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An Experimental Test of Precautionary Bidding

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Abstract: Auctions often involve goods exhibiting a common knowledge ex-post risk that is independent of buyers' private values or their signals regarding common value components. Esö and White (2004) showed theoretically that ex-post risk leads to precautionary bidding for DARA bidders: Agents reduce their bids by more than their appropriate risk premium. Testing precautionary bidding with data from the field seems almost impossible. We conduct experimental first-price auctions that allow us to directly identify the precautionary premium and find clear evidence for precautionary bidding. Bidders are significantly better off when a risky object rather than an equally valued sure object is auctioned. Our results are robust if we control for potentially confounding decision biases.

JEL classification: C91, D44, D81
Keywords: precautionary bidding, prudence, auction, experiment

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1. Introduction

Consider an auction with pure *ex-post risk*: The value of the auctioned good is risky, with the risk being independent of private or common value components and signals thereof. The risk is known ex-ante and is common knowledge among buyers. In the language of decision theory, the auctioned good is a risky lottery. Esö and White (2004), henceforth EW, theoretically study auctions with ex-post risk in the affiliated value model by Milgrom and Weber (1982). They show for the standard first-price auction that bidders exhibiting decreasing absolute risk aversion (DARA) unambiguously reduce their bids by more than the appropriate risk premium, an effect they call *precautionary bidding*.[1] The intuition is that DARA bidders prefer higher income in the case they win the auction and have to bear the ex-post risk involved in the good, and therefore bid more conservatively. This effect is similar to the precautionary saving motive where agents transfer current wealth into future periods with more income uncertainty (Kimball (1990)).

Examples for auctions with ex-post risk are numerous and financially significant. Television rights for Olympic Games are usually auctioned off before the host city is selected from a set of competitors. The winner bears the risk of a more or less attractive host, a risk arising from information unavailable to any bidder at the time the rights are allocated. More generally, all goods whose resale value or quality is uncertain ex-ante to all buyers involve some ex-post risk. Precautionary bidding, if empirically relevant, has several important implications for auction design in general, and more specifically for information revelation by sellers and information acquisition by buyers. For instance, according to theory, sellers have an incentive to reduce the risk exhibited by the auctioned object as much as possible, and buyers have a strategic incentive to disregard some information. It therefore seems warranted to establish the empirical validity of precautionary equilibrium.

Despite the ubiquity of ex-post risk in auctions and its potential relevance, however, no empirical study on precautionary bidding has been conducted so far. A direct test of precautionary bidding with field data is not easily available, because it requires the observation of both the bidders' risk tolerance and the riskiness of the good. Neither of these parameters is normally observed by the analyst. In order to provide the first empirical assessment of precautionary bidding, we conduct experimental laboratory auctions where the controlled setting allows us to identify the precautionary premium directly.

[1] In their article EW provide results for various auction formats. We focus on first-price auctions here.

Our main experiment finds strong support for bidding behavior being consistent with precautionary bidding in first-price auctions. Bidders are significantly better off in first-price auctions when a risky object rather than an equally valued sure object is auctioned. Although our empirical hypotheses are derived from EW's theoretical framework, the experimental tests that we conduct for the data from the experiment are in fact model-free, relying only on observable certainty equivalents. In addition, we provide results of a parametric expected utility analysis. The latter shows that risk-averse Nash equilibrium predicts bidding behavior in deterministic auctions reasonably well, but it fails to predict bidding behavior in auctions with ex-post risk. This strongly corroborates the finding from our model-free test. In a control experiment we address alternative explanations based on behavioral biases in decision-making that might have influenced our results in the main experiment. The data from this control experiment are in line with our conclusions from the main experiment and show the robustness of the precautionary bidding effect.

The remainder of the paper is laid out as follows. In the next section we introduce the theoretical framework and the predictions of the precautionary bidding model. In Section 3 we present our experimental design in detail. Section 4 reports the results from the main experiment, and Section 5 provides evidence from the control experiment and from additional robustness checks. Finally, in Section 6, we discuss our results and conclude.

2. Theoretical framework and predictions

Almost all analyses of bidding behavior in auctions today assume that objects are non-risky, although agents are often assumed to have noisy signals regarding the true value of the object. Risk aversion plays a role in first-price auctions, because it reduces bid shading and, therefore, increases the bid in comparison to the risk-neutral Nash equilibrium (e.g., Cox, Smith and Walker, 1982, 1985; Maskin and Riley, 1984; Kagel, Harstad and Levin, 1987). The only study so far that considers pure ex-post risk in common auctions formats is Esö and White's (2004) theoretical analysis of the affiliated value model by Milgrom and Weber (1982).

We follow their setup and assume that there are n potential bidders for a given object. Bidder i receives a private signal $s_i \in [\underline{s}, \bar{s}]$. The joint distribution of the signal follows the properties of affiliation described in Milgrom and Weber (1982). The risky ex-post monetary value of the object for bidder i is $v_i = v(s_i, s_{-i}) + z_i$, where v is strictly increasing in its first argument, s_{-i} denotes the highest signal of all bidders other than bidder *i*, and z_i is the realization of a random variable, $\tilde{z}_i$, with zero mean. The realizations of the random variable come from a symmetric joint distribution and are independent of the signals, but they can be (perfectly) correlated across bidders. By definition, if z_i is non-degenerate, the object is risky. The utility function of bidders *u* is strictly concave and thrice differentiable. For DARA bidders, $-(\partial^2 u/\partial x^2)/(\partial u/\partial x)$ is strictly decreasing.

EW prove in this framework that, holding everything else constant, DARA bidders in the first-price auction have unambiguously higher indirect utilities in a symmetric equilibrium when z_i is non-degenerate, i.e., the object is risky.[2] The formal proof is provided in EW (2004, pp. 84-85). In the following, we give a brief intuition for the result and derive theoretical predictions based on EW's model regarding the buyer's equilibrium bids for a risky good and for her (risk free) certainty equivalent of this risky good. Our identification of precautionary bidding in the experiment will be based on the comparison of bids for risky lotteries and their certainty equivalents on the individual level.

In the first-price auction, for risk-averse agents who maximize expected utility with a DARA utility function, the introduction of a mean-preserving ex-post risk has three effects. *First*, the value of the object for the agent is reduced by the risk premium. Agents replace the value of the risky object v_i by its certainty equivalent $CE_i(v_i)$ before making their bids. For risk-averse bidders by definition $CE_i(v_i) < E[v_i]$, where $E[.]$ denotes the expected value. *Second*, the riskiness of the object introduces a background risk, making bidders become more risk-averse regarding other risks (Eeckhoudt, Gollier and Schlesinger, 1996). Hence, in the presence of ex-post risk they will shade their bids less than predicted by the appropriate risk premium, because the possibility of reducing the chance to lose the object in the auction becomes more attractive than the risky gain of a higher payoff by decreasing the bid.

With only these two effects at work, we would have $b_i(v_i) > b_i(CE_i(v_i))$ for the bids b_i for risky objects and their certainty equivalents. There is a *third* effect, however, the precautionary effect. This effect causes bidders to bid less aggressively because each extra unit of income is more valuable to them in the case they win the auction for the risky object as opposed to its certainty equivalent, due to the background risk. In other words,increasing the probability of winning the auction through a higher bid becomes more costly in the presence

[2] The main result extends immediately to situations where another independent noise is added to make already noisy valuations even riskier (Kihlstrom, Romer and Williams (1981)).

of ex-post risk. This effect is related to the prudence premium (Gollier 2001; Eeckhoudt and Schlesinger, 2006).

Taking all three effects together, EW prove that for DARA bidders in equilibrium the total effect of ex-post risk on the reduction of one's bid is unambiguously larger than just the risk premium.[3] This implies the following result.

RESULT 1 (based on Esö and White, 2004): *Consider an affiliated private value first-price auction with n symmetric DARA buyers. In equilibrium it holds that the bids for a risky object with value* v_i *and for its certainty equivalent* $CE_i(v_i)$ *satisfy*

$$b_i(v_i) < b_i(CE_i(v_i)). \tag{1}$$

The precautionary bidding effect is similar to the precautionary saving motive where agents transfer more wealth into the future when they face a higher future income risk (Kimball, 1990). Compared to precautionary saving, however, in first-price auctions individual risk attitudes and the level of riskiness of the object affect equilibrium bidding through multiple channels that point into different directions (see effects two and three above). In particular, increased risk aversion leads to less bid-shading (effect two). This makes the result of an unambiguously negative effect of precautionary bidding on the bid the more remarkable. It also implies, *ceteris paribus*, that buyers are better off bidding for a risky object than for the equivalent risk-free object.

Our experimental test of precautionary bidding is obtained by directly comparing an agent's bid for a risky prospect with her bid for her individual certainty equivalent for the same prospect in a first-price auction with affiliated values. Reformulating Result 1 gives our main hypothesis.

