Spite vs. Risk: Explaining overbidding*

A theoretical and experimental investigation

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We use an experiment to compare a theory of risk-aversion and a theory of spite as an explanation for overbidding in auctions. As a workhorse we use the second-price all-pay and the first-price winner-pay auction. Both risk and spite are used to rationalize deviations from risk-neutral equilibrium bids.

We exploit that equilibrium predictions in the second-price all-pay auctions for spite are different than those for risk-aversion.

We find that spite is a more convincing explanation for bidding behavior for the second-price all-pay auction. Not only can spite rationalize observed bids, also our measure for spite is consistent with observed bids.

Keywords: Auction, Overbidding, Spite, Risk, Experiment
JEL: C91; C72; D44; D91

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1. Introduction

In this paper we compare spite and risk as possible motives for deviations from risk neutral Bayesian Nash equilibria (RNBNE) in auctions. We use the second-price all-pay auction and the first-price winner-pay auction as two devices to compare the effect of risk aversion and spite on bids. With the help of a lab experiment we find that spite explains bidding behavior in the second-price all-pay auction better than risk. We also find that risk seems to be the better predictor in the first-price winner-pay auction. This paper makes three contributions:

Theoretical To the best of our knowledge we are the first to extend the theoretical model of spiteful behavior and risk averse behavior to second-price all-pay auctions.

Experimental To the best of our knowledge we are the first to relate observed bidding behavior to measured spite.

Main We compare two alternative explanations for overbidding – risk versus spite – and show that in some auctions – the second-price all-pay auction – spite can be explain behavior better than risk aversion.

Auctions are a relevant part of everyday life. Auctions are commonly used as selling mechanisms for example in online auctions (like ebay), government auctions (like spectrum auctions) and at charity events (like silent auctions). Moreover, (all-pay) auctions are a good model of non-market interaction. For example, fights between animals (Riley, 1980; Smith, 1974)[1], competition between firms (Fudenberg and Tirole, 1986; Ghemawat and Nalebuff, 1985; Oprea et al., 2013), the voluntary provision of public goods (Bilodeau et al., 2004), legal expenditures in litigation environments (Baye et al., 2005), the settlement of strikes, fiscal and political stabilization, the timing of exploratory oil drilling, and many more (see Hörisch and Kirchkamp, 2010, p. 1) are applications of (all-pay-)auctions. Thus, having a detailed understanding of behavior in auction settings is crucial for economists.

Risk neutral Bayesian Nash equilibria (RNBNE) can be used to derive bechnmark predictions for these auction formats. However, observational and laboratory evidence suggests for many auction formats that bidders do not always follow the RNBNE. Bids tend to be higher than the RNBNE in all-pay auctions,[2] in rent-seeking contests,[3] and in winner-pay auctions.[4] Several authors propose explanations why bids might deviate from RNBNE.[5] Explanations, like risk aversion, joy of winning, anticipated regret etc., work for some, but not for all auction formats.[6] Among these explanations, risk aversion is perhaps the most common explanation. A more recent explanation, however, is the spite motive.

[1] Smith (1974) uses a war-of-attrition game with common valuations to model fights between animals.

[2] See Noussair and Silver (2006); Ernst and Thöni (2013); Goeree et al. (2002); Chen et al. (2015); Lugovskyy et al. (2010).

[3] Potters et al. (1998).

[4] Morgan et al. (2003); Andreoni et al. (2007); Barut et al. (2002).

[5] Filiz-Ozbay and Ozbay (2007, 2010); Cooper and Fang (2008); Andreoni et al. (2007); Cox et al. (1985, 1988); Fibich et al. (2006); Kagel and Levin (1993); Kirchkamp and Reiss (2008); Engelbrecht-Wiggans and Katok (2009); Kirchkamp et al. (2008); Armantier and Treich (2009).

[6] Kagel and Levin (1993); Kirchkamp et al. (2008); Engelbrecht-Wiggans and Katok (2009); Andreoni et al. (2007); Katuscak et al. (2013).

In this paper we suggest that, at least in some situations, spite might organise our data better than risk aversion. We present equilibrium analyses and empirical evidence from a conducted experiment.

As a workhorse we use two auction formats: the second-price all-pay auction and first-price winner-pay auction. We have chosen these two formats since they react differently to risk and spite. For both auction formats spite leads to an increase in equilibrium bids as long as valuations are not too high. Risk aversion, however, leads to a decrease in bids in the second-price all-pay auction and to an increase in bids in the first-price winner-pay auction.

In our experiment, we measure spitefulness, preferences for risk, and bids. We find that spite explains bidding behavior better than risk in the second-price all-pay auction. Risk seems to be the better predictor in the first-price winner-pay auction.

The remainder of the paper is structured as follows: We briefly summarize the relevant literature in Section 2. In Section 3 we present the model and the theoretical predictions. Section 4 will explain the design of the experiment. In Section 5 we show the results of the experiment. Section 6 concludes.

2. Literature

In this paper we study second-price all-pay auctions and first-price winner-pay auctions with sealed-bids and private information.[7] We restrict our attention to auctions where the highest bidder wins.[8] We also assume that the number of bidders is known.[9]

2.1. Literature on overbidding

In many experiments, overbidding (relative to RNBNE) has been observed and explained with the help of a number of motives, ranging from risk aversion, over anticipated regret, to spite. Obviously, we cannot do right by the vast literature on overbidding. Nevertheless, we will present a few selected findings from this literature. Three particularly important motives to explain overbidding are: risk aversion, anticipated regret and joy of winning.

Already in the 80s risk aversion has been suggested by Cox et al. (1985, 1988) as an explanation of overbidding. In the contex of all-pay auctions Fibich et al. (2006) study risk averse players to explain overbidding. However, Kagel and Levin (1993), Kirchkamp et al. (2008),

[7]Equilibria for all-pay auctions with common values are provided by Hendricks et al. (1988) and Kovenock et al. (1996). Sacco and Schmutzler (2008) provide mixed strategy equilibria for common value auctions where the prize is influenced by the own behavior. Feess et al. (2008) show a pure equilibrium strategy in case of handicapped players. Klose and Kovenock (2015) show equilibria for the case of externalities which depend on the bidders' identities. Bertoletti (2016) show equilibria for common value all-pay auctions with reserve price. Dechenaux and Mancini (2008) and Baye et al. (2005) model ligation systems with all-pay auctions. The case of affiliated valuations is studied by Krishna and Morgan (1997).

Intermediate situations between the first-price and second-price all-pay auction are studied by Albano (2001).

[8]The survey by Dechenaux et al. (2015) includes rent-seeking games where the ex-post allocation is stochastic and where also bidders who did not submit the highest bid have a chance to win the auction.

[9]Bos (2012) considers the situation where the number of bidders is unknown.

and Engelbrecht-Wiggans and Katok (2009) argue that risk aversion might be by itself not enough to explain overbidding. Kagel and Levin (1993) point out that risk aversion does not explain bidding behavior in third-price auctions very well. In equilibrium risk averse bidders should bid less than the RNBNE. Bidders in their experiment, however, bid more.

Anticipated regret is another motive to explain overbidding in winner-pay auctions. Filiz-Ozbay and Ozbay (2007, 2010) propose that players anticipate their regret after a wrong choice. Using laboratory experiments Filiz-Ozbay and Ozbay (2007, 2010) provide empirical evidence for their supposition. However, Katuscak et al. (2013) do not replicate this finding with a large sample and thus argue against anticipated regret.

An additional explanation for overbidding suggested by Cooper and Fang (2008) is joy of winning. In turn, Andreoni et al. (2007) provide evidence against joy of winning.[10]

Even though overbidding is very common in many auctions types, it is worth noting that some auctions don't seem to be affected by overbidding. For example, in the English auction with affiliated private information – which is rather different from our setting – bids in experiments converge quickly to the RNBNE (Kagel et al., 1987). In this paper we do not and cannot speak to all auctions formats. The main goal of this paper is to show that *in some auctions*, in our case specifically the second-price all-pay auction, spite is a better predictor for behavior than risk aversion.

We pick risk aversion as the main comparison to spite. The rationale behind our choice is that risk aversion seems to be the strongest competitor in explaining deviations from the equilibrium. We pick the second-price all-pay auction since theoretical predictions for risk aversion and spite are nicely disentangled in this auction and since this auction is often used as a model of very competitive situations.[11]

2.2. Literature on spite

In addition to the above-discussed explanations, spite has been suggested as another motive for overbidding. For example, Andreoni et al. (2007) suggest that spite may cause overbidding. Bartling and Netzer (2016, p.23) propose that "spiteful preferences are an important determinant of overbidding in the second-price auction". Several recent papers study the impact of spite on equilibrium bids. Morgan et al. (2003) may have been the first to consider spite in the equilibrium for winner-pay auctions. Similarly, Brandt et al. (2007); Sandholm and Tang (2012); Sandholm and Sharma (2010) and Mill (2017) study equilibrium bids with

[10] A large number of other factors, internal and external to the bidders, have been studied. Among the external factors, it has been shown that the speed of the auction (Katok and Kwasnica, 2008), the structure of the presented games (Cox and James, 2012) and outside options (Kirchkamp et al., 2009) influence bids. Among the factors internal to bidders learning (Güth et al., 2003; Dittrich et al., 2012; Ockenfels and Selten, 2005), information provision (Kagel et al., 1987; Hyndman et al., 2012), bidding heuristics (Kirchkamp and Reiss, 2008), bounded rationality (Anderson et al., 1998), inability to assess winning probabilities (Armantier and Treich, 2009), the Allais paradox (Nakajima, 2011), and even the menstrual cycle (Chen et al., 2013) have been shown to relate to bidding behavior.

[11] For example the war-of-attrition (Riley, 1980; Smith, 1974), competition between firms (Fudenberg and Tirole, 1986; Ghemawat and Nalebuff, 1985; Oprea et al., 2013), legal expenditures in litigation environments (Baye et al., 2005). More examples and applications of the second-price all-pay auction can be found in Hörisch and Kirchkamp (2010).

spiteful preferences for winner-pay auctions. Further,Nishimura et al. (2011) study spite in common-valuations-auctions and, most recently, Bartling et al. (2017) consider equilibria where bidders could have spiteful preferences towards the auctioneer. However, all these investigations have primarily been of theoretical nature.

While the above studies suggest spite as a theoretically convenient explanation of overbidding in auctions, spite also seems to be empirically a common motive in several contexts. For example, Saijo and Nakamura (1995) find spiteful behavior in Voluntary Contribution Mechanisms.[12] Further, Fehr et al. (2008) use experiments to show that spiteful behavior is rather wide spread in the least developed parts of India. To the best of our knowledge, the two only papers studying spite empirically in auctions are Kimbrough and Reiss (2012) and Bartling et al. (2017). Kimbrough and Reiss investigate behavior in a modified second-price winner-pay auction. In their experiment losers of an auction can (and frequently do) increase their own bid to reduce the winner's payoff. Such an increase in bids is consistent with spiteful behavior. Bartling et al. (2017) study whether spiteful preferences towards a seller affects bids. Bartling et al. exogenously vary the presence of human subjects in the roles of the seller to answer whether spite towards the seller might be at play. They do not find any systematic evidence of spiteful preferences.

To the best of our knowledge, no paper studies spite in all-pay auctions. More importantly, no paper has measured spite and combined a theory of spiteful bidding with actually spiteful behavior in an auction-setting.

In the next section, we will determine equilibrium bids for risk-averse and for spiteful bidders[13] in the context of the second-price all-pay auction and the first-price winner-pay auction.

3. Model

In the following, we will derive the Bayesian Nash equilibrium for spiteful bidders and for risk averse bidders in the second-price all-pay auction and the first-price winner-pay auction.[14]

3.1. Second-price all-pay auction

3.1.1. Spite in the second-price all-pay auction

Consider a situation with one prize and two risk neutral bidders, $k \in \{i, j\}$. Bidders have a utility function $u(x)$ and private valuations v_k. Valuations follow a distribution function F with density function f, i.e. $v \sim F(0, \overline{v})$, and $f(x) = dF(x)/dx$. Each bidder k submits a bid b_k following a monotonic bidding function $b_k = \beta_k(v_k)$. Consider the case $b_j \geq b_i$. In

[12] Cason et al. (2002) show that this pattern did not prevail in the U.S.

[13] We realise that bids in a laboratory experiment are seldom equilibrium bids. However, we think it is useful to use the Bayesian Nash equilibrium as a benchmark. It would be possible to allow for different types of equilibria or to allow for out-of-equilibrium behavior. This, however, would go beyond the scope and the page limit of this paper.

[14] The risk neutral Bayesian Nash equilibrium for spiteful bidders in the first-price all-pay auction is shown in Appendix A.

the second-price all-pay auction both players pay the second highest bid (b_i). The prize is allocated to the bidder with the highest bid. If $b_i = b_j$, the prize is distributed randomly.

For the candidate equilibrium we assume $\beta_k(0) = 0$.[15] Furthermore, we assume that the first derivative $\beta_k'(x) = d\beta_k(x)/dx$ and the inverse $\beta_k^{-1}(b_k) = v_k$ exist. The payoff of the winning bidder j is $(v_j - b_i)$. The payoff of the losing bidder i is $-b_i$.

In line with the literature on spite in auctions[16] we assume that a spiteful loser i experiences a disutility $\alpha \cdot (v_j - b_i)$ where α describes the amount of spite. A non-spiteful bidder is characterized by $\alpha = 0$. Here we assume that $\alpha \in [0, 1)$. We do not consider $\alpha < 0$ which could represent sympathy or profit sharing. We also rule out $\alpha > 1$, i.e. that an other bidder's gain is more important than the own loss. This (standard) model of spite implies a number of simplifications: Spite only affects the loser of the auction. Spite is linear and independent of the valuation.[17] Spite is symmetric, i.e. all bidders have the same α.[18]

We call $\Phi^{\text{II-AP}}_{\text{Spite}}(b_i, v_i)$ the payoff of player i:

$$\Phi^{\text{II-AP}}_{\text{Spite}}(b_i, v_i) = \begin{cases} u\left(v_i - b_j\right) & \text{if } b_i > b_j \text{ (} i \text{ wins)} \\ \frac{1}{2}u\left(v_i - b_i\right) + \frac{1}{2}u\left(-b_i - \alpha(v_j - b_i)\right) & \text{if } b_i = b_j \text{ (a tie)} \\ u\left(-b_i - \alpha(v_j - b_i)\right) & \text{if } b_i < b_j \text{ (} j \text{ wins)} \end{cases} \tag{1}$$

We assume that bidder i with valuation v makes a bid b. The opponent, bidder j with valuation v_j, makes a bid $b_j = \beta_j(v_j)$. The expected utility of a spiteful bidder i is given as follows:

$$\mathbb{E}(b, v) = \underbrace{\int_0^{\beta_j^{-1}(b)} u(v - \beta_j(v_j))\, f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ wins and obtains the prize} \\ \text{and pays the loser's bid}}} + \underbrace{\int_{\beta_j^{-1}(b)}^{\bar{v}} u(-b - \alpha(v_j - b))\, f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ loses and pays the own bid} \\ \text{and additionally experiences spite}}} \tag{2}$$

Rearranging the FOC yields:

$$\beta_j'(\beta_j^{-1}(b)) = \frac{(u(v - b) - u(-b - \alpha(\beta_j^{-1}(b) - b))\, f(\beta_j^{-1}(b))}{(1 - \alpha) \int_{\beta_j^{-1}(b)}^{\bar{v}} u(-b - \alpha(v_j - b))'\, f(v_j)\, dv_j}$$

[15]We assume a monotonic and symmetric bidding function. A selfish bidder with a valuation of zero could only win if the opponent has a valuation of zero, too. Hence, there is no benefit of bidding anything above 0. For a spiteful bidder it might make sense to bid above zero if the bid would be costless (standard second-price winner-pay auction) as this spiteful bidder could reduce the payoff of the opponent by this increased bid. However, in the all-pay case, one could never offset the downside of paying for the own bid by making the opponent bid more as long as $\alpha \leq 1$. Hence, zero is the best choice.

[16]See Bartling et al. (2017); Morgan et al. (2003); Brandt et al. (2007); Sandholm and Tang (2012); Sandholm and Sharma (2010); Mill (2017).

[17]Again, this is standard. It does not seem that our theoretical results hinge on the linearity assumption.

[18]Again, this is a standard assumption. Modeling spite as a random variable would make the theoretical derivation intractable. Further, in a situation where bidders have no information about their opponents, bidders might follow the social-projection-bias (Krueger, 2007) and, hence, assume that their opponents are as spiteful as the bidders themselves.

For the symmetric equilibrium and risk neutrality we obtain[19]

$$\beta_j'(\nu) = \frac{\nu + \alpha(\nu - b)\, f(\nu)}{(1-\alpha)(1-F(\nu))} = \frac{\nu(1+\alpha)\, f(\nu)}{(1-\alpha)(1-F(\nu))} - \frac{\alpha(b)\, f(\nu)}{(1-\alpha)(1-F(\nu))}. \tag{3}$$

Solving the differential Equation (3) with initial value $b(0) = 0$ gives us the symmetric equilibrium bidding function $b^{\text{II-AP}}_{\text{Spite}}$:

$$b^{\text{II-AP}}_{\text{Spite}}(\nu) = \frac{\alpha+1}{1-\alpha}(1-F(\nu))^{\frac{\alpha}{1-\alpha}} \int_0^{\nu} s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}\, ds = \frac{\alpha+1}{\alpha}\left(\nu - \frac{\int_0^{\nu}(1-F(s))^{\frac{\alpha}{\alpha-1}}\, ds}{(1-F(\nu))^{\frac{\alpha}{\alpha-1}}}\right) \tag{4}$$

For $\alpha = 0$, Equation (4) becomes the familiar equilibrium bidding function for second-price all-pay auctions without spite:

$$b^{\text{II-AP}} := b^{\text{II-AP}}_{\alpha=0} = \int_0^{\nu} s\, f(s)(1-F(s))^{-1}\, ds$$

For uniformly distributed valuations, $F(x) = x$, we have the following equilibrium bid:

$$b^{\text{II-AP}}_{\text{Spite}}(\nu) = \frac{(\alpha+1)}{\alpha(2\alpha-1)}\left((1-\alpha)\left((1-\nu)^{\frac{\alpha}{1-\alpha}} - 1\right) + \nu\alpha\right) \tag{5}$$

From Equation (5) we have $\lim_{\alpha\to 0} b^{\text{II-AP}}_{\text{Spite}}(\nu) = -\log(1-\nu) - \nu$ and $\lim_{\alpha\to 1} b^{\text{II-AP}}_{\text{Spite}}(\nu) = 2\nu$. Figure 1 illustrates the case of uniform valuations. The left graph in the Figure shows that bids are monotonically increasing in valuations. To simplify the notation we assume in the following that valuations $\nu \in [0, 1]$. It is easy to see the following:

Proposition 1. *The bidding function in the second-price all-pay auction is increasing in bidder's valuation:*

$$\frac{db^{\text{II-AP}}_{\text{Spite}}}{d\nu} \geq 0$$

The proof is shown in Appendix B. The right part of Figure 1 shows that bids are increasing in spite if valuations are sufficiently small. For large valuations, equilibrium bids decrease when spite increases. Looking again at Equation (5) we find the following:

Observation 1. *For the case of uniformly distributed valuations in the second-price all-pay auction bids increase in spite for low valuations and they decrease in spite for high valuations.*

Things are different in the first-price all-pay auction. In Proposition 8 in Appendix A we show that in first-price all-pay auctions bids are always increasing in spite.

[19] Of course, the payoff given by Equation 1 is not the only possibility to motivate Equation 3. For example, we could in the case $b_i < b_j$ (j wins), replace the payoff $u(-b_i - \alpha(\nu_j - b_i))$ by $u(-b_i - \alpha(\nu_i - b_i))$. This new model would have a different interpretation than spite. Here we only show that spite is one (out of perhaps several) theoretical possibilities to explain this shape of a bidding function. However, in Section 5.4.2 we show that an empirical measure of spite is in line with this shape of the bidding function.

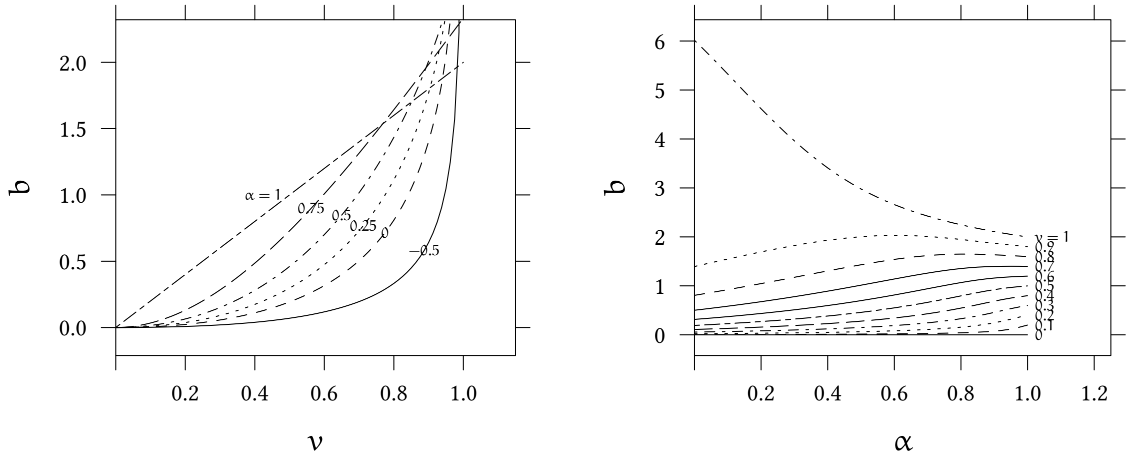


Figure 1: Equilibrium bids in second-price all-pay auctions for spiteful bidders.
Equilibrium bids in second-price all-pay auctions for different valuations v (left panel) and for different levels of spite α (right panel) for uniformly distributed valuations (see Equation (5)).

3.1.2. Risk aversion in the second-price all-pay auction

To compare spite with risk aversion we will derive the equilibrium bidding function for risk averse bidders. We assume that the risk preferences can be described as constant absolute risk aversion (CARA).[20] Again we assume two players $k \in \{i, j\}$ who are competing for an object which each player values with $v_k \in [0, 1]$. Valuation are drawn from a distribution with density function $F(v)$ and distribution function $f(v)$. Both bidders use a bidding function $\beta_k(v_k)$. Both players have the same utility function $u(x) = -r\, e^{(-x/r)}$. Here we rule out spite, i.e. $\alpha = 0$. As above we assume that bidder i with valuation v makes a bid b. The opponent, bidder j with valuation v_j, makes a bid $b_j = \beta_j(v_j)$. The expected utility of a risk averse bidder i in the second-price all-pay auction is given by the following equation:

$$\mathbb{E}(b, v) = \underbrace{\int_0^{\beta_j^{-1}(b)} u(v - \beta_j(v_j))\, f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ wins and obtains the prize} \\ \text{and pays the loser's bid}}} + \underbrace{\int_{\beta_j^{-1}(b)}^{\overline{v}} u(-b)\, f(v_j)\, dv_j}_{\text{bidder } i \text{ loses and pays the own bid}} \tag{6}$$

Rearranging the FOC yields:

$$\beta_j'(\beta_j^{-1}(b)) = \frac{(u(v - b) - u(-b)\, f(\beta_j^{-1}(b))}{\int_{\beta_j^{-1}(b)}^{\overline{v}} u(-b)'\, f(v_j)\, dv_j} = \frac{\left(-e^{\frac{b-v}{r}} + e^{\frac{b}{r}}\right) r\, f(\beta_j^{-1}(b))}{\int_{\beta_j^{-1}(b)}^{\overline{v}} e^{\frac{b}{r}}\, f(v_j)\, dv_j}$$

[20] We use CARA and not CRRA since in all-pay auctions bidders may experience negative payoffs. Hence, CRRA would imply complex utilities, which is difficult to interpret.

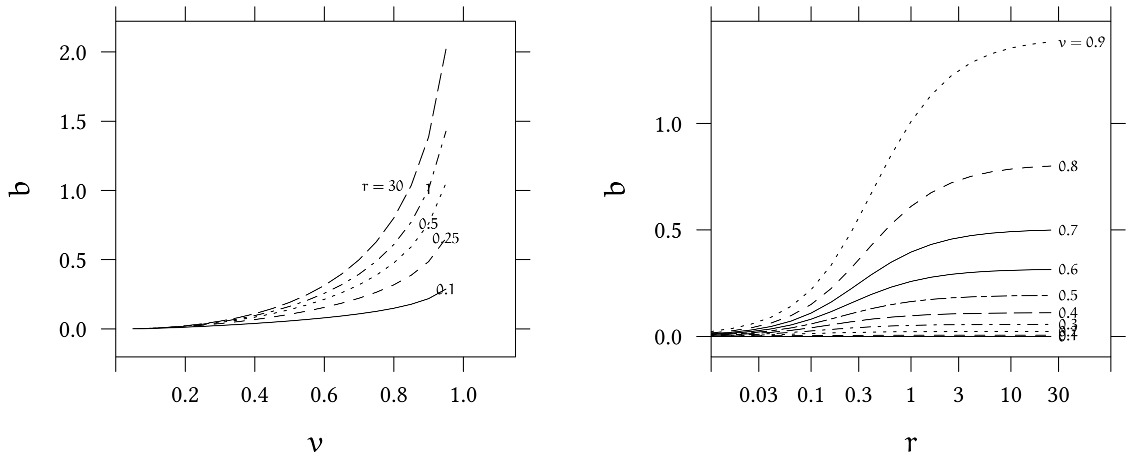


Figure 2: Equilibrium bids in second-price all-pay auctions for risk averse bidders.
Equilibrium bids in second-price all-pay auctions for different valuations v (left panel) and different levels of risk r (right panel) with uniform distributions of valuations (see Equation (7)). Increasing r indicates decreasing risk aversion (for $r = \infty$ we would have risk neutrality).

