \leq b_2 \leq b_1 + 1$. One observation in FPA was excluded for not fitting any of the categories: the second bidder could win and gain but wins at a loss. The classification of rational losers' bids allow for deviations of 1 ECU (in case of bids around v_2 in both directions). If bid is within $[b_1 - 1, b_1]$ and $[v_2 - 1, v_2 + 1]$, it is categorized as within the latter (1.1% of all cases).

4.1.1. Conditional Bids in FPA

In the first-price auction, when observing $b_1 \geq v_2$ bidder 2 is unable to gain from winning the auction. This happens in 25.5% of all cases. In 99.3% of these, bidder 2 acts optimally by bidding below b_1. The remaining cases, with bidder 2 winning at a loss, account for only 0.2% of all cases. Similarly, in cases with $b_1 < v_2$, bidder 2 indeed wins the auction with positive payoff in 97.4% of such cases.[16] Most (76.4%) of these winning bids extract the full gain from winning (up to rounding). The remaining winning bids, accounting for 17.2% of all auctions, were above $b_1 + 1$, resulting in an average forgone gain of 16.8 ECU, or 33.5% of the maximum possible.

Regressions of relative loss – defined as the forgone surplus divided by the maximum possible – on period and leak probability reveal no dependence on leak probability (coefficient of leak probability: .0115, $p = .471$) and a moderate but significant decrease with experience (coefficient on period: -.00166, $p = .018$).[17] Despite some sub-optimality, Hypothesis 1a is therefore confirmed.

Result 1. *Conditional bids in FPA are mostly optimal. Bidders rarely lose when winning could have been profitable, or win with a loss (2.6% and 0.8%, respectively). Some bids do not extract the entire possible gain (independent of leak probability) but less so with more experience.*

4.1.2. Conditional Bids in SPA

Moving to second-price auctions, the overall picture is similar. Out of the 52.5% of cases, in which bidder 2 observes $b_1 < v_2$, the vast majority (98.8%) has bidder 2 winning. Of the cases with $b_1 \geq v_2$, only 6.7% result in bidder 2 winning at a loss of 24.89 ECU on average. Such losses occur at the beginning of the experiment and rapidly disappear with experience.[18] Thus, Hypothesis 1b is only partly confirmed.

Result 2. *Conditional bids in SPA are mostly optimal. Bidders rarely fail to win a potentially profitable auction (0.6% of all cases) and the small share of auctions in which second movers win at a loss (3.2% of all cases) mostly happen early in the experiment.*

Rational Losers in SPA. In total, in 44.3% of all cases the informed second bidder has a lower valuation than the first bid ($v_2 < b_1$) and underbids in order to lose.[19] In the right panel of Figure 2 we categorize such conditional bids of "*rational losers*" according to the three focal points *truthful*, *cooperative*, and *spiteful*, as well as two intermediate types. As most participants submitted integer bids, whereas the values included two decimal digits, we allow for deviations of 1 ECU in the categorization. More specifically, we first categorize nearly truthful bids of $b_2(b_1, v_2) = v_2 \pm 1$, followed by those of 1 ECU or less (*cooperative*), and those of $b_1 - 1$ or more (*spiteful*). All remaining bids are either *between* $v_2 + 1$ *and* $b_1 - 1$, or *between 1 and* $v_2 + 1$. With 61.2% and 56.8% the majority of all conditional bids of rational losers are close to one of the three focal points in the one- and two-sided treatments, respectively. This includes a sizable share of 24.6% and 14% of conditional bids close to first mover bids in the one- and two-sided treatment, respectively. A similar classification of bids by rational losers in the FPA reveals no bids falling into the latter category, and overall only 42.6% in one-sided (47.3% in two-sided) fall within one of the remaining two focal categories. This suggests our finding of focal behavior in the SPA is not fortuitous.[20]

Individual Types.. The distribution of conditional bid types individually for every participant reveals that, except for one, all participants faced a first bid higher than their own valuation at least twice. Of those 95 participants, 27 always reacted with the same type of conditional bid, and a total of 28 (37) chose the same response category at least 90% (80%) of the time. As another test of individual consistency, we regressed the relative conditional bids on a constant with fixed participant effects, resulting in an adjusted $R^2 = 0.406$.

For a closer analysis of individual consistency and the type distribution, we ran the following analysis: First, we calculated the absolute deviation from each of the three focal strategies for every conditional bid where the observed bid b_1 exceeds v_2. We then classified each individual into one of the three categories, based on the smallest average absolute deviation. According to this classification, 53.12% of individuals are mostly truthful bidders, 27.08% spiteful, and 19.79% cooperative. To test the reliability of this classification, we did some further analysis based on the absolute deviations of conditional bids from their participant type. Overall, the median absolute deviation is 2.00, and the

[16] This number is obtained from Figure 2a as $\frac{17.2\%+55.5\%}{17.2\%+55.5\%+1.9\%}$.

[17] Mixed effects regression of relative loss on valuation, leak probability, and period. Over all 36 rounds, the regression predicts a reduction in relative forgone gain by 6 percentage points, based on the overall average of 33.5%.

[18] Half of all winning-at-a-loss bids occur in the first ten periods, and only 10% occur in the last eight periods of altogether 36 periods.

[19] This proportion is less than the 50% expected by chance if first bidders bid their value since, in contrast to the overbidding typically observed in second-price auctions, first bidders bid, for strategic reasons, on average less than their value.

[20] In the one-sided treatment of the FPA, 28.7%, 56.5%, 13.9%, and 0.9% of all conditional bids by rational losers were close to 0, between 0 and v_2, around v_2, and between v_2 and b_1, respectively. In the two-sided treatments it were 34.1%, 52%, 13.3%, and 0.7%, respectively.

median of the average absolute deviation for each individual (MoAAD) is 11.90. For comparison, we repeated this analysis on simulated bids, by replacing every conditional bid $b_2(b_1, v_2)$ for $v_2 < b_1$ with a random draw from the uniform distribution $[0, b_1]$. The results of 10,000 such simulations yield an average median deviation of conditional bids from second mover type of 22.02 (range 19.07–24.88) and an average of the MoAAD of 26.53 (range 23.26–29.58).

But is this all merely a result of rational losers repeating their unconditional bid? Of rational loser bids of bidder 2 whose unconditional bid is optimal in the sense of $b_2(\emptyset, v_2) \leq v_2$, 33.8% repeat their bid, 18.5% bid higher, and 47.8% lower.Taken all together, this suggests we have identified systematic patterns in behavior, and most individuals can be classified into one of the three categories.

Stability over Time.. Within each treatment the distribution among types of conditional bids vary considerably but mostly unsystematically over the course of the experiment. For a closer analysis of rational loser bids we look at relative conditional bids α defined as the ratio of the shifted conditional bid divided by the shifted observed first bid, i.e. $\alpha_2 = [b_2(b_1, v_2) - 20]/(b_1 - 20)$ (cf. Corollary 2). Figure 3 shows the estimated values of α by treatment and cycle. The figure reveals that relative conditional bids are fairly stable. Mixed effects regressions of relative conditional bids on cycle and value confirm that, except for *one-sided-3/4*, relative conditional bids are stable over time, with overall α estimated at 0.43 with 95% CI [0.35,0.51].[21] When excluding the first cycle, there are no time effects at all.[22]

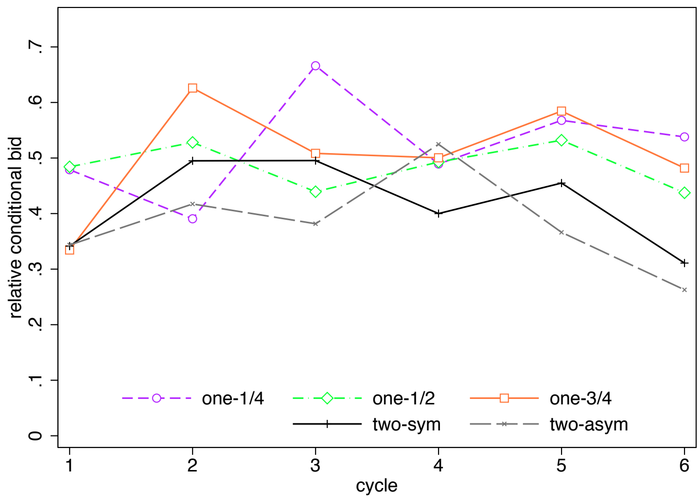

Figure 3: Relative Conditional Bids of Rational Losers in SPA
The figure plots $\frac{b_2(b_1,v_2)-20}{b_1-20}$ for rational losers by cycle for different leak probabilities.