HYPOTHESIS 1: *In the affiliated private value first-price auction, buyers' bids for a risky object will be lower than their bids for a risk-free object whose value is equal to their individual certainty equivalent of the risky object.*

As noted before, in most settings the (perceived) riskiness of the good and the degree of bidders' risk aversion cannot easily be measured in the field, making buyers' certainty equivalents of goods sold in auctions unobservable. As a corollary, direct comparisons

[3] For DARA bidders the prudence premium is larger than the risk premium.

between bids for risky and risk-free goods with an identical certainty equivalent are impossible. Our experimental test of precautionary bidding directly compares bids for independently elicited certainty equivalents with bids for the appropriate risky objects on the individual level.

Hypothesis 1 is derived from EW's precautionary bidding model under the assumption of expected utility theory. Since our empirical test is only based on comparisons of bids for risky prospects and observable certainty equivalents, however, it is in fact model-free, and Hypothesis 1 can be interpreted as an empirical definition of the precautionary effect in first-price auctions.

3. Experimental design

3.1 The auction

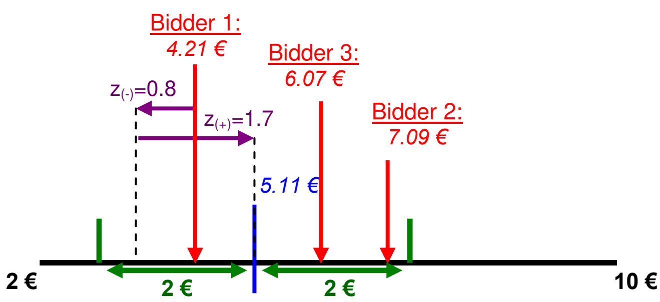
In the experiment, we follow the affiliated private value implementation of Kagel *et al.* (1987), adjusted to the setup in which either sure prospects or risky prospects are sold. In particular, for sure prospects the subjects knew their private valuation, and for risky prospects they knew the prospect they could win in the auction. Their valuations were correlated because of a two-step procedure used to draw valuations and prospects from some interval of the whole payoff range (Kagel *et al.*, 1987, p. 1277). That is, a high private value observed by the agent makes it more likely that the other bidders also have high values.

More specifically, our experimental subjects participated in a series of twelve anonymous first-price auctions. In each of them, they could bid for an object from an endowment of €10 in groups of three bidders. In order to produce matched bids for prospects and their individual certainty equivalents, each participant was bidding for two risky prospects and her two corresponding individual certainty equivalents that were elicited before in four out of the twelve auctions (see Section 3.2 for details of the elicitation procedure). We call the specific bidder whose certainty equivalent is used the *bidder of interest* and the matched observations for the risky object and the appropriate individual certainty equivalent an *auction pair*. In the remaining eight auctions the private valuation of the bidder was drawn according to the procedure described in the following paragraph, with each of the other two bidders being the bidder of interest four times in turn.

For risk-free prospects, the bidder of interest's certainty equivalent for the matched prospect provided her private valuation v_i. For the other two bidders in the group the valuations were determined as follows: v_i was first reduced by a random number $z_{(-)}$, which was drawn from the interval [€0, €2], and then increased by a random number $z_{(+)}$ from the same interval. The number obtained, $v_0^D = v_i + z_{(+)} - z_{(-)}$, forms the midpoint of a €4-interval in which all three deterministic valuations (hence, superscript *D*) lie. Subjects did not learn the midpoint of the interval. Hence, the valuations of the other two bidders within a group were drawn from the interval $[€v_0^D - €2, €v_0^D + €2]$. By construction, the value v_i lies in the interval and can assume any position in this interval, like the two other valuations. Figure 1 illustrates the procedure for v_i = €4.21, v_0 = €5.11, and Bidder 1 as bidder of interest.

For risky prospects, the procedure was similar. The bidder of interest had to bid for a risky prospect, presented in terms of its expected value plus or minus a fixed and announced amount $K \in \{2,3,4,5\}$ with equal probability.[4] For each prospect, *K* follows uniquely from the rewriting of the gamble presentation in the preceding risk elicitation stage of the experiment (see Section 3.2 for details). The risky prospects for the other two bidders were determined as described for sure objects, but taking as v_i the expected value of the risky prospect for the bidder of interest. This gives expected values for the other two bidders in the range $[€v_0^R - €2, €v_0^R + €2]$, to which the same ex-post risk of size *K* was added for all bidders.

FIGURE 1: ILLUSTRATION OF VALUATION ASSIGNMENT



For example, assume that Bidder 1 indicated a certainty equivalent of €4.21 for the prospect [0.5: €6.36, 0.5: €2.36] in the risk elicitation task preceding the auction experiment. In the auction experiment, she would face one auction as illustrated in Figure 1 and another auction that would be described as offering an object with risky value of €4.36 that will, with a probability of 0.5 each, either be increased or decreased by an amount of *K* = €2. The two

[4] The presentation is identical to the theoretical formulation of ex-post risk as a noise added to a private valuation. Note that *K* took on the different values for different auctions but was always clearly announced before bidding.

other bidders in the group would face a randomly drawn sure valuation out of the permissible range in the first auction and a randomly drawn risky valuation out of the permissible range (according to the procedure described above) in the second auction.

Subjects were instructed about the general procedure of drawing values and the method of affiliation in great detail (see the Appendix B for the experimental instructions), but they were neither aware of the presence of a bidder of interest, nor of the fact that we took their certainty equivalents and prospects from the preceding risk elicitation stage, nor of the private valuations of the two other bidders. More precisely, they were simply told that the private valuations of the three bidders come from a €4-interval lying within a larger interval and were distributed randomly along this €4-interval (which was true by construction). Everything else was common knowledge among participants. Neither intermediate auction results nor bids were revealed before the end of the experiments, and groups stayed together for all twelve auctions.[5]

After the twelve auctions, one auction was randomly selected for real payment of the full amount in euro. The auction winners paid their bids and received the payoff from the auction, possibly depending on the result of the ex-post risk, and they kept the rest of their €10-endowment that they had not used for bidding. Subjects who did not win the auction kept their endowment of €10. All randomizations concerning risky equal-chance events in the experiment were conducted by throwing dice at the subjects' desks.

Remember that the twelve auction rounds give us, per subject, two matched auction pairs (bids) for identical sure and risky valuations, and four more observations for bids for sure valuations. That is, in total we know individual valuations in eight out of the twelve auctions and can use this information for econometric analyses. We do not observe the valuation for subjects who were not the bidder of interest in the remaining four auctions for risky prospects. Only the bidder of interest submits a bid for a prospect for which we previously elicited her valuation in the risk preference elicitation stage that is described in the next sub-section.

[5] Groups were formed randomly, but subjects who were close to each other in their risk attitude rank (within a session of 15 subjects) from the preceding risk elicitation had a higher chance to end up in the same group. This procedure approximates the assumption of identical risk attitudes for bidders in EW's model and was explained in neutral terms to the participants (see the instructions).

3.2 Elicitation of risk preferences

At the beginning of the experiment, we elicited subjects' certainty equivalents for eleven risky prospects. All prospects were binary-outcome prospects with a 50% chance of each outcome (see Table 1, columns 1-3). Certainty equivalents were elicited using the Becker-DeGroot-Marschak (1963) incentive mechanism (henceforth, BDM). Subjects were asked to state for each prospect their minimum selling price p_s between the low and the high outcome of the prospect. They knew that a random buying price p_b between these two outcomes would be drawn to determine if the prospect is sold to the experimenter if $p_b \geq p_s$, in which case the subject received the randomly drawn buying price, or is not sold otherwise, in which case the subject received the outcome of the prospect.

The BDM mechanism has been used extensively in preference elicitation and is valid in our expected utility framework (e.g., Karni and Safra, 1987; Halevy, 2007). However, no BDM randomizations or risky prospects were resolved at this stage in order to prevent wealth differences between subjects in the auctions to come. Subjects were instructed that at the end of the experiment they would be paid on the basis of the outcome of one of the risky prospects or receive the random buying price, depending on the outcome of the BDM procedure.

TABLE 1: RISKY PROSPECTS USED IN THE EXPERIMENT

Prospect no.	High payoff (prob. 50%)	Low payoff (prob. 50%)	Expected value	Average CE with BDM[a]	Average CE with choice list[b]
1	12.76	4.76	8.76	7.82	8.18
2	8.30	2.30	5.30	5.00	5.18
3	10.70	2.70	6.70	6.03	6.23
4	6.52	2.52	4.52	4.10	4.41
5	13.22	5.22	9.22	8.54	8.61
6	8.06	2.06	5.06	4.70	5.04
7	6.36	2.36	4.36	3.94	4.38
8	13.20	3.20	8.20	7.83	7.67
9	9.76	5.76	7.76	7.22	7.47
10	12.76	6.76	9.76	8.93	9.21
11	8.01	2.01	5.01	4.68	5.00

Numbers in columns 2-6 show amounts in €.
[a] CE = Certainty equivalent; BDM = Becker-DeGroot-Marschak mechanism.
[b] For an explanation of the right-most column, see Section 5.