Assuming symmetry, i.e. $\beta_j^{-1}(b) = v$, we get:

$$\beta_j'(v) = \frac{r \cdot e^{\frac{b}{r}}(1 - e^{\frac{-v}{r}})\, f(v)}{e^{\frac{b}{r}}(1 - F(v))}$$

Hence the equilibrium bid is as follows:

$$\beta_{\text{Risk}}^{\text{II-AP}}(v) = \int_0^v \frac{r(1 - e^{\frac{-s}{r}})\, f(s)}{(1 - F(s))} ds \tag{7}$$

Figure 2 illustrates the case of uniformly distributed valuations. From Equation (7) we can conclude the following:

Proposition 2. *The equilibrium bid of a risk averse bidder is smaller than the bid of a risk neutral bidder:*

$$\beta_{\text{Risk}}^{\text{II-AP}}(v) \leq \beta_{\text{RNBNE}}^{\text{II-AP}}(v)$$

The proof of Proposition 2 is shown in Appendix B.

3.2. First-price winner-pay auction

3.2.1. Spite in the first-price winner-pay auction

Morgan et al. (2003) introduced spite to the first-price and second-price winner-pay auction. The equilibrium bid in the first-price winner-pay auction for the two-player case is given by:

$$b_{\text{Spite}}^{\text{I}}(v) = v - \int_0^v \frac{F(t)^{1+\alpha} dt}{F(v)^{1+\alpha}} \tag{8}$$

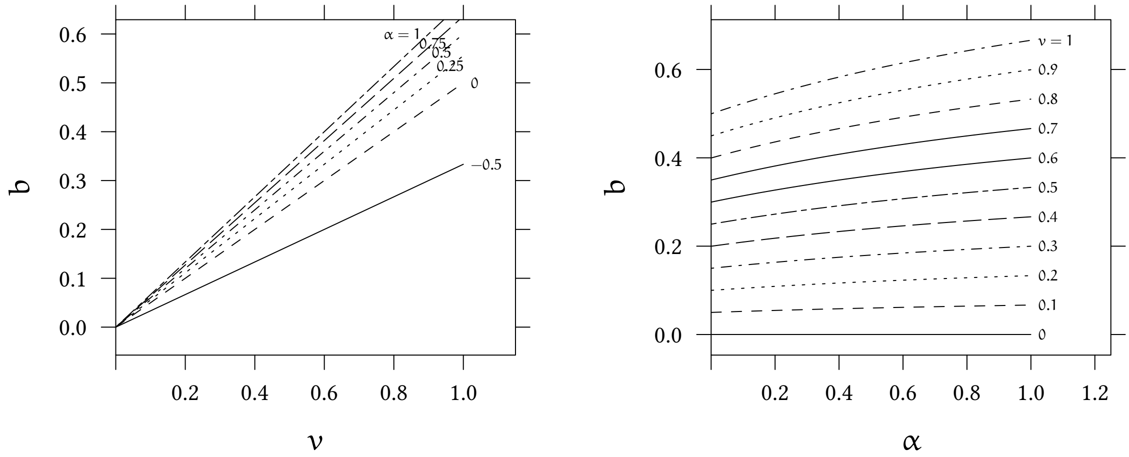


Figure 3: Equilibrium bids in first-price winner-pay auctions for spiteful bidders.
Equilibrium bids in first-price winner-pay auctions for different valuations v and different levels of spite α with uniform distributions of valuations (see Equation (8)).

Morgan et al. (2003) point out that more spiteful bidders have a steeper equilibrium bidding function in valuations. This can easily be seen for uniformly distributed valuations. In this case (8) implies that $b^{I}_{\text{Spite}}(v) = (1+\alpha)/(2+\alpha)\,v$. Figure 3 shows equilibrium bids in first-price winner-pay auctions for different valuations v and different levels of spite α.

Morgan et al. (2003) show that spiteful bidders overbid in equilibrium in the first-price winner-pay auction.

Proposition 3 (Morgan et al., 2003)**.** *A spiteful bidder bids more than a risk neutral selfish bidder in the first-price winner-pay auction:*

$$\beta^{I}_{S}(v) \geq \beta^{I}_{\text{RNBNE}}(v)$$

3.2.2. Risk in the first-price winner-pay auction

Riley and Samuelson (1981) and Maskin and Riley (1984) show that in first-price winner-pay auctions risk averse bidders bid more than risk neutral bidders (see Riley and Samuelson, 1981, Proposition 4).

Proposition 4 (Riley and Samuelson, 1981)**.** *In the first-price winner-pay auction a risk averse bidder bids more than a risk neutral bidder:*

$$\beta^{I}_{\text{RNBNE}}(v) \leq \beta^{I}_{\text{Risk}}(v)$$

It has been argued that spite and risk might result in identical equilibrium predictions. Specifically, Morgan et al. (2003, Proposition 4) point out that in the first-price winner-pay auction risk averse bidders with CRRA utility $u(v) = v^{\rho}$ who are not spiteful use the same bidding function as a spiteful, but risk neutral bidder with spite parameter $\alpha = 1/\rho - 1$. Figure 1 shows equilibrium bids of spiteful bidders for different valuations v and different levels of spite α. The figure looks looks the same for risk averse bidders with relative risk aversion $\rho = 1/(1+\alpha)$.

3.3. Revenue in the second-price all-pay auction and the first-price winner-pay auction

For spiteful bidders, we can derive the following proposition.[21]

Proposition 5. *For spiteful bidders revenues can be ranked as follows:*

$$\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}(v)) \geq \mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}(v)) \geq \mathbb{E}(m^{\text{I}}_{\text{Spite}}(v)) \geq \mathbb{E}(m^{\text{I}}_{\text{selfish}}(v)) \tag{9}$$

The proof of Proposition 5 can be found in Appendix C.3. Proposition 5 states, in particular, that for spiteful bidders revenue is larger in the second-price all-pay auction than in the first-price winner-pay auction. For risk averse bidders we obtain the opposite result:

Proposition 6. *For risk averse bidders revenues can be ranked as follows:*

$$\mathbb{E}(m^{\text{II-AP}}_{\text{Risk}}(v)) \leq \mathbb{E}(m^{\text{I}}_{\text{Risk}}(v))$$

The proof is show in Appendix C.4.

4. Design of the experiment and Hypotheses

To investigate the model presented above, we use a laboratory experiment. In the experiment, we first measure preferences for spitefulness and for risk. We will discuss the different measures of these preferences in Section 4.1. In the next step of the experiment participants bid either in a second-price all-pay auction or in a first-price winner-pay auction. We will discuss bidding behavior in Section 4.2. In Section 4.3 we will discuss the payment of subjects. Section 4.4 depicts the hypotheses for the experiment.

4.1. Preferences for Spitefulness and Risk

To measure preferences for risk we use a Holt and Laury (2002) task. We will discuss this measure in Section 4.1.1. We are not aware of a standard task to measure spiteful preferences. We use, hence, three different measures. One of the measures we use has been proposed by Marcus et al. (2014). We will discuss this measure in Section 4.1.2. Another measure has been proposed by Kimbrough and Reiss (2012). We will discuss their measure in Section 4.1.3. We propose our own measure in Section 4.1.4. Each measure was explained to participants in great detail using video-instructions.[22]

[21] In Appendix C we derive the revenue ranking for the first-price all-pay auction and the second-price winner-pay auction.

[22] Appendix G.2 provides the text of the videos. The videos can be found at https://www.kirchkamp.de/research/SpiteVsRisk.html.

4.1.1. Risk according to Holt and Laury (2002)

We measure preferences for risk with the help of a Holt and Laury (2002) task. This measure uses ten paired lottery choices.[23] Each choice compares a risky lottery and a less risky lottery. The ten choices differ in the probabilities of the good outcomes of the lotteries. As Holt and Laury (2002, p.1648) we use the total number of safe choices as a measure of risk aversion. Participants who choose a large number of the risky options are considered more risk loving. Participants who choose more of the safer options are considered more risk averse.

There are several alternative tasks to measure risk attitudes (see, for example, Crosetto and Filippin, 2013). The main reasons for using the task developed by Holt and Laury (2002) is its extensive use in experimental economics. Further, a very recent meta-analysis of behavioral risk measures and risk responses in different contexts shows that the Holt and Laury (2002) task is significantly correlated with several questionnaires measuring risk (`https://paolocrosetto.shinyapps.io/METARET/`).[24] Thus, the Holt and Laury (2002) task is arguably effective in measuring risk. Moreover, our measure of risk seems to be effective in predicting bids in our experiment.

4.1.2. Spite according to Marcus et al. (2014)

In the questionnaire by Marcus et al. (2014) participants are asked to rate 17 statements. Here are two examples:[25]

- If I am checking out at a store and I feel like the person in line behind me is rushing me, then I will sometimes slow down and take extra time to pay.
- I would rather no one get extra credit in a class if it meant that others would receive more credit than me.

Participants were asked to indicate their agreement on a scale between 1 and 5. Higher scores on the scale indicate more spitefulness. The measure of spitefulness with this task is the average agreement with the statements. The distribution of spitefulness with this measure is shown in the left part of Figure 4.

4.1.3. Spite according to Kimbrough and Reiss

As a second measure for spitefulness we use a modification of Kimbrough and Reiss (2012). They observe spiteful behavior with the help of a variant of a second-price auction.[26] We first asked participants to supply a bid function for a second price auction with one opponent (Figure 16 in Appendix D.4). Then valuations for ten independent auctions were generated

[23] Lotteries are shown in Table 4 in Appendix D.1. Details of the implementation are illustrated in Appendix G.1, Second Task (B).

[24] In a recent paper Engel and Kirchkamp (2019) also show how to deal with inconsistent choices on multiple price lists. Currently, such an approach would exceed the scope of the paper but might be a valuable extension.

[25] All statements are shown in Appendix D.2.

[26] See Appendix D.4 for details.

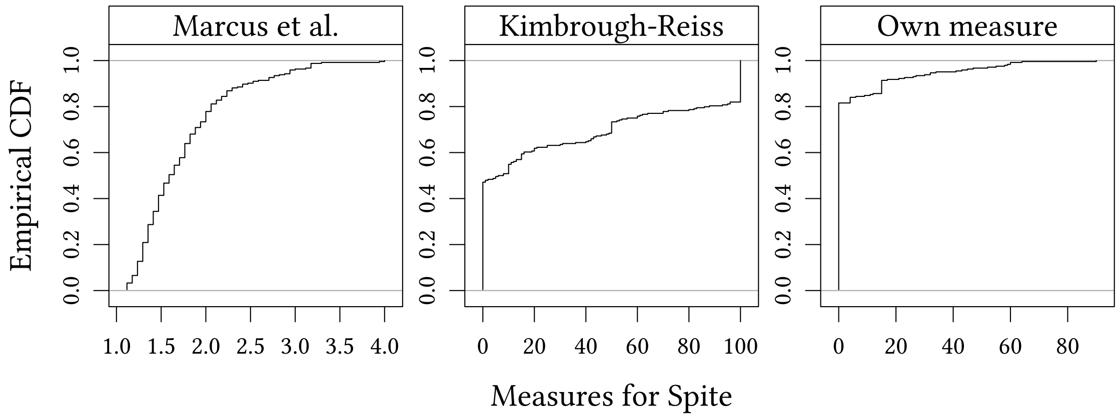


Figure 4: Distribution of measures for spite.

randomly. For each of these auctions bids were determined according to the stated bid functions. Participants were informed about the outcome of each auction. Participants were told who had won the auction and the winner's bid (Figure 17). In the next (and crucial) step, participants could decide separately for the won and lost auctions to either keep their own bid or to increase their own bid. The increase was elicited as the percentage (between 0 and 100%) of the difference between the winner's and the loser's bid (Figure 18). Bidder could not increase their own bid by more than 100% of the difference between the winner's and the loser's bid. Hence, in this step bidders could never change the winner of the auction. They could only diminish the winner's payoff. Furthermore, we elicit the willingness to pay for this adaptation of bids.

Participants who had increased their losing bid are considered spiteful – as they decrease the payoff of the winners. The spite-measure is a continuous measure between 0% (no adjustment) and 100% (if the loser increases the own bid up to the winner's bid and thus reduces the winner's payoff to zero). The distribution of spite for this measure is shown in the middle of Figure 4.

4.1.4. Our own measure for spitefulness

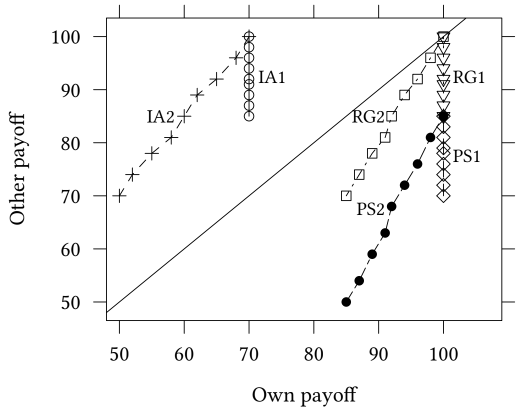
For our own measure of spitefulness we ask participants to decide six times among 9 possible allocations similar to the SVO slider measure by Murphy et al. (2011) and Murphy and Ackerman (2014). Figure 5 shows the six sets we use.[27] For each set participants had to chose their preferred allocation.

In each of the six sets the allocation with the highest payoff for the other player maximizes the own payoff. Deviations from this allocation only reduce the payoff of the other player. These deviations never increase the own payoff. A deviation can, hence, be seen as a sign of spitefulness. This deviation is costless in sets IA1, RG1 and PS1. It is costly in IA2, RG2, and PS2.

[27] Details of the allocations are shown in Appendix D.3.

	You	70	70	70	70	70	70	70	70	70
IA1		○	○	○	○	○	○	○	○	○
	Other	100	98	96	94	92	91	89	87	85
	You	70	68	65	62	60	58	55	52	50
IA2		○	○	○	○	○	○	○	○	○
	Other	100	96	92	89	85	81	78	74	70
	You	100	100	100	100	100	100	100	100	100
RG1		○	○	○	○	○	○	○	○	○
	Other	100	98	96	94	92	91	89	87	85
	You	100	98	96	94	92	91	89	87	85
RG2		○	○	○	○	○	○	○	○	○
	Other	100	96	92	89	85	81	78	74	70
	You	100	100	100	100	100	100	100	100	100
PS1		○	○	○	○	○	○	○	○	○
	Other	85	83	81	79	78	76	74	72	70
	You	100	98	96	94	92	91	89	87	85
PS2		○	○	○	○	○	○	○	○	○
	Other	85	81	76	72	68	63	59	54	50

(a) The six allocation sets for our own slider measure as shown on the screen.



(b) A graphical representation of the six allocation sets.

Figure 5: Own measure of spitefulness.

For each of the six sets players choose one allocation. For each set we consider the Pareto efficient allocation not spiteful. Less efficient allocations will be considered more spiteful.

While one reason for these deviations can be spite, there are other explanations. Deviations in sets IA1 and IA2 can be a sign of “inequality aversion”. Deviations in sets RG1 and RG2 can be a sign of “concerns for relative gain”.

As a measure for spitefulness we take the sum of points by which the payoff of the other player is reduced. Anybody who is not spiteful would leave 570 points to the other player. The lowest possible number of points a spiteful person could leave to the other is 430. This maximally spiteful person would, hence, reduce the payoff of the other by 140 points. Higher values indicate, hence, higher spitefulness.

Based on this measure only 18% of participants were behaving spitefully at all. Only 12% of participants were willing to pay for this behavior. A distribution of the combined spite measure is shown in the right graph in Figure (4).

4.1.5. Other controls

We use the slider measure by Murphy et al. (2011) and Murphy and Ackerman (2014) to control for social value orientation and inequality aversion. We use the questionnaire of Back et al. (2013) to control for rivalry.

4.2. Design of the auction

After measuring preferences for spite,[28] SVO and risk preferences, participants played either the second-price all-pay auction or the first-price winner-pay auction. We explained to

[28]The implementation of Kimbrough and Reiss (2012) and our all-pay auction were counterbalanced as both parts are auctions and we want to control for order effects here.

participants in great detail (using video-instructions) the rules of the auction.[29] Participants played the auction for 15 rounds with stranger matching. Most matching groups had a size of 6 participants.[30]

We use the strategy method to elicit bid functions. In each round participants were asked to state a bid for valuations of 0, 10, 20,..., 90, 100. Figure 6 shows an example of the bidding interface. Bids for intermediate valuations were linearly interpolated. To give more feedback in each round, each pair of bidders played ten auctions, each time for a random pair of valuations. Figure 7 shows an example of the feedback interface. For each of the ten auctions participants learn their own valuation, their own bid, and their opponent's bid. Participants also learn the outcome of the auction and how much they had won or lost.

4.3. Payment

Participants were paid at the end of the experiment for one random task, i.e. either one lottery from the risk-measure or one allocation from the SVO slider measure or the Spite-Measure or the adaptation of Kimbrough and Reiss (2012) or one of the auctions.[31,32]

For each task we converted ECU (experimental currency unit) to Euros using separate rates to make sure that for the different tasks average payoffs were similar. For the same reason participants received a higher initial endowment in the all-pay auction.

4.4. Hypotheses

4.4.1. Bids in the first-price winner-pay auction:

We use the Bayesian Nash equilibrium to motivate our Hypotheses. Following Propositions 3 and 4 we should expect spiteful bidders and risk averse bidders to bid more than non-spiteful risk neutral bidders.

Hypothesis 1.1. *Increased spitefulness will lead to higher bids in the first-price winner-pay auction.*

Hypothesis 1.2. *Increased risk aversion will lead to higher bids in the first-price winner-pay auction.*

4.4.2. Bids in the second-price all-pay auction:

Following Observation 1 we expect that in the second-price all-pay auction bids increase in spite for low valuations and they decrease in spitefulness for high valuations.[33]

[29]Appendix G.2 provides the text of the videos. The videos can be found at `https://www.kirchkamp.de/research/SpiteVsRisk.html`.

[30]Details can be found in Table 6 in Appendix E.

[31]In case of the all-pay auction only one of the 10×15 auctions was paid out.

[32]Hence, only one random problem was selected to become payoff-relevant. See Azrieli et al. (2018) for a detailed argument. See also Charness et al. (2016) for a methodological review.

[33]In Appendix A we discuss the first-price all-pay auction. There we predict that spiteful bidders will bid more, in particular when their valuation is high.

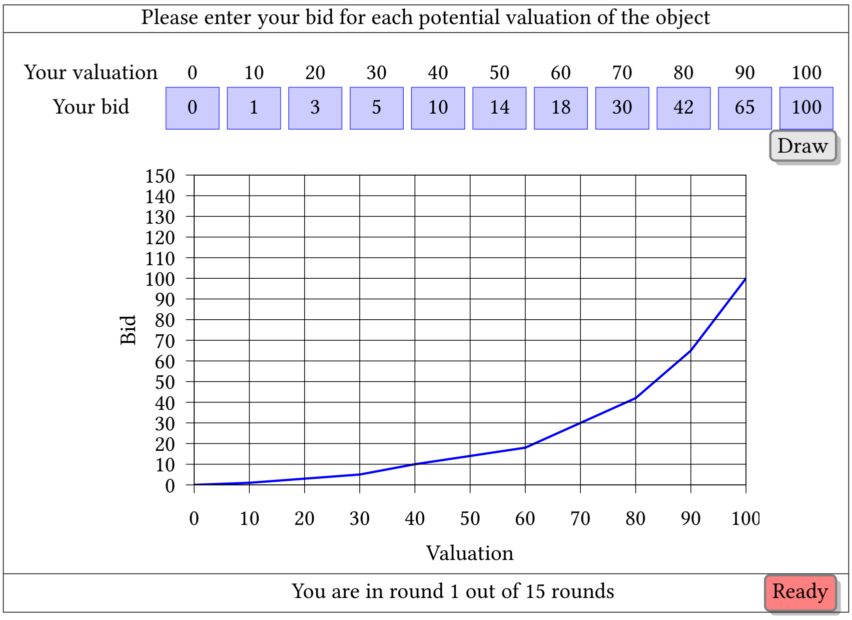


Figure 6: Interface of the bidding stage.
Imputing the bidding function for the possible valuations between 0 and 100. The bidding function is drawn after the input of the respective bids.

Auction	9	7	2	4	1	3	8	10	6	5
Your valuation	20	31	34	40	42	45	58	72	84	100
Your bid	3	6	7	10	11	12	17	32	51	100
Other's valuation	?	?	?	?	?	?	?	?	?	?
Other's bid	28	13	4	4	11	13	2	3	1	1
Won/lost	lost	lost	won	won	won	lost	won	won	won	won
Points gained/lost	-3	-6	30	36	31	-12	56	69	83	99

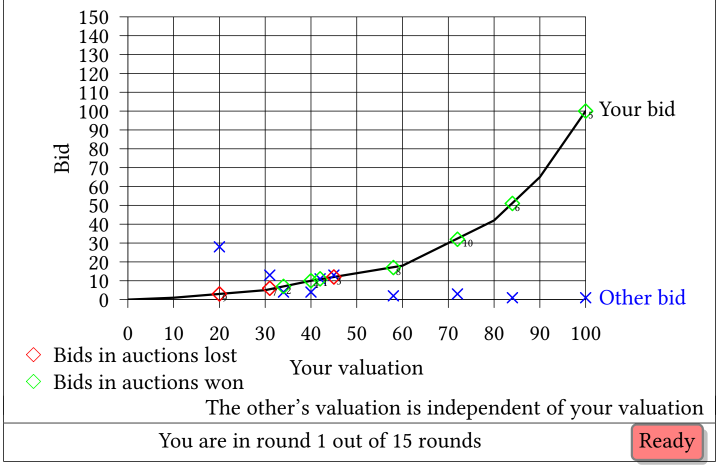


Figure 7: Interface of the feedback stage.
Mapping the 10 random valuations and the respective bids on the bidding function. Additionally subjects could see the opponent's bid, whether they won and the amount they won/lost.

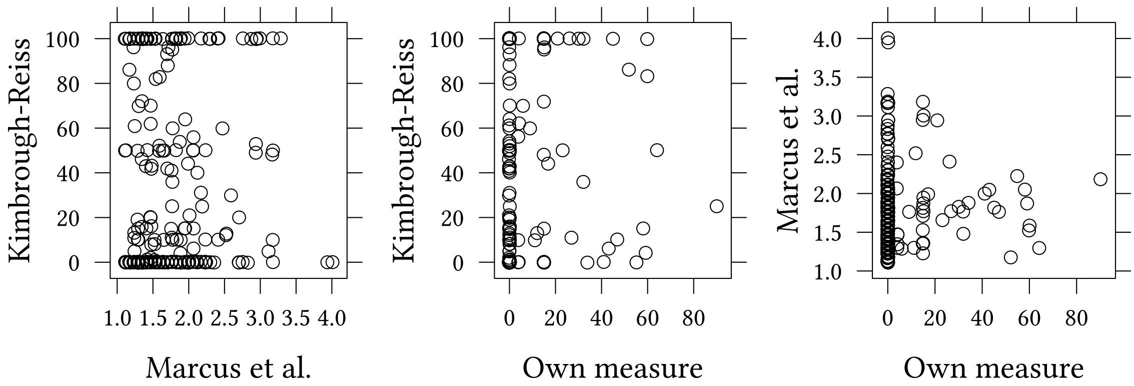


Figure 8: Joint distribution of measures for spite.

Hypothesis 2.1. *Bids increase in spite for low valuations and they decrease in spite for high valuations.*

We expect, hence, that bidders with spiteful preferences will bid more than the RNBNE for small valuations. They will bid less than the RNBNE for large valuations. Following Proposition 2 we expect that risk averse bidders underbid compared to risk neutral bidders.