Treatment Effects and Bid Function. We test for treatment effects by regressing absolute and relative conditional bids on leak probability, using mixed effects regressions. Using only data from *one-sided*, leak-probabilities do not affect bids of rational losers (effect of leak probability on relative conditional bid: 0.045, $p = .355$).

From the perspective of first movers, the bidding behavior of all informed second movers who underbid them – rational or not – is relevant. In Figure 4 we plot losing conditional second mover bids $b_2(b_1, v_2)$, such that $b_2(b_1, v_2) < b_1$, against valuation v_2, separately for each of the *one-sided* conditions and for role B bidders in *two-sym*. For rational loser bids we indicate the categorization from before, using the same color coding. In order to identify aggregate bid functions per treatment, we ran a mixed effects regression of losing conditional bids in SPA on transformed valuation $v_2' = v_2 - 20$, reported in column (5) of Table 4 and plotted in Figure 4. We use transformed valuation

[21] Mixed effect regression includes constant and valuation as regressors. Coefficient on Period (p-value): *one-sided-1/4*: .00903 ($p = .528$); *one-sided-1/2*: .00738 ($p = .522$) ; *one-sided-3/4*: .0258 ($p = .025$); *two-sym*: .0017 ($p = .896$); *two-asym*: .0011 ($p = 0.894$).

[22] Coefficient on Period (p-value): *one-sided-1/4*: .0277 ($p = .117$); *one-sided-1/2*: .00664 ($p = .648$); *one-sided-3/4*: -.0011 ($p = .924$); *two-sym*: -.01857 ($p = .155$); *two-asym*: -.0162 ($p = 0.181$).

to render the interpretation of the estimated intercept more obvious. The model includes controls for every treatment condition, interacted with v'. The t-statistics, reported in parentheses, are based on Huber-White sandwich estimations of standard errors. From the *two-sided* treatments we only included *two-sym* bids of role B participants. Based on Wald tests, in all *one-sided* conditions, the resulting intercept is significantly larger than 20 ($p \leq .0074$), and the slope in v' is significantly smaller than 1 ($p < .001$). In *two-sym* the slope is also significantly smaller than 1 ($p < .001$) but the intercept does not differ significantly from 20 ($p = .117$). Comparing intercept and slope between conditions, there are no significant differences between all three *one-sided* conditions (intercept: all $p \geq .435$, slope: all $p > .294$). Bidding behavior in *two-sym*, however, stands out with a significantly smaller intercept than in *one-sided 1/2* and *3/4* ($p = .005$ and $p = .040$) and a significantly larger slope than in *one-sided 3/4* ($p = .008$). We summarize our results:

Result 3. *Conditional bids of rational losers in SPA are (i) fairly consistent within individual bidder participants, with about 53% being mostly truthful, 27% spiteful, and 20% cooperative; (ii) stable across cycles; and (iii) unaffected by leak probabilities below 1.*

Result 4. *For small valuations, average losing conditional bids are above truthful bidding in all* one-sided *conditions, and reactions to changes to v are less than 1.*

Effect of Ex-ante Equality. The *two-sided* conditions allow to test for procedural fairness or (a)symmetry effects on bids of rational losers in SPA. Table 3 reports regressions of relative conditional bids in the *two-sided* treatments with a dummy for *two-sym*. The first model includes data for both experimental roles, A and B, the second and third for role A and B only, respectively. Contrary to Hypothesis 5, relative conditional bids are higher in *two-sym* than in *two-asym* in all models, significantly for role A.[23]

Result 5. *Relative conditional bids of rational losers in SPA are larger in* two-sym *than in* two-asym*, rejecting Hypothesis 5.*

Table 3: Ex-ante Fairness and Optimal Loser Bids

	(1) both roles	(2) role A	(3) role B
two-sym	0.0263	0.048**	0.0084
	(1.37)	(2.18)	(0.37)
_cons	0.561***	0.530***	0.588***
	(19.50)	(14.65)	(19.35)
N	422	201	221
p	0.172	0.0296	0.708

Note: Linear mixed effects regressions on rational losers' bids in the two-sided treatments with random intercept effects on participant nested in random effect on matching group. t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.1.3. Unconditional Bids

Columns (1) to (4) of Table 4 report mixed effects regressions of unconditional bids, i.e. bids from first- and uninformed second movers. Bids are again regressed on transformed valuation $v_i' = v_i - 20$, and all estimations include only data from *baseline*, *one-sided*, and *two-sym*, where we use role A data for first-mover bids and role B data for second-mover bids. Again, regressions include a random intercept effect on the participant nested in a random effect on matching group, and the t-statistics reported in parentheses are based on the Huber-White sandwich estimator. The first two models are for FPA only. The constant and effect on v' describe the bid function in *baseline*. Dummies *one-sided-1/4*, 1/2, and 3/4 measure differences in the intercept, interaction effects such as *one*-1/4 $\times v'$ measure differences in the reaction to changes in valuations.

[23] First bidders gain the most in the cooperative equilibrium. Compared to the symmetric treatment, bidders in role A are more likely to be in the first-mover position in the asymmetric treatment, and may therefore behave more cooperatively (as second bidders) hoping that their partners will behave similarly.

Table 4: Aggregate Bid Functions

	(1)	(2)	(3)	(4)	(5)
	FPA		SPA		
	1st mover	2nd mover	1st mover	2nd mover	
	b_1	$b_2(\emptyset, v_2)$	b_1	$b_2(\emptyset, v_2)$	$b_2(b_1, v_2)$ if $b_2 < b_1$
Constant†	15.20***	18.12***	22.05***	21.66***	36.25***†
	(14.61)	(10.00)	(10.23)	(9.89)	(5.97)
one-sided 1/4	-0.623	-2.645	1.451	-1.940	–†
	(-0.67)	(-1.38)	(0.50)	(-0.96)	
one-sided 1/2	-0.649	-2.526	-2.660	0.732	2.612
	(-0.40)	(-1.24)	(-1.39)	(0.30)	(0.54)
one-sided 3/4	0.148	-4.578**	-1.987	2.911	1.507
	(0.14)	(-2.08)	(-0.76)	(1.06)	(0.36)
two-sym	-3.073	-4.068**	1.657	1.315	-11.29
	(-1.47)	(-2.06)	(0.50)	(0.39)	(-1.50)
v'	0.627***	0.605***	1.011***	1.007***	0.586***†
	(20.23)	(22.01)	(27.23)	(27.98)	(6.38)
one-1/4 $\times v'$	-0.00481	-0.0247	-0.0621	0.00587	–†
	(-0.18)	(-0.73)	(-1.13)	(0.15)	
one-1/2 $\times v'$	0.00113	-0.0393	-0.0114	-0.0520	-0.144
	(0.03)	(-0.94)	(-0.36)	(-1.08)	(-1.05)
one-3/4 $\times v'$	0.0293	-0.0671*	-0.0281	-0.0892	-0.145
	(0.86)	(-1.71)	(-0.83)	(-1.53)	(-0.97)
two-sym $\times v'$	-0.0374	-0.0249	-0.132***	-0.140*	0.104
	(-1.17)	(-0.67)	(-2.68)	(-1.84)	(0.83)
N; #Subj; #Groups			1440; 48; 12		534; 48; 12
p(Chi^2)	$< .001$	$< .001$	$< .001$	$< .001$	$< .001$

Note: Linear mixed effects regressions with random intercept effects on participant nested in effect on matching group. *t* statistics in parentheses based on Huber White sandwich estimation of standard errors * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Regressions include data from conditions *baseline* (columns 1-4 only), *one-sided*, and *two-sym*. For *two-sym*, only role A (B) responses were used for 1st (2nd) mover bids. Transformed valuation $v' = v - 20$ used instead of v.

† In models (1) to (4) the constant (coefficient on v') is the intercept (slope) in *baseline*, in model (5) it stands for *one-sided 1/4*.