3.3 Laboratory protocol and subjects

Computer-based experiments were conducted at the experimental laboratory MELESSA of the University of Munich, using the experimental software z-Tree (Fischbacher, 2007) and the organizational software Orsee (Greiner, 2004). Seventy-five undergraduate students without experience in auction experiments participated in 5 sessions with 15 subjects each. Sessions lasted up to two hours, and the average final payoff was €23.75, including a show-up fee of €4. Subjects received written instructions which were read aloud and had the opportunity to ask questions in private. Examples and/or test questions were given for each stage of the experiment, and a stage only began when all subjects correctly understood the procedures.

The experiment started with the risk elicitation stage. Subjects received instructions for this stage, but knew that there would be further stages in the experiment. Upon completion, subjects received instructions for the second stage of the experiment. This stage was purely instructional, i.e., it was intended to make subjects acquainted with bidding in auctions with and without ex-post risk. Subjects participated in twelve affiliated private value first-price sealed-bid auctions for six risky and six sure prospects. Auctions were held anonymously in groups of three people, with new groups formed in every auction. Again, subjects with a similar risk rank from the elicitation stage had a higher chance to end up in the same bidder group in each auction. Subjects could bid from an endowment of 10 tokens in each auction. All bids within a group, the winning bid and the winner were announced immediately after each auction to acquaint subjects with the affiliated value model and with bidding for uncertain prospects. Only at the end of the entire experiment, one auction from this training stage was randomly selected and subjects were paid according to the outcome. Furthermore, payments were scaled down by a factor of 1/10 (compared to the main auction experiment in stage 3). With the exception of the size of earnings and the specific procedure of taking prospects and certainty equivalents from the risk elicitation stage, this second stage of the experiment was identical to the main auction stage that was to follow. After stage 2 had ended, subjects received instructions for the main stage of the experiment, the twelve auctions as described in Section 3.1.

Remember that subjects were not informed about the matched structure and the bidder of interest in the main stage of the experiment. Note that, while prospects were identical to the ones in the risk elicitation for the bidder of interest, the presentation of the prospects was quite different. They were framed in terms of ex-post risk instead of binary gambles and were not easily recognized as the same prospects as in the first stage[6], also because the training stage introduced a significant time lag.

At the end of the experiment, all random aspects of the experiment were resolved, and subjects learned what they had earned in each of the three stages of the experiment. They were paid privately and in cash and then dismissed from the laboratory.

4. Results of the main experiment

Column 5 in Table 1 shows the average certainty equivalents for the lotteries elicited in the first stage of the experiment. On average, subjects exhibit risk aversion, with CEs smaller than expected values for all prospects (Wilcoxon signed-ranks tests; $p < 0.01$). Figure 2 provides clear evidence consistent with the precautionary bidding effect. For the 150 matched auction pairs (2 auction pairs for each of the 75 subjects), it gives the number of pairs in which a buyer made a lower, identical, or higher bid for the risky prospect than for its CE. Remember that $b_i(v_i) < b_i(CE_i(v_i))$ is a direct, model-free test on the individual level for the precautionary bidding theory. Clearly, risky prospects elicit lower bids than their certainty equivalents (Wilcoxon signed-ranks test; $p < 0.01$). In 109 matched auction pairs, a lower bid was submitted for the risky prospect than for its certainty equivalent, in comparison to only 35 pairs with higher bids for the risky prospect. There were virtually no identical bids, suggesting that subjects did not simply remember prospects and their certainty equivalents from stage 1 and tried to be consistent.[7]

Alternatively, one can perform a parametric utility analysis to assess precautionary bidding. The first benchmark measure for the evaluation of sure and risky prospects in our experiment are risk-neutral Nash equilibrium bids (Kagel *et al.* 1987), given in equation (2).

$$b(v_i) = v_i - \frac{2\varepsilon}{n} + \frac{1}{n} \cdot \frac{2\varepsilon}{(n+1)} \cdot \exp[-\frac{n}{2\varepsilon} \cdot (v_i - (\underline{s} + \varepsilon))] \tag{2}$$

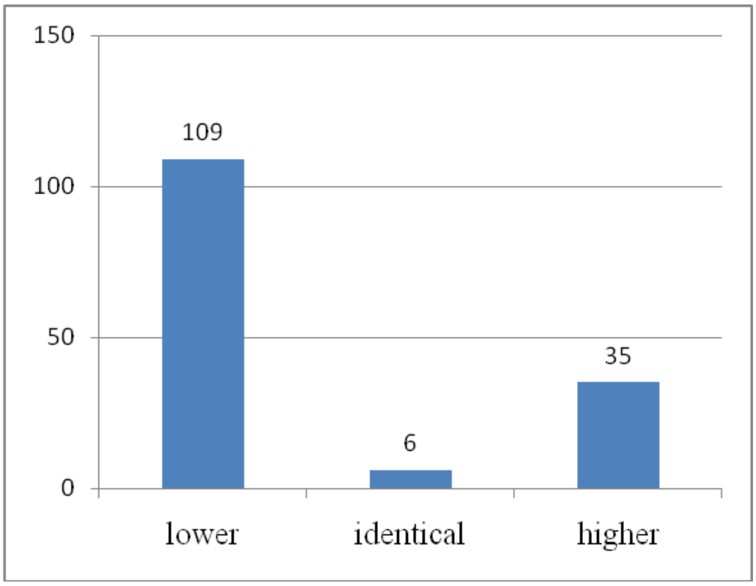
In the case of our experiment, $n = 3$ (number of bidders), $\varepsilon = 2$ (radius of the smaller interval), and $\underline{s} = 0$ (lower bound of the larger interval). For each auction and each bidder we calculate the risk-neutral Nash equilibrium bids from individual valuations. We find

[6] If so, it would make our results even stronger. Details are provided in the next section.

[7] Note that even if some bidders of interest had recognized the prospects from the risk elicitation stage in the later auction stage and understood the construction of our matched auction pairs, they had no more relevant information on values and intervals than the other bidders in the group. Empirically, we have no evidence whatsoever of bidders of interest bidding differently than the other bidders.

significant overbidding for the sure prospects, consistent with previous findings in the experimental literature for risk-averse subjects (Cox *et al.*, 1988).[8] The actual bids are significantly higher than the Nash bids (Wilcoxon signed-ranks test, $p < 0.01$). For risky prospects we find significant underbidding with respect to the risk-neutral Nash equilibrium bids (Wicoxon signed-ranks test, $p < 0.01$). As a robustness check, one can aggregate relative overbidding and underbidding on the individual level. The basic result for the 75 subjects does not change, and both tests are still significant ($p < 0.01$ for sure prospects, and $p < 0.05$ for risky prospects).

FIGURE 2: COMPARISON OF BIDS FOR RISKY PROSPECTS
WITH BIDS FOR THEIR CERTAINTY EQUIVALENTS



Note: Number of pairs in which the bid for a risky prospect was (lower/identical/higher) than the bid for its certainty equivalent (within-person comparisons).

In a next step, we estimate an individual utility function for each subject based on the data we have from the certainty equivalent elicitation stage. This allows us to calculate risk-averse Nash equilibrium bids for each bidder and auction based on the individual risk aversion parameters and the (expected) value of the risky or deterministic prospects. These Nash bids are then again compared to the actual bids.

More specifically, we use nonlinear least squares estimations to fit a constant relative risk aversion utility function (CRRA), $u(x) = x^{1-r}/(1-r)$, with risk aversion parameter r, for

[8] Overbidding is a common empirical phenomenon in first-price auctions. Explanations fall roughly into three categories: risk aversion, inter-personal comparisons, and non-equilibrium behavior or learning. Recent summaries are in Crawford and Iriberri (2007) and Engelbrecht-Wiggans and Katok (2007).

all 75 subjects individually.[9] For each risky and for each risk-free auction, we can then calculate risk-averse Nash equilibrium bids and compare them to the actual bids. Nash bids are calculated according to the equilibrium bidding formula in Kagel *et al.* (1987).

$$b(v_i, \rho) = v_i - \frac{2\varepsilon \cdot (1-\rho)}{n} + \frac{1}{n} \cdot \frac{(1-\rho)^2 \cdot 2\varepsilon}{(n+1-\rho) \cdot n} \cdot \exp[-n \cdot [v_i - (\underline{s} + \varepsilon)] / 2\varepsilon \cdot (1-\rho)], \qquad (3)$$

with $\rho = r$ (risk parameter of the utility function).