Hypothesis 2.2. *Increased risk aversion leads to lower bids.*

5. Results

We conducted the experiments in June 2015 (the second-price all-pay auction) and in May 2017 (the first-price winner-pay auction) at the laboratory of the school of economics of the University of Jena (Germany). We recruited 244 participants in 14 sessions using the online recruiting platform ORSEE (Greiner, 2015). We implemented the experiment using z-Tree (Fischbacher, 2007). Instructions were presented as 25-minute-videos followed by test questions for the auction and for the spite-measure based on Kimbrough and Reiss (2012). The entire experiment lasted for about 100 minutes. Participants earned on average 15.83€ (≈ 9.5 € an hour), which was at that time slightly above the minimum wage. We had 41% male and 59% female participants with a median age of 24. Participants were on average in their third year of studying and about 14% were students of business or economics.[34]

5.1. Measures of Spite

Figure 8 shows the joint distribution of the three measures for spite. There is no evident correlation. For the three instruments we find a Cronbach α of 0.118 (CI $= [0.0277, 0.216]$). The two behavioral measures are correlated significantly ($r = 0.137$, $p = 0.033$). The questionnaire is not significantly correlated with the two behavioral measures ($r = 0.079$, $p \geq 0.05$; $r = 0.061$, $p \geq 0.05$). Apparently, the three instruments seem to measure different aspects of spiteful preferences.

Having said that, we find substantial consistency within the two scales which are based on repeated measurements. For the 17 questions of Marcus et al. (2014) we find a Cronbach α of 0.863 (CI $= [0.83, 0.903]$). For the six choices from our own measure we find a Cronbach α of 0.707 (CI $= [0.635, 0.788]$).

Neither the questionnaire nor our own measure seems to be strictly one-dimensional. For the questionnaire, we find that the first element of a principal component analysis explains 33.2% of the variance, (CI $= [27.8, 37.8]$). For our own measure, we find that the first element of a principal component analysis explains 76.6% of the variance, (CI $= [65.9, 86.6]$).

As there is, in general, no easy way to disentangle which of the three spite-measures is better in measuring spite, we will look at the combined (normalized) measures. As an additional robustness check we provide the main regressions for each of the three individual measures in Appendix F.4. Results are very similar for the three measures.

To support the plausibility of the combined (normalized) measure of spite we correlate it with the SVO slider measure. As SVO measures rather prosocial behavior and our spite measure is measuring rather antisocial behavior, we expect the two measures to be negatively correlated. Indeed, this is what we see: the two measures are correlated significantly and negatively ($r = -0.164$, $p = 0.01$).

5.2. Measures of Risk

Figure 9 shows the distribution of the Holt and Laury (2002) measure for risk attitude (see Table 4 in Appendix D.1). Only 11.48% of all subjects choose the safer (left) lottery four times, i.e. their behavior is consistent with risk neutrality. Most subjects (83.61%) choose the safer lottery more than four times, thus behave as if they were risk averse. The remaining 4.92% choose the safer lottery fewer than four times, i.e. behave as if they were risk loving. These proportions are very similar to results reported in Holt and Laury (2002).

The measures of risk and spite are supposed to measure different things. Indeed, risk is neither correlated significantly with our measure of spite ($r = 0.004$, $p \geq 0.05$), nor is risk correlated with the SVO-measure ($r = 0.001$, $p \geq 0.05$).

[34] In the second-price all-pay auction 138 subjects were recruited in 8 sessions with 45% male participants with a median age of 24 with 12% of subjects being students of business or economics.

In the first-price winner-pay auction 106 subjects were recruited in 6 sessions with 36% male participants with a median age of 25 with 16% of subjects being students of business or economics.

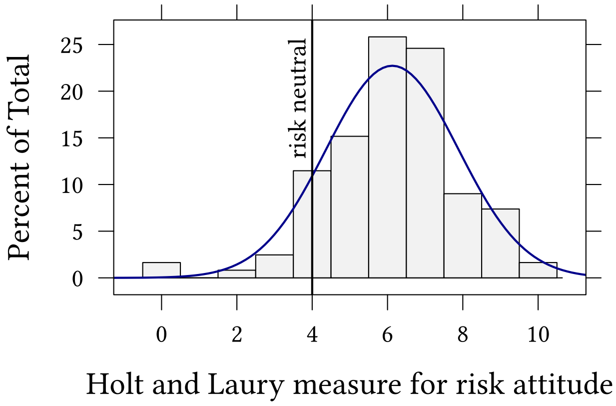


Figure 9: Distribution of Holt and Laury (2002) measure for attitude towards risk.

5.3. Aggregated Bids

In this section we will present an overview of bidding behavior based on aggregated bids. In Section 5.4 we will continue with a more detailed model to explain individual bids.

Figure 10 shows overbidding, i.e. the difference between average bids minus RNBNE bids in the two auction formats.

The right part of Figure 10 shows behavior in the first-price winner-pay auction. For small valuations we see that overbidding is approximately zero. For larger valuations overbidding increases. Predictions for both spiteful preferences and risk aversion are in line with this behavior.

The left part of Figure 10 shows behavior in the second-price all-pay auction. For the second-price all-pay auction, spiteful preferences and risk aversion make quite different predictions. Risk aversion predicts underbidding for all valuations. Spiteful preferences predict overbidding for intermediate valuations and underbidding only for very large valuations. Observed bids (thick line) seem to follow the pattern predicted by spiteful preferences, and not the one predicted by risk aversion. We find overbidding up to a rather high valuation and underbidding afterwards.

While the figure suggests that spite might be a more convincing explanation than risk for most valuations, risk aversion is still in line with the observed underbidding for high valuations. Could it be that risk explains bids better at least for large valuations? Could a model of risk averse bidders perhaps perform so well for large valuations that this extra performance compensates the comparatively worse performance of risk aversion for small valuations?

To answer this question formally, we estimate the following model:

$$\mathrm{Bid}_{i,t,j,\nu} = \beta^{\mathsf{T}}_{\text{II-AP}} + \zeta_{i,j} + \eta_j + \epsilon_{i,j,k,l} \tag{10}$$

where $\mathrm{Bid}_{i,t,j,\nu}$ is the bid of subject i in group j in period t for valuation ν. $\zeta_{i,j}$ is a random effect for bidder i in group j, η_j is a random effect for group j, and $\epsilon_{i,j,k,l}$ is the residual. $\beta^{\mathsf{T}}_{\text{II-AP}}$

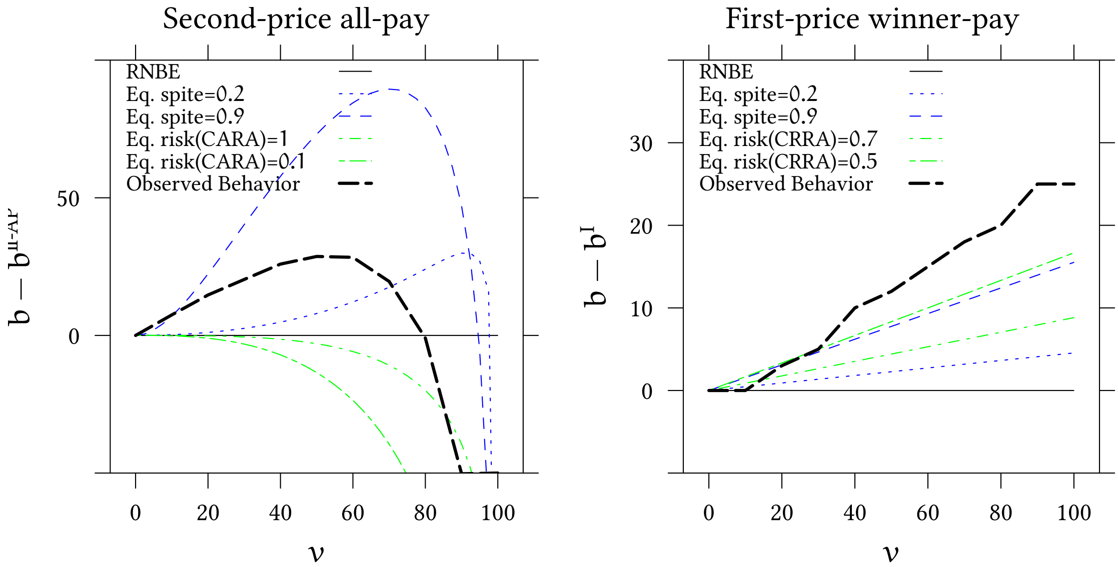


Figure 10: Median overbidding: Theory and observations.
The left graph shows median overbidding ($b - b^{\text{II-AP}}$) in the second-price all-pay auction. As a reference we include theoretical overbidding for spiteful ($\alpha > 0$) and for risk averse (CARA, $r < \infty$) bidders.
The right graph shows median overbidding ($b - b^{\text{I}}$) in the first-price winner-pay auction. As a reference we include theoretical overbidding for spiteful ($\alpha > 0$) and for risk averse (CRRA, $\rho < 1$) bidders.

is the equilibrium bidding function for the second-price all-pay auction according to either Equation (5) or (7). T indicates the type of the model: spiteful preferences (Equation (5)) or risk aversion (Equation (7)).

We fit the parameters (either α (spite parameter) or r (risk parameter)) of the theoretical bidding function by maximizing the log-likelihood of the model.[35] We find that the model with spiteful bidders explains the bidding behavior significantly better ($\chi^2_0 = 50.316$, $p \leq 0.001$) than the model without spite. The model with risk averse bidders, however, is not significantly better ($\chi^2_0 = 0$) than the one without risk aversion.

For the second-price all-pay auction, we conclude the following:

Result 1.1. *Behavior in the second-price all-pay auction is significantly better described by a theory of spite but not by a theory of risk aversion.*

For the first-price winner-pay auction, we have seen in Section 3.2.2 that for a CRRA risk averse bidder with a coefficient of relative risk aversion ρ equilibrium bids are equivalent to equilibrium bids of a spiteful bidder with spite parameter $\alpha = 1/\rho - 1$. Trivially, for the first-price winner-pay auction, both theories describe behavior equally well.

Result 1.2. *Spite and risk perform equally well in describing behavior in the first-price winner-pay auction.*

[35] We use a limited-memory modification of the Broyden-Fletcher-Goldfarb-Shanno quasi-Newton method to find the maximum while restricting all α to be in $(0, 1)$ and r to be in $(0, 10^{10})$. The best performing α is 0.664 (i.e. substantially spiteful) while the best performing r is 10^{10} (i.e. close to risk neutrality).

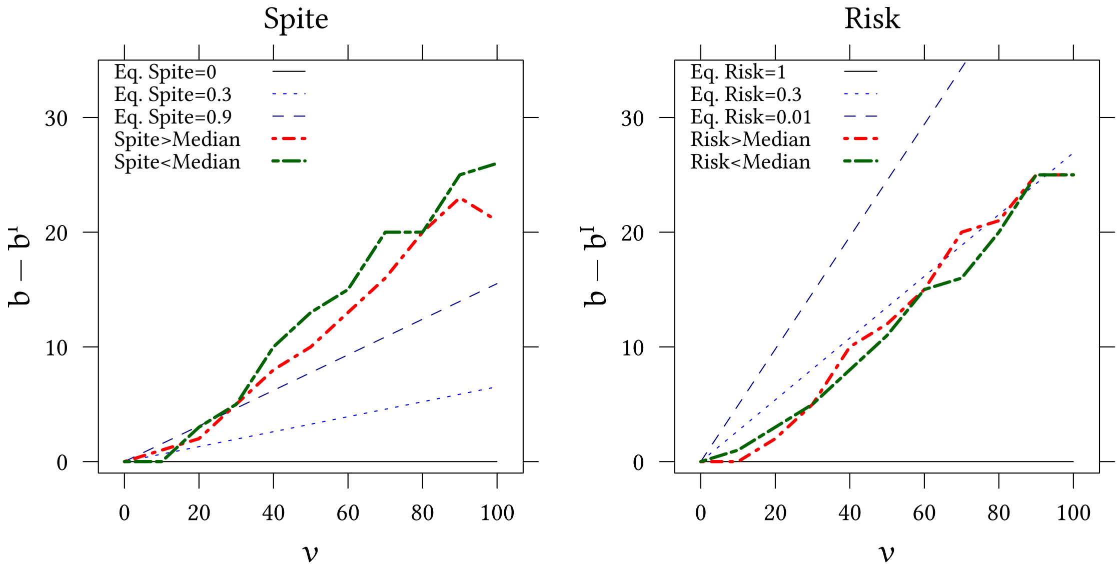


Figure 11: Spite and risk in the first-price winner-pay auction.
The left graph shows theoretical overbidding for spiteful bidders as well as median overbidding for above and below median spiteful experiment-participants. The right graph shows theoretical overbidding for risk averse bidders as well as median overbidding for above and below median risk averse experiment-participants. The theoretical predictions for risk averse bidders are derived from Morgan et al. (2003) based on CRRA-risk-preferences (risk of one denotes risk neutrality and decreasing numbers indicate increasing risk aversion).

Let us next check whether the elicited preferences for spite and risk contribute to an explanation of observed bids.

First-price winner-pay auction Figure 11 is an extension of the right part of Figure 10. Similar to Figure 10, also Figure 11 shows median overbidding, i.e. bids minus RNBNE bids. Different from Figure 10, Figure 11 is based on a median split. We divide participants into more and less spiteful bidders in the left panel. Similarly, we divide participants into more or less risk averse bidders in the right panel. The figure includes equilibrium predictions for different levels of spite in the left panel and for risk aversion in the right panel.

For the first-price winner-pay auction, Figure 11 does not suggest a substantial influence of spite or risk aversion on bids.

Second-price all-pay auction Figure 12 shows overbidding for the second-price all-pay auction for participants with different preferences for spite or risk. As in Figure 11 we use a median split for spite in the left part of Figure 12 and a median split for risk in the right part of Figure 12. We include equilibrium overbidding for different levels of spite in the left part and for different levels of risk preferences in the right part.

As predicted by theory, the difference between bids of more and less spiteful bidders increases up to a high valuation and decreases quickly afterwards. Also in line with theory the difference between bids of more and less risk averse bidders is negatively increasing in the valuation.

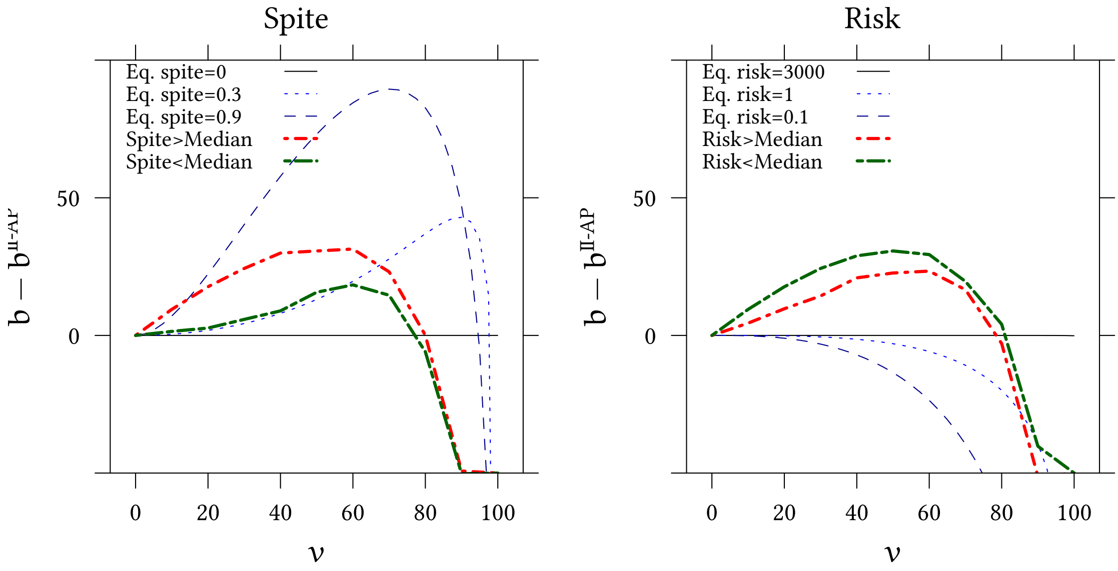


Figure 12: Median overbidding in the second-price all-pay auction.
The left graph shows theoretical overbidding for spiteful bidders as well as median overbidding for above and below median spiteful experiment-participants. The right graph shows theoretical overbidding for risk averse bidders (CARA) as well as median overbidding for above and below median risk averse experiment-participants. Risk of infinity denotes risk neutrality and decreasing numbers indicate increasing risk aversion.

A formal comparison What we have seen in Figures 11 and 12 can be confirmed more formally. In Section 5.4 we will look at individual bids. Here, to get a first impression, we explain average overbidding (per participant) for the two auction formats with the help of the following mixed effects model:

$$\overline{\mathrm{Bid}_{i,j} - b^{I}} = \beta_0 + \beta_{\mathrm{Spite}}\mathrm{Spite}_{i,j} + \beta_{\mathrm{Risk}}\mathrm{Risk}_{i,j} + \eta_j + \epsilon_{i,j} \qquad (11)$$

We call $\overline{\mathrm{Bid}_{i,j} - b^{I}}$ the average overbidding of participant i in group j over all valuations and all rounds that participant played. $\mathrm{Spite}_{i,j}$ is the sum of the three spite measures for participant i in group j. $\mathrm{Risk}_{i,j}$ is the risk aversion for this person, and η_j is the group specific random effect. Table 1 shows estimation results.

As we have seen in Figure 12 we confirm for the second-price all-pay auction that spite is significantly associated with overbidding. Risk aversion significantly associated with underbidding. Both observations are in line with theory (Equations (5) and (7)).

As we have seen in Figure 11, in the first-price winner-pay auction neither risk nor spite contribute significantly to overbidding.

Summary of aggregate results For the first-price winner-pay auction, we have seen in this section that bids can be rationalized equally well with risk aversion or spiteful preferences. However, our measures of these preferences do not seem to explain actual bids.

For the second-price all-pay auction, instead, our measure for spite and our measure for risk preferences explains actual bids in line with the equilibrium prediction. More spiteful bidders bid more, as they should. More risk averse bidders bid less, again as they should.

	Second-price all-pay auction	First-price winner-pay auction
Spite	3.70^{*} (1.67)	0.05 (0.40)
Risk	-7.39^{*} (3.05)	0.09 (0.79)
Constant	11.48^{***} (3.05)	11.61^{***} (0.99)
Observations	138	106
Log Likelihood	−682.60	−370.37
Akaike Inf. Crit.	1,375.20	750.75
Bayesian Inf. Crit.	1,389.83	764.06
Notes:	$^{+}: p < 0.1$; $^{*}: p < 0.05$; $^{**}: p < 0.01$;	$^{***}: p < 0.001$;

Table 1: Mixed effects model of the average overbidding as a function of spite and risk. The table shows estimation results of overbidding in both auction types.

Most importantly, however, we find that most of the deviation of bids from RNBNE bids seems to be due to spiteful preference, not due to risk aversion.

5.4. Individual bids

Let us next turn to individual bids. We will start with the first-price winner-pay auction in Section 5.4.1 and turn to the second-price all-pay auction in Section 5.4.2.

5.4.1. First-price winner-pay auction

In Section 5.3 we did not find a substantial effect of preferences for risk and spite on aggregate bids for the first-price winner-pay auction. To present a more detailed image we will use individual bids in the current section. We will employ a linear mixed effects model with several controls.[36] Equation (12) describes the different models:

$$
\begin{aligned}
\mathrm{Bid}_{i,t,j,v} - b^{I} &= \beta_0 + \beta_1 \mathrm{Period} + \beta_2 v + \zeta_{i,j} + \eta_j + \epsilon_{i,j,k,l} + C_M \\
C_1 &= 0 \\
C_2 &= \beta_3 \mathrm{Spite}_i + \beta_4 \mathrm{Spite}_i \times v \\
C_3 &= C_2 + \beta_5 \mathbb{1}_{\mathrm{Gender}=\female} + \beta_6 \mathrm{Risk}_i + \beta_7 \mathrm{rivalry}_i + \beta_8 \mathrm{SVO}_i + \beta_9 \mathrm{IA}_i \\
C_4 &= \beta_{10} \mathrm{Risk}_i + \beta_{11} \mathrm{Risk}_i \times v \\
C_5 &= C_4 + \beta_{12} \mathbb{1}_{\mathrm{Gender}=\female} + \beta_{13} \mathrm{Spite}_i + \beta_{14} \mathrm{rivalry}_i + \beta_{15} \mathrm{SVO}_i + \beta_{16} \mathrm{IA}_i
\end{aligned}
\tag{12}
$$

Here $\zeta_{i,j}$ is a random effect for bidder i in group j, η_j is a random effect for group j, and $\epsilon_{i,j,k,l}$ is the residual. The base specification is C_1. Models C_2 and C_3 control for spite. C_4 and C_5 control for risk. Table 2 shows estimation results for Equation (12).

[36] Actually, for the first-price winner-pay auction, there is not a big difference between estimating bids and overbidding. Overbidding in the first-price winner-pay auction is the bidding behavior minus half of the valuation. Thus, estimating bids would give us the same coefficients, except a marginal increase (1/2) in valuations.

	C_1	C_2	C_3	C_4	C_5
Period	-0.09^{***} (0.02)	-0.09^{***} (0.02)	-0.09^{***} (0.02)	-0.09^{***} (0.02)	-0.09^{***} (0.02)
v	0.21^{***} (0.003)	0.21^{***} (0.003)	0.21^{***} (0.003)	0.21^{***} (0.003)	0.21^{***} (0.003)
Spite		0.53 (0.40)	0.33 (0.51)		-0.15 (0.50)
Spite $\times v$		-0.01^{***} (0.002)	-0.01^{***} (0.002)		
Risk			-0.06 (0.79)	-1.46^{+} (0.80)	-1.59^{*} (0.80)
Risk $\times v$				0.03^{***} (0.003)	0.03^{***} (0.003)
Male			-4.98^{**} (1.65)		-4.98^{**} (1.65)
Rivalry			0.86 (0.86)		0.86 (0.86)
SVO			0.04 (0.06)		0.04 (0.06)
IA			0.46 (0.63)		0.46 (0.63)
Constant	1.96^{+} (1.01)	1.96^{+} (1.02)	2.92^{+} (1.60)	1.96^{+} (1.02)	2.92^{+} (1.60)
Observations	17,490	17,490	17,490	17,490	17,490
Log Likelihood	$-69{,}248.54$	$-69{,}233.82$	$-69{,}227.71$	$-69{,}200.08$	$-69{,}194.64$
Akaike Inf. Crit.	138,509.10	138,483.60	138,481.40	138,416.10	138,415.30
Bayesian Inf. Crit.	138,555.70	138,545.80	138,582.40	138,478.30	138,516.30
Notes:	$^{+}: p < 0.1$; $^{*}: p < 0.05$; $^{**}: p < 0.01$; $^{***}: p < 0.001$;				

Table 2: Estimation results for Equation (12) (overbidding for the first-price winner-pay auction).

The table shows estimation results for the different models C_1, C_2,C_3, C_4, and C_5. Spite is the sum of the three spite measures. (We show individual estimates for the interaction effects for the three measures in Figure 19 in Appendix F.4). IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure. 17490 observations refer to 106 participants in the first-price winner-pay auction making 11 decisions in each of the 15 rounds of the game.

Model C_1 assumes a simple linear relationship between valuation v and bids. This can be rationalized with a theory of risk averse bidders but also with a theory of spiteful bidders.

Result 2.1. *Overbidding in the first-price winner-pay auction is consistent with the theory of spiteful bidders and also with theory on risk averse bidders.*

Models C_2 and C_3 allow us to investigate Hypothesis 1.1. We find that, contrary to the theoretical prediction, more spite is associated with a less steep bidding function (the interaction of Spite $\times$ v is negative and significant).[37]

Result 2.2. *Contrary to the theoretical prediction, more spite is associated with a less steep bidding slope in the first-price winner-pay auction (the interaction of Spite $\times$ v is negative and significant).*

With models C_4 and C_5 we will investigate Hypothesis 1.2. We find that risk aversion, in line with theory, is associated with steeper bids (the interaction of Risk $\times$ v is positive and significant).[38]

[37]In Figure 14 we show the development of this interaction over time. We find that the effect becomes stronger during the experiment. In Figure 19 we show separate estimation results for the three different measures of spite. Only spite in the sense of Marcus et al. (2014) is consistent with our Hypothesis 1.1.

[38]While the effect seems small in Figure 11, it still amounts to a relative increase of 15% in the estimated slope of the bidding function (model C_4).

Result 2.3. *In line with theory, more risk aversion is associated with a steeper bidding slope in the first-price winner-pay auction.*

The left part of Figure 14 shows how the interaction terms change over time during the experiment. We find that the above mentioned effects become stronger during the experiment.

In columns C_3 and C_5 of Table 2 we add controls for gender, rivalry, social value orientation, and inequality aversion. These extra controls do not change substantially the coefficients for spite and risk. Gender is a highly significant factor of overbidding. Furthermore, overbidding decreases over time. One could interpret this decrease as a sign of learning.