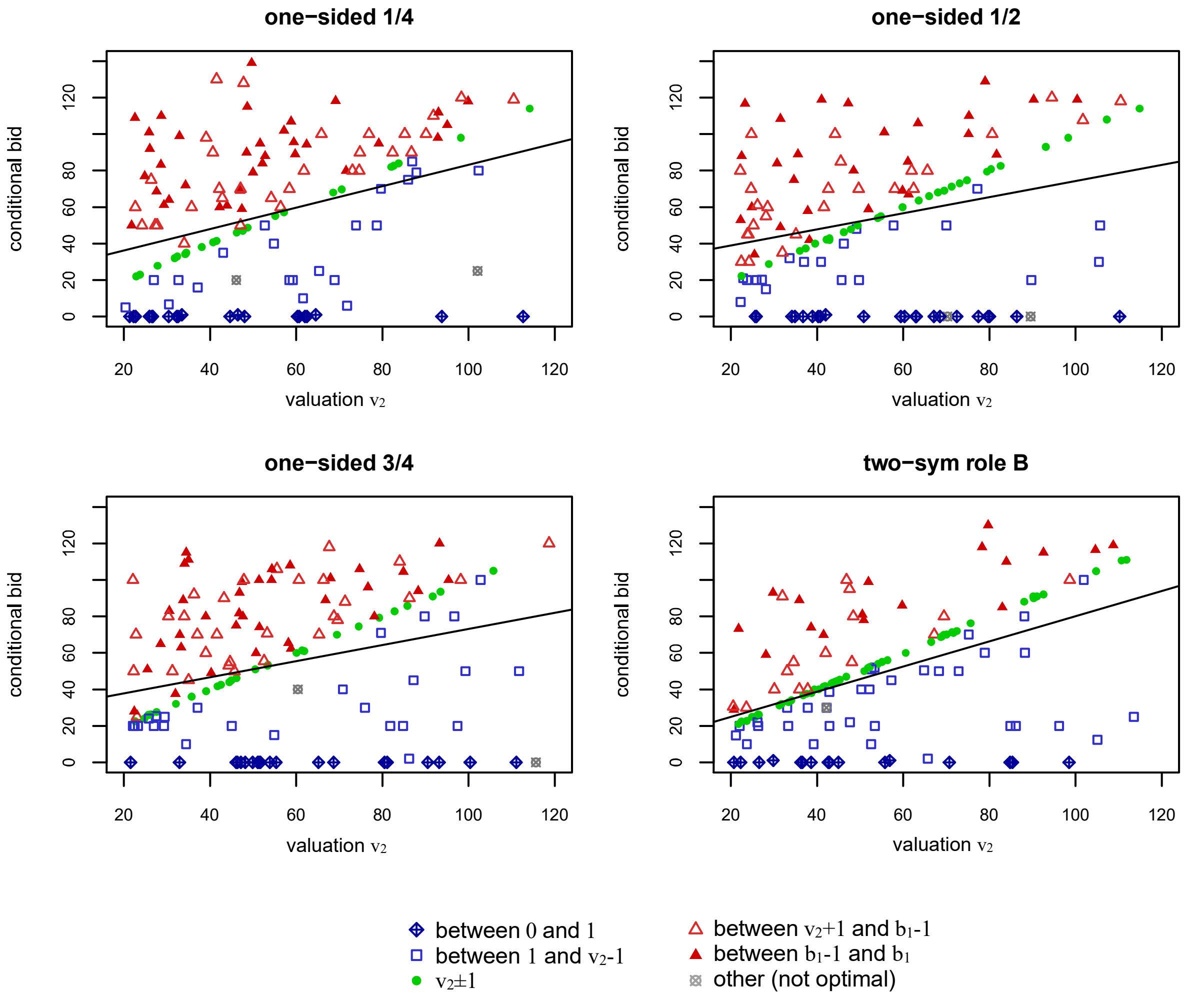

Figure 4: Losing conditional bids in SPA

Losing conditional bids in SPA (i.e. $b_2(b_1, v_2)$ such that $b_2 < b_1$) for *one-sided 1/4*, *one-sided 1/2*, and *one-sided 3/4*, and for role B bidders in *two-sym*, as a function of valuation v_2. Data from all Periods. Regression lines are taken from estimation result in column (5) of Table 4

Unconditional Bids in FPA. According to the benchmark solution, FPA estimations should identify an intercept of 20 and a slope in v' of 1/2, irrespective of role and leak probability. Model (1) estimates bid functions of first movers in FPA. As all coefficients other than for intercept and v' are insignificant, there are no significant differences between *baseline* and leak-conditions. Wald tests find no significant differences between the different conditions. The intercept is significantly smaller than 20, and the reactivity to v' is significantly larger than 1/2 in all treatment conditions. [24]

Model (2) estimates bid functions for unconditional bids of second movers. Contrary to first movers, there are some significant differences across probability conditions. The intercept in *one-sided 3/4* is significantly smaller than in *baseline* ($p = .037$) and *one-sided 1/2* ($p = .0398$), and the reaction to v' is weakly significantly smaller than in *baseline* ($p = .088$).

Compared to the benchmark solution, for a positive leak probability the intercept is significantly smaller than 20 (all $p < .001$), while in *baseline* it does not differ significantly ($p = .301$). The slope, on the other hand, is

[24] Comparison between treatment conditions: intercept $p > .133$; slope $p > .1755$. In all treatment conditions: Wald-tests: H0: Intercept=20 vs. H1: Intcpt.< 20: $p < .001$. H0: Slope $v' = 0.5$ vs. H1: $v' > 0.5$ $p < 0.024$.

significantly larger than 1/2 in all conditions (all $p \leq .0107$) except for *one-sided 3/4* ($p = .1475$). Except for second movers in *one*-3/4, the estimated biding functions in v' intersect with the benchmark solution in all conditions, with an intersection between 18.21 (second movers in *benchmark*) and 87.83 (first movers in *two-sym*). The estimated bid function for second movers in *one*-3/4 lies below the benchmark solution for all v'.

Result 6. *Unconditional bids in FPA are mostly invariant in leak probability, as predicted by Hypothesis 2, with the exception of small unconditional bids made by second movers in* one-sided 3/4*. Compared to the benchmark, we find on average underbidding for small, and overbidding for large valuations.*

Unconditional Bids in SPA. Models (3) and (4) in Table 4 report estimations of aggregate bid functions for first and uninformed second movers in SPA, respectively, and Figure 5 produces scatterplots of first mover bids b_1 against valuations v_1. For uninformed second movers, unable to influence the other's bid, it is weakly dominant to bid their value. Indeed, model (4) of Table 4 shows an intercept of approximately 20 and a slope of approximately 1 in all one-sided treatments.[25] Except for *two-sym*, there are no significant differences in bidding behavior across treatment conditions, confirming hypothesis 3.[26]