Equation (3) can only be applied if $r < 1$. Several subjects in our experiment are more risk-averse than that. We therefore truncate their risk aversion parameter r at 0.99, which underestimates the actual level of their risk aversion. Nash bids are virtually identical to actual bids for sure prospects (Wilcoxon signed-ranks test, $p = 0.83$). However, we observe strong underbidding, i.e., precautionary bidding compared to the benchmark solution for risky prospects (Wilcoxon signed-ranks test, $p < 0.01$). The robustness check of using relative bids, aggregated on the individual level, gives the same general picture ($p = 0.55$ for sure prospects; $p < 0.01$ for risky prospects).

In order to avoid arbitrary parametric utility assumptions and to fully exploit the model-free nature of our test of precautionary bidding, we estimate the quantitative effect of ex-post risk on bids by using regression analyses, controlling for the panel structure with eight observations per subject.[10] Plotting valuations and bids suggested a linear specification.[11] We include a dummy variable for bids made for risky prospects and a coefficient that captures the interaction of valuations with the presence of the ex-post risk. Model I in Table 2 shows that for sure prospects buyers shade their bids by 15 cents per euro valuation. In the presence of risk, bids are reduced by another 18 cents per euro valuation for the prospect. That is, the precautionary bidding effect is observed, because *equally valuable* risky and sure prospects elicit significantly different bids. Bidders shade their bid approximately twice as much if the good is affected by ex-post risk than when it is not.

In models II and III in Table 2 we address the robustness of the effect with respect to the risk-aversion rank of a specific certainty equivalent or of a specific bidder. The least risk-averse certainty equivalent *for a given prospect* has rank 1 and the most risk-averse certainty equivalent has rank 15 within an experimental session. Similarly, the subject in each session with the lowest average risk-aversion rank *over all eleven prospects* has rank 1 etc. From a

[9] We selected a CRRA utility function because it has been widely applied in the literature on risk aversion and first-price auctions. It obviously has the DARA property.

[10] Remember that for each subject, we know private valuations for two risky and six sure prospects.

[11] Models with non-linear specifications as a robustness check are provided in the Appendix A.

psychological perspective, it could be argued that the effect found in the auction is driven by subjects who do not exhibit a stable risk attitude or who reveal too large certainty equivalents by mistake in the first stage of the experiment, and successively make very low bids in the auction (regression to the mean). Note that buyers who provided relatively high certainty equivalents will have low risk ranks. We distinguish between individual certainty equivalents that are high for a certain prospect and may come from different bidders for different prospects (model II) and bidders who generally state high certainty equivalents (model III). In Table 2, we show the regression results when we exclude observations or bidders with the lowest three risk ranks. In the two alternative specifications the precautionary effect stays both economically and statistically significant. Standard errors increase due to the loss of more than 100 observations in each model, but the estimates are very robust. Note that while we have chosen to exclude the lowest three ranks, our results do not change when we exclude fewer or some more of the high certainty equivalents. Further, a standard regression-to-the-mean explanation would equivalently imply that low-certainty-equivalent bidders should have higher actual valuations, and, therefore, increase their bids for the risky prospects compared to the matched certainty equivalents. This effect, were it present, would reduce the observed precautionary bidding effect.

TABLE 2: DETERMINANTS OF BIDDING BEHAVIOR (FIXED EFFECT PANEL REGRESSION)

Dependent variable Bid	I (BDM)	II (BDM, excl. bids with low risk rank[a])	III (BDM, excl. bidders with low risk rank[b])
Valuation	0.849**	0.874**	0.831**
	(0.024)	(0.026)	(0.026)
Risk	0.030	0.322	-0.351
	(0.281)	(0.301)	(0.330)
Risk×Valuation	-0.181**	-0.229**	-0.133**
	(0.045)	(0.051)	(0.051)
Constant	0.073	0.007	0.127
	(0.155)	(0.163)	(0.178)
# Obs. (bids)	600	461	480
# Obs. (bidders)	75	74	60
R^2	0.67	0.69	0.69

Risk rank: Discrete variable ranging from 1 (least risk-averse) to 15 (most risk-averse).
[a] Bids with lowest risk ranks excluded (ranks 1 to 3 out of 15).
[b] Bidders with lowest risk rank in their session excluded (ranks 1 to 3 out of 15).
** significant at 1% level; BDM = Becker-DeGroot-Marschak mechanism.

Several alternative, though ad-hoc, explanations of our data are conceivable. One could, for instance, claim that all subjects consistently reveal too high certainty equivalents in the elicitation stage. Although the BDM mechanism is widely used for preference elicitation

(Halevy, 2007, p. 507), an upward bias for BDM selling prices has sometimes been reported (Isaac and James, 2000; Plott and Zeiler, 2005). If all subjects reported too large certainty equivalents, the negative effect of risk on bids could be explained by downward revision of the valuations of risky prospects in the auctions.

Another possible, non-expected-utility explanation builds on the behavioral concept of loss aversion. If outcomes are described in terms of gains and losses from some reference point, subjects hold lower valuations of a prospect compared to a description in terms of gains only. In the risk elicitation stage of the experiment, prospects were described as binary gambles with two positive outcomes. Because of the affiliated value structure with sure and risky prospects, it was more natural to describe prospects in terms of a valuation plus ex-post risk in the auctions. The natural ex-post risk description may have, however, led subjects to frame the prospects in terms of an equal-chance gain or loss from the reference point of the sure valuation. This might have made the risky prospects less attractive than in the binary presentation in the risk elicitation, and, therefore, appear less valuable than the matched certainty equivalents.

Although these behavioral biases provide more ad-hoc explanations than the precautionary bidding model, they have been shown to be descriptively relevant in other situations and may provide a psychologically convincing alternative explanation to the equilibrium model. We therefore conducted a control experiment that is able to assess potential effects of selling price bias and loss aversion, described in detail in the following section.

5. Control experiment

5.1 Design and hypotheses

The control experiment (conducted with 75 new subjects in five sessions) was completely identical to the main experiment, except for the following two features. First, the subjects' certainty equivalents were elicited by a choice list. For each prospect, subjects made 21 choices between the risky prospect and a sure payoff, with all choices shown simultaneously on the screen (see screenshot in Appendix B). The lowest sure payoff was equal to the low outcome of the prospect, and the highest sure payoff was equal to the high payoff of the prospect, and these two choices were actually pre-determined for the subjects on the screen in order to enforce stochastic dominance. The nineteen choices between the high and the low sure payoff were equally spaced in monetary units. These choices had to be filled in by the subjects, and the certainty equivalent was calculated as the midpoint between the highest sure amount for which the subject prefers the risky prospect HS_i and the lowest sure amount for which she prefers the sure payoff LS_i, i.e. $CE_i = (HS_i + LS_i)/2$. Because we needed a unique switching point to calculate individual certainty equivalents for the subsequent auction stages of the experiment, we only allowed a single switching point for each individual in the choice list. As in the main experiment, at the end of the experiment one prospect was randomly selected for real pay. For this prospect, one of the 21 choices was randomly selected, and subjects were paid for this stage according to their decisions for the selected choices.

The second design change regards the inclusion of another choice list at the end of the experiment that has been interpreted as a measure of loss aversion and has been widely used recently (Fehr and Götte, 2007, p. 316; Gächter, Johnson and Herrmann, 2007; Fehr, Götte and Lienhard, 2008). Subjects are offered a series of prospects, giving an equal chance of either a gain or a loss that they could choose to play or not to play (Table 3). They were free to accept or reject any prospect, that is, we did not require single switching from acceptance to rejection as the loss increases along the list.[12] Payments for this choice list were according to decision in *all* six choices, depending on the outcome of the risky prospects.

TABLE 3: CHOICE LIST MEASURE OF LOSS AVERSION

Prospect (50%–50%)	Accept to play?	
Lose € 2 or win € 6	Yes O	No O
Lose € 3 or win € 6	Yes O	No O
Lose € 4 or win € 6	Yes O	No O
Lose € 5 or win € 6	Yes O	No O
Lose € 6 or win € 6	Yes O	No O
Lose € 7 or win € 6	Yes O	No O

Adapted from Gächter *et al.*, 2007.

For losses smaller than €6, rejecting to play the prospect implies a significant loss in expected value that may be explained more easily by a gain-loss framing and a kinked utility function of wealth changes than by a concave utility of wealth. It has also been shown that the predictions of reference-dependent utility models hold mainly for people who reject most of the prospects in this choice list (Fehr and Götte, 2007). While we do not aim to add to the

[12] In fact, all subjects had a single switching point.

debate regarding utility curvature versus loss aversion, we call subjects who reject more prospects in this task *more loss averse,* in line with the alternative behavioral hypothesis we aim to test. Assuming the loss-aversion explanation for the choice list clearly implies that the precautionary effect should be driven by the most loss-averse subjects. Loss-averse subjects could value the prospects lower if presented in terms of ex-post risk in the auction rather than as a binary lottery in the initial risk elicitation stage, leading to a reduction of bids for risky prospects compared to their elicited certainty equivalents. This leads to the following two hypotheses originating from behavioral considerations.