5.4.2. Second-price all-pay auction

In Section 5.3 we found for the second-price all-pay auction a noticeable effect of preferences for risk and spite on aggregate bids. In the current section we will use individual bids to present a more detailed picture. Similar to Section 5.4.1 we will use a mixed effects model.[39] Since overbidding for the first-price winner-pay auction is (in equilibrium) linear in valuations, we used in Section 5.4.1 a specification linear in valuations. For the second-price all-pay auction, matters are different. Here, overbidding is non-linear in valuations. Hence, we follow a non-linear approach in the current section. Specifically, we use a generalized additive model (GAM) where overbidding is modeled as a smooth function of the valuation.[40]

A second non-linearity that we have to account for is that in equilibrium of the second-price all-pay auction spite leads to a non-linear increase in bids.[41] Risk aversion has a non-linear effect on bids, too.[42] For higher levels of spite we expect more overbidding up to a certain level, but underbidding for high valuations. For higher levels of risk aversion we expect more underbidding which becomes stronger for high valuations. To simplify the interpretation of our results, we use a piece-wise linear function with a constant slope for valuations

[39]We are mainly interested in overbidding-behavior. Nevertheless, we estimate bidding behavior in Appendix F.1.

[40]We used the default thin plate regression spline. Cubic regression splines, cyclic cubic regression splines and P-splines (a specific version of B-Splines) result in qualitatively the same outcome, as can be seen in Appendix F. We also estimate the same regression with the help of piece wise linear splines. Results are robust to these specification.

[41]See Equation (5), Figure 1 for bids and Figure 12 for overbidding.

[42]See Equation (7), Figure 2 for bids and Figure 12 for overbidding.

below 50 and a constant slope for valuations above 50.[43,44] We compare five different models:

$$
\begin{aligned}
\mathrm{Bid}_{i,t,j,\nu} - b^{\text{II-AP}} =& \beta_0 + \beta_1 \mathrm{Period} + \zeta_{i,j} + \eta_j + \epsilon_{i,j,k,l} + C'_M \\
C'_1 =& s(\nu) \\
C'_2 =& C'_1 + \beta_2 \mathrm{Spite}_i + \beta_3 \mathrm{Spite}_i \cdot \nu_{[0,50]}(\nu) + \beta_4 \mathrm{Spite}_i \cdot \nu_{[50,100]}(\nu) \\
C'_3 =& C'_2 + \beta_5 \mathrm{IA}_i + \beta_6 \mathbb{1}_{\mathrm{Gender}=\female} + \beta_7 \mathrm{Risk}_i + \beta_8 \mathrm{rivalry}_i + \beta_9 \mathrm{SVO}_i \\
C'_4 =& C'_1 + \beta_{10} \mathrm{Risk}_i + \beta_{11} \mathrm{Risk}_i \cdot \nu_{[0,50]}(\nu) + \beta_{12} \mathrm{Risk}_i \cdot \nu_{[50,100]}(\nu) \\
C'_5 =& C'_2 + \beta_{13} \mathrm{IA}_i + \beta_{14} \mathbb{1}_{\mathrm{Gender}=\female} + \beta_{15} \mathrm{Spite}_i + \beta_{16} \mathrm{rivalry}_i + \beta_{17} \mathrm{SVO}_i
\end{aligned} \tag{13}
$$

Here $\zeta_{i,j}$ is a random effect for bidder i in group j, η_j is a random effect for group j, and $\epsilon_{i,j,k,l}$ is the residual. $s(\nu)$ is the thin plate regression spline over the valuation. To facilitate interpretability, $\nu_{[0,50]}(\nu)$ and $\nu_{[50,100]}(\nu)$ are defined as follows:

$$\nu_{[0,50]}(\nu) = \min(0, \nu/50 - 1) \tag{14}$$

$$\nu_{[50,100]}(\nu) = \max(0, \nu/50 - 1) \tag{15}$$

Coefficients of interactions of $\nu_{[0,50]}$ capture, hence, the marginal effect of this interaction for small valuations. Coefficients of interactions of $\nu_{[50,100]}$ capture the marginal effect of this interaction for large valuations.[45] Estimation results are shown in Table 3. Figure 13 shows estimation results for the fitted spline $s(\nu)$ from Equation (13).

In line with Hypothesis 2.1 we see that, for all models, C'_1, C'_2, C'_3, C'_4, and C'_5, overbidding first increases up to a certain point and then, for high valuations, turns into underbidding.

Result 3.1. *In line with spiteful preferences, bidders bid more than the* RNBNE *for small valuations and, respectively, less for large valuations.*

Hypothesis 2.1 can be assessed with the help of models C'_2 and C'_3. Indeed, with increasing spite overbidding increases more strongly for $\nu < 50$ and then decreases for $\nu > 50$.[46]

Result 3.2. *Bids increase in spite for low valuations and they increase less for high valuations.*

Hypothesis 2.2 can be assessed with the help of models C'_4 and C'_5: For small valuations ($\nu < 50$) the interaction of risk aversion and ν is clearly negative. Underbidding is increasing in valuation and in risk aversion. This is in line with Hypothesis 2.2. For larger valuations ($\nu > 50$) our data neither supports not contradicts Hypothesis 2.2. The interaction effect is small and not significant.

[43]Results are robust to using a cut-off different from 50.

[44]Technically: We use a B-spline of degree 1 with one knot at 50. In Appendix F.3 we alternatively model the non-linearity by using squared valuations. The results are robust to those specifications.

[45]The direct effect of ν is already in $s(\nu)$. Hence, the scaling of ν doesn't matter.

[46]In Figure 14 we show the development of this interaction over time. We find that the effect becomes stronger during the experiment. In Figure 19 we show separate estimation results for the three different measures of spite. For all measures we find that the interaction between spite and ν is stronger for $\nu < 50$ and weaker for $\nu > 50$. Detailed estimation results, similar to Table 3, but for the different measures of spite, are shown in Section F.4.

	C'_1	C'_2	C'_3	C'_4	C'_5
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		4.06* (1.69)	4.83* (1.96)		4.10* (1.95)
Spite × $v_{[0,50]}$		1.49** (0.47)	1.49** (0.47)		
Spite × $v_{[50,100]}$		-1.18* (0.47)	-1.18* (0.47)		
Risk			-6.02* (2.91)	-7.85* (3.08)	-7.10* (2.94)
Risk × $v_{[0,50]}$				-3.48*** (0.86)	-3.48*** (0.86)
Risk × $v_{[50,100]}$				0.46 (0.86)	0.46 (0.86)
Male			-19.05** (6.11)		-19.05** (6.11)
Rivalry			-0.70 (3.09)		-0.70 (3.09)
SVO			0.41+ (0.24)		0.41+ (0.24)
IA			-1.84 (2.51)		-1.84 (2.51)
Constant	14.92*** (3.15)	14.89*** (3.11)	14.83* (6.48)	14.87*** (3.10)	14.83* (6.48)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.69	-120499.39	-120490.12	-120493.49	-120484.68
Akaike Inf. Crit	241027.38	241018.78	241010.24	241006.97	240999.36
Bayesian Inf. Crit.	241083.91	241099.54	241131.38	241087.73	241120.5
Notes:	$^{+}: p < 0.1$;	$^{*}: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 3: Estimation results for Equation (13) (overbidding in the second-price all-pay auction).

The table shows estimation results for the different models C'_1, C'_2, C'_3, C'_4, and C'_5. Thin plate regression splines are used for $s(v)$. Spite is the sum of the three spite measures. (We show individual estimates for the interaction effects for the three measures in Figure 19 and in Section F.4). IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure. Standard errors are shown in parentheses. 23760 observations refer to 18 participants of the first session of the experiment playing 20 rounds plus 120 participants of all remaining sessions playing 15 rounds. In each round 11 decisions were made.

Result 3.3. *For small valuations increased risk aversion is associated with lower bids.*

The right part of Figure 14 shows how the interaction terms change over time during the experiment. We find that the above mentioned effects become stronger during the experiment.

In columns C'_3 and C'_5 in Table 3 we add controls for gender, rivalry, social value orientation, and inequality aversion. Adding these controls does not change substantially the coefficients for spite and risk. As with our estimation for the first-price winner-pay auction in Equation (12), also in Equation (13) for the second-price all-pay auction gender is a highly significant factor of overbidding. As in the first-price winner-pay auction, overbidding decreases over time.

All in all, estimation results for Equation (13) suggest that the theory of spiteful bidding performs rather well in the second-price all-pay auction. As expected, more spitefulness is related to more overbidding for small valuations and to more underbidding for large valuations. We also find some support for the theory of risk averse bidders: At least for small valuations more risk aversion is related to more underbidding. Overall behavior is more in line with spiteful bidding than with risk aversion.

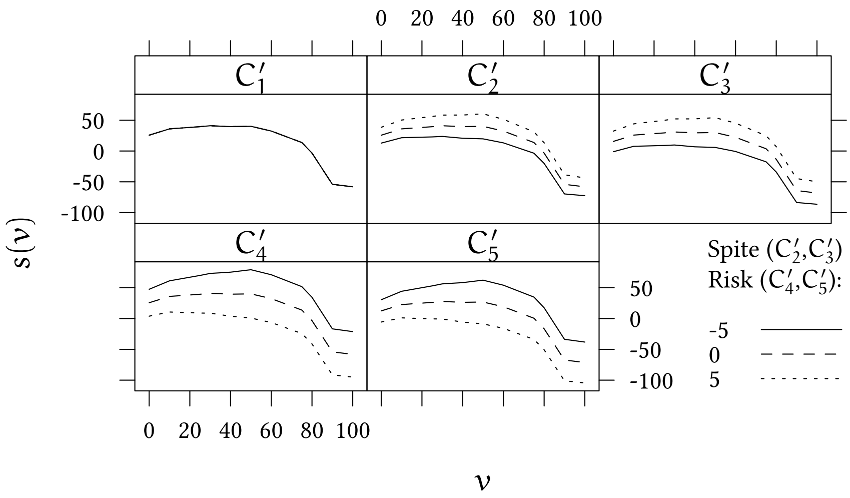


Figure 13: Estimation results for the spline from Equation (13) (overbidding).
The Figure show splines for different models C'_1, C'_2, C'_3, C'_4, and C'_5 and for different (normalized) levels of spite (in models C'_2, C'_3) and different (normalized) levels of risk (in models C'_4, C'_5).

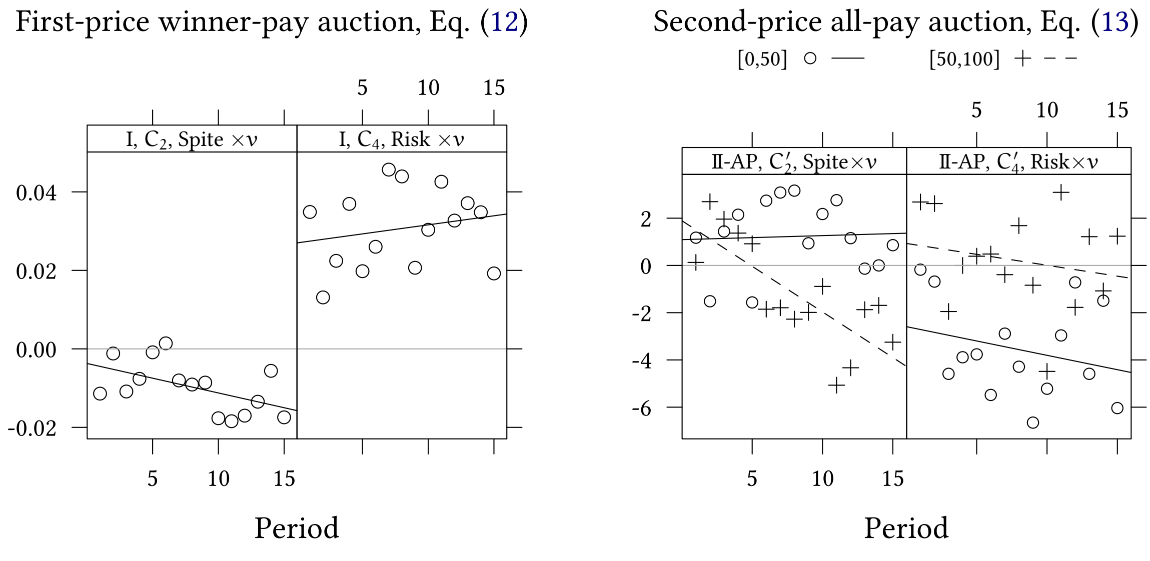


Figure 14: Estimation of interaction coefficients from Equations (12) and (13) over time
To show the change of behavior during the experiment we estimate Equations (12) and (13) separately for each period. The vertical axis shows the interaction of Spite and Risk with ν for models C'_2 and C'_4, respectively.

6. Discussion and Conclusion

In this paper we want to contribute – with the help of theory and experiments – to a better understanding of bidding behavior in auctions. We propose that spite could be a relevant factor to explain bids. As a workhorse we use the second-price all-pay auction and the first-price winner-pay auction.

We show that, in equilibrium, spite and risk should have an influence on bids in these two auction formats. For the second-price all-pay auction, spite leads to overbidding and risk aversion leads to underbidding. For the first-price winner-pay auction, spite should have the same effect as risk aversion: both should lead to overbidding.

For the participants in our experiment we use three different measures of spiteful preferences: a questionnaire, an allocation task and an experimental design similar to Kimbrough and Reiss (2012). We use a Holt and Laury (2002) task to measure preferences for risk.

Our measures of spiteful preferences and risk aversion predict bidding behavior, in particular in the second-price all-pay auction, quite well. In line with theory, bidders who are more spiteful make higher bids. Bidders who are more risk averse make lower bids. This effect of spite and risk seems to increase during the experiment. Most importantly, in the second-price all-pay auction the overall effect of spite seems to dominate the effect of risk.

In the first-price winner-pay auction bidding behavior is well explained by risk preferences. Spite performs less well as a predictor in the first-price winner-pay auction. Contrary to the equilibrium prediction, more spitefulness seems to be associated with a smaller slope of the bidding function in the first-price winner-pay auction. In line with the equilibrium prediction more risk aversion is associated with a steeper slope of the bidding function.

To summarize, spite seems to be a very appealing explanation for bidding behavior in some situations, e.g. the second-price all-pay auction. However, we cannot generalize this findings to other situations, e.g. the first-price winner-pay auction. One might speculate that it is perhaps the higher variance of payoffs in the second-price all-pay auction which give more room to spite.

Overall, we aim to make three contributions to the current literature: 1) We extend the theoretical model of spiteful and risk averse behavior to second-price all-pay auctions, 2) we relate a measure of spite to observed bidding behavior and most importantly 3) we compare two alternative explanations for overbidding – risk vs. spite – and show that in some auctions – the second-price all-pay auction – spite can explain behavior better than risk aversion.

Theoretical investigations (such as Morgan et al. (2003)) have suggested that spite contributes to behavior in auctions. The implication of our results is that empirically spite could be a relevant factor at least in some institutions, e.g. the second-price all-pay auction. We have also seen that spite does not seem to be the *ultima ratio* as it does not explain behavior in the first-price winner-pay auction in our experiment well. Thus, future research will need to study under which situations spite is a good predictor, under which situations spite is even better than the standard explanation of risk aversion, and when spite does not perform well in explaining behavior.

Obviously, our paper has some limitations: In our benchmark, we consider symmetric equilibria only. However, the second-price all-pay auction has asymmetric equilibria, too – for example a bully-sucker-equilibrium (Levin and Kagel, 2005), where the bully bids the maximum and the sucker knuckles under and bids zero.

Further possible extensions of our work could focus on the model of spite. In this paper we have assumed that only the loser of an auction is spiteful. Furthermore, we have treated spite only as a constant, independent of valuation and bid and identical for all members of the population. All these assumptions are taken from the current literature on spite in auctions (Bartling et al., 2017; Morgan et al., 2003; Brandt et al., 2007; Sandholm and Tang, 2012; Sandholm and Sharma, 2010; Mill, 2017). These assumptions simplify the theoretical approach. Further theoretical work, however, might relax these assumptions.

Future research can also focus on comparing spite against other viable possible alternative explanations of overbidding (like joy-of winning, anticipated regret, etc.). The main reason for choosing risk aversion as the main comparison to spite was to pick the strongest competitor. Risk aversion seems to be the most common and accepted explanation for overbidding in most formats. We wanted to provide evidence that spite is more than just a possibile rationalisation of observed behavior among many. We wanted to show that, at least in some competitive situations, spite does better than risk aversion.

As mentioned earlier, there is overwhelming evidence for deviations from risk neutral Bayesian Nash equilibria (RNBNE) for several auction formats. In this paper we have explored two such formats, the first-price winner-pay auction and the second-price all-pay auction. We have chosen these formats, because the deviation from RNBNE is substantial. This deviation can help us to distinguish motives like spitefulness and risk aversion. For other auction formats, bids are closer to RNBNE. For example, Kagel et al. (1987) find no overbidding for the English auction with affiliated valuations. Such a situation is, of course, less suitable to distinguish risk and spite.

We have also seen that the concept of spite itself seems to be hard to grasp. The correlation of the three measures for spite we are using is positive. However, the correlation is not too large. Also our approach, to simply sum up the normalized values of each measure, is pragmatic.

Further, this paper shows that our measure of spite correlates with the bidding behavior in the second-price all-pay auction, as predicted by the corresponding equilibria. However, we do not show causal evidence. Even though we are the first to link measured spite and bidding empirically, we did not manipulate the spitefulness of our subjects in the experiment. This gives room to omitted variable bias. We tackle this issue by controlling for demographic and additional personality measures in the regression. Further, the shape of the actual bidding behavior and the equilibrium predictions are very similar. This similarity should reduce the risk of an omitted variable bias. We are also not aware of any research manipulating the spitefulness of subjects.[47] It is also noteworthy that the main result of this paper – i.e. the average bidding behavior in the second-price all-pay auction is much more in line with the equilibrium predictions of spiteful bidders than risk averse bidders – is independent of our measure of spite.

[47] An exception is a recent attempt by Mill and Morgan (2019) who try to manipulate spite by assigning subjects to either ingroup or outgroup opponents in an auction. Their results support the view that spite might play a role in bidding behavior.

Despite these limitations we can, nevertheless, conclude that spite is a relevant and important motive in auctions. In particular, our results seem to suggest that the spite motive could be as relevant and important as risk aversion in some competitive situations.

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Appendix – for online publication only

A. Bids in the first-price all-pay auction

Two bidders i and j have private valuations for a prize with values v_k, $k \in \{i, j\}$. Both submit a bid b_k following a monotonic bidding function $\beta_k(v_k)$ with first derivative $\beta_k'(x) \equiv \frac{d\beta(x)}{dx}$ and inverse $\beta_k^{-1}(b_k) = v_k$. Valuations are distributed according to F, i.e. $v \sim F(0, \bar{v})$, and $f(x) = \frac{dF(x)}{dx}$. The prize is allocated to the player with the highest bid. If $v_i = v_j$, the prize is distributed randomly. We assume that both bidders have the same utility function $u(x)$.

Following a standard argument in equilibrium $\beta_k(0) = 0$.[48] u is the utility function and we assume bidders to be risk neutral.

To integrate spite into the model we assume that the losing participant gains an additional disutility of α-times the payoff of the winning player. Assume without loss of generality that $b_j > b_i$, i.e. bidder j is the winner. Then $\alpha \cdot (v_j - \beta_j(v_j))$ reflects bidder i's spite.[49] The absence of spite is equivalent $\alpha = 0$. We assume that $\alpha \in [0, 1)$, i.e. we do not consider $\alpha < 0$ which could represent sympathy or profit sharing.

The payoff of player i is as follows:

$$\Phi^{\text{I-AP}}_{\text{Spite}}(\beta_i, v_i) = \begin{cases} u(v_i - \beta_i(v_i)) & \text{if } \beta_i > \beta_j \text{ (} i \text{ wins)} \\ \frac{1}{2}u\left(v_i - b_i\right) + \frac{1}{2}u\left(-b_i - \alpha(v_j - b_i)\right) & \text{if } b_i = b_j \text{ (a tie)} \\ u(-\beta_i(v_i) - \alpha(v_j - \beta_j(v_j))) & \text{if } \beta_i < \beta_j \text{ (} j \text{ wins)} \end{cases} \tag{16}$$

We follow the standard approach and assume that bidder i with valuation v_i makes a bid b. The expected utility of this bidder is given as follows:

$$\mathbb{E}(b, v) = \underbrace{\int_0^{\beta_j^{-1}(b)} u(v - b) f(v_j)\, dv_j}_{\text{bidder } i \text{ wins and obtains the prize}} + \underbrace{\int_{\beta_j^{-1}(b)}^{\bar{v}} u(-b - \alpha(v_j - \beta_j(v_j))) f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ loses and pays the own bid} \\ \text{and additionally experiences spite}}} \tag{17}$$

Rearranging the FOC leads to:

$$\beta_j'(\beta_j^{-1}(b)) = \frac{(u(v - b) - u(-b - \alpha(\beta_j^{-1}(b) - \beta_j(\beta_j^{-1}(b))))f(\beta_j^{-1}(b))}{\int_0^{\beta_j^{-1}(b)} u(v - b)' f(v_j)\, dv_j + \int_{\beta_j^{-1}(b)}^{\bar{v}} u(-b - \alpha(v_j - \beta_j(v_j)))' f(v_j)\, dv_j}$$

Assuming a symmetric equilibrium bidding function, we obtain the following condition:

$$\beta_j'(v) = \frac{((v - b) - (-b - \alpha(v - b)))f(v)}{1} = (1 + \alpha)v f(v) - \alpha f(v) b \tag{18}$$

[48] We assume a monotonic and symmetric bidding function. A selfish bidder with a valuation of zero could only win if the opponent has a valuation of zero, too. As one cannot influence the payoff of the opponent there is no benefit in bidding above zero as one has to pay for this bid. Hence, zero is the best choice.

[49] Note that spite is similar but not equivalent to the negative aspect of inequality aversion. The latter would consider relative gain $\alpha \cdot (v_j - \beta_j(v_j) - \beta_i(v_j))$.

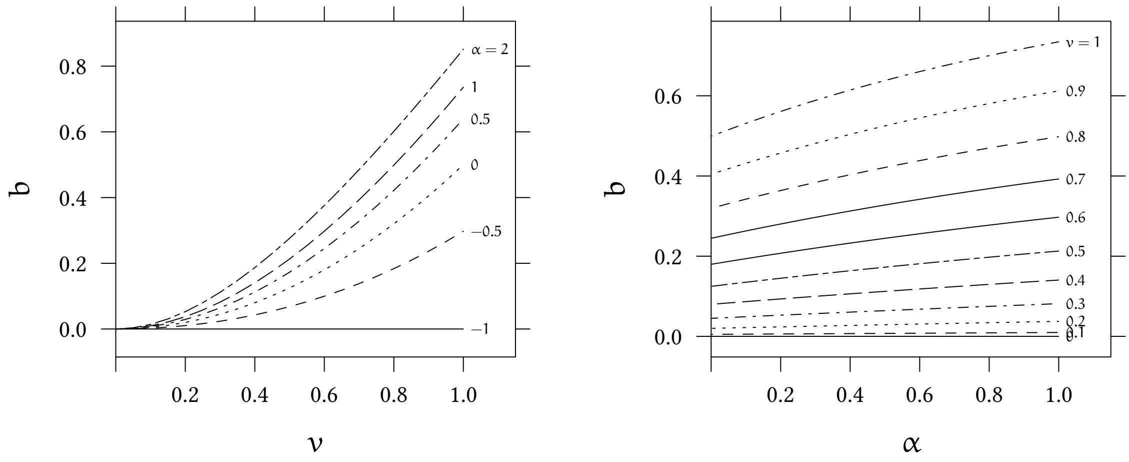


Figure 15: Equilibrium bids in first-price all-pay auctions.
Equilibrium bids in first-price all-pay auctions for different valuations v and different levels of spite α with uniform distributions of valuations (see Equation (21)).