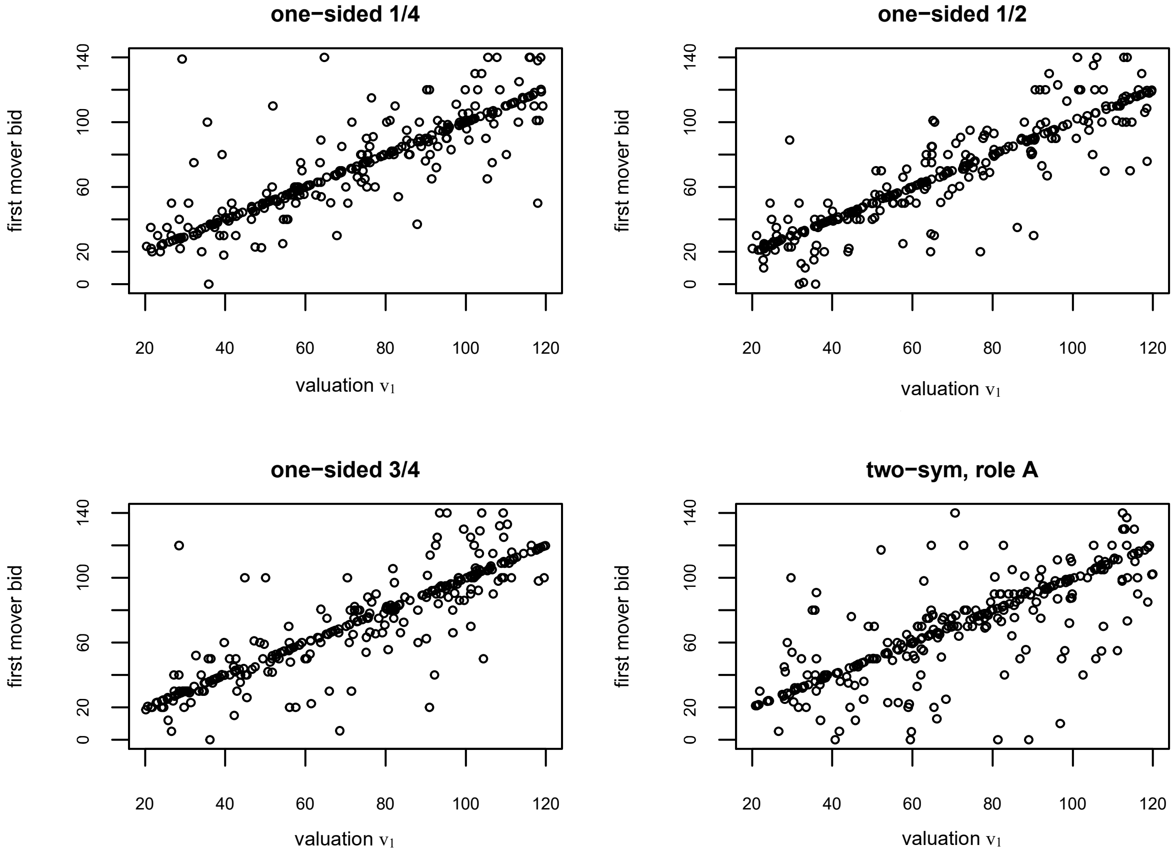

Figure 5: First mover bids in SPA
First mover bids in SPA for *one-sided 1/4*, *one-sided 1/2*, and *one-sided 3/4*, and for role A bidders in *two-sym*, as a function of valuation v_2. Data from all Periods.

Result 7. *In SPA, average bids of uninformed second movers do not differ significantly from value bidding in all conditions with leaks, and for leak probabilities less than one, bidding is unaffected by leak probability.*

[25] Wald tests for intercept equal 20 and slope equal 1 result in $p > 0.114$ for all treatments.
[26] Wald tests: $p > 0.1037$ for all intercepts and $p > 0.0544$ for all slopes.

Recall that losing conditional bids in SPA are, *on average*, larger than truthful bids for small valuations, as evidenced by the large intercepts of the bid functions. Due to Proposition 3, the optimal strategy of risk neutral first movers is to underbid for small valuations. Contrary to this, model (3) in Table 4 and the scatterplots of first mover bids in Figure 5 reveal that, except for first mover bids in *two-sym*, bidding behavior does not differ significantly from value bidding throughout,[27] what can be rationalized by (strong) risk aversion.[28] But there are some further comparative statics one needs to check. As except for *two-sym*, losing conditional bids do not vary with leak probability, irrespective of risk preferences, first mover bids should decrease in leak probability due to the SP-Spiteful behavior of second movers for small valuations. Limiting our attention to the *one-sided* conditions, we find weak evidence for this, to the extend that the intercept in *one-sided 1/2* is significantly smaller than in *one-sided 1/4* ($p = .0386$), while there are no significant differences in the coefficient of v'. There are, however, no further significant differences, neither concerning the intercept nor the reaction to v' (all $p \geq .168$).[29] Again, the bidding function in *two-sym* stands out, with a significantly larger intercept than in *one-3/4*, and a significantly weaker reactivity to v' than in all other conditions, except for *one-1/4*.

Result 8. *Average SPA bids of first movers do not differ significantly from value bidding for leak probabilities less than 1. The observed differences between treatments do not indicate that first mover bidding is well adjusted to the behavior of informed second movers.*

4.2. Aggregate Outcomes

Figure 6 displays expected bidder surplus, revenue, and efficiency (total surplus) by auction mechanism and probability condition. Table 5 reports mixed effects regressions of these variables on treatment dummies and Period. For all probability conditions except *baseline*, we calculated expected outcomes to abstract from randomizations during the sessions.[30] In *one-sided*, first (second) movers correspond to role A (B) participants. In *two-asym* and *two-sym*, the surplus is reported separately for first- and second movers: for example in *two-asym*, the first mover is participant B with probability 1/4 and A with 3/4. For the *baseline* we report the surplus separately for experimental roles.

The regressions reported in Table 5 are based on maximum likelihood estimations of linear mixed effect models including random group effects as well as two separate participant random effects, for A and for B participants. The regressors are dummies for the five probability conditions, a dummy D_{SP} for the second-price auctions and interaction terms, indicated by "×." The t-statistics, reported in parentheses, are based on Huber-White sandwich estimations. The bars in Figure 6 are the margins of the regressions in Table 5, and the 90% confidence intervals, indicated by whiskers, are based on the Huber-White standard errors.

4.2.1. Effect of Leak Probability on Outcomes

Table 6 complements Table 5 by reporting regressions of outcomes in the *one-sided* treatments with leak probability as a continuous independent variable. Given the differences in procedures and the markedly different bidding behavior, we excluded the *two-sided* conditions. For FPA, the coefficients on leak probability (Prob{leak}) confirm Hypothesis 4:

Result 9. *In FPA, second mover surplus significantly increases whereas first mover surplus, revenue and efficiency significantly decrease with increasing leak probability.*

In the *one-sided* conditions of SPA, first mover and uninformed second mover bids do not vary with leak probability, and are close to value bidding. While aggregate bid functions of informed second movers deviate from value bidding, these deviations are relatively mild and overbidding for small values and underbidding for large ones likely cancel out across all possible values. Thus, aggregate bidder surplus should not vary significantly with leak probability (cf. Table 1, and Figure 1). There is, however, substantial variance in bids, especially in losing conditional bids. While the opposing effects of such deviations on bidder's surplus may offset each other, they should unambiguously decrease efficiency, which is furthermore amplified by leaks. Empirically, the coefficients on Prob{leak} confirm this.

[27] All *one-sided* conditions and *baseline*: Wald tests, comparing intercepts to 20: all $p \geq .1670$, and comparing slope to 1: all $p \geq .2128$. Condition *two-sym*: intercept not different from 20 ($p = .1764$), but slope sign. smaller than 1 ($p = .0073$).

[28] Equilibrium first mover bids in SP-spiteful increase with risk aversion and approach value bidding for strong risk aversion, see Proposition 3.

[29] The marked difference in *one-sided 1/2* seems to be a one-off result, as the intercept in *one-3/4* and *two-sym* is larger again (though insignificantly).

[30] Suppose in SPA for *one-sided-1/2*, independent bids of A and B were 20 and 100, and the conditional bid of the latter was 20. Irrespective of the actual outcome in the experiment, we then used the expected revenue $0.5 \times 100 + 0.5 \times 20 = 60$.

Table 5: Outcomes

	(1) Surplus FM/A	(2) Surplus SM/B	(3) Revenue	(4) Efficiency
_cons	11.16***	12.01***	57.92***	81.34***
	(6.81)	(7.06)	(29.37)	(37.84)
one-sided 1/4	2.210	4.195*	-4.582**	1.952
	(0.94)	(1.87)	(-2.11)	(0.64)
one-sided 1/2	-0.119	7.531**	-8.093***	-0.475
	(-0.05)	(2.50)	(-4.45)	(-0.18)
one-sided 3/4	-1.022	7.353***	-7.539***	-1.115
	(-0.46)	(3.01)	(-3.52)	(-0.37)
two-sym	-5.417**	10.70***	-12.49***	-2.621
	(-2.44)	(4.07)	(-7.26)	(-1.12)
two-asym	-4.549**	9.349***	-9.380***	-0.751
	(-2.02)	(3.46)	(-3.48)	(-0.26)
$D_{SP}\times$baseline	5.330***	2.842*	-6.311***	1.481
	(3.51)	(1.87)	(-3.10)	(0.64)
$D_{SP}\times$one-1/4	3.133**	-0.640	0.750	2.904
	(1.98)	(-0.30)	(0.46)	(1.44)
$D_{SP}\times$one-1/2	5.449***	-0.498	-0.878	4.133*
	(3.36)	(-0.18)	(-0.43)	(1.71)
$D_{SP}\times$one-3/4	6.358***	-5.949**	2.272	2.370
	(4.16)	(-2.17)	(1.06)	(0.98)
$D_{SP}\times$two-sym	9.386***	-5.586***	4.179**	2.122
	(5.67)	(-2.80)	(1.99)	(1.13)
$D_{SP}\times$two-asym	9.389***	-4.177**	0.0208	0.0072
	(6.40)	(-2.15)	(0.01)	(0.00)
N / # Groups		3456(24)		
p	$< .0001$	$< .0001$	$< .0001$	$< .0001$

Note: Linear mixed effects regressions with random intercept effects on role A and B participant nested in effect on matching group. t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. D2nd is an indicator variable for the second price rule and "×" indicates an interaction effect. Efficiency is measured as the value of the auction winner. Not reported: separate control variables for Period in *baseline*, *one-sided*, and *two-sided* conditions (all three insignificant).