HYPOTHESIS 2 (BDM Selling): *Hypothesis 1 holds only for certainty equivalents elicited through BDM selling prices.*

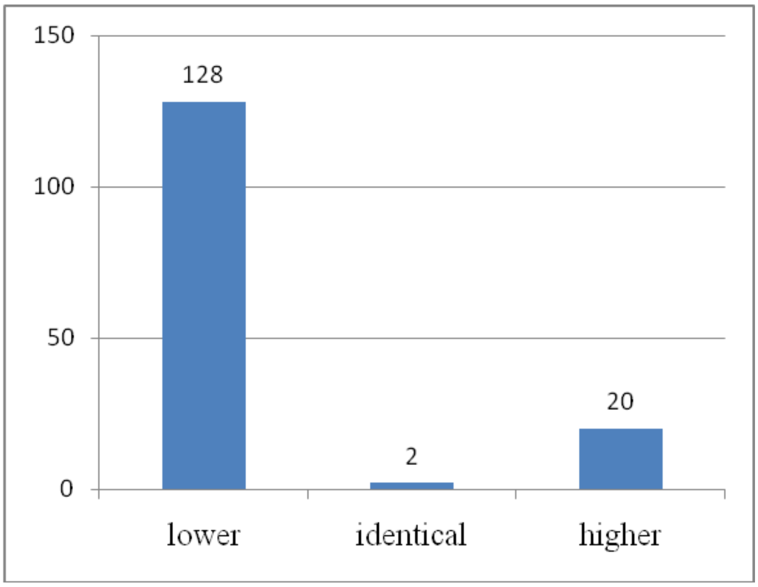
HYPOTHESIS 3 (Loss Aversion): *Hypothesis 1 holds only for loss averse bidders.*

5.2 Results of the control experiment

Table 1 shows in the right-most column that under the choice list procedure the elicited certainty equivalents were not smaller than under the BDM selling price procedure. In fact, certainty equivalents for prospects 4, 7, 9, and 11 were even significantly larger for the choice list procedure (Mann-Whitney-U-tests, $p < 0.05$); all other certainty equivalents were not significantly different for the two methods. These first results indicate already that there was no upward bias through the BDM elicitation of certainty equivalents. Further, Figure 3 shows an identical pattern as for the main experiment, with the precautionary effect being even stronger on average. Of the 150 matched pairs of auctions the risky prospect elicited lower bids than its certainty equivalent in the large majority of cases (Wilcoxon-signed-ranks-test, $p < 0.01$). We can therefore clearly reject behavioral Hypothesis 2.

Conducting a parametric utility analysis for risk-free prospects, we again observe significant overbidding in comparison to the risk-neutral Nash equilibrium bids (Wilcoxon-signed-ranks-test, $p < 0.01$), and for risky prospects we observe risk-neutral Nash bids that are much larger than actual bids (Wilcoxon-signed-ranks-test, $p < 0.01$). Overbidding now does not vanish when one compares actual bids to the risk-averse equilibrium Nash bids based on CRRA utility functions (Wilcoxon signed-ranks test, $p < 0.01$) for sure prospects. However, underbidding is nevertheless highly significant for risky prospects (Wilcoxon signed-ranks test, $p < 0.01$). Not surprisingly, given the similarity of the descriptive results from the main experiment and the control experiment, all our conclusions regarding precautionary bidding from the utility analysis for the main experiment remain valid for the choice list procedure. This is also true for taking average bids, aggregated on the individual level, as the basis for the statistical comparison.

FIGURE 3: COMPARISON OF BIDS FOR RISKY PROSPECTS WITH BIDS FOR THEIR CERTAINTY EQUIVALENTS IN THE CONTROL EXPERIMENT



Note: Number of pairs in which the bid for a risky prospect was (lower/identical/higher) than the bid for its certainty equivalent (within-person comparisons)

As in the main experiment we estimate the quantitative effect of ex-post risk on bids using fixed effects panel regressions, shown in Table 4. Model I in the table shows our basic regression, now for the choice list (CL) experiment. The results are very similar to the main experiment, with bid shading of about 15 cents per euro valuation and a significant precautionary effect of another 28 cents per euro reduction under ex-post risk. In models II to IV we test for differences between the precautionary effect for BDM and CL first stages, using the complete data from both experiments. Model II uses all observations and includes an interaction dummy taking up the difference between the BDM and the CL experiment. The precautionary effect remains significant and its magnitude (a 20 cent reduction in the bids per euro valuation) is considerable.

Figure 4 shows the distribution of the number of prospects rejected in the loss aversion measurement task. Note that all subjects switched at most once, and all switched from accepting the first prospects (see Table 3, small losses) to rejecting the later prospects (larger losses).

FIGURE 4: LOSS AVERSION

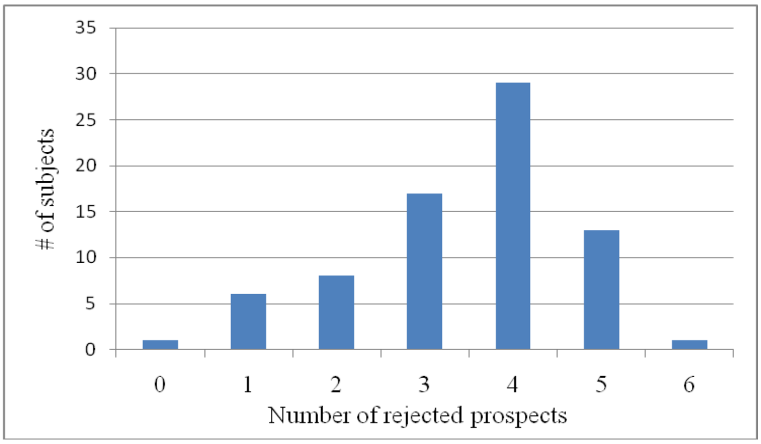


TABLE 4: DETERMINANTS OF BIDDING BEHAVIOR (FIXED EFFECT PANEL REGRESSION) - TOTAL

Dependent variable: Bid	I (CL)	II (CL & BDM)	III (CL, LA dummy)	IV (CL, LA continuous)
Valuation	0.853**	0.851**	0.857**	0.856**
	(0.020)	(0.016)	(0.020)	(0.020)
Risk	0.371	0.190	-0.430	0.447
	(0.256)	(0.190)	(0.254)	(0.257)
Risk×valuation	-0.276**	-0.205**	-0.238**	-0.212**
	(0.039)	(0.032)	(0.040)	(0.046)
Risk×valuation×CL	-	-0.044*	-	-
		(0.017)		
Risk×valuation×LAd	-	-	-0.084**	-
			(0.022)	
Risk×valuation×LAc	-	-	-	-0.022**
				(0.008)
Constant	-0.159	-0.042	0.187	-0.181
	(0.137)	(0.103)	(0.136)	(0.137)
# Obs. (bids)	600	1200	600	600
# Obs. (bidders)	75	150	75	75
R^2	0.74	0.71	0.75	0.74

** significant at 1% level; *significant at 5% level.
BDM = Becker-DeGroot-Marschak mechanism; CL = choice list mechanism; LAd = loss aversion dummy, LAc = loss aversion continuous.

The median number of rejected prospects is 4, replicating the findings in Fehr *et al.* (2008) and Gächter *et al.* (2007). In regression model III we include the loss aversion measure as a dummy for those bidders who reject four or more prospects (median split), and in regression model IV we include the raw number of rejected prospects. Both regressions show that loss aversion does increase the precautionary bidding effect. The loss aversion measures increase the model fit and add significantly to the precautionary effect. However, the coefficients for the precautionary bidding effect stay at around 20 cents per euro valuation and remain highly significant. Thus, our results clearly reject hypothesis 3. The precautionary bidding effect is robust and cannot be explained solely by the two behavioral effects.

6. Summary and conclusion

Esö and White (2004) show theoretically that ex-post risk in affiliated value auctions has an unambiguous effect for bidders with decreasing absolute risk aversion: risky prospects elicit lower bids in a first-price auction than their certainty equivalents. This is a strong result given several simultaneous effects of risk aversion on bid shading in the first-price auction. If precautionary bidding is descriptively relevant, the result has empirical implications for optimal information collection and revelation by sellers, strategic information acquisition by buyers and, more generally, auction design. Esö and White argue that a test of the descriptive power of the model cannot easily be obtained because it requires knowledge of risk and risk attitudes, and both are difficult to observe in the field.