Solving the ODE (18) with the initial value $b(0) = 0$ we obtain the symmetric equilibrium bidding function $b^{\text{I-AP}}_{\text{Spite}}$:

$$b^{\text{I-AP}}_{\text{Spite}}(v) = e^{-\alpha F(v)} \int_0^v (\alpha+1) s\, f(s) e^{\alpha F(s)} ds = \frac{\alpha+1}{\alpha}\left(v - \frac{1}{e^{\alpha F(v)}} \int_0^v e^{\alpha F(s)} ds\right) \tag{19}$$

For $\alpha = 0$, Equation (19) becomes the familiar equilibrium bidding function for all-pay auctions without spite:

$$b^{\text{I-AP}} := b^{\text{I-AP}}_{\alpha=0} = \int_0^v s\, f(s)\, ds \tag{20}$$

For uniformly distributed valuations, $F(x) = x$, we have

$$b^{\text{I-AP}}_{\text{Spite}}(v) = \frac{\alpha+1}{\alpha}\left(v + \frac{e^{-\alpha v} - 1}{\alpha}\right). \tag{21}$$

The left part of Figure 15 illustrates in particular the following:

Proposition 7. *The bidding function in the first-price all-pay auction is increasing in the bidder's valuation:*

$$\frac{db^{\text{I-AP}}_{\text{Spite}}}{dv} \geq 0$$

Proof of Proposition 7:

$$\begin{aligned}
\frac{db^{\text{I-AP}}_{\text{Spite}}}{dv} &= \frac{1}{e^{\alpha F(v)}}\left(-\alpha f(v) \int_0^v (\alpha+1) s f(s) e^{\alpha F(s)} ds + (\alpha+1) v f(v) e^{\alpha F(v)}\right) \\
&= \frac{(\alpha+1) f(v)}{e^{\alpha F(v)}} \int_0^v e^{\alpha F(s)} ds \geq 0
\end{aligned}$$

$\blacksquare$

The right part of Figure 15 illustrates the following:

Proposition 8. *Bids in the first-price all-pay auction are increasing in spite:*

$$\frac{db^{\text{I-AP}}_{\text{Spite}}}{d\alpha} \geq 0$$

Proof of Proposition 8: We want to show the following:

$$\begin{aligned}
\frac{db^{\text{I-AP}}_{\text{Spite}}}{d\alpha} &= \frac{1}{e^{\alpha F(v)}} \left(\int_0^v sf(s)e^{\alpha F(s)} \left((\alpha+1)(F(s)-F(v)) + 1 \right) ds \right) \\
&= \int_0^v sf(s) \underbrace{e^{\alpha(F(s)-F(v))} \left((\alpha+1)(F(s)-F(v)) + 1 \right)}_{:=Q(\alpha, F(v), F(s))} ds \\
&\geq 0
\end{aligned}$$

Let us rewrite $F(v) = w$ and $F(s) = z$ and therefore $F(z)^{-1} = s$ and $F(w)^{-1} = v$ are the case. Hence, $Q(\alpha, w, z) := e^{\alpha(z-w)} \left((\alpha+1)(z-w) + 1 \right)$.
When we now consider the derivative of $Q(\alpha, w, z)$ in α we see that:

$$\begin{aligned}
\frac{d(Q(\alpha, w, z))}{d\alpha} &= (-z+w)\, e^{\alpha\,(z-w)} \,(-\alpha\, z + \alpha\, w - z + w - 2) \\
&= \underbrace{(z-w)}_{\leq 0} e^{\alpha\,(z-w)} \underbrace{\left(\underbrace{(\alpha+1)}_{\leq 2} \underbrace{(z-w)}_{\geq -1} + 2 \right)}_{\geq 0} \\
&= \leq 0
\end{aligned}$$

Also considering the derivative of $Q(\alpha, w, z)$ in w we see that:

$$\begin{aligned}
\frac{d(Q(\alpha, w, z))}{dw} &= \left(-1 + (-z+w)\,\alpha^2 + (-2-z+w)\,\alpha \right) e^{\alpha\,(z-w)} \\
&= -e^{\alpha\,(z-w)} \left(1 + \alpha \underbrace{\left(\underbrace{(\alpha+1)}_{\leq 2} \underbrace{(z-w)}_{\geq -1} + 2 \right)}_{\geq 0} \right) \\
&= \leq 0
\end{aligned}$$

Our goal is to show that the following equation holds (which would be Proposition 8)

$$\int_0^{F(w)^{-1}} F(z)^{-1} Q(\alpha, w, z) dz \geq 0$$

Using the derivatives of $Q(\alpha, w, z)$ in w and in α we get:

$$\begin{aligned}
\int_0^{F(w)^{-1}} F(z)^{-1} Q(\alpha, w, z) dz &\geq \int_0^{F(w)^{-1}} F(z)^{-1} Q(1, w, z) dz \geq \int_0^{F(1)^{-1}} F(z)^{-1} Q(1, 1, z) dz \\
\int_0^{F(1)^{-1}} F(z)^{-1} Q(1, 1, z) dz &= \int_0^{F(1)^{-1}} F(z)^{-1} e^{z-1} \left((2)(z-1)+1\right) = \\
&= \int_0^{F(1)^{-1}} F(z)^{-1} \underbrace{e^{z-1} \left((2z-1)\right)}_{=Q(1,1,z)} dz
\end{aligned}$$

Considering this we see that this is positive even for the lowest possible values.

$$\int_0^1 Q(1, 1, z) dz = 3 \cdot e^{-1} - 1 \approx 0.1 \geq 0$$

Now we can also show that the function $Q(\alpha, w, z)$ is increasing in z

$$\begin{aligned}
\frac{d(Q(\alpha, w, z))}{dz} &= -\left(-1 + (-z+w)\,\alpha^2 + (-2-z+w)\,\alpha\right) e^{\alpha\,(z-w)} \\
&= e^{\alpha\,(z-w)} \left(1 + \alpha \underbrace{\left(\underbrace{(\alpha+1)}_{\leq 2} \underbrace{(z-w)}_{\geq -1} + 2 \right)}_{\geq 0} \right) \\
&= \geq 0
\end{aligned}$$

Now as we know that $F(z)^{-1}$ is an increasing function. Moreover, we we know that $\frac{d(Q(\alpha,w,z))}{dz} \geq 0$ and also $\int_0^1 Q(\alpha, w, z) dz \geq \int_0^1 Q(1, 1, z) dz \geq 0$. Thus, we conclude the following:

$$\int_0^{F(w)^{-1}} F(z)^{-1} Q(\alpha, w, z) dz \geq \int_0^{F(1)^{-1}} F(z)^{-1} e^{z-1} \left((2)(z-1)+1\right) \geq 0 \qquad \blacksquare$$

In particular bids in the first-price all-pay auction with spite ($\alpha > 0$) are larger than or equal to bids without spite ($\alpha = 0$), i.e. $b^{\text{I-AP}}_{\text{Spite}} - b^{\text{I-AP}} \geq 0$.

Proposition 9. *The difference between equilibrium bids with spite and without spite is increasing in bidder's valuation (for uniform distribution):*

$$\frac{d(b^{\text{I-AP}}_{\text{Spite}} - b^{\text{I-AP}})}{dv} \geq 0$$

Proof of Proposition 9: To prove that the deviation is increasing in valuation in the first-price winner-pay auction with uniform distribution we can use the result of (7)

$$\begin{aligned}
\frac{d(b_{\text{Spite}}^{\text{I-AP}} - b_{\text{selfish}}^{\text{I-AP}})}{dv} &= \frac{1}{e^{\alpha F(v)}}\left(-\alpha f(v)\int_0^v (\alpha+1)sf(s)e^{\alpha F(s)}ds + (\alpha+1)vf(v)e^{\alpha F(v)}\right) - vf(v) \\
&= f(v)\left(\frac{(\alpha+1)}{e^{\alpha F(v)}}\int_0^v \underbrace{e^{\alpha F(s)}}_{\geq 1} ds - v\right) \\
&= \alpha f(v)\left(\frac{(\alpha+1)}{e^{\alpha F(v)}}\left(\frac{ve^{\alpha F(v)}}{\alpha} - \int_0^v sf(s)e^{\alpha F(s)}ds\right) - \frac{v}{\alpha}\right) \\
&= \alpha f(v)\left(v - \frac{(\alpha+1)}{e^{\alpha F(v)}}\int_0^v sf(s)e^{\alpha F(s)}ds\right) \\
&= \frac{\alpha f(v)}{e^{\alpha F(v)}}\left(\underbrace{ve^{\alpha F(v)} - (\alpha+1)\int_0^v sf(s)e^{\alpha F(s)}ds}_{M}\right)
\end{aligned}$$

To see that this is indeed positive we show that the derivative of M is positive:

$$\begin{aligned}
\frac{d(M)}{dv} &= e^{\alpha F(v)} + v\alpha f(v)e^{\alpha F(v)} - (1+\alpha)vf(v)e^{\alpha F(v)} \\
\leftrightarrow &= e^{\alpha F(v)}(1 - v\cdot f(v))
\end{aligned}$$

Obviously $\frac{d(M)}{dv}$ is positive for $f(v) = 1$. We can also easily see that $M(0) = 0$. Therefore, the deviation is increasing in valuation in the first-price winner-pay auction for $\alpha \geq 0$ for uniform distribution. ■

Proposition 9 is actually quite intuitive. Consider two bidders competing for an object in the first-price winner-pay auction. For a low valuation, the probability of winning is low, too. In this situation, bidders will suffer from spite almost always. As a result, the overall value of the auction is small and bids will be small, too. If, on the other hand, valuations are high bidders will want to avoid the disutility from losing by increasing their bids. As a result, we see that when spite increases also bids increase.

B. Bids in the second-price all-pay auction

Proof of Proposition 1:

$$\begin{aligned}
\frac{db_{\text{Spite}}^{\text{II-AP}}}{dv} &= \underbrace{\frac{1+\alpha}{1-\alpha}(1-F(v))^{\frac{2\alpha-1}{1-\alpha}} f(v)}_{q\geq 0}\left(v(1-F(v))^{\frac{\alpha}{\alpha-1}} - \frac{\alpha}{1-\alpha}\int_0^v s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}\right) \\
&= q\left(v(1-F(v))^{\frac{\alpha}{\alpha-1}} - v(1-F(v))^{\frac{\alpha}{\alpha-1}} + \int_0^v (1-F(s))^{\frac{\alpha}{\alpha-1}}\right) \\
&\geq 0
\end{aligned}$$

■

Proof of Proposition 2:

$$\beta^{\text{II-AP}}_{\text{Risk}}(0) = 0$$
$$\beta^{\text{II-AP}}_{\text{RNBNE}}(0) = 0$$

Let us proof by contradiction. We know that risk averse and risk neutral bidders start at the same point. We assume for now that risk averse players have a higher slope compared to risk neutral bidders:

$$\begin{aligned}
\beta^{\text{II-AP}'}_{\text{Risk}}(\nu) &\geq \beta^{\text{II-AP}'}_{\text{RNBNE}}(\nu) \\
\frac{r(1-e^{\frac{-\nu}{r}})f(\nu)}{(1-F(\nu))} &\geq \frac{\nu f(\nu)}{(1-F(\nu))} \\
r(1-e^{\frac{-\nu}{r}}) &\geq \nu \\
(1-e^{\frac{-\nu}{r}}) &\geq \frac{\nu}{r} \qquad \text{here we use } r \geq 0 \\
(e^{\frac{\nu}{r}}-1) &\geq e^{\frac{\nu}{r}}\frac{\nu}{r} \\
(e^{m}-1) &\geq^{**} e^{m}m \qquad \text{we substitute } \frac{\nu}{r} = m \\
\underbrace{e^{m}(1-m)-1}_{L(m)} &\geq 0
\end{aligned}$$

We can show that $L(m)$ is decreasing $(\frac{\partial L(m)}{m} = -me^{m})$ in m and as $L(0) = 0$ we obtain a contradiction as $e^{m}(1-m) - 1 \leq 0 \; \forall m \in \mathbb{R}_{+}$. ■

C. Revenue

We have seen that the introduction of spite could explain overbidding in all-pay auctions. In addition, it would be interesting to see some results on revenue ranking in case of spiteful bidders.

In this paper we are only looking at two players and therefore the revenue of the seller is just two times the ex-ante expected payment, which is the bid multiplied by the probability to pay the bid:

$$\begin{aligned}
\text{Expected payment} : m(\nu) =& \text{Bid}(\nu) \cdot \text{Prob(Paying Bid)} \\
\text{Ex-ante expected payment} : \mathbb{E}[m(\nu)] :=& \text{expected revenue for one player} \\
=& \frac{1}{2} \cdot \text{expected revenue for the seller}
\end{aligned}$$

Now we can look at the revenues of the all-pay auctions with spite:

C.1. Revenue in the first-price all-pay auction

Proposition 10. *The revenue in the first-price all-pay auctions with two players is given by:*

$$R^{\text{I-AP}}_{\text{Spite}} = 2\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) = 2\int_0^1 \frac{(e^{-\alpha F(s)} - e^{-\alpha})}{\alpha}(\alpha+1)s\, f(s)e^{\alpha F(s)}ds \tag{22}$$

The revenue in the second-price all-pay auctions with two players is given by:

$$R^{\text{II-AP}}_{\text{Spite}} = 2\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}) = 2\int_0^1 2\frac{\alpha+1}{2-\alpha}s\, f(s)(1-F(s))ds \tag{23}$$

Proof of Proposition 10:

$$\begin{aligned}
R^{\text{I-AP}}_{\text{Spite}} = 2\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) &= 2\int_0^1 b^{\text{I-AP}}_{\text{Spite}} f(v)dv \\
&= 2\int_0^1 f(v)e^{-\alpha F(v)}\int_0^v (\alpha+1)s\, f(s)e^{\alpha F(s)}dsdv \\
&= 2\int_0^1\int_s^1 f(v)e^{-\alpha F(v)}dv(\alpha+1)s\, f(s)e^{\alpha F(s)}ds \\
(\text{for}\alpha \neq 0:) \quad &= 2\int_0^1 \left.\frac{e^{-\alpha F(v)}}{-\alpha}\right|_s^1 (\alpha+1)s\, f(s)e^{\alpha F(s)}ds \\
&= 2\int_0^1 \frac{(e^{-\alpha F(s)} - e^{-\alpha})}{\alpha}(\alpha+1)s\, f(s)e^{\alpha F(s)}ds
\end{aligned}$$

$$\begin{aligned}
R^{\text{II-AP}}_{\text{Spite}} = 2\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}) &= 2\int_0^1 b^{\text{II-AP}}_{\text{Spite}}(2(1-F(v)))f(v)dv \\
&= 2\int_0^1 \frac{\alpha+1}{1-\alpha}\int_0^v s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}ds(1-F(v))^{\frac{\alpha}{1-\alpha}}(2(1-F(v)))f(v)dv \\
&= 2\int_0^1\int_s^1 (1-F(v))^{\frac{1}{1-\alpha}}2f(v)dv\frac{\alpha+1}{1-\alpha}s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}ds \\
&= 2\int_0^1 \left.(1-F(v))^{\frac{2-\alpha}{1-\alpha}}2\frac{1-\alpha}{\alpha-2}\right|_s^1 \frac{\alpha+1}{1-\alpha}s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}ds \\
&= 2\int_0^1 \left((1-F(s))^{\frac{2-\alpha}{1-\alpha}}2\frac{1-\alpha}{2-\alpha}\right)\frac{\alpha+1}{1-\alpha}s\, f(s)(1-F(s))^{\frac{1}{\alpha-1}}ds \\
&= 2\int_0^1 2\frac{\alpha+1}{2-\alpha}s\, f(s)(1-F(s))ds
\end{aligned}$$

■

C.2. The impact of spite on revenue

Proposition 11. *Spite increases revenue in case of the first-price and second-price all-pay auction.*

$$\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) \geq \mathbb{E}(m_{\text{selfish}}) \tag{24}$$
$$\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}) \geq \mathbb{E}(m_{\text{selfish}}) \tag{25}$$

Proof of Proposition 11: We first compare the revenues of spiteful bidders in first-price all-pay auctions and standard-selfish revenue

$$\begin{aligned}
R^{\text{I-AP}}_{\text{Spite}} - R^{\text{selfish}} &= \\
2\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}} - m_{\text{selfish}}) &= 2\frac{\alpha+1}{\alpha}\int_0^1 s\,f(s)(1-e^{-\alpha}e^{\alpha F(s)})ds - 2\int_0^1 s\,f(s)(1-F(s))ds \\
&= 2\int_0^1 s\,f(s)(\frac{\alpha+1}{\alpha} - \frac{\alpha+1}{\alpha}e^{\alpha(F(s)-1)} - 1 + F(s))ds \\
&= 2\int_0^1 s\,f(s)(\frac{1}{\alpha} - \frac{\alpha+1}{\alpha}e^{\alpha(F(s)-1)} + F(s))ds
\end{aligned}$$

It is quite straightforward that this difference is positive as we know that $b^{\text{I-AP}}_{\text{Spite}} \geq b^{\text{I-AP}}$. To see this:

$$\begin{aligned}
& b^{\text{I-AP}}_{\text{Spite}} && \geq b^{\text{I-AP}} \\
\rightarrow\quad & f(v)\cdot b^{\text{I-AP}}_{\text{Spite}} && \geq f(v)\cdot b^{\text{I-AP}} \\
\rightarrow\quad & \textstyle\int_0^1 f(v)\cdot b^{\text{I-AP}}_{\text{Spite}}\,dv && \geq \int_0^1 f(v)\cdot b^{\text{I-AP}}\,dv \\
\rightarrow\quad & \mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) && \geq \mathbb{E}(m_{\text{selfish}}) \\
\rightarrow\quad & 2\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) && \geq 2\mathbb{E}(m_{\text{selfish}}) \\
& R^{\text{I-AP}}_{\text{Spite}} && \geq R^{\text{selfish}}
\end{aligned}$$

We now compare the revenues of spiteful bidders in second-price all-pay auctions and standard-selfish revenue

$$\begin{aligned}
\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}} - m_{\text{selfish}}) &= 2\int_0^1 2\frac{\alpha+1}{2-\alpha}s\,f(s)(1-F(s))ds - 2\int_0^1 s\,f(s)(1-F(s))ds \\
&= 2\int_0^1 s\,f(s)(1-F(s))\left(2\frac{\alpha+1}{2-\alpha} - 1\right)ds
\end{aligned}$$

As we are interested just whether the difference is positive we check only: $2\frac{\alpha+1}{2-\alpha} - 1 \geq 0 \leftrightarrow 2\alpha + 2 \geq 2 - \alpha \leftrightarrow 3\alpha \geq 0$. Obviously, $\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}} - m_{\text{selfish}})$ is positive for all $\alpha \geq 0$.
$\Rightarrow R^{\text{II-AP}}_{\text{Spite}} \geq R^{\text{selfish}} \qquad \forall\alpha \geq 0$ ■

C.3. Revenue with spite under the different auction formats

We have seen that the revenues are higher if bidders are experiencing spite relative to the selfish case. In the following we want to rank revenues for the different auction formats (first-price and second-price winner-pay and all-pay auctions, respectively) for spiteful bidders.

Proof of Proposition 5: We will prove the different parts of Proposition 5 one after the other. In Lemma 1 we will show that $\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}(v)) \geq \mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}(v))$. In Lemma 2 we show that $\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}(v)) \geq \mathbb{E}(m^{\text{I}}_{\text{Spite}}(v))$. Finally we will show in Lemma 3 that $\mathbb{E}(m^{\text{I}}_{\text{Spite}}(v)) \geq \mathbb{E}(m_{\text{selfish}}(v)$ which completes the proof of Proposition 5.

Let us first look at the revenues of the all-pay auctions.

Lemma 1. *The expected revenue of the second-price all-pay auction in case of spiteful bidders is higher than the expected revenue of the first-price all-pay auction with spiteful bidders.*

$$\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}}) \leq \mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}) \tag{26}$$

Proof of Lemma 1:

$$\begin{aligned}
\mathbb{E}(m^{\text{I-AP}}_{\text{Spite}} - m^{\text{II-AP}}_{\text{Spite}}) &= \int_0^1 \frac{(e^{-\alpha F(s)} - e^{-\alpha})}{\alpha}(\alpha+1)s\, f(s) e^{\alpha F(s)} ds - \int_0^1 2\frac{\alpha+1}{2-\alpha} s\, f(s)(1-F(s))ds \\
&= (\alpha+1)\int_0^1 s\, f(s)\left(\frac{1}{\alpha} - \frac{1e^{\alpha F(s)}}{\alpha e^{\alpha}} - \frac{2}{2-\alpha}(1-F(s))\right) ds \\
&= (\alpha+1)\int_0^1 s\, f(s)\left(\frac{(2)e^{\alpha} - 3\alpha e^{\alpha} - 2e^{\alpha F(s)} + e^{\alpha F(s)}\alpha + 2\alpha F(s) e^{\alpha}}{(2-\alpha)(\alpha)e^{\alpha}}\right) ds \\
&= (\alpha+1)\int_0^1 s\, f(s)\left(\frac{(\alpha-2)e^{\alpha F(s)} + 2(1+(F(s)-\frac{3}{2})\alpha)e^{\alpha}}{(2-\alpha)(\alpha)e^{\alpha}}\right) ds \\
&= (\alpha+1)\int_0^1 s\, f(s)\underbrace{\left(\frac{(\alpha-2)e^{\alpha(F(s)-1)} + 2(1+(F(s)-\frac{3}{2})\alpha)}{(2-\alpha)(\alpha)}\right)}_{:=n(F(s),\alpha)} ds
\end{aligned}$$

If we could show that $n(F(s), \alpha) \leq 0$ it would be obvious that the difference is negative. Therefore, we show that this is negative by contradiction.

$$\begin{aligned}
& n(F(s),\alpha) && > 0 \rightarrow \frac{(\alpha-2)e^{\alpha(F(s)-1)} + 2(1+(F(s)-\frac{3}{2})\alpha)}{(2-\alpha)(\alpha)} > 0 \\
\leftrightarrow\quad & \tfrac{(\alpha-2)}{2} && > -e^{-\alpha(F(s)-1)}(1+(F(s)-\frac{3}{2})\alpha) \\
\rightarrow\quad & \tfrac{(\alpha-2)}{2}e^{-1+\frac{1}{2}\alpha} && > -e^{(1+(F(s)-\frac{3}{2})\alpha)}(1+(F(s)-\frac{3}{2})\alpha) \\
\leftrightarrow\quad & \mathcal{W}(\tfrac{(\alpha-2)}{2}e^{-1+\frac{1}{2}\alpha}) && > -(1+(F(s)-\frac{3}{2})\alpha) \\
\leftrightarrow\quad & F(s) && > \frac{3}{2} - \frac{1}{\alpha} - \frac{\mathcal{W}(\frac{(\alpha-2)}{2}e^{\frac{(\alpha-2)}{2}})}{\alpha} \\
\leftrightarrow\quad & F(s) && > \frac{3}{2} - \frac{1}{\alpha} - \frac{\frac{(\alpha-2)}{2}}{\alpha} = 1
\end{aligned}$$

Whereas $\mathcal{W}(.)$ represents the Lambert W-function. ■

Next we are going to look at the expected revenues of the winner-pay vs. all-pay auction:

Lemma 2. *Expected revenue with the first-price all-pay auction is higher than in the first-price winner-pay auction if bidders are spiteful.*

$$\mathbb{E}(m_{\text{Spite}}^{\text{I-AP}}) \geq \mathbb{E}(m_{\text{Spite}}^{\text{I}}) \tag{27}$$

Expected revenue with the second-price all-pay auction is higher than in the first-price winner-pay auction if bidders are spiteful.

$$\mathbb{E}(m_{\text{Spite}}^{\text{II-AP}}) \geq \mathbb{E}(m_{\text{Spite}}^{\text{I}}) \tag{28}$$

Proof of Lemma 2:

$$\begin{aligned}
R_{\text{Spite}}^{\text{I}} - R_{\text{Spite}}^{\text{I-AP}} &= 2\mathbb{E}(m_{\text{Spite}}^{\text{I}} - m_{\text{Spite}}^{\text{I-AP}}) \\
&= 2\frac{1+\alpha}{1-\alpha}\int_0^1 (s\, f(s)(F(s)^{\alpha} - F(s)) \\
&\quad -2\int_0^1 \frac{(e^{-\alpha F(s)} - e^{-\alpha})}{\alpha}(\alpha+1)s\, f(s)e^{\alpha F(s)}ds \\
&= 2(1+\alpha)\int_0^1 s\, f(s)\underbrace{\left(\frac{F(s)^{\alpha} - F(s)}{1-\alpha} - \frac{1-e^{\alpha(F(s)-1)}}{\alpha}\right)}_{:=g(F(s),\alpha)} ds
\end{aligned}$$

Let us now set $g(F(s),\alpha) := g(k,\alpha)$:

$$\begin{aligned}
\frac{dg(k,\alpha)}{dk} &= \frac{\frac{\alpha k^{\alpha}}{k} - 1}{1-\alpha} + e^{\alpha(k-1)} \\
\frac{\frac{dg(k,\alpha)}{dk}}{dk} &= \alpha\left(e^{\alpha(k-1)} - k^{\alpha-2}\right)
\end{aligned}$$

Now we want to prove that the second derivative of $g(k,\alpha)$ is negative. Hence, we assume the opposite.

$$\begin{aligned}
& \alpha\left(e^{\alpha(k-1)} - k^{\alpha-2}\right) && > 0 \\
\rightarrow\quad & e^{\alpha(k-1)}k^{2-\alpha} && > 1 \\
\rightarrow\quad & e^{\alpha(k-1)}k > e^{\alpha(k-1)}k^{2-\alpha} && > 1 \\
\rightarrow\quad & e^{\alpha(k)}k\alpha && > e^{\alpha}\alpha \\
\rightarrow\quad & k\alpha && > \mathcal{W}(e^{\alpha}\alpha) = \alpha \\
\rightarrow\quad & k && > 1
\end{aligned}$$

Whereas $\mathcal{W}(.)$ represents the Lambert W-function.