Table 6: Effect of Leaking Probability on Outcomes

	First-Price Auction			
	(1) Surplus FM/A	(2) Surplus SM/B	(3) Revenue	(4) Efficiency
Prob{leak}	-6.406***	6.321**	-6.034*	-6.121*
	(-2.69)	(2.03)	(-1.92)	(-1.66)
Period	-0.109**	0.114	0.0996	0.0918
	(-2.56)	(1.59)	(1.48)	(1.10)
_cons	15.49***	14.35***	53.73***	83.93***
	(9.03)	(8.61)	(25.36)	(31.00)
N / # Groups		864(12)		
p	0.0081	0.0579	0.0490	0.0911
	Second-Price Auction			
	(5) Surplus FM/A	(6) Surplus SM/B	(7) Revenue	(8) Efficiency
Prob{leak}	0.0606	-4.320	-3.349	-7.215**
	(0.02)	(-0.75)	(-0.75)	(-1.99)
Period	-0.0270	0.0183	0.0413	0.0298
	(-0.27)	(0.20)	(0.65)	(0.31)
_cons	15.73***	19.05***	54.13***	88.75***
	(6.95)	(5.66)	(26.14)	(33.04)
N / # Groups		864(12)		
p	0.963	0.751	0.685	0.109

Note: Data from *one-sided* conditions only. Linear mixed effects regressions with random intercept effects on role A and B participant nested in effect on matching group. Efficiency is measured as the value of the auction winner. t statistics in parentheses. * $p < 0.1$, $^{**}p < 0.05$, *** $p < 0.01$.

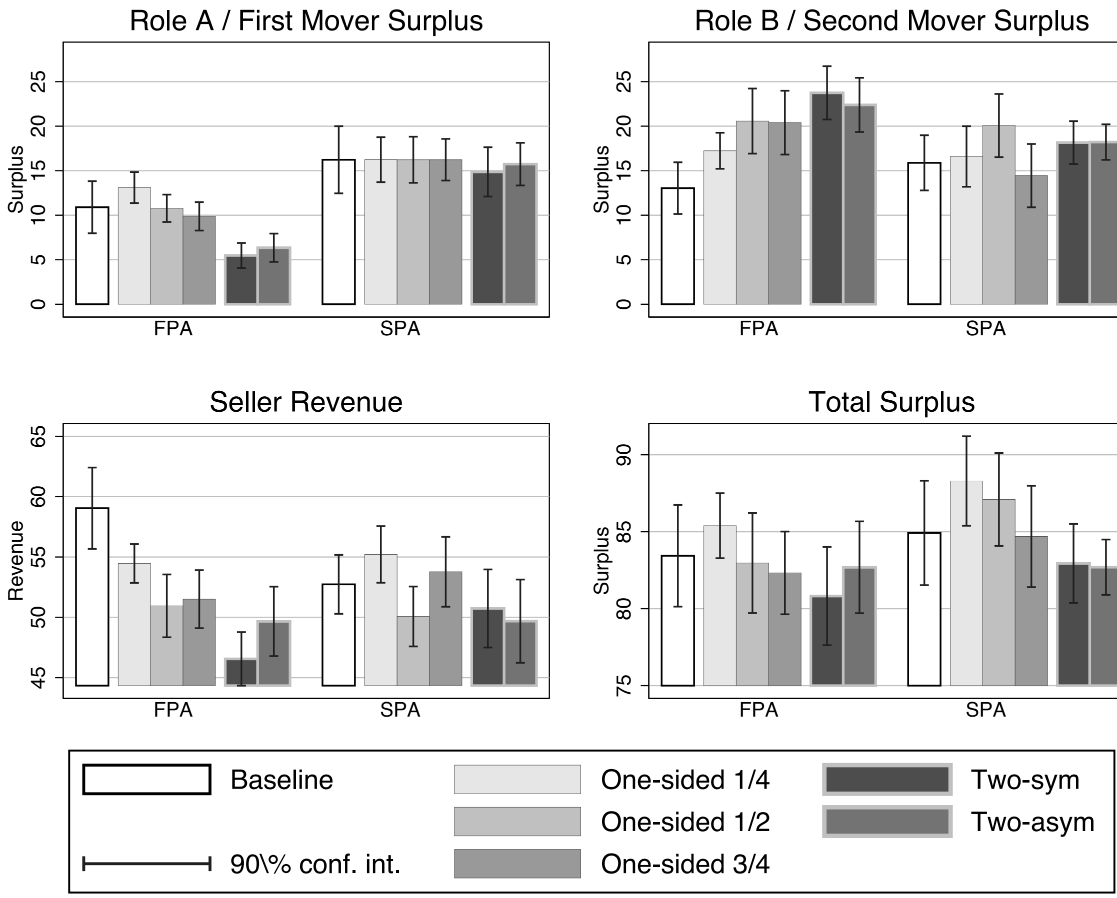

Figure 6: Outcomes

Note: Ex-ante expected outcomes (independent of random draws in experiment). Bars report margins of estimation results in Table 5, whiskers indicate 90% confidence interval. Bidder Surplus: in *baseline* by experimental role (A or B), in all other conditions separately for first and second movers.

Result 10. *In SPA, first and second mover bidder surplus as well as seller revenue do not react systematically to changing leak probability. Efficiency significantly decreases with leak probability.*

4.2.2. Comparison of Auction Mechanisms

In line with existing evidence the coefficient on $D_{SP}\times$baseline in models (1) to (4) in Table 5 suggests:

Result 11. *Without leaks, seller revenue is significantly larger in FPA, bidders earn significantly more in SPA (for both roles), but efficiency is insignificantly higher in SPA.*

With leaks in SPA all, except losing conditional bidders, behave like value bidders, and all previous results indicate that deviations from value bidding cancels out over the entire range of values. Bidding in FPA, is also invariant to changes in the leak probability, and deviations from the benchmark go in opposite directions for low and large values. In FPA but not in SPA, however, *realized* leaks allow the second bidder to win even with the lower value and to reduce the price when winning with the higher value. This explains that seller revenue is decreasing in leak probability in FPA, while for SP-truthful it remains constant and above that in FPA (cf. section 3.1). The insignificant, and in most cases positive interaction effect of D_{SP} with the dummies for the *one-sided* conditions in model (3) show that, as expected, the revenue dominance of FPA is lost when leaks matter.

Result 12. *With leaks, seller revenue is no longer higher in FPA than in SPA. In* two-sym*, i.e. for a leak probability of 1, seller revenue is even significantly larger in SPA. .*

Using SP-truthful as the closest approximation of SPA bidding, our result for seller revenue suggests that first mover surplus is larger in SPA, and second mover surplus in FPA. As indicated by all interaction effects of D_{SP} with the treatment dummies for conditions with leaks in model (1) of Table 5, for first movers this is confirmed throughout. For second movers (see model 2), effects mostly go in the predicted direction, but surplus is only significantly smaller in SPA for leak probabilities of 3/4 or more. According to our theoretical predictions, SPA are more efficient than FPA, except for SP-Cooperative which, however, seems an unlikely result in the light of our data. While the effect in model (4) by and large confirms that SPA are more efficient, except for condition *one-sided 1/2*, this is insignificant.

Result 13. *With leaks, first mover surplus is significantly larger in FPA than in SPA. Second mover surplus does not differ across mechanisms for small leak probabilities but becomes significantly higher in SPA for leak probability 3/4 (and 1). Efficiency is larger in SPA but significantly only in* one-sided 1/2*.*

5. Conclusion

The most prominent auction formats are first- and second-price sealed-bid auctions, along with their strategically equivalent Dutch and (for independent private values) English auctions. Existing experimental evidence strongly suggests that, in the case of independent private values, first-price auctions generate higher seller revenue, while second-price auctions are more efficient,[31] but prone to ring formation.[32] While research has looked into effects of information revelation about private values, the effect of revelation of actual early bids on bidding behavior has so far been overlooked. Bid revelation can result from the firm having to commit to a strategy before bidding commences. For example, the winning firm in an ascending bid auction for building rights is often required to put down a down payment. In this case, the payment has to be pre-approved by the management (or a pre-approved credit line must be obtained). If this information is leaked, it is likely to affect a competitor's strategy. Similarly, firms are often large and complex organizations. Especially producers of very complex and customized goods face a difficult price finding procedure, with many levels of management being required to approve a bid before submission. In such cases one may need to consider the risk of leaks.