We designed an experimental auction for risky and sure prospects where we directly compared bids for risky prospects with bids for their relevant certainty equivalents on the individual level. Although it has been derived from Esö and White's theoretical results under expected utility, our design in fact provides a model-free test and behavioral definition of precautionary bidding. We find robust evidence for the predicted precautionary effect. Bids are significantly lower for risky prospects than for the appropriate certainty equivalent for the huge majority of our experimental subjects. In other words, bidders are significantly better off bidding for a risky object than for an equivalently valued sure object. Consistent with the experimental auction literature, we find on average overbidding with respect to the risk-neutral Nash equilibrium for sure objects, and that risk-averse Nash equilibrium under expected utility describes bidding behavior for sure objects reasonably well. Corroborating the precautionary bidding effect, in the presence of ex-post risk, there is significant underbidding with respect to the risk-neutral *and* the risk-averse Nash bids. Various control conditions show that the effect is not simply driven by ad-hoc behavioral explanations.

As Kimball (1990, p. 54) argued, the precautionary effect relates to the propensity of people to "prepare and forearm oneself on the face of uncertainty". The current analysis shows that this effect becomes important in auctions involving ex-post risk. If a buyer wins the auction and has to carry the risk, she wants to be prepared by holding more wealth and will bid less aggressively for the risky good. Although the precautionary effect is quite intuitive in risky auction settings, it may come as a surprise to observe it in an experimental setting. The finding is less surprising, however, given that risk aversion effects in auction experiments are a standard finding, and, in particular, that also behavior consistent with decreasing absolute risk aversion (DARA) has already been observed in experimental markets. Levy (1994) conducted a dynamic portfolio choice experiment where subjects made investment decisions under changing wealth levels. Payoffs were given in terms of a few thousand experimental euro, but they translated into typical laboratory payoffs by dividing the market earnings by a factor of 1000. Levy found clear evidence for decreasing absolute risk aversion in terms of experimental wealth. No effect of real wealth on risk taking in the experiment has been observed, however. Levy suggested that subjects make their decision within the frame of payoffs relevant in the experiment and therefore show sensitivity to otherwise rather small changes in payoffs.

A similar finding is provided by Deck and Schlesinger (2010). They demonstrate the relevance of higher order risk attitudes, in particular the importance of prudence, in typical laboratory student populations and payoffs. Also in our setting, the additional ex-post risk in terms of experimental earnings loomed large compared to expected experimental payoffs, making precaution become a relevant motive. Note that the experimental demonstration of prudence by Deck and Schlesinger lends support to the interpretation of our results in terms of precautionary bidding. For bidders with decreasing absolute risk aversion, absolute prudence is larger than absolute risk aversion, leading to the additional precautionary premium.

Our results demonstrate precautionary bidding in experimental auctions. With stakes much higher in real world auctions for consumer products at online platforms, or even higher stakes in auctions for art, licenses or procurement contracts, it is natural to expect precautionary bidding to be an important factor that affects bids and market prices. In some settings, however, the precautionary bidding effect may be mitigated by other influences that lead to an upward bias in bidding. Goeree and Offerman (2003) test explanations of the winner's curse using auctions with noisy signals of an uncertain private value. In the context of the current study, this would be similar to resolving the risky prospects ex-ante and providing subjects with a noisy signal of the outcome. Goeree and Offerman observe too optimistic bidding for these private value auctions, similar to the winner's curse for common values, an effect they call the *news curse*. In situations where buyers receive noisy signals of the value of a risky good, the precautionary effect may therefore be counterbalanced by the news curse. With such potentially countervailing effects influencing bidding behavior with ex-post risk, it seems a fruitful direction for future research to directly study the market effects derived from precautionary bidding theory, including the buyers' selection into auctions for risky or risk-free goods, and the incentives for sellers to invest in the reduction of ex-post risk (Esö and White, 2004, p. 87).

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Appendix: Not for publication [will be made available online]

Appendix A: Non-linear specifications

TABLE A.1: NON LINEAR SPECIFICATIONS (FIXED EFFECT PANEL REGRESSION)

Dependent variable Bid	I (BDM)		II (CL)		III (CL, LA dummy)	
Valuation	1.059**		1.076**		1.089**	
	(0.123)	F(2,520)	(0.110)	F(2,520)	(0.108)	F(2,518)
(Valuation)²	-0.016	=635.23**	-0.016*	=904.35**	-0.016*	=939.96**
	(0.009)		(0.008)		(0.007)	
Risk	1.51		0.087		0.30	
	(0.792)		(0.743)		(0.732)	
Risk×Valuation	-0.181**		-0.182		-0.202	
	(0.045)	F(2,520)	(0.222)	F(2,520)	(0.220)	F(2,518)=
Risk×(Valuation)²	0.039	=10.44**	-0.007)	=26.49**	0.003	5.17**
	(0.020)		(0.016)		(0.016)	
Risk×Valuation×LAd	-		-		0.079	
					(0.076)	F(2,518)=
Risk×(Valulation)²×LAd	-		-		-0.022*	10.13**
					(0.010)	
Constant	-0.558		-0.885		-0.938*	
	(0.396)		(0.377)		(0.371)	
# Obs. (bids)	600		600		600	
# Obs. (bidders)	75		75		75	
R^2	0.68		0.74		0.75	

* significant at 5% level; ** significant at 1% level.
BDM = Becker-DeGroot-Marschak mechanism.; CL = choice list mechanism.
LAd = loss aversion dummy.

Appendix B: Experimental instructions (translated from German)

Welcome to the experiment and thank you for participating!
From now on please do not speak with other participants

General Procedure

The purpose of this experiment is to study decision making. In the experiment you can earn money which will be paid out afterwards.
During the experiment you and the other participants are requested to make decisions. Your decisions, as well as the decisions of the other participants, will determine your monetary payoff according to the rules explained below. The whole experiment will take about two hours. If you have any questions during the experiment, please raise your hand. One of the experimenters will come to answer your questions at your desk.
For convenience we only use male notations in the following instructions.

Anonymity
In some parts of the experiment you will be grouped with other participants. Neither during the experiment nor afterwards you or the other participants will learn about the identity of other group members. Neither during the experiment nor afterwards the other participants will learn about your experimental earnings. We will never connect names with experimental results. At the end of the experiment you will have to sign a receipt about your personal earnings which only serves for accounting purposes. The sponsor of this experiment does not receive any experimental data.

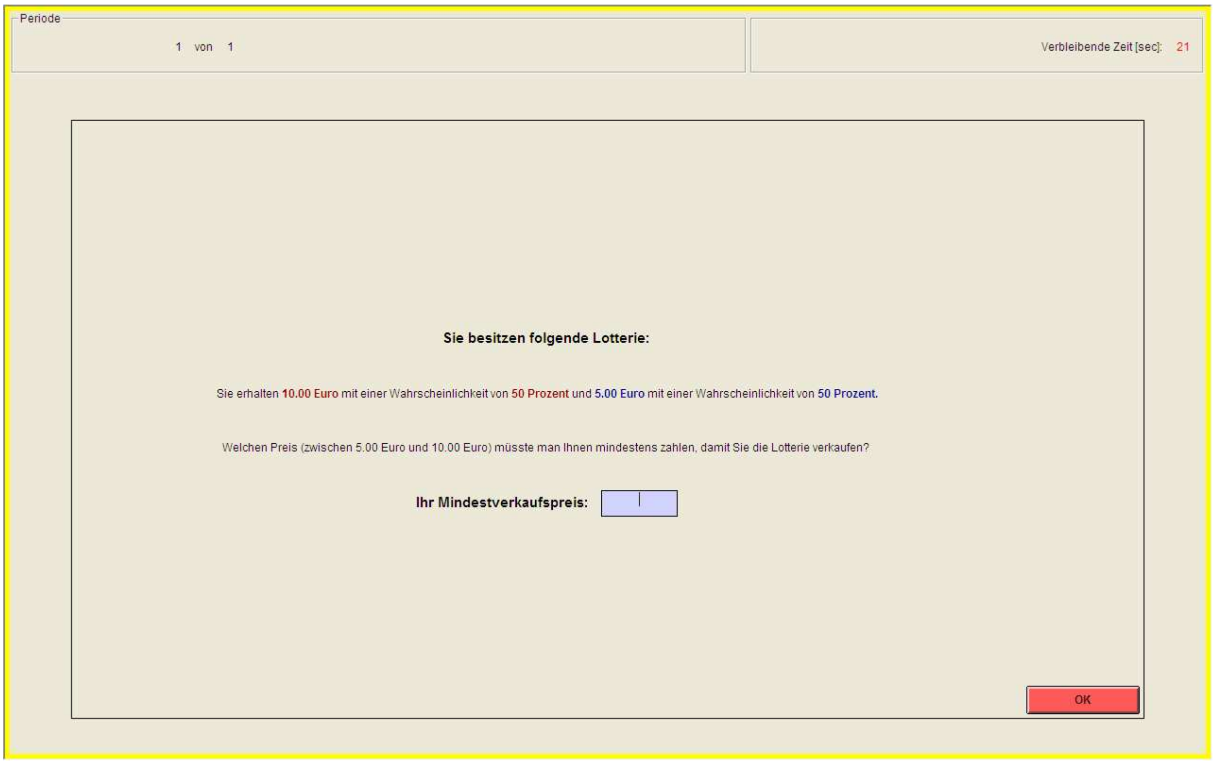
Auxiliaries
At your desk you will find a pen. For calculations you will find a link to the Windows calculator on the screen.