Thus, we know that $\max(k) = 1$ and hence $k \not> 1$ and hence we know that $\frac{\frac{dg(k,\alpha)}{dk}}{dk} \leq 0$.

$$\begin{aligned}
& \left(\frac{\frac{dg(k,\alpha)}{dk}}{dk}\right) \leq 0 && \rightarrow \quad \min(\frac{dg(k,\alpha)}{dk}) = \frac{dg(k,\alpha)}{dk}|_{k=1} = 0 \\
\Rightarrow\quad & \frac{dg(k,\alpha)}{dk} \geq 0 && \rightarrow \quad \max(g(k,\alpha)) = g(k,\alpha)|_{k=1} = 0 \\
\Rightarrow\quad & g(k,\alpha) \leq 0
\end{aligned}$$

Therefore :

$$2(1+\alpha)\int_0^1 s\,f(s)\underbrace{\left(\frac{F(s)^{\alpha}-F(s)}{1-\alpha}-\frac{1-e^{\alpha(F(s)-1)}}{\alpha}\right)}_{=g(s,\alpha)\leq 0} ds \leq 0$$

$$\Rightarrow \quad \mathbb{E}(m^{\text{I}}_{\text{Spite}}-m^{\text{I-AP}}_{\text{Spite}}) \leq 0 \Rightarrow \qquad R^{\text{I-AP}}_{\text{Spite}} \geq R^{\text{I}}_{\text{Spite}}$$

The second part of the lemma is just straightforward, as we know due to Lemma 1 that the revenue of the second-price all-pay auction is higher than the revenue of the first-price all-pay auction. Thus, we can easily conclude that

$$\mathbb{E}(m^{\text{II-AP}}_{\text{Spite}}) \geq \mathbb{E}(m^{\text{I}}_{\text{Spite}}) \Rightarrow \qquad R^{\text{II-AP}}_{\text{Spite}} \geq R^{\text{I}}_{\text{Spite}} \qquad \blacksquare$$

Lemma 3. *Spite increases revenue in case of the first-price winner-pay auction.*

$$\mathbb{E}(m^{\text{I-WP}}_{\text{Spite}}) \geq \mathbb{E}(m_{\text{selfish}}) \tag{29}$$

Proof of Lemma 3: This Lemma is shown in Morgan et al. (2003) as part of Proposition 4.4 and is proved in Appendix A.4.

Summarizing our results we have seen that in theory spiteful bidders would bid more than selfish bidders. Now, we have seen that this behavior would lead to more revenue for the seller. Also, we have seen that the revenue equivalence principle is not applicable with spiteful bidders, and the result is that all-pay auctions are yielding higher revenue than the first-price winner-pay auction. Moreover, we have seen that the second-price all-pay auctions yield even higher revenue than the first-price all-pay auction.

C.4. Revenue with risk aversion

Proof of Proposition 6: The proof follows easily from the following two lemmas:

Lemma 4. *A seller's revenue in the second-price all-pay auction is lower if bidders are risk averse.*

Lemma 5. *A seller's revenue in the first-price winner-pay auction is higher if bidders are risk averse.*

The first Lemma is obvious as we already have shown that risk averse bidders are underbidding in the second-price all-pay auction and hence, a bidder has a smaller expected payment and hence, a seller has a smaller expected revenue.

The second Lemma is also straightforward as a seller has a higher expected revenue if bidders overbid (see Riley and Samuelson, 1981, Proposition 4). ■

C.5. Expected payoff with spite

To investigate whether it would be ex-ante individually rational for a bidder in our auction to participate in the auction we derive the expected utility for our bidders. The expected utility for a spiteful bidder is given by the following:

$$\mathbb{E}(b^*, v) = \underbrace{\int_0^v u(v - b^*(v_j))\, f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ wins and obtains the prize} \\ \text{and pays the loser's bid}}} + \underbrace{\int_v^1 u(-b^* - \alpha(v_j - b^*))\, f(v_j)\, dv_j}_{\substack{\text{bidder } i \text{ loses and pays the own bid} \\ \text{and additionally experiences spite}}}$$

where b^* is given by Equation (4). For simplicity, we assume a uniform distribution as participants of our experiment were given this distribution function. Thus, the expected utility of a risk neutral spiteful bidder is given by:

$$\begin{aligned}
\mathbb{E}(b^*, v) = &\int_0^v v - \frac{(\alpha+1)}{\alpha(2\alpha-1)} \left((1-\alpha)\left((1-v_j)^{\frac{\alpha}{1-\alpha}} - 1\right) + v_j\alpha\right) dv_j \\
&+ \int_v^1 -\frac{(\alpha+1)}{\alpha(2\alpha-1)} \left((1-\alpha)\left((1-v)^{\frac{\alpha}{1-\alpha}} - 1\right) + v\alpha\right) - \alpha(v_j - b)\, dv_j \\
=& v^2 - \frac{1}{2}\frac{v^2(\alpha+1)}{2\alpha-1} + \frac{(\alpha+1)(1-\alpha)v}{\alpha(2\alpha-1)} - \frac{(\alpha+1)(1-\alpha)^2\left(1-(1-v)^{\frac{1}{1-\alpha}}\right)}{\alpha(2\alpha-1)} \\
&- \frac{1}{2}\alpha(1-v^2) - \frac{(\alpha+1)\left((1-\alpha)\left((1-v)^{\frac{\alpha}{1-\alpha}} - 1\right) + v\alpha\right)(1-v)}{\alpha(2\alpha-1)} \\
&+ \frac{(\alpha+1)\left((1-\alpha)\left((1-v)^{\frac{\alpha}{1-\alpha}} - 1\right) + v\alpha\right)(1-v)}{(2\alpha-1)} \\
=& \frac{1}{\alpha(2\alpha-1)}\Bigg[\alpha(2\alpha-1)v^2 - \frac{\alpha v^2(\alpha+1)}{2} + (\alpha+1)(1-\alpha)v \\
&-(\alpha+1)(1-\alpha)^2\left(1-(1-v)^{\frac{1}{1-\alpha}}\right) - \frac{\alpha^2(2\alpha-1)(1-v^2)}{2} - (1+\alpha)(\alpha-1)^2(1-v)^{\frac{1}{1-\alpha}} \\
&+(1+\alpha)(\alpha-1)^2(1-v) + v\alpha(1+\alpha)(\alpha-1) - v^2\alpha(1+\alpha)(\alpha-1)\Bigg] \\
=& \frac{1}{\alpha(2\alpha-1)}\Bigg[v^2\left((\alpha)(2\alpha-1) - \frac{\alpha(\alpha+1)}{2} - \alpha(\alpha^2-1)\right) - \frac{\alpha^2(2\alpha-1)}{2} \\
&+ \frac{v^2\alpha^2(2\alpha-1)}{2} + (1+\alpha)v(\alpha-1)^2 + (1-v)(1+\alpha)v(\alpha-1)^2 - (1+\alpha)(\alpha-1)^2\Bigg] \\
=& \frac{1}{\alpha(2\alpha-1)}\Bigg[\frac{v^2}{2}\left((\alpha^2)(2\alpha-1) - \alpha(\alpha+1) - 2\alpha(\alpha^2-1) + 2(\alpha)(2\alpha-1)\right) \\
&-v\left((1+\alpha)v(\alpha-1)(\alpha-1-(\alpha-1))\right) - \frac{\alpha^2}{2}(2\alpha-1)\Bigg] \\
=& \frac{v^2}{2} - \frac{\alpha}{2}
\end{aligned}$$

It is obviously evident that a bidder without spite would always have a positive utility. A spiteful bidder, however, might obtain a negative utility if the own valuation is relatively small (as the negative utility of the opponent winning kicks in). To see whether a bidder would choose to enter the auction if the bidder would have the option – which was not the case in our experiment, as all bidders had to take part – we look at the ex-ante utility.

Therefore, we study the expected utility over all possible valuations:

$$\begin{aligned}\mathbb{E}^{\text{Ex-ante}}(b^*, v) &= \int_0^1 \mathbb{E}(b^*, v) dv \\ &= \int_0^1 \frac{v^2}{2} - \frac{\alpha}{2} dv = \frac{1}{6} - \frac{\alpha}{2}\end{aligned}$$

We can easily see that a bidder with spite factor $\alpha < \frac{1}{3}$ would decide to enter the auction. All bidders more spiteful than that would decide to abstain if given the chance.

D. Measuring preferences for risk and spitefulness

D.1. Risk preferences

The lotteries for the Holt and Laury (2002) task are shown in Table 4. Details of the implementation are illustrated in Appendix G.1, Second Task (B).

D.2. Spitefulness – Marcus et al. (2014)

The measure of Marcus et al. (2014) is based on a rating of 17 statements. Participants are asked to indicate their agreement on a scale between 1 and 5. Higher scores on the scale indicate more spitefulness. Marcus et al. (2014) propose to use the average of the stated agreements as a measure for spitefulness.

- I would be willing to take a punch if it meant that someone I did not like would receive two punches.
- I would be willing to pay more for some goods and services if other people I did not like had to pay even more.
- If I was one of the last students in a classroom taking an exam and I noticed that the instructor looked impatient, I would be sure to take my time finishing the exam just to irritate him or her.
- If my neighbor complained about the appearance of my front yard, I would be tempted to make it look worse just to annoy him or her.
- It might be worth risking my reputation in order to spread gossip about someone I did not like.
- If I am going to my car in a crowded parking lot and it appears that another driver wants my parking space, then I will make sure to take my time pulling out of the parking space.
- I hope that elected officials are successful in their efforts to improve my community even if I opposed their election. (reverse scored)
- If my neighbor complained that I was playing my music too loud, then I might turn up the music even louder just to irritate him or her, even if meant I could get fined.
- I would be happy receiving extra credit in a class even if other students re-

ceived more points than me. (reverse scored)

- Part of me enjoys seeing the people I do not like fail even if their failure hurts me in some way.
- If I am checking out at a store and I feel like the person in line behind me is rushing me, then I will sometimes slow down and take extra time to pay.
- It is sometimes worth a little suffering on my part to see others receive the punishment they deserve.
- I would take on extra work at my job if it meant that one of my co-workers who I did not like would also have to do extra work.
- If I had the opportunity, then I would gladly pay a small sum of money to see a classmate who I do not like fail his or her final exam.
- There have been times when I was willing to suffer some small harm so that I could punish someone else who deserved it.
- I would rather no one get extra credit in a class if it meant that others would receive more credit than me.
- If I opposed the election of an official, then I would be glad to see him or her fail even if their failure hurt my community.

D.3. Spitefulness – Own Measure

Our own spite measure is assessing spite similar to the social value orientation task of Murphy et al. (2011) and Murphy and Ackerman (2014). In their slider task participants are presented with 6 (or 15, if inequality aversion is also measured) sets of allocations. Each set contains 9 allocations. Each allocation determines the own payoff and the payoff of the other participant. Participants have to choose a preferred allocation for each set.

Similarly, our spite measure uses six sets of allocations. As in Murphy et al. (2011) and Murphy and Ackerman (2014), each set contains 9 allocations. An overview of the six sets is shown in Figure 5.

The leftmost allocation is always the non-spiteful allocation and the rightmost allocation is always the maximally spiteful allocation. In the experiment each set was shown on a separate screen. Two sets were presented in reverse order.

Each of the six tasks is supposed to measure one feature of spite. The sets IA1 and IA2 are measuring spite when it is behaviorally in line with inequality aversion. A decision maker with positive concerns for social efficiency would choose the allocation with the highest payoff for the other player since this choice also maximizes the own payoff. A spiteful person but also an inequality averse person would choose possibly a different allocation. In IA1 being spiteful has no cost. Decision makers get 70 ECU for sure and can basically reduce the payoff of the opponent. In IA2 spitefulness has a cost. In both IA1 and IA2 it may be that the motivation of the decision maker of not maximizing the payoff of the other player could be to either harm the other (spite) or to decrease the overall inequality.

RG1 and RG2 are measuring spite when spite is behaviorally in line with relative gain. Again, a decision maker with positive concerns for social efficiency would choose the allo-

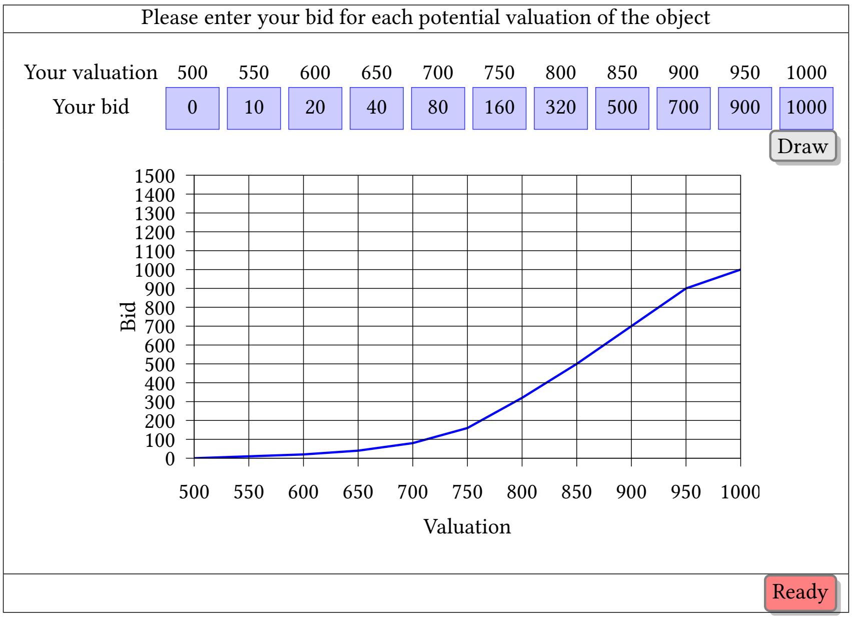


Figure 16: Interface of the Kimbrough and Reiss (2012)-spite measure.
Imputing the bidding function for the possible valuations between 500 and 1000. The bidding function is drawn after the input of the respective bids.

cation with the highest payoff for the other player since this choice also maximizes the own payoff. In RG1 a person who deviates from this choice is considered spiteful as this person decreases the payoff of the opponent. However, this behavior would also be in line with the behavior of a bidder who wants to have relativly better payoff compared to the opponent (which is often considered spite). RG2 is a variant of RG1 where the spiteful choice is costly.

In PS1 and PS2 the efficient outcome implies already a positive relative standing of the decision maker who can only decrease the payoff of the other player. We take the last two sets as extreme spite. PS2 is a variant of PS1 where the spiteful choice is costly.

The allocation of the overall spite in this measure can be seen in Figure 4 (on the right).

The decisions of the individual set can be seen in Table 5.

D.4. Spitefulness – Kimbrough and Reiss (2012)

In the original paper by Kimbrough and Reiss (2012) participants were matched into groups of three and played 16 rounds of a second-price winner-pay auction. Participants would bid for an object for which they had an individual induced value $v \sim U[500, 1000]$. After the auction participants did a real effort task. Thereafter, participants learned whether they had won or lost the auction. In a next (and crucial) step, participants could increase their bid from the earlier auction. They also had a possibility to buy the object they were competing for at a random price $p \sim U[300, 500]$ if they lost.

We change some aspects of Kimbrough and Reiss (2012)'s design. We excluded the outside option. We also excluded the real effort task. We also use the strategy method to elicit one bid

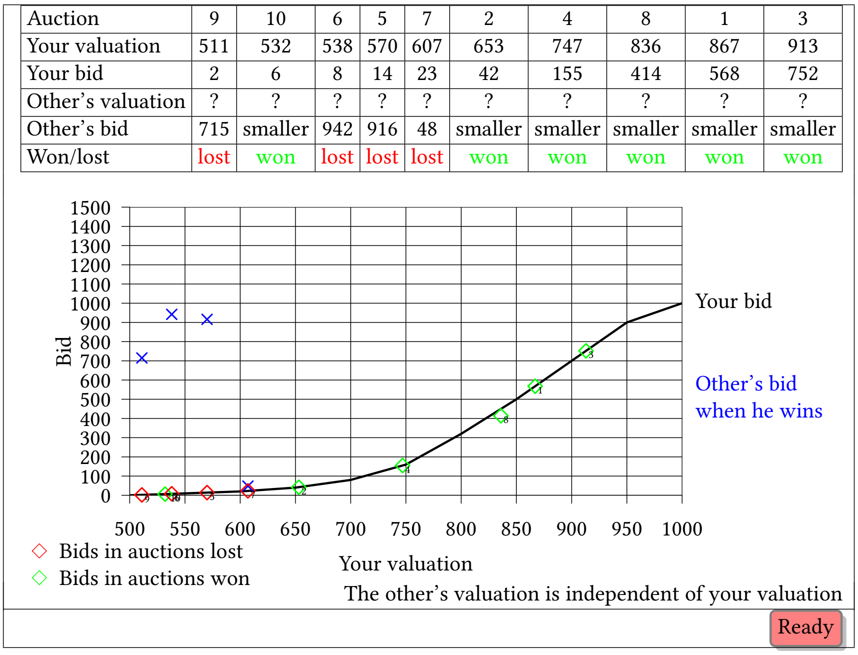


Figure 17: Interface of the feedback of each auction.
Mapping the 10 random valuations and the respective bids on the bidding function. Additionally subjects could see the opponent's bid (if the opponent won) and whether they won or lost.

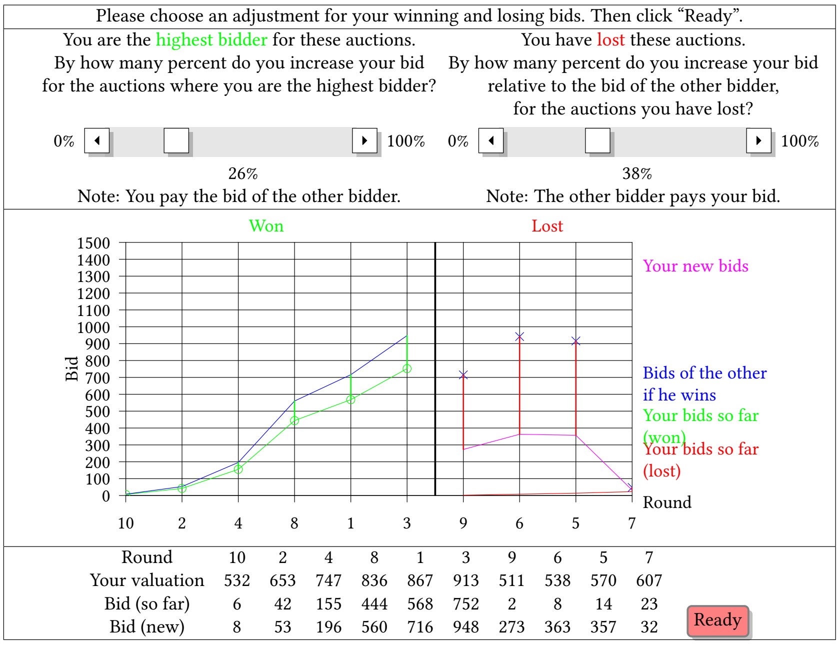


Figure 18: Interface of the bid adaptation.
To reduce the demand effect participants were allowed to increase their losing but also the winning bid. Auctions were ordered so that participants made decisions for auctions they had won in the left part of the screen and for auctions they had lost in the right part.

function for all auctions. Furthermore, we measure the willingness to pay for the adaptation of the bid. All in all, our measure consists of the following four stages:

Stage 1 Participants ($I_{\{1,2\}}$) submit an initial bid function ($B_{I_{\{1,2\}}}(v)$). Here we use the strategy method (see Figure 16). We present participants with the possible valuations between 500 and 1000 in steps of 50. They were asked to indicate their bid for each valuation .

Stage 2 10 random valuations with $v \sim U[500, 1000]$ were drawn for each participant. For each participant we use their bid function to determine the bid for each valuation. Each valuation and bid of each pair represents one auction. Participants were then informed about the highest bid and the winner in each of the 10 auctions (see Figure 17).

Stage 3 Participants were asked separately for the auctions they had lost and for the auctions they had won by how much they wanted to increase their bids. They could increase their bids by any percentage between 0 and 100% of the difference between winning and losing bid. Hence, the outcome of the auction could not be affected by the final bids. In any case, the initial bids still determined who had won which auction. The final bids only determined how much the winner needed to pay. The interface is shown in Figure 18.[50]

Stage 4 We essentially use a second-price winner-pay auction to elicit the individual willingness to pay for the adjustment from Stage 3. Participants were randomly matched into pairs with a new partner. They were asked to state how much they were willing to pay for their final bid to be implemented. For each pair the final bids of the person who stated a higher willingness to pay were implemented. That participants had to pay the willingness to pay of their partner from stage 4. Since we use a second-price winner-pay auction it is a dominant strategy for participants to reveal the true willingness to pay for the adjustment of bids. Here, we do not use this data as this stage is arguable rather complicated for subjects to grasp.

E. Matching groups

Most matching groups had a size of 6 participants. Details can be found in Table 6.

F. Further regressions

F.1. Estimating bidding behavior in the second-price all-pay auction

In the main part of the paper we estimated the overbidding behavior for the second-price all-pay auction. In this subsection we will estimate the bidding behavior directly. To estimate

[50] An indicator, that there may be a demand effect existing (or participants did not fully understood this part) is that 67% of the participants increased their bid also in the winning case. It may also be, that participants wanted to ensure that they won or they experienced joy of winning—but in any case behavior can be driven by these motivations only if the task is not completely understood.

the bidding behavior we will use a mixed-effects model, as spite, risk, social value orientation (SVO) etc. are fixed effects but the individuals and the matching-group are random effects. In line with the overbidding, we expect increased spite will will be associated with higher bids for intermediate valuations. We compare five different models which differ only in the controls $C_1, \ldots, C_5$.

$$\begin{aligned}
\mathrm{Bid}_{i,t,j,\nu} =& \beta_0 + \beta_1 \mathrm{Period} + \beta_2 \nu_{[0,50]} + \beta_3 \nu_{[50,100]} + \zeta_{i,j} + \eta_j + \epsilon_{i,j,k,l} + C_M \\
C_1 =& 0 \\
C_2 =& \beta_4 \mathrm{Spite}_i + \beta_5 \mathrm{Spite}_i \times \nu_{[0,50]} + \beta_6 \mathrm{Spite}_i \times \nu_{[50,100]} \\
C_3 =& C_2 + \beta_7 \mathbb{1}_{\mathrm{Gender}=\female} + \beta_8 \mathrm{Risk}_i + \beta_9 \mathrm{rivalry}_i + \beta_{10} \mathrm{SVO}_i + \beta_{11} \mathrm{IA}_i \\
C_4 =& \beta_{12} \mathrm{Risk}_i + \beta_{13} \mathrm{Risk}_i \times \nu_{[0,50]} + \beta_{14} \mathrm{Risk}_i \times \nu_{[50,100]} \\
C_5 =& C_4 + \beta_{15} \mathbb{1}_{\mathrm{Gender}=\female} + \beta_{16} \mathrm{Spite}_i + \beta_{17} \mathrm{rivalry}_i + \beta_{18} \mathrm{SVO}_i + \beta_{19} \mathrm{IA}_i
\end{aligned} \tag{30}$$

where $\zeta_{i,j}$ is a random effect for bidder i in group j, η_j is a random effect for group j, and $\epsilon_{i,j,k,l}$ is the residual. $\nu_{[0,50]}(\nu)$ and $\nu_{[50,100]}(\nu)$ are defined in Equation (14) and (15) above.

	C_1	C_2	C_3	C_4	C_5
Period	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)
$\nu_{[0,50]}$	30.63^{***} (0.86)	30.63^{***} (0.86)	30.63^{***} (0.86)	42.82^{***} (3.14)	42.82^{***} (3.14)
$\nu_{[50,100]}$	33.79^{***} (0.86)	33.79^{***} (0.86)	33.79^{***} (0.86)	32.17^{***} (3.14)	32.17^{***} (3.14)
Spite		4.06^{*} (1.70)	4.73^{*} (1.90)		4.00^{*} (1.89)
Spite $\times\ \nu_{[0,50]}$		1.49^{**} (0.47)	1.49^{**} (0.47)		
Spite $\times\ \nu_{[50,100]}$		-1.18^{*} (0.47)	-1.18^{*} (0.47)		
Risk			-3.41^{*} (1.71)	-4.49^{*} (1.78)	-4.02^{*} (1.72)
Risk $\times\ \nu_{[0,50]}$				-1.99^{***} (0.49)	-1.99^{***} (0.49)
Risk $\times\ \nu_{[50,100]}$				0.27 (0.49)	0.27 (0.49)
Male			-19.07^{**} (6.25)		-19.07^{**} (6.25)
Rivalry			-0.62 (3.23)		-0.62 (3.23)
SVO			0.40 (0.25)		0.40 (0.25)
IA			-0.15 (0.20)		-0.15 (0.20)
Constant	58.79^{***} (3.19)	58.77^{***} (3.16)	96.76^{***} (27.28)	86.20^{***} (11.29)	100.53^{***} (27.32)
Observations	23,760	23,760	23,760	23,760	23,760
Log Likelihood	$-120,475.50$	$-120,466.70$	$-120,452.50$	$-120,460.60$	$-120,446.90$
Akaike Inf. Crit.	240,965.00	240,953.30	240,935.00	240,941.20	240,923.90
Bayesian Inf. Crit.	241,021.50	241,034.10	241,056.10	241,022.00	241,045.00
Notes:	$^{+}: p < 0.1$; $^{*}: p < 0.05$; $^{**}: p < 0.01$; $^{***}: p < 0.001$;				

Table 7: Estimation of Equation (30).