Our theoretical analysis reveals that the stylized empirical facts may not hold when information about an early bid may be leaked to later bidders. Moreover, comparative statics across auction mechanisms are ambiguous due to multiple equilibria in second-price auctions. The experimental outcomes in the first-price auctions are as predicted. Unconditional bids are not affected by leak probability, but actual leaks increase the second mover's payoff while reducing first mover payoff, seller revenue, and overall efficiency. Interestingly, these qualitative effects hold in spite of significant deviations from equilibrium bidding by first movers and uninformed second movers. In both mechanisms, bids by informed second movers are overwhelmingly rational. In the second price auction, where informed second bids are crucial for equilibrium selection, we observe considerable heterogeneity in bidding behavior, with the majority of bids resembling one of the three focal equilibria, truthful, spiteful, or cooperative. While most deviations from truthful bidding seem to cancel out, in the aggregate we find overbidding (SP-Spite) for small and underbidding (SP-Cooperative) for high valuations. Bidding by uninformed second movers, on the other hand is very close to weakly dominant value bidding. If first movers reacted optimally to the bidding behavior of informed and uninformed second movers, they should therefore react to changes in the leak probability. Overall, there is no evidence for such behavior, and in our main treatments first mover bidding is, on average, equivalent to value bidding throughout. Consequently, leak probability exerts no systematic effect on expected seller revenue. Nonetheless, due to the pronounced effect in first-price auctions, leaks affect the comparison between the two pricing rules: The first-price rule is no longer favorable from the seller's perspective, and in the symmetric treatment with leak probability 1, the second-price mechanism even provides a higher revenue to the seller.[33]

Our behavioral conclusions are in line with those of Andreoni et al. (2007), who similarly manipulate information of bidders about their opponents. In their experiment, four bidders learn the realized *valuations* rather than the *bids* of none, one, or all three other bidders. Thus, their setting does not invoke strategically adjusted unconditional bids in second-price auctions according to the different equilibria, which are the focus of our theoretical and experimental analysis. Notwithstanding, we share some of Andreoni et al.'s (2007) conclusions, namely that weakly dominated bids

[31] Heterogeneous risk aversion is able to rationalize both phenomena.
[32] Gandenberger (1961) shows that historically they were avoided for public procurement.
[33] Explicit collusion may also eliminate the revenue dominance of first-price auctions (Llorente-Saguer & Zultan, 2017; Hu et al., 2011; Hinloopen & Onderstal, 2014)

are rare and less frequent with more experience; that behavior is qualitatively consistent with the comparative statics in first-price auctions; and that a substantial proportion of second movers with no chance of gaining from winning the auction overbid their own value while still underbidding the first bid, consistent with spite. Unlike Andreoni et al. (2007), we also observe a substantial proportion of cooperative bidding. This difference can be explained by a fundamental difference between their and our setup: rational losers in our experiment *know* when the high bid is above their valuation, whereas in Andreoni et al. (2007) this is only true if other bidders bid truthfully. In the latter case, possible bid shading by others may deter cooperative bidding.[34]

In summary it can be concluded that informational leaks, allowing later bidders to react to earlier bids, can be crucial when comparing first- and second-price auctions. For uniform distributions, benchmark bidding is unaffected in first-price auctions, however leaks do affect allocation outcomes. For second-price auctions leaks imply multiplicity of equilibria, with truthful, spiteful, and cooperative bidding being focal.[35] While theoretically, fairness concerns could affect which of those equilibria bidders prefer, we do not find evidence to this effect.

Regarding our more technical restriction of a uniform distribution of valuations, we can offer some tentative predictions. Theoretical results by Arozamena & Weinschelbaum (2009) suggest that leaks in first-price auctions should not affect bidding behavior of uninformed bidders under power function distributions. In our experiments this invariance is confirmed for uniform distributions and it seems unlikely to change for different ones. In second price auctions, theoretical results only depend on distributional assumptions in case of SP-Spiteful. While we observe spiteful bids by informed second movers, there is no evidence that first movers react optimally. Further experimental research is necessary to establish whether this would change for other distributions, but given the strong behavioral salience of value bidding it seems unlikely.

One straightforward extension of our model is the introduction of marginal bidding costs. Rational losers would then refrain from bidding, reducing the set of second price auction equilibria to the cooperative one. In our experiments, cognitive costs associated with elaborating on a conditional bid different to the already submitted unconditional one may involve such marginal costs. Our result that only about one third of rational loser bids repeat an otherwise rationalizable unconditional bid therefore suggests that small bidding costs are irrelevant. Other interesting questions arise from endogenizing leak probability by introducing espionage, strategic leaks or both. In our setting, incentives for engaging in espionage are stronger in FPA than SPA. Further research, both theoretical and experimental, may establish whether this holds if leaks are endogenous.

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[34] Roth & Ockenfels (2002), for example, suggest that expecting bid shading from others in second-price auctions provides a (partial) explanation for sniping in online auctions.

[35] Even without leaks, second-price auctions have multiple equilibria but in weakly dominated strategies, cf. Plum (1992) and Blume & Heidhues (2004).

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Appendix A. Derivation of Corollary 1

For bidder 1 the expected surplus depends on v_1 via

$$\pi_1(v_1) = [p\frac{v_1}{2} + (1-p)v_1](\frac{v_1}{2}) = (1-\frac{p}{2})\frac{v_1^2}{2}.$$

Thus bidder 1's expected profit is

$$E[\pi(v_1)] = (1-\frac{p}{2})\frac{1}{2}E[v_1^2] = (1-\frac{p}{2})\frac{1}{2}\int_0^1 v_1^2 dv_1 = \frac{1}{6} - \frac{p}{12}.$$

When uninformed, bidder 2's expected surplus is $\pi_2(v_2) = \frac{v_2^2}{2}$. Ex-ante this yields $E[\pi_2(v_2)] = E[\frac{v_2^2}{2}] = \frac{1}{6}$. When bidder 2 is informed about b_1 and $v_2 \geq \frac{1}{2}$, bidder 2 expects to earn $v_2 - \frac{1}{4}$, whereas for $v_2 \leq \frac{1}{2}$, informed bidder 2 can expect v_2^2. Ex-ante informed bidder 2 expects $\int_0^{\frac{1}{2}} v_2^2 dv_2 + \int_{\frac{1}{2}}^1 (v_2 - \frac{1}{4})dv_2 = \frac{1}{24} + \frac{1}{2} - \frac{1}{8} - (\frac{1}{4} - \frac{1}{8}) = \frac{7}{24}$. Thus, bidder 2's total expected profit is $p\frac{7}{24} + (1-p)\frac{1}{6} = \frac{1}{6} + \frac{p}{8}$.

When F is uniform, with probability $1-p$ revenue equals $\max\{v_1, v_2\}/2$ as usual. With probability p, however, the revenue equals $v_1/2$, and therefore total expected revenue is

$$(1-p)E[\frac{\max\{v_1, v_2\}}{2}] + pE[\frac{v_1}{2}] = (1-p)\cdot\frac{1}{3} + p\frac{1}{4} = \frac{1}{3} - \frac{p}{12}.$$

Since for efficiency, the sum of all expected surpluses of the seller and both bidders should be $\frac{2}{3}$, the efficiency loss is $\frac{2}{3} - (\frac{1}{3} - \frac{p}{12}) - (\frac{1}{6} - \frac{p}{12}) - (\frac{1}{6} + \frac{p}{8}) = \frac{p}{6} - \frac{p}{8} = \frac{p}{24}$. We summarize the above in the following Corollary.

Appendix B. Outcomes in SPA

We derive bidder surplus, seller revenue and total efficiency for the three focal equilibria in SPA.

Appendix B.1. Outcomes in SP-Truthtelling

In the SP-Truthtelling equilibrium neither bids of bidder 1 nor bidder 2 are affected by the leak probability and therefore all ex-ante expected outcomes are as in the standard simultaneous case.