The Experiment
The experiment consists of three parts. You will receive detailed instructions for each part after finishing the previous. In each part you can earn money. The sum of earnings will determine your final income.

Part 1[13]

Part 1 consists of a sequence of lotteries. Such a lottery could be structured as follows.

[13] For the main experiment, i.e. the Becker-deGroot-Marschak mechanism.



In the above example you would earn € 10 with 50% probability and € 5 with 50% probability.

For each lottery you have **two possibilities**:

1. You can **gamble** or
2. You can **sell the lottery**

Proceedings are as follows: You are asked to state a **minimal selling price** for the presented lottery. Minimal selling price denotes the price for which you are willing to sell the lottery. This price has to be within a predetermined range. For the above example the range would be from € 5 to € 10.
After stating a minimal selling price (an €-amount within the given range with two digits behind the comma) the **computer randomly generates a buying offer**. The offer is drawn from the same interval which predetermines the range of your choice – in the above example, between € 5 and € 10. Each two-digit number within this interval can be drawn with the same probability. The computer's buying offer is purely random and totally independent from your chosen minimal selling price.
Afterwards the computer's buying offer and your chosen minimal selling price will be matched. **If the computer's buying offer is higher or equal to your minimal selling price**, you sell the lottery to the computer and receive an **amount equal to the computer's buying offer**. **If the computer's buying offer is smaller than your minimal selling price**, **no sale** takes place. You gamble and receive the lottery outcome. The procedure of the "gamble" will be explained in detail below.

Example 1: Let's assume for the lottery shown above you choose a minimal selling price of € 7. Let's further assume the computer randomly generates a buying offer of € 9.50. In this case the computer's buying offer is at least as high as your minimal selling price. You sell the lottery to the computer and receive an amount equal to the computer's buying offer, namely € 9.50.

Example 2: Let's once more assume you choose a minimal selling price of € 7 for the lottery shown above. This time the computer randomly generates a buying offer of € 6.50. Then the computer's buying offer is lower than your minimal selling price. You do not sell the lottery to the computer. You keep the lottery and gamble. Hence, you either receive € 5 with 50% probability or € 10 with 50% probability.

Please note:
The randomly generated computer offer is independent of your decision about your minimal selling price. Since in case of a purchase your amount received is not determined by the minimal selling price but by the computer's buying offer you should truly state the **minimal price for which you are just willing to sell the lottery**.

Altogether you will state minimal selling prices for **11 lotteries**. At the end of the experiment the **computer randomly picks one lottery**. Since you don't know which one, it is in your own interest to consider carefully all your decisions for all the lotteries. Then, the computer randomly generates a buying offer.
If the buying offer is higher or equal to your minimal selling price, you sell the lottery to the computer and receive an amount equal to the buying offer. If the buying offer is smaller than your minimal selling price, no sale takes place. In this case you gamble and receive the outcome of the lottery. More precisely, the experimenter comes to your desk and you **roll a six-sided dice**. For the example above you would receive € 5 if you roll the numbers 1, 2 or 3 or € 10 if you roll the numbers 4, 5 or 6.
At the top right corner you will find a timer which gives you some temporal orientation for your decision. You can exceed this time limit (especially for the initial decisions, this might often be the case).

Part 2[14]

In part 2 in each round (in each auction) all participants will be matched in **groups of three**. The group composition may chance from auction to auction. But you will always be matched with **participants who have a similar risk attitude**. (As a measure of risk attitude we use your decisions of part 1. From now on, none of your decisions will influence subsequent parts of the experiment).
You and both other group members will take part in an **auction** for fictitious goods. For such a good you receive a **private valuation (V)**. This private valuation may deviate from valuations that the two other members of your group receive. **Private valuations are determined as follows:** In a first step the computer will draw a random number out of a **larger interval**. Let's assume that the computer randomly chooses € 9.00. € 9.00 subsequently serves as the midpoint of a **smaller interval**. Later the private valuations will be drawn from this smaller interval. The smaller interval always has a **width of four**, meaning that in our example your private valuation as well as the private valuations of both other group members will be drawn from an interval between € 7.00 and € 11.00. Let's assume that the computer randomly allocates you a private valuation of € 8.50. You will learn about your private valuation before the auction starts. In this case you know that this number is drawn from a smaller interval with width 4, and you also know that the midpoint of the smaller interval is drawn from a larger interval. But **you do not know the midpoint of the smaller interval**.
After all group members learned about their private valuations, each group member bids for the good [**bid=(B)**]. Each group member receives an **endowment (E) of € 10**. Bids above the endowment are allowed. Please note that this may possibly cause losses which will be subtracted from gains from other parts of the experiment. A group's highest bidder acquires the good and pays her bid. Outbid group members do not have to pay their bids. In case of a tie, a coin toss decides. Earnings are determined as follows:

Earnings:
- <u>Highest bidder</u>: E – B + V
- <u>Outbid group members</u>: E

Some auctioned goods however exhibit **risk**. The risk structure is always the same. **With 50% probability** your private valuation **increases by** a certain **amount (R)** and **with 50% probability** your private valuation **decreases by** the **same amount**. Let's assume an amount (R) of € 3. In this case the earnings of the highest bidder will be either reduced or increased by € 3 both with a probability of 50%. The amount **(R) is identical for all group members** (of course, only the winner has to bear the risk). Prior to each auction you will always learn if the auctioned good exhibits risk and if so by which amount (R) the winner's earnings will be increased or reduced.
Altogether, you will participate in **12 auctions**. After each auction you will learn whether you have purchased the good. In addition, you learn about the other group members' bids. In case the auctioned good exhibit some risk, the resolution of the risk will take place at the end of the experiment. For each of the 12 auctions you have an endowment of € 10. At the end of the experiment, **one auction will be randomly selected** and the results of this auction will be paid out. Since you don't know which one, it is in your own interest to consider carefully all your decisions for all 12 auctions. Each group member receives her earnings from this auction. Since this part is supposed to make you familiar with bidding in an auction and to give you a better understanding of the auction mechanism **all earnings will be divided by a factor of 10**.

[14] Handed out after completion of Part 1.

Thus, an outbid player in the selected auction receives € 10 * 0.1 = € 1. A player who submitted the highest bid in the selected auction will receive her endowment minus her bid plus her valuation (if the good exhibits some risk: plus/minus (R)) divided by 10.
If you purchased a good which exhibit some risk in the selected auction, the resolution of the risk takes place at the end of the experiment. More precisely, the experimenter will come to your desk and you roll a six-sided dice. For the numbers 1, 2 or 3 your earnings will be reduced by the amount (R), and for the numbers 4, 5 or 6 your earnings will be increased by the same amount.

Part 3[15]

This part is very similar to part 2. Again all participants will be matched in **groups of three** to participate in a number of auctions. As you know from part 2, you will always be matched with participants who have a **similar risk attitude** (as a measure of risk attitude we use again your decisions in part 1). Prior to each auction you will learn about your **private valuation** which will be determined **similarly to part 2**. Unlike in part 2, in this part your earnings **will NOT be divided by the factor 10**.
As in part 2 you bid either for goods with a certain value or for goods with a risky value depending on the auction. For each auction you have an **endowment of € 10**. Bids above the endowment of € 10 are allowed, but in case you make a loss, it will be subtracted from gains in other parts of the experiment. Earnings are determined as described in the instructions for part 2.
Altogether, you will participate in **12 auctions**. Unlike in part 2, you will neither learn subsequently to each auction whether you have purchased the good, nor what others have bid. Instead, after the submission of bids the next auction commences.
If the auctioned good exhibit some risk, the resolution of the risk takes place at the end of the experiment. At the end of the experiment **one auction** will be **randomly selected** and the results of this auction will be **paid out**. Since you do not know which one will be chosen, it is in your own interest to consider carefully all your decisions for all 12 auctions. Each group member receives her earnings from this auction.