Spite is the sum of the three (normalized) spite measures. IA is the sum of the (normalized) inequality aversion score obtained from the slider measure and the (normalized) score obtained from inequality allocation of our own spite measure.

Estimation results are shown in Table 7. It can be seen that spite has a significant positive effect on the bidding behavior for small valuations. This is in line with theory: with increasing spite one would find more overbidding for small valuations. For high valuations ($v \in [50, 100]$) spite has a negative and significant effect.

Concerning risk, we can see that increasing risk aversion has the predicted effect for small valuations. This is also in line with theory on risk averse bidding. For large valuations the interaction of Risk and $v_{[50,100]}$ is small and not significant.

Obviously valuations also have a significant and positive effect on bids. Furthermore, female bidders bid significantly more than men. The decrease in bidding over the rounds could be interpreted as a learning effect of overbidding.

Result 4.1. *Spite has a significant positive effect on bids for intermediate valuations.*

Result 4.2. *Risk has a significant negative effect on bids.*

F.2. Estimation results for Equation (13) with alternative spline implementations

Table 9, 10 and 11 show the estimation results for Equation (13) with B-Splines, cyclic cubic splines and P-splines. Table 8 shows also the estimation results for Equation (13), however, instead of using a spline we use piece-wise linear splines. It is evident that the results are robust to these alternative implementations.

	C'_1	C'_2	C'_3	C'_4	C'_5
Period	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)
Valuation$_{25}$	13.59^{***} (1.14)	13.59^{***} (1.14)	13.59^{***} (1.14)	19.68^{***} (1.91)	19.68^{***} (1.91)
Valuation$_{50}$	14.24^{***} (0.95)	14.24^{***} (0.95)	14.24^{***} (0.95)	26.42^{***} (3.21)	26.42^{***} (3.21)
Valuation$_{75}$	-16.50^{***} (1.02)	-16.50^{***} (1.02)	-16.50^{***} (1.02)	-5.13^{+} (2.69)	-5.13^{+} (2.69)
Valuation$_{100}$	-95.69^{***} (1.03)	-95.69^{***} (1.03)	-95.69^{***} (1.03)	-85.13^{***} (2.95)	-85.13^{***} (2.95)
Spite	3.33^{*} (1.69)	4.06^{*} (1.70)	4.73^{*} (1.90)		4.00^{*} (1.89)
Spite $\times$ $v_{[0,50]}$		1.49^{**} (0.48)	1.49^{**} (0.48)		
Spite $\times$ $v_{[50,100]}$		-1.18^{*} (0.48)	-1.18^{*} (0.48)		
Risk			-3.41^{*} (1.70)	-4.49^{*} (1.78)	-4.02^{*} (1.72)
Risk $\times$ $v_{[0,50]}$				-1.99^{***} (0.50)	-1.99^{***} (0.50)
Risk $\times$ $v_{[50,100]}$				0.27 (0.50)	0.27 (0.50)
Male			-19.07^{**} (6.25)		-19.07^{**} (6.25)
Rivalry			-0.62 (3.23)		-0.62 (3.23)
SVO			0.40 (0.25)		0.40 (0.25)
IA			-0.15 (0.20)		-0.15 (0.20)
Constant	27.82^{***} (3.21)	27.82^{***} (3.21)	65.81^{*} (27.29)	43.07^{***} (11.36)	57.40^{*} (27.35)
Observations	23,760	23,760	23,760	23,760	23,760
Log Likelihood	$-120{,}829.50$	$-120{,}824.10$	$-120{,}810.00$	$-120{,}818.30$	$-120{,}804.60$
Akaike Inf. Crit.	241,679.00	241,672.30	241,653.90	241,660.60	241,643.20
Bayesian Inf. Crit.	241,759.70	241,769.20	241,791.20	241,757.50	241,780.50
Notes:	$^{+}: p < 0.1$;	$^{*}: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 8: Estimation results for Equation (13) (overbidding) with piece wise linear splines. The table shows estimation results for the different models C'_1, C'_2,C'_3, C'_4, and C'_5. Splines have knots at valuations 25, 50, and 75 (Valuation$_k = \max(0, 1 - |v - k|/25)$). Spite is the sum of the three spite measures. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

	C'_1	C'_2	C'_3	C'_4	C'_5
Period	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)	-0.40^{***} (0.05)
Valuation_{33}	31.14^{***} (2.25)	31.14^{***} (2.25)	31.14^{***} (2.25)	29.95^{***} (3.38)	29.95^{***} (3.38)
Valuation_{66}	35.25^{***} (1.66)	35.25^{***} (1.66)	35.25^{***} (1.66)	37.57^{***} (3.43)	37.57^{***} (3.43)
Valuation_{100}	-93.63^{***} (1.10)	-93.63^{***} (1.10)	-93.63^{***} (1.10)	-83.08^{***} (2.99)	-83.08^{***} (2.99)
Spite		4.06^{*} (1.70)	4.73^{*} (1.90)		4.00^{*} (1.89)
Spite $\times\ \nu_{[0,50]}$		1.49^{**} (0.48)	1.49^{**} (0.48)		
Spite $\times\ \nu_{[50,100]}$		-1.18^{*} (0.48)	-1.18^{*} (0.48)		
Risk			-3.41^{*} (1.70)	-3.51^{*} (1.77)	-3.05^{+} (1.71)
Risk $\times\ \nu_{[0,50]}$				-0.20 (0.40)	-0.20 (0.40)
Risk $\times\ \nu_{[50,100]}$				-1.52^{***} (0.40)	-1.52^{***} (0.40)
Male			-19.07^{**} (6.25)		-19.07^{**} (6.25)
Rivalry			-0.62 (3.23)		-0.62 (3.23)
SVO			0.40 (0.25)		0.40 (0.25)
IA			-0.15 (0.20)		-0.15 (0.20)
Constant	25.73^{***} (3.24)	25.70^{***} (3.21)	63.70^{*} (27.29)	46.21^{***} (11.34)	60.54^{*} (27.34)
Observations	23,760	23,760	23,760	23,760	23,760
Log Likelihood	−120,946.20	−120,937.50	−120,923.30	−120,933.10	−120,919.40
Akaike Inf. Crit.	241,908.30	241,897.00	241,878.60	241,888.20	241,870.90
Bayesian Inf. Crit.	241,972.90	241,985.80	242,007.80	241,977.10	242,000.10
Notes:	$^{+}: p < 0.1$; $^{*}: p < 0.05$; $^{**}: p < 0.01$; $^{***}: p < 0.001$;				

Table 9: Estimation results for Equation (13) (overbidding) with B-Splines (degree three). The table shows estimation results for the different models C'_1, C'_2,C'_3, C'_4, and C'_5. B-Splines with degree three are used ($\text{Valuation}_{33} = 3(x-100)^2 \cdot x/10^6$, $\text{Valuation}_{66} = 3(100-x) \cdot x^2/10^6$, $\text{Valuation}_{100} = x^3/10^6$). Spite is the sum of the three spite measures. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

	C_1'	C_2'	C_3'	C_4'	C_5'
Period	-0.40*** (0.06)	-0.40*** (0.06)	-0.40*** (0.06)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		4.06* (1.69)	4.73* (1.86)		4.00* (1.84)
Spite × $\nu_{[0,50]}$		1.49** (0.52)	1.49** (0.52)		
Spite × $\nu_{[50,100]}$		-1.18* (0.52)	-1.18* (0.52)		
Risk			-3.41* (1.66)	-4.54** (1.76)	-4.08* (1.68)
Risk × $\nu_{[0,50]}$				-7.17*** (0.45)	-7.17*** (0.45)
Risk × $\nu_{[50,100]}$				-4.70*** (0.45)	-4.70*** (0.45)
Male			-19.07** (6.09)		-19.07** (6.09)
Rivalry			-0.62 (3.15)		-0.62 (3.15)
SVO			0.40 (0.24)		0.40 (0.24)
IA			-0.15 (0.19)		-0.15 (0.19)
Constant	14.92*** (3.16)	14.89*** (3.12)	52.90* (26.58)	38.56*** (11.11)	52.89* (26.58)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-122872.72	-122866.39	-122857.07	-120787.13	-120778.28
Akaike Inf. Crit	245757.43	245750.77	245742.14	241592.26	241584.55
Bayesian Inf. Crit.	245805.89	245823.46	245855.2	241664.94	241697.61
Notes:	$^{+}: p < 0.1$;	$^{*}: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 10: Estimation results for Equation(13) (overbidding) with cyclic cubic regression splines.

The table shows estimation results for the different models C_1', C_2',C_3', C_4', and C_5'. cyclic cubic regression splines are used. Spite is the sum of the three spite measures. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

	C'_1	C'_2	C'_3	C'_4	C'_5
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		4.06* (1.69)	4.73* (1.86)		4.00* (1.84)
Spite × $v_{[0,50]}$		1.49** (0.47)	1.49** (0.47)		
Spite × $v_{[50,100]}$		-1.18* (0.47)	-1.18* (0.47)		
Risk			-3.41* (1.66)	-4.46* (1.76)	-4.00* (1.68)
Risk × $v_{[0,50]}$				-1.94*** (0.48)	-1.94*** (0.48)
Risk × $v_{[50,100]}$				0.21 (0.48)	0.21 (0.48)
Male			-19.07** (6.09)		-19.07** (6.09)
Rivalry			-0.62 (3.15)		-0.62 (3.15)
SVO			0.40 (0.24)		0.40 (0.24)
IA			-0.15 (0.19)		-0.15 (0.19)
Constant	14.92*** (3.15)	14.89*** (3.11)	52.89* (26.58)	38.56*** (11.11)	52.89* (26.58)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.61	-120499.31	-120489.99	-120493.51	-120484.66
Akaike Inf. Crit	241027.22	241018.61	241009.98	241007.03	240999.32
Bayesian Inf. Crit.	241083.75	241099.37	241131.12	241087.78	241120.46
Notes:	$^+ : p < 0.1$;	$^* : p < 0.05$;	$^{**} : p < 0.01$;	$^{***} : p < 0.001$;	

Table 11: Estimation results for Equation (13) (overbidding) with P-splines.
The table shows estimation results for the different models C'_1, C'_2,C'_3, C'_4, and C'_5. P-splines are used. Spite is the sum of the three spite measures. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

F.3. Polynomial approach (instead of linear spline)

Table 12 show the estimation results for Equation (13) using the following econometric model:

$$\begin{aligned}
\text{Bid}_{i,t,j,v} - b^{\text{II-AP}} =& \beta_0 + \beta_1\text{Period} + \zeta_{i,j} + \eta_j + \epsilon_{i,j,k,l} + C'_M \\
C'_1 =& s(v) \\
C'_2 =& C'_1 + \beta_3\text{Spite}_i + \beta_4\text{Spite}_i \cdot v + \beta_5\text{Spite}_i \cdot v^2 \\
C'_3 =& C'_2 + \beta_6\text{IA}_i + \beta_7\mathbb{1}_{\text{Gender}=♀} + \beta_8\text{Risk}_i + \beta_9\text{rivalry}_i + \beta_{10}\text{SVO}_i \\
C'_4 =& C'_1 + \beta_{11}\text{Risk}_i + \beta_{12}\text{Risk}_i \cdot v + \beta_{13}\text{Risk}_i \cdot v^2 \\
C'_5 =& C'_2 + \beta_{14}\text{IA}_i + \beta_{15}\mathbb{1}_{\text{Gender}=♀} + \beta_{16}\text{Spite}_i + \beta_{17}\text{rivalry}_i + \beta_{18}\text{SVO}_i \qquad (31)
\end{aligned}$$

where $\zeta_{i,j}$ is a random effect for bidder i in group j, η_j is a random effect for group j, and $\epsilon_{i,j,k,l}$ is the residual. $s(v)$ is the thin plate regression spline over the valuation.

	C'_1	C'_2	C'_3	C'_4	C'_5
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		2.53 (1.70)	3.19^{+} (1.87)		4.00* (1.84)
Spite $\times v$		0.05** (0.02)	0.05** (0.02)		
Spite $\times$ v^2		0.001** (0.001)	0.001** (0.001)		
Risk			-3.41* (1.66)	-2.37 (1.78)	-1.90 (1.69)
Risk $\times v$				-0.06*** (0.02)	-0.06*** (0.02)
Risk $\times$ v^2				0.001** (0.001)	0.001** (0.001)
Male			-19.07** (6.09)		-19.07** (6.09)
Rivalry			-0.62 (3.15)		-0.62 (3.15)
SVO			0.40 (0.24)		0.40 (0.24)
IA			-0.15 (0.19)		-0.15 (0.19)
Constant	14.92*** (3.15)	14.89*** (3.11)	52.89* (26.58)	38.56*** (11.11)	52.89* (26.58)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.69	-120500.4	-120491.08	-120493.18	-120484.33
Akaike Inf. Crit	241027.38	241020.8	241012.17	241006.37	240998.66
Bayesian Inf. Crit.	241083.91	241101.56	241133.3	241087.12	241119.8
Notes:	$^{+}: p < 0.1$;	$^{*}: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 12: Estimation results for Equation (31).

The table shows estimation results for the different models C'_1, C'_2,C'_3, C'_4, and C'_5. Thin plate regression splines are used. Spite is the sum of the three spite measures. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

F.4. Estimating Equation (13) with the individual spite measures

Table 13, 14 and 15 show the estimation results for Equation (13) using the three spite measures separately. The estimations are mainly in line with the results of the normalized combined spite-measure.

	C_1'	C_2'	C_3'	C_4'	C_5'
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		0.12 (0.08)	0.10 (0.08)		0.08 (0.08)
Spite × $v_{[0,50]}$		0.05* (0.02)	0.05* (0.02)		
Spite × $v_{[50,100]}$		-0.03 (0.02)	-0.03 (0.02)		
Risk			-3.19+ (1.68)	-4.59** (1.76)	-3.91* (1.70)
Risk × $v_{[0,50]}$				-2.18*** (0.49)	-2.18*** (0.49)
Risk × $v_{[50,100]}$				0.46 (0.49)	0.46 (0.49)
Male			-18.75** (6.19)		-18.75** (6.19)
Rivalry			1.25 (3.04)		1.25 (3.04)
SVO			0.43+ (0.25)		0.43+ (0.25)
IA			0.01 (0.18)		0.01 (0.18)
Constant	14.92*** (3.15)	12.02** (3.95)	27.30 (23.84)	38.56*** (11.11)	27.30 (23.84)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.69	-120503.35	-120494.6	-120492.17	-120485.11
Akaike Inf. Crit	241027.38	241026.69	241019.19	241004.34	241000.23
Bayesian Inf. Crit.	241083.91	241107.45	241140.33	241085.1	241121.36
Notes:	$^+: p < 0.1$;	$^*: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 13: Estimation results for Equation (13) (overbidding) (Kimbrough-Reiss).
The table shows estimation results for the different models C_1', C_2',C_3', C_4', and C_5'. Thin plate regression splines are used. Spite is the Kimbrough-Reiss spite measure. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

	C_1'	C_2'	C_3'	C_4'	C_5'
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		0.43+ (0.23)	0.33 (0.26)		0.26 (0.26)
Spite × $v_{[0,50]}$		0.17** (0.06)	0.17** (0.06)		
Spite × $v_{[50,100]}$		-0.07 (0.06)	-0.07 (0.06)		
Risk			-3.00+ (1.68)	-4.59** (1.76)	-3.72* (1.69)
Risk × $v_{[0,50]}$				-2.18*** (0.49)	-2.18*** (0.49)
Risk × $v_{[50,100]}$				0.46 (0.49)	0.46 (0.49)
Male			-18.62** (6.20)		-18.62** (6.20)
Rivalry			1.79 (3.04)		1.79 (3.04)
SVO			0.41+ (0.25)		0.41+ (0.25)
IA			-0.08 (0.21)		-0.08 (0.21)
Constant	14.92*** (3.15)	13.02*** (3.33)	35.36 (25.57)	38.56*** (11.11)	35.36 (25.57)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.69	-120501.3	-120493.18	-120492.17	-120485.12
Akaike Inf. Crit	241027.38	241022.61	241016.37	241004.34	241000.25
Bayesian Inf. Crit.	241083.91	241103.36	241137.5	241085.1	241121.38
Notes:	$^+: p < 0.1$;	$^*: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 14: Estimation results for Equation (13) (overbidding) (Own measure).
The table shows estimation results for the different models C_1', C_2',C_3', C_4', and C_5'. Thin plate regression splines are used. Spite is the own spite measure. IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

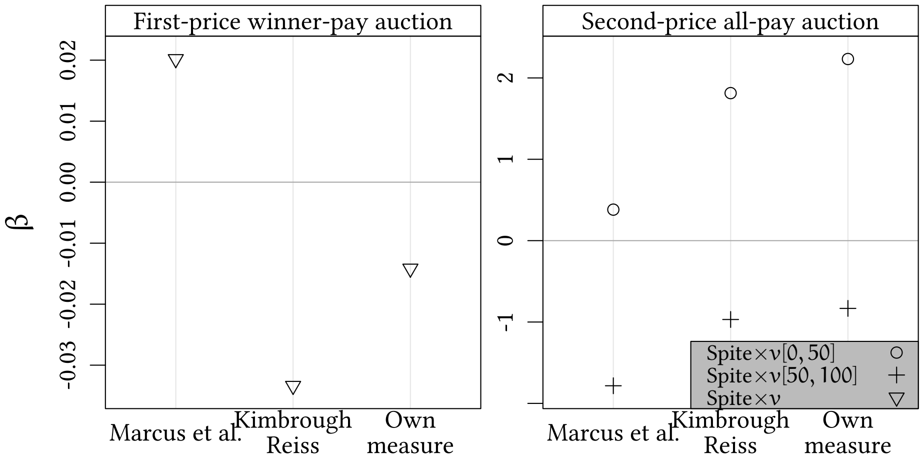


Figure 19: Estimation of Equations (12) and (13) for different measures of spite.
To show the effect of different measures of spite we estimate Equations (12) and (13) with interactions for the three different measures at the same time. The vertical axis shows the interaction of Spite with v for models C_2' and C_4', respectively. Detail estimation results for the second-price all-pay auction are shown in Section F.4.

	C_1'	C_2'	C_3'	C_4'	C_5'
Period	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)	-0.40*** (0.05)
Spite		5.17 (5.71)	12.38+ (6.37)		11.56+ (6.32)
Spite × $v_{[0,50]}$		0.30 (1.57)	0.30 (1.57)		
Spite × $v_{[50,100]}$		-2.72+ (1.57)	-2.72+ (1.57)		
Risk			-3.45* (1.68)	-4.59** (1.76)	-4.17* (1.69)
Risk × $v_{[0,50]}$				-2.18*** (0.49)	-2.18*** (0.49)
Risk × $v_{[50,100]}$				0.46 (0.49)	0.46 (0.49)
Male			-21.03*** (6.20)		-21.03*** (6.20)
Rivalry			-1.76 (3.50)		-1.76 (3.50)
SVO			0.45+ (0.25)		0.45+ (0.25)
IA			-0.02 (0.18)		-0.02 (0.18)
Constant	14.92*** (3.15)	7.35 (10.35)	21.71 (23.71)	38.56*** (11.11)	21.71 (23.71)
Observations	23760	23760	23760	23760	23760
Log Likelihood	-120506.69	-120504.37	-120494.07	-120492.17	-120483.99
Akaike Inf. Crit	241027.38	241028.74	241018.14	241004.34	240997.97
Bayesian Inf. Crit.	241083.91	241109.5	241139.27	241085.1	241119.11
Notes:	$^{+}: p < 0.1$;	$^{*}: p < 0.05$;	$^{**}: p < 0.01$;	$^{***}: p < 0.001$;	

Table 15: Estimation results for Equation (13) (overbidding) (Spite-Score).
The table shows estimation results for the different models C_1', C_2', C_3', C_4', and C_5'. Thin plate regression splines are used. Spite is the score from the spite questionnaire (Marcus et al., 2014). IA is the sum of the inequality aversion score obtained from the slider measure and the score obtained from inequality allocation of our own spite measure.

F.5. Revenue

F.5.1. Hypotheses

Above, in Section 4.4, we have formulated our hypotheses in terms of bids. In the paper we don't focus on a comparison of revenue in the two different auction formats to keep the paper concise. Still, we can derive hypotheses from the equilibrium prediction. Following Proposition 5 we expect the following:

Hypothesis 3.1. *Revenue in the second-price all-pay auction is higher than in the first-price winner-pay auction, if bidders are spiteful.*

Following Proposition 6 we expect the following:

Hypothesis 3.2. *Revenue in the second-price all-pay auction is lower than in the first-price winner-pay auction, if bidders are risk averse.*

Hypotheses 3.1 and 3.2 make different predictions. If spite is a motive driving bidding behavior, then we should find support for Hypothesis 3.1. If, however, risk aversion is driving the behavior, we expect to find the opposite (Hypothesis 3.2). We present results in Appendix F.5.2.

F.5.2. Results

To compare the revenue for the seller of both auction types we approximate for every subject the expected revenue extracted by the seller, given the subjects' bidding function and given the behavior of the other bidders. For that purpose we draw for every subject 100 random valuations from a uniform distribution – hence, every subject participates in 100 potential auctions. For each subject we use the bids this subject would make given her bidding function. We match every subject's bids with the bids of every other subject (within an auction type) and estimate the average payment to the seller, for all random valuations. We use this procedure for every round, as subject's bids change throughout the game.[51]

To obtain the standard errors we bootstrap the revenue means of every subject. Figure 20 shows the bootstrapped estimates for both auction types over rounds. It can be seen that the revenue seems to be higher in the second-price all-pay auction during the first rounds. However, while the revenue of the first-price winner-pay auction decreases only very slowly, the revenue in the second-price all-pay auction decreases more quickly over time. These results (C_3^R) are supported by a mixed-effects regression as reported in Table 16. The initial revenue-surplus of the second-price all-pay auction reduces over time and even swaps for late rounds, which explains why we do not find a significant difference between the average revenues of these two auction types (C_1^R).

Hence, we can neither support Hypothesis 3.1 nor 3.2. It seem like revenue is higher in the second-price all-pay auction in the beginning, which would provide support for the hypothesis that spite plays a more important role than risk aversion. As this effect disappears, however, we cannot say whether risk or spite dominate the behavior on average.

[51]Essentially, this procedure does account for a subject specific effect. To simplify matters we assume here that the group specific effect is negligibly small.

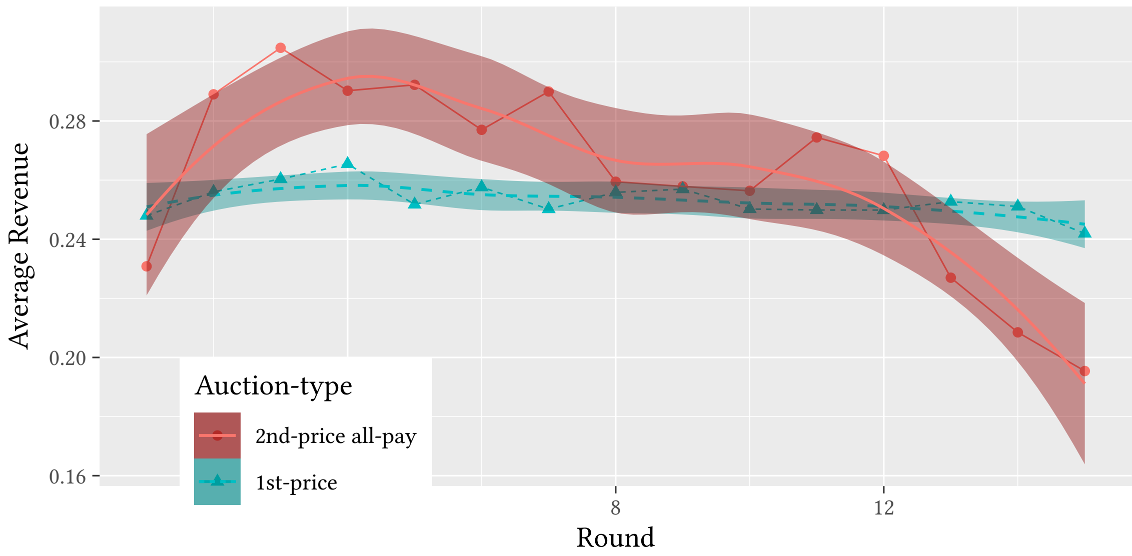


Figure 20: Mean revenues in both auction-types with standard error bands.