Appendix B.2. Outcomes in SP-Spiteful Bidding

For F uniform and spiteful bidding, we have $b_1(v_1) = \frac{v_1}{1+p}$. In the SP-Spiteful equilibrium, bidder 1's expected surplus is

$$p\int_0^1 \frac{v_1}{1+p}(v_1 - \frac{v_1}{1+p})dv_1 + (1-p)\int_0^1 \frac{v_1}{1+p}\left(v_1 - \frac{v_1}{2(1+p)}\right)dv_1 = \frac{1}{6(1+p)},$$

and bidder 2's expected surplus is

$$p\cdot\int_0^1 (1-\frac{v_1}{1+p})(1-\frac{v_1}{1+p})\frac{1}{2}dv_1 + (1-p)(1+p)\int_0^{\frac{1}{1+p}} (1-b_1)^2\frac{1}{2}db_1 = \frac{1+3p(1+p)}{6(1+p)^2}.$$

The Seller's revenue is

$$p\frac{1}{2(1+p)} + (1-p)\int_0^{v_1}\left[\frac{v_1}{1+p}\cdot\frac{v_1}{2(1+p)} + (1-\frac{v_1}{1+p})\frac{v_1}{1+p}\right]dv_1 = \frac{1+2p}{3(1+p)^2},$$

and thus, the efficiency loss is

$$\frac{p^2}{6(1+p)^2}.$$

Appendix B.3. Outcomes in SP-Cooperation

In the SP-Cooperation equilibrium, bidder 1's expected surplus is

$$p \cdot \int_0^{1-p} \frac{v_1}{1-p} \cdot v_1 dv_1 + p^2 \cdot \frac{2-p}{2}$$
$$+ (1-p)\left[p((1-\frac{p}{2})-\frac{1}{2}) + (1-p)\int_0^1 \int_0^{b_1} (b_1(1-p)-b_2)db_2 db_1\right]$$
$$= \frac{1+p+p^2}{6},$$

and bidder 2's expected surplus equals

$$p \cdot \int_0^{1-p} (1-\frac{v_1}{1-p})(1-\frac{v_1}{1-p})\frac{1}{2}dv_1 + (1-p)(1-p)\cdot\frac{1}{6} = \frac{1-p}{6}.$$

The expected revenue is

$$p \cdot \int_0^{1-p} (1-\frac{v_1}{1-p})\frac{v_1}{1-p}dv_1 + (1-p)(\frac{p}{2}+\frac{1-p}{3}) = \frac{1-p^2}{3}.$$

Appendix C. Translated Instructions

This is a translation of the German instructions and control questions for the first-price mechanism. Participants first received a set of general instructions titled "Instructions". This was followed by a set of computerized control questions on a total of four screens. Within each screen, participants had to answer all questions correctly in order to proceed. In case they made one or more mistakes, a pop-up window informed them about the number of mistakes and they had to go back and correct their answer(s). Once every participant had correctly answered all control questions, they received a new set of instructions describing the procedure in more detail ("Procedure"). Where the instructions or questions differed in the SPA, we indicate this by [`SPA`: different text]. *The correct answers for the control questions are indicated in squared brackets next to each question.*

Instructions

Welcome to this experiment on economic behavior. Your final payoff in Euro will depend on your decisions, those of other participants and random draws. Please read these instructions carefully, switch off your phone, and do not communicate with other participants. If you have a problem or question, please raise your hand and wait for a supervisor to help you.

In the experiment, monetary amounts are denominated in *ECU* (for *experimental currency unit*). The experiment consists of several rounds. Following the final round, we will randomly select **five** for payment. The sum of amounts you earned in those five rounds will then be added up, exchanged into Euro and paid to you in cash. The exchange will be made at the following rate: **1 ECU = €0.13**

For arriving in time, you receive €2.50.

In every round you will interact with another participant than in the previous round. This participant will be chosen at random. No other participant will learn anything about your identity from us. The instructions are identical for all participants.

General Procedure

In every round you and the other participant take part in an auction. Each one of you bids for a token. This token has a monetary value for each one of you. In the following, we call this amount "**value**". Your *value* and the *value* of the other participant are determined randomly at the beginning of every round. The value is a random amount between 20.00 and 120.00 (with two decimal points), where every possible realization is equally likely. The two values for you and the other participant are determined separately and independently of each other. It is therefore highly unlikely for the two to coincide. You will only be informed about your **own** value.

In every round both participants submit a **bid**. A **bid** can be any number between 0.00 and 140.00 (with two decimal points). The one with the **higher** bid wins the auction, earns his **value** and pays his bid [`SPA`: the bid of the other participant]. The participant with the lower bid earns nothing and pays nothing.

How to Bid

First, both **simultaneously** submit a **First Bid**. However, these **First Bids** are not always relevant. With a known probability (see below), **one** of the participants will learn the **First Bid** of the **other** participant and can submit a new bid. This new bid, which we will call **Second Bid**, can be any number between 0.00 and 149.00, irrespective of the First Bids. If someone was able to submit a new bid, then this **Second Bid** is his relevant bid. Otherwise, the First Bid is relevant. However, it never happens that both can submit a Second Bid.

With known probability p it is you who can observe the other participant's First Bid and submit a Second Bid. With probability q it is the other participant who can see your First Bid and submit a Second Bid. With residual probability $1 - p - q$ no one can submit a new bid and, thus, only the First Bids are relevant. In some rounds both $p = 0$ and $q = 0$, in others only $q = 0$ or $p = 0$ or probabilities are such that $p + q = 1$ and therefore $1 - p - q = 0$. You are informed about the probabilities p, q, and $1 - p - q$ at the beginning of every round.

Identical Bids

The participant with the higher relevant bid wins the auction. Should the two relevant bids be identical, then the winner is determined as follows: If only both First Bids are relevant, the winner is randomly determined (each one with equal probability). Otherwise, the participant whose Second Bid is relevant, wins the auction.

Outcome

- The participant with the smaller **relevant** bid earns 0 ECU.
- The participant with the larger **relevant** bid earns his **value** minus his **relevant bid** [`SPA`: the **relevant bid of the other participant**].

The chart on the next page illustrates the general procedure.

Losses

Please note that you will make a loss if you win the auction and your relevant bid [`SPA`: the relevant bid of the other participant] exceeds your **value**. In case you make losses, we subtract them from your fixed payments (€2.50 show-up fee and €2.50 for answering the control questionnaire). If these amounts do not suffice, you will have to work off the remainder.

Control Questions

Please answer a set of control questions on your computer screens. For answering these questions you receive an additional €2.50.

Control Questions

Screen Q1

Please indicate for each of the following statements whether it is "correct" or "false":

a) There are always two participants bidding for a token. [c]

b) The value of this token for a participant, is a random value between 20.00 and 120.00 ECU. [c]

c) Your value and that of the other participant will always be identical. [f]

d) Your value is the same in every round. [f]

e) You will be informed about the value of the other participant. [f]

Screen Q2

Please indicate for each of the following statements whether it is correct or false:

a) Both participants are informed about probabilities p, q, and 1-p-q. [c]

b) Each participant only knows the probability that he himself can submit a second bid. [f]

c) If both bids are identical, no one wins the auction. [f]

d) In case the second bid is selected to be relevant, and the second bid equals the first bid of the other participant, then the one whose second bid is relevant wins the auction. [c]

e) You receive the sum of outcomes of all rounds. [f]

f) Only five rounds are being paid. [c]

Screen Q3

Suppose your value is 20, and the value of the other participant is 120. Your relevant bid is 77 and that of the other participant is 66.

a) Who wins the auction?

   - I win [c]
   - The other one wins [f]

b) How much do you earn? [`FPA`: -57; SPA: -46]

c) How much does the other participant earn? [0]

Screen Q4

Suppose, your value is 20, and the value of the other participant is 120. Your relevant bid is 55 and that of the other is 88.

a) Who wins the auction?

   - I win [f]
   - The other one wins [c]

b) How much do you earn? [0]

c) How much does the other participant earn? [`FPA`: 32; `SPA`: 65]

Procedure

The procedure in the experiment will slightly differ from what we explained above. As described, first both participants submit a First bid. Then a random draw decides with known probabilities p, q, and $1-p-q$ whether and, if so, who can submit a Second Bid.