Result 5.1. *Initially the second-price all-pay auction provides higher revenue, which is in line with theory of spiteful behavior. This effect however, disappears over time.*

G. Instructions

The experiment was conducted in German. All participants obtained the following handout (translated into English). Participants also saw video instructions, which are available upon request. The video instruction put into writing and translated into English can be found in Appendix G.2.

G.1. Handout

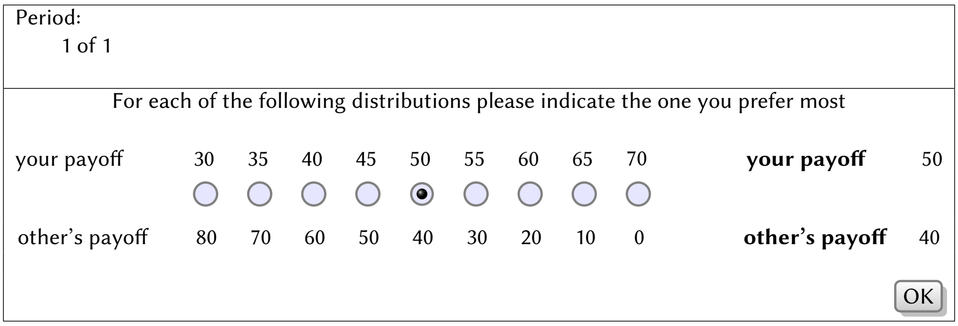
Payoff

- 3.50€ for your participation
- 2.50€ for answering the questionnaire
- Payoff from one Task (either A, or B, or C, or D)

First Task (A)

- Every participant will be assigned another participant
- You will make 21 decisions
- One Task will be randomly paid out
- 1 Point = 6 Euro-cents

Example:



In this example you obtain 50 points + the points from the decision of another person.

Second Task (B)
In this task you have to decide 10 times between two lotteries A and B.
Only one of those 10 decisions will be paid out.

Example:

Lottery A	**Lottery B**	**Your choice**
In 1 out of 10 cases you will earn 1800 points and in 9 out of 10 cases you will earn 1440 points	In 1 out of 10 cases you will earn 3465 points and in 9 out of 10 cases you will earn 90 points	Lottery A ○ ○ Lottery B OK

In this example you would get the following payoff in one out of 10 cases:
1800 points in case you choose Lottery A and 3465 in case you choose Lottery B.

And you would get the following payoff in 9 out of 10 cases:
1440 points in case you choose Lottery A and 90 in case you choose Lottery B.

- 1 Point = .5 Euro-cents

Task D
Task

- You play 10 auctions with another participant
- If your bid is higher than the bid of the other participant you win the auction. Otherwise, you lose the auction.
- For that purpose 10 random valuations between 500 and 1000 will be drawn for you and your fellow player each.
- Valuation: the amount you obtain in case you win the auction
- Decision: How much do you bid for each of the possible valuations
- In case you win you obtain your valuations as payoff and you have to pay the bid of the loser
- In case you lose you don't get any payoff and you don't have to pay anything.

Procedure:
1 Part: Decision
For all possible valuations between 500 and 1000 you indicate your bid.

2 Part: Result
In this part, you can see your bids and the bids of the other player if he won the auction. You also see which random valuations have been drawn for you and which auctions you won.

3 Part: Adaptation
You can increase your bids. However, you cannot change the outcome of the auction. E.g. if you have lost an auction then it will still stay this way.

2 Part: Implementation
To determine whether your adaptation will be implemented you have to bid with another player for whether the adaptation will be implemented or not.
If you bid more than this other player your adaptation will be implemented and you have to pay the bid of this new player for the adaption.
If you bid less, you don't pay anything, however, you adaption will also not be implemented.

Payoff

- 1 point= 0.01 €
- If task D is determined as payoff-relevant only one of the 10 auctions will be paid out
- You additionally get a 5€ payment if this task is paid out
- **+ Payoff**=
If you win the auction: Valuation - Bid of the losers (old or new) - bid for the implementation of the adaptation (in case the adaptation will be implemented for you)
If you lose the auction: - bid for the implementation of the adaptation (in case the adaptation will be implemented for you)

Task C
Task

- You play 15 rounds.
- You play every round 10 auctions with a new participant
- If your bid is higher than the bid of the other participant you win the auction. Otherwise, you lose the auction.
- For that purpose 10 random valuations between 0 and 100 will be drawn for you and your fellow player each. (E.g. both of you will have different valuations)
- Valuation: the amount you obtain in case you win the auction
- Decision: How much you bid for each of the possible valuations

- In case you win you obtain your valuations as payoff and [[First price auction instructions (FSP): you have to pay your own bid]][[second-price all-pay auction instructions (SNPAP): you have to pay the bid of the loser]]

- In case you lose you don't get any payoff and [[FSP: you don't have to pay anything]][[SNPAP: you have to pay your own bid]].

Procedure:
1 Part: Decision
For all possible valuations between 0 and 100 you indicate your bid.
The maximal possible bid is 150 points.

2 Part: Result
In this part, you can see your bids and the bids of the other player. You also see which random valuations have been drawn for you and which of the 10 auctions you won.

Payoff

- 1 point= 0.10 €

- If task C is determined as payoff-relevant only one of the 15 rounds will be paid out.

- If task C is determined as payoff-relevant only one of the 10 auctions will be paid out.

- You additionally get a 7€ payment if this task is paid out.

- **+ Payoff**=
  If you win the auction: Valuation [[FSP: -your bid]] [[SNPAP: - Bid of the losers]]
  If you lose the auction: [[FSP: 0]] [[SNPAP: - your bid]]

G.2. Text of the Video instructions

At the beginning of the experiment subjects watched a video which explained the different parts of the experiment. In the following we show the text of the videos translated into English. The German version of the text is available upon request from the authors. The videos can be obtained here: https://www.kirchkamp.de/research/SpiteVsRisk.html

Text to the video: General instructions

Welcome to this economic experiment. Today's experiment consists of four sub-experiments. Let us call them, for simplicity, A, B, C, and D. Additional to these tasks you will answer a questionnaire at the end. Let us come to the reimbursement of today's experiment. You will get 3.50€ for the participation in this experiment. You will get additional 2.50€ for answering the questionnaire. And you will get the payment from one of the tasks. Either from Task A, or Task B, or Task C, or Task D. Prior to each task, you will see an instructive video.

Text to the video: SVO (Murphy et al., 2011)

Let us now come to the first sub-experiment. In this sub-experiment every participant will be randomly assigned to another participant. For example, participant A will be assigned participant B, and participant B will be assigned participant C and so every participant will be assigned a different participant. Accordingly, the decision of participant A will be influential for the payoff of participant B and the decision of participant B will have an influence on the payoff of participant C and so forth. You will make 21 decisions over distributions. Only one decision will be randomly picked for payoff in case this sub-experiment is chosen for payoff. Here you see an example for one such decision. The decision consists of choosing one of the distributions. This distribution influences your payoff and the payoff of your fellow participant, who was randomly assigned to you. Let us assume you choose the distribution marked by the red circle. Then you will see your payoff on the top right side. On the lower top side, you can see how much the participant assigned to you will get as payoff. In this example, you earn 50 points. The participant assigned to you gets 40 points in this example. Let us assume this decision will be randomly drawn to be payoff-relevant at the end of the experiment. Let us further assume that you, as player A, choose the decision marked by the red circle. Then you would earn 50 points. Let us further assume that the player, to whom you were randomly assigned, let us call him player Z, chooses the same decision. Then you would get 40 points from this player. In this sub-experiment, every point is worth 6 cents. In the just mentioned example, you would earn 50 points for your decision plus 40 points for the decision of the player who influences your payoff. All together you would earn 90 points, which is worth 5.40€. If this task is chosen for payoff you will earn, in addition to the 3.50€ for participating in the experiment and the 2.50€ for answering the questionnaire, the payoff of one randomly drawn distribution. Please do not forget to click “done” at the end of a decision. If you have any further questions please press the red button on your keyboard and we will come to you. Otherwise, we wish you good luck.

Text to the video: Risk

Let us now come to the second task. Here you have to decide 10 times between Lottery A and Lottery B. Only one of the 10 decisions will be randomly implemented. Here you can see how the interface will later look like for you. In this column, you have to make your decision. Here you can choose between Lottery A and Lottery B. Only one of the 10 decisions will be randomly implemented for you and will influence your payoff. Hence, the first decision could be drawn. Or the fourth. Or the tenth. Which decision will be payoff-relevant for you will be determined randomly by the computer and will be announced to you at the end. Let us take a closer look at one such decision. Let us look for example at the first row. Here you see Lottery A and Lottery B. You now have to decide between Lottery A and Lottery B. In this example you would earn in one out of ten cases the following payoff: 1800 points if you have chosen Lottery A and 3465 points if you have chosen Lottery B. And in nine out of ten cases you would earn the following payoff: 1440 points if you have chosen Lottery A and 90 points if you have chosen Lottery B. In this sub-experiment, every point is worth .50 cents.

If this sub-experiment is drawn for payoff only one lottery will be randomly chosen and the lottery will be played according to your choice. If this task is chosen for payoff you will earn 3.50€ for participating in the experiment and the 2.50€ for answering the questionnaire plus the payoff from this sub-experiment. If you have any further questions please press the red button on your keyboard and we will come to you. Otherwise, we wish you good luck.

Text to the video: Auction

Let us now come to task C. Please note: At the end of this video you will answer 3 control questions to check whether you have understood this task. This task consists of 15 rounds. Each round you will play 10 auctions with a new player. If this sub-experiment is chosen for payoff only one of the auctions will be randomly paid out. In this sub-experiment every point is worth [[FSP: 20]] [[SNPAP: 10]] cents. Every auction consists of the following parts: In every auction, two players take part who bid for a prize. In this example player A and player B. Both players value the prize randomly differently. Hence, player A values the prize with valuation A and player B values the prize with valuation B. E.g. valuation corresponds to how worth the prize is to one player. Both submit a bid according to their valuation. Let us assume that the bid of player A is higher than the bid of player B. In this case player A wins the auction and his payoff is: The valuation of player A minus [[FSP: the own bid]][[SNPAP: the bid of the loser- in this case player B.]] Player B loses the auction, e.g. he is not getting any payoff [[SNPAP: however he still has to pay his bid]]. Let us now come to the decision in this task. In every round, you play 10 auctions with one randomly assigned player. You will decide for all possible valuations how much you want to bid. Out of all possible valuations, 10 valuations will be drawn randomly by the computer and you will bid according to your decision. To repeat: The payoff of one auction is calculated as the following: If you win the auction you gain your valuation minus [[FSP: your own bid.]][[SNPAP: the bid of the loser, in this case your co-player.]] Let us consider the following example: let us assume your valuation is 60 points. And the bid of your co-player for his, to you unknown, valuation is 40. If you have bid for example 50 points, then you win the auction, as you bid more than your co-player. And you obtain the following payoff: Your valuation minus [[FSP: your own bid.]][[SNPAP: the bid of the loser.]] Hence, 60 points, because this corresponds to your valuation, minus [[FSP: 50 points, hence, your own bid. Which results in 10 points which equates to 2€.]][[SNPAP: 40 points, the bid of the loser. Which results in 20 points which equates to 2€.]] If you have bid for example 30 points, then you lose the auction, as you bid less than your co-player, who bid 40 points. [[FSP: Hence, you obtain a payoff of 0 points.]][[SNPAP: Hence you pay the bid of the loser. In this case, you would pay 30 points, which equates to 3€.]] In case both bid the same one player will be randomly announced the winner and the other the loser. Your interface will look like the following. The red circle shows here your possible valuations. In the red marked area, you have to indicate how much you would bid if your valuation would be 0, 10, 20 etc. The maximal possible bid is 150 points. On the button, you see in which of the 15 rounds you are currently in. If you click on "draw" you can see how much you would bid if your randomly drawn valuation is a number between 0 and 10 or between 10 and 20 or 20 and 30 and so on. Every number between 0 and

100 can be randomly picked by the computer to be your valuation. At the bottom, you see the possible valuations and on the left you see your bids according to your function. Let us assume your random valuation is 75. Then you would bid according to your input 40 points. If you are happy with your bidding function please click "done". Here you see the results of every of the 10 auctions in the first round. Here you can see your random valuations for each of the auctions. The red circle shows here how you bid according to your input. And here you see the bid of your co-player. In the red marked area you can see whether you won or lost the auction. And hence, how many points you have won and lost, respectively. Let us, for example, look at the first auction. Here you can see how much you bid and how much your co-player bid. [[FSP: Let us, for example, look at the seventh auction. If this auction will be drawn for payoff, you would lose and earn 0 points.]][[SNPAP: Let us, for example, look at the ninth auction. If this auction will be drawn for payoff, you would lose and pay 3 points.]] Here you can see the auctions ones more graphically. The red dots represent those auctions you have lost. The green dots represent those auctions you have won. The blue crosses represent, in every auction, the bids of your co-player. If you click on "done", you will be directed to a new round, in which you will play again 10 auctions with a new player. If this task is chosen for payoff you will earn, in addition to the 3.50€ for participating in the experiment and the 2.50€ for answering the questionnaire, 7€. Plus the payoff of one auction out of the 15 rounds. Note that you can win but you can also lose those auctions. If you have any further questions please press the red button on your keyboard and we will come to you. Otherwise, we wish you good luck.

Text to the video: Market (Kimbrough-Reiss)

Let us now come to task D. Please note: At the end of this video you will answer 5 control questions to check whether you have understood this task. In this task, you play one round in which you will play 10 auctions. Only one of the auctions will be randomly paid out. In this sub-experiment, every point is worth 1 cent. Every auction consists of the following parts: In every auction, two players take part who bid for a prize. In this example player A and player B. Both players value the prize randomly differently. Hence, player A values the prize with valuation A and player B values the prize with valuation B. E.g. valuation corresponds to how worth the prize is to one player. Both submit a bid according to their valuation. Let us assume that the bid of player A is higher than the bid of player B. In this case player A wins the auction and his payoff is: The valuation of player A minus the bid of the loser- in this case player B. Player B loses the auction, e.g. he is not getting any payoff and his payment is 0 points. Let us now come to the procedure in this sub-experiment. This sub-experiment consists of four parts. Let us come to the decision. You play 10 auctions with one randomly assigned player. You will decide for all possible valuations how much you want to bid. Out of all possible valuations, 10 valuations will be drawn randomly by the computer and you will bid according to your decision. Here you see the interface in task D. The red circle shows here your possible valuations. Here you have to indicate how much you would bid if your valuation would be 500, 550, 600 etc. If you click on "draw" you can see how much you would bid if your randomly drawn valuation is a number between 500 and 550 or between

550 and 600 and so on. Every number between 500 and 1000 can be randomly picked by the computer to be your valuation. On the horizontal axis you see your valuations and on the vertical axis you see your bids according to your input. Let us assume your random valuation is 870. Then you would bid according to your input 600 points. If you are happy with your input please click on "done". Let us now come to the second part of the task: the result. Here you see the 10 auctions. Here you can see your random valuations for each of the auctions. The red circle shows here how you bid according to your input. Here you can see whether the bid of your co-player was smaller or higher than your bid. Here you can see whether you won or lost the auction. In those auctions in which you lost you can see the bid of your co-player The payoff of one auction is calculated as the following: If you win the auction you gain your valuation minus the bid of the loser, in this case your co-player. If you lose the auction you obtain 0 points as your payoff. Let us consider the following example: let us assume your valuation is 650 points. And the bid of your co-player for his, to you unknown, valuation is 540. If you have bid for example 600 points, then you win the auction, and you obtain your valuation minus the bid of the loser as payoff. In this case 650, your valuation, minus 540, the bid of your co-player. Hence, 110 points which equates to 1.10€. If you have bid for example 530 points, then you lose the auction, as you bid less than your co-player. Hence, you obtain a payoff of 0 points. In case both bid the same one player will be randomly announced the winner and the other the loser. Let us now come to the third part of task D: the adaptation. In the adaptation you can increase your bid, in those auctions you won. You can also increase your bid in those auctions you lost. However, you cannot overbid your co-player. E.g. if you have lost an auction it will stay this way. Here you can see the interface for the adaptation. Here you can see your bids. The green lines mark your bids in those auctions you have won, and the red lines mark your bids in those auctions you have lost. The red circle marks here the bids of your co-player, if he has won the auctions. Here you can view your new bids. You can view the increased bids in those auctions you have won and you can view the increased bids in those auctions you have lost. You can adapt your bids by moving the ruler in the marked circle. At the bottom, you can see the same information once more. You can see your valuations. Your former bids and your new bids. Note that the adaptation is not implemented for every player. Whether your adaptation is implemented depends on a further bid. You can do that in the fourth part of task D: the implementation. Here you bid for the adaptation. For that purpose, you will be assigned a new partner. You decide how much you are willing to pay for implementing the adaptation. If your new partner bids more than you, his adaptation will be implemented and yours will not. However, he will need to pay for this implementation as much as you were willing to pay for the adaptation. If you bid more than your new partner, your adaptation will be implemented and his will not. However, you will need to pay for this implementation as much as he was willing to pay for the adaptation. The player, whose adaptation is not implemented, does not need to pay his bid for the adaptation. Note: As you and your co-player are assigned a new player it might happen that the adaptation of both players is implemented. It can, however, also happen that no adaption or only one of the adaptations is implemented. Here you see the interface for the implementation. Here you type in how much you are willing to pay to adapt the bid in those auctions you lost. Here you type in how much you are willing to pay to adapt the bid in those auctions in which you are the highest bidder. The payoff in this task, after adaptation,

Please answer the following questions
When entering numbers please insert integers only

A bids 528 and B bids 739, who wins the auction?
If the valuation of A is 650 and the bid of B is 550, how much payoff would A obtain, if A bids 700?
If the valuation of A is 650 and the bid of B is 550, how much payoff would A obtain, if A bids 500?
If the valuation of A is 520 and the bid of B is 550, how much payoff would A obtain, if A bids 580?
If a wins the adaptation of his bids, can it be that also the co-player of player A wins the adaptation?

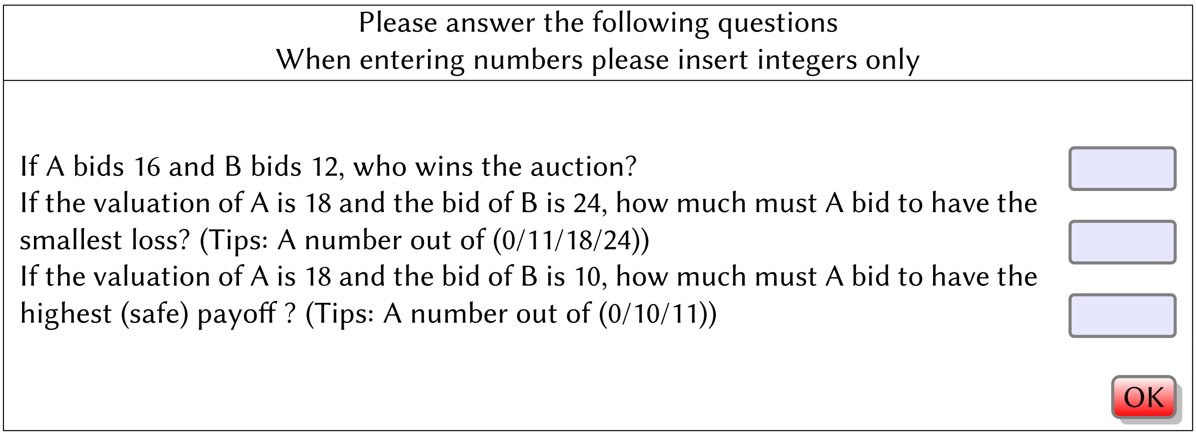
OK

Figure 21: Control questions in the spite measure (Kimbrough-Reiss).

is calculated as follows: If you win the auction you obtain as payoff your valuation minus the bid of the loser. At that, you have to pay either the old bid of the loser or the new one, dependent on whether the adaption of your co-player was implemented. In addition, you pay the amount you are willing to pay for the adaptation of those auctions you won. If you lose the auction, you have to pay, dependent on whether your adaption was implemented or not, the amount for the adaption. If this task is chosen for payoff you will earn, in addition to the 3.50€ for participating in the experiment and the 2.50€ for answering the questionnaire, 7€. Plus the payoff of one auction. Note that you can win but you can also lose those auctions. If you have any further questions please press the red button on your keyboard and we will come to you. Otherwise, we wish you good luck.

G.3. Control questions

To check and enhance the understanding of subjects, subjects had to solve the following two sets of control questions. Subjects had seven attempts to solve these questions. If subjects were not able to solve them after seven attempts they were presented the correct answers. Questions are shown in Figures 21 and 22.


Please answer the following questions
When entering numbers please insert integers only

If A bids 16 and B bids 12, who wins the auction?

If the valuation of A is 18 and the bid of B is 24, how much must A bid to have the smallest loss? (Tips: A number out of (0/11/18/24))

If the valuation of A is 18 and the bid of B is 10, how much must A bid to have the highest (safe) payoff ? (Tips: A number out of (0/10/11))

OK

Figure 22: Control questions in the second-price all-pay auction.

Lottery A	Lottery B
In 1 out of 10 cases you will earn 1800 points and in 9 out of 10 cases you will earn 1440 points	In 1 out of 10 cases you will earn 3465 points and in 9 out of 10 cases you will earn 90 points
In 2 out of 10 cases you will earn 1800 points and in 8 out of 10 cases you will earn 1440 points	In 2 out of 10 cases you will earn 3465 points and in 8 out of 10 cases you will earn 90 points
In 3 out of 10 cases you will earn 1800 points and in 7 out of 10 cases you will earn 1440 points	In 3 out of 10 cases you will earn 3465 points and in 7 out of 10 cases you will earn 90 points
In 4 out of 10 cases you will earn 1800 points and in 6 out of 10 cases you will earn 1440 points	In 4 out of 10 cases you will earn 3465 points and in 6 out of 10 cases you will earn 90 points
In 5 out of 10 cases you will earn 1800 points and in 5 out of 10 cases you will earn 1440 points	In 5 out of 10 cases you will earn 3465 points and in 5 out of 10 cases you will earn 90 points
In 6 out of 10 cases you will earn 1800 points and in 4 out of 10 cases you will earn 1440 points	In 6 out of 10 cases you will earn 3465 points and in 4 out of 10 cases you will earn 90 points
In 7 out of 10 cases you will earn 1800 points and in 3 out of 10 cases you will earn 1440 points	In 7 out of 10 cases you will earn 3465 points and in 3 out of 10 cases you will earn 90 points
In 8 out of 10 cases you will earn 1800 points and in 2 out of 10 cases you will earn 1440 points	In 8 out of 10 cases you will earn 3465 points and in 2 out of 10 cases you will earn 90 points
In 9 out of 10 cases you will earn 1800 points and in 1 out of 10 cases you will earn 1440 points	In 9 out of 10 cases you will earn 3465 points and in 1 out of 10 cases you will earn 90 points
In 10 out of 10 cases you will earn 1800 points and in 0 out of 10 cases you will earn 1440 points	In 10 out of 10 cases you will earn 3465 points and in 0 out of 10 cases you will earn 90 points

Table 4: Choices in the Holt and Laury (2002) task.

Submeasures	No Spite in %	Spite in %	Average Spite
IA	84.00	16.00	3.17
IA-WP	91.00	9.00	1.36
RG	97.00	3.00	0.19
RG-WP	95.00	5.00	0.77
PS	96.00	4.00	0.42
PS-WP	96.00	4.00	0.31
$\sum$	82.00	18.00	4.87

Table 5: The allocation of choices considered (non-)spiteful in the six allocational tasks of our own spite measure.

	Participants per matching group		
	4	6	8
Second-price all-pay auction	1	21	1
First-price winner-pay auction	1	17	0

Table 6: Number of matching groups

Most matching groups had 6 participants. For a few experiments not all participants showed up, hence, we used smaller matching groups in 2 cases. In 1 case we used a bigger matching group as unexpectedly few participants showed up.

	C_1^R	C_2^R	C_3^R
1st-price auction	-0.01 (0.02)	-0.01 (0.02)	-0.04^{*} (0.02)
Period		-0.003^{***} (0.0004)	-0.005^{***} (0.001)
1st-price auction × Period			0.004^{***} (0.001)
Constant	0.26^{***} (0.01)	0.29^{***} (0.01)	0.30^{***} (0.01)
Observations	3,660	3,660	3,660
Log Likelihood	2,638.92	2,659.34	2,665.96
Akaike Inf. Crit.	$-5,267.84$	$-5,306.67$	$-5,317.91$
Bayesian Inf. Crit.	$-5,236.81$	$-5,269.44$	$-5,274.48$
Notes:	$^{+}: p < 0.1$; $^{*}: p < 0.05$; $^{**}: p < 0.01$; $^{***}: p < 0.001$;		

Table 16: Estimating revenue for both auction-types.