However, you will only be informed about the outcome of this random draw at the end of the round. Instead, irrespective of this outcome, we will inform you about the others first bid and ask you how you would behave, should you be able to submit a Second Bid. Of course, this Second Bid is only relevant if the random draw actually determined that you can submit a second bid. More specifically,

1. You are informed about your own value.
2. You are informed about probabilities $1-p-q$, p, and q.
3. Both participants simultaneously determine their First Bid.
4. The Computer randomly determines according to these probabilities whether someone and, if so, who can submit a Second Bid. **You will not be informed about the result of this random draw before the end of the round.**

5. If the probability that you can submit a Second Bid is positive,
   - you are informed about the First Bid of the other participant
   - and can submit a Second Bid.
6. The round ends and you are informed about:
   - The outcome of the random draw, i.e., which bids are relevant,
   - who has won the auction, and
   - your outcome in ECU.

Do you have any questions? Please do not hesitate to ask one of the experimenters.

Appendix D. Screenshots

The following Figures are screenshots from the decision screens of a role B participant in treatment *two-asym*, i.e. of the participant with a 75% chance of being the second mover.

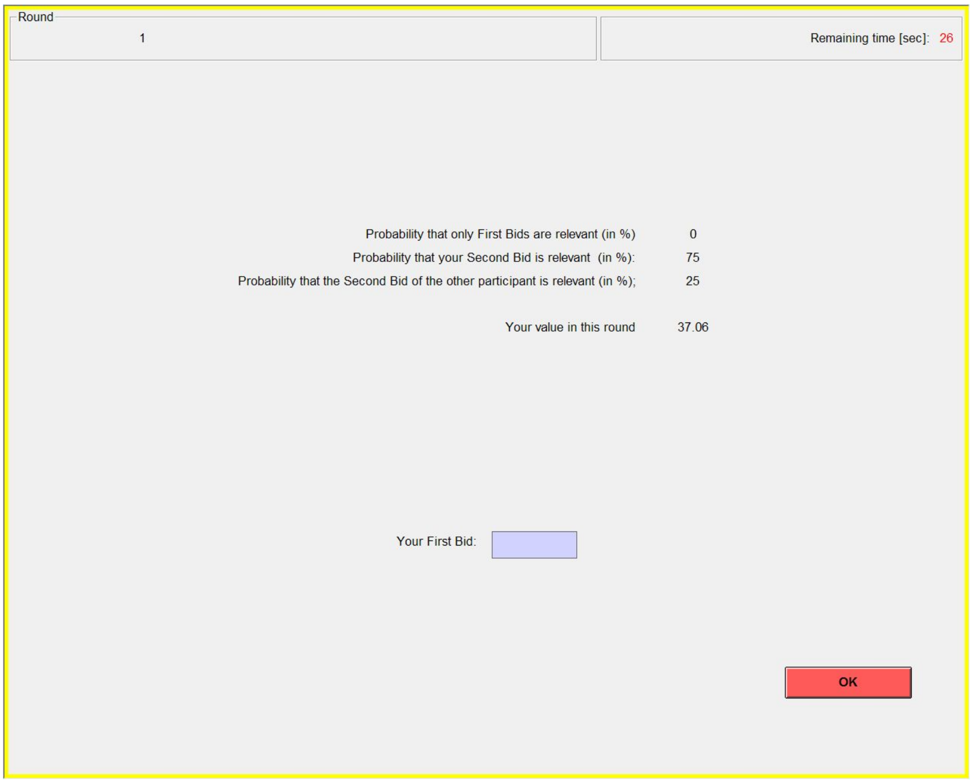

Figure D.7: Screenshot First Bid in two-asym

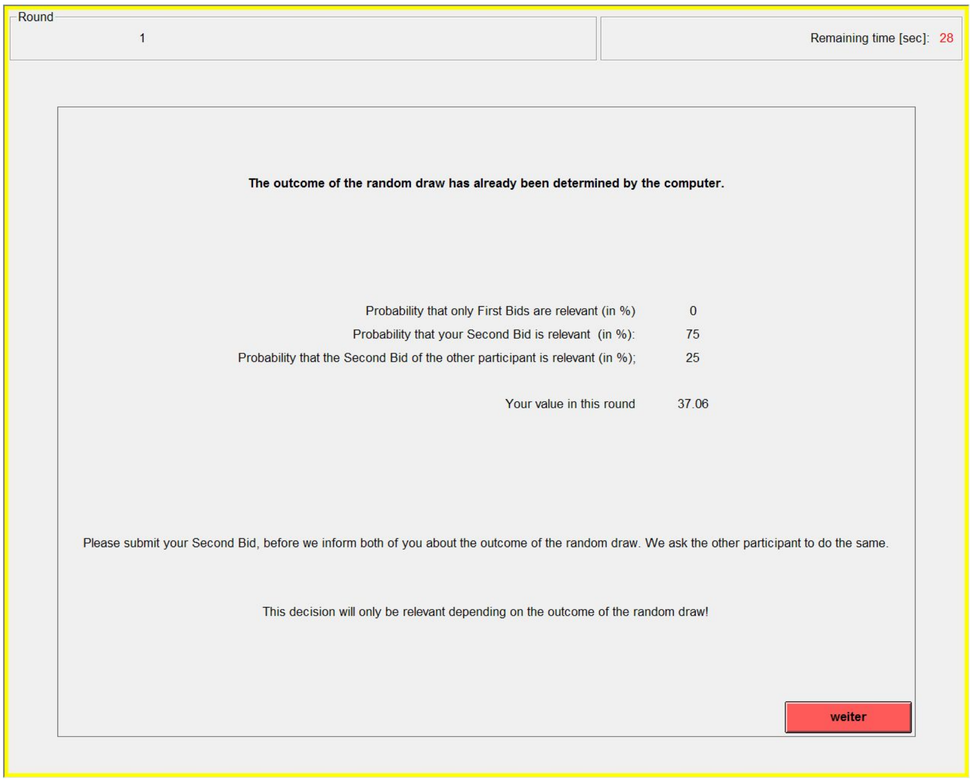

Figure D.8: Screenshot information Second Bid in two-asym

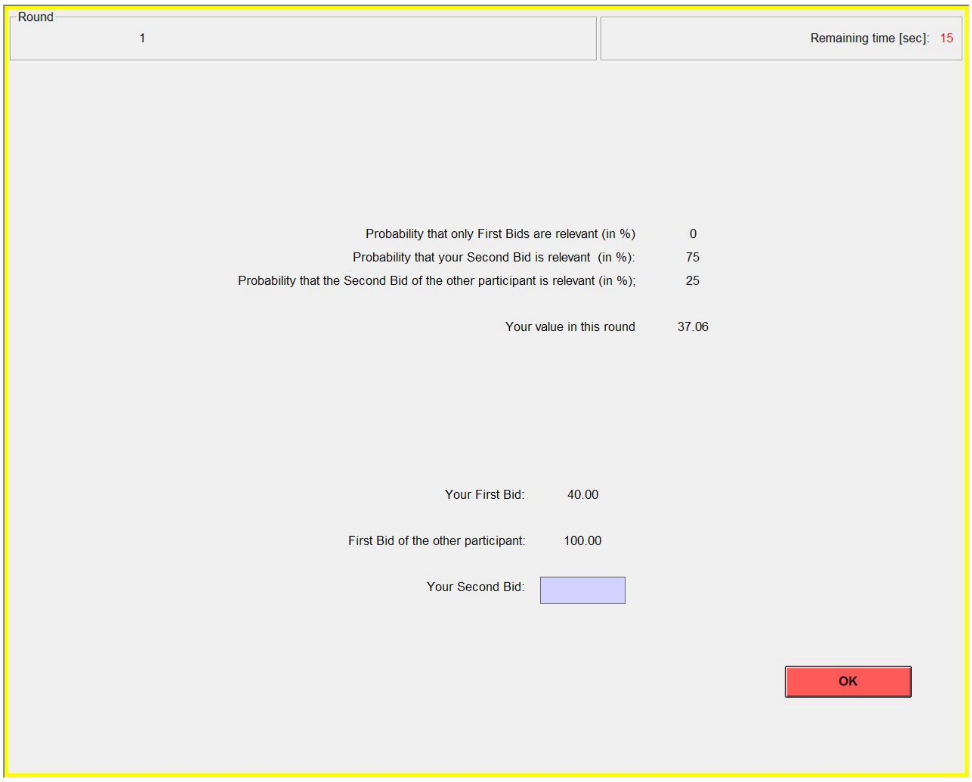

Figure D.9: Screenshot Second Bid in two-asym