Examples:

Example 1 (non-risky good):

Players A, B and C have been grouped together. For a non-risky good they receive the following **valuations**:

A: € 4.50; **B:** € 8.10; **C:** € 6.50

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a) Let's assume knowing their valuations players submit the following bids:

A: € 4.00; **B:** € 6.00; **C:** € 5.00

Player B submitted the highest bid and thus bought the good. She has to pay a price equal to her bid, namely € 6.00. This results in the following **earnings** in this auction:

A: € 10.00 (E); **B:** € 10.00 (E) – € 6.00 (B) + € 8.10 (V) = € 12.10; **C:** € 10.00 (E)

In case this auction is drawn to determine payoffs, players A and C receive € 10.00 and player B € 12.10.

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b) Let's assume knowing their valuations players submit the following bids:

[15] Handed out after completion of Part 2

A: € 4.00; **B:** € 8.10 €; **C:** € 5.00

Player B submitted the highest bid and thus bought the good. She has to pay a price equal to her bid, namely € 8.10. This results in the following **earnings** in this auction:

A: € 10.00 (E); **B:** € 10.00 (E) - € 8.10 (B) + € 8.10 (V) = € 10.00; **C:** € 10.00

In case this auction is drawn to determine payoffs, all players receive € 10.00.

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c) Let's assume knowing their valuations players submit the following bids:

A: € 3.00; **B:** € 6.00; **C:** € 9.00

Player C submitted the highest bid and thus bought the good. She has to pay a price equal to her bid, namely € 9.00. This results in the following **earnings** in this auction:

A: € 10.00 (E); **B:** € 10.00 (E); **C:** € 10.00 (E) - € 9.00 (B) + € 6.50 (V) = € 7.50

In case this auction is drawn to determine payoffs, players A and B receive € 10.00 and player C € 7.50.

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d) Let's assume knowing their valuations players submit the following bids:

A: € 15.00; **B:** € 8.00; **C:** € 4.00

Player A submitted the highest bid and thus bought the good. She has to pay a price equal to her bid, namely € 15.00. This results in the following **earnings** in this auction:

A: € 10.00 (E) - € 15.00 (B) + € 4.50 (V) = - € 0.50; **B:** € 10.00 (E); **C:** € 10.00 (E)

In case this auction is drawn to determine payoffs, players B and C receive € 10.00 and player A makes a loss of € 0.50. This loss will be deducted from gains made in other parts of the experiment.

Example 2 (risky good):

Players A, B and C have been grouped together. For a risky good they receive the following **valuations**:

A: € 11.70; **B:** € 9.10; **C:** € 8.30

The good exhibits a risk. Its value will increase by € 3 (R) with 50% probability or decrease by € 3 with 50% probability.

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a) Let's assume knowing their valuations players submit the following **bids**:

A: € 11.00; **B:** € 5.00; **C:** € 4.00

Player A submitted the highest bid and thus bought the good. She has to pay a price equal to her bid, namely € 11.00. Due to the risk she has to gamble at the end of the experiment (in case this auction is drawn to be payoff-relevant). Let's assume she is rolling a two with the dice. Hence, her valuation for the purchased good is reduced by € 3. This results in the following **earnings** for this auction:

A: € 10.00 (E) - € 11.00 (B) + € 11.70 (V) - € 3.00 (R) = € 7.70; **B:** € 10.00 (E); **C:** € 10.00 (E)

In case this auction is drawn to determine payoffs, players B and C receive € 10.00 and player A € 7.70.

b) Let's assume players submit the same bids as in a) but this time player A rolls a four at the end of the experiment. Hence, her valuation for the purchased good is increased by € 3. This results in the following **earnings** in this auction:

A: € 10.00 (E) - € 11.00 (B) + € 11.70 (V) + € 3.00 (R) = € 13.70; **B:** € 10.00 (E); **C:** € 10.00 (E)

In case this auction is drawn to determine payoffs, players B and C receive € 10.00 and player A € 13.70.

1) Questions:

Please choose "True" or "False":

- A player, who did not purchase a good, has zero earnings:
  □ True □ False
- A player bidding exactly her valuation for a non-risky good will earn not more than € 10.
  □ True □ False
- A player bidding more than her valuation for a non-risky good and winning will earn less than in case of not bidding at all.
  □ True □ False
- Altogether you can't make losses in this part.
  □ True □ False
- If I submit a bid below my own valuation, I will earn € 10 in case of not winning and the difference between my valuation and my bid in case of winning.
  □ True □ False
- The lower my bid, the lower my chance of winning the auction.
  □ True □ False
- The higher my bid, the higher my earnings in case of winning.
  □ True □ False

2) Exercises

Players A, B and C have been grouped together. For a non-risky good they receive the following **valuations**:

A: € 5.50; **B:** € 2.70; **C:** € 5.60

Knowing their valuations the players submit the following **bids**:

A: € 3.00; **B:** € 2.00; **C:** € 1.00

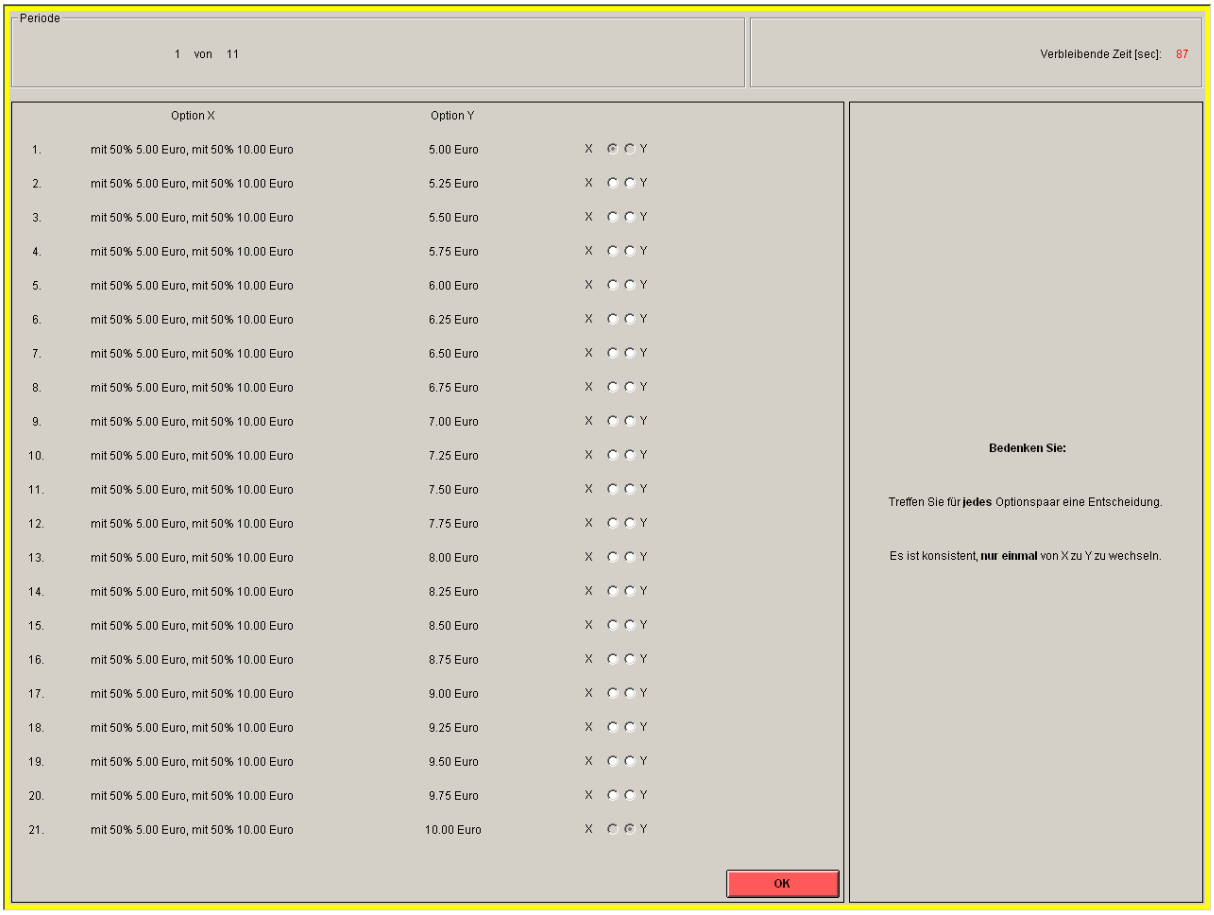
- Which player purchases the good in the auction?
  Your answer: _______________
- What are the earnings of player A?
  Your answer: _______________

- What are the earnings of player B?
  Your answer: _______________

- What are the earnings of player C?
  Your answer: _______________

Part 1[16]

In this part you have to go through a number of lists. You can always choose between two alternatives in these lists: with **option X** you receive a **lottery,** and with **option Y** you receive a **sure payment**. On a given list, option X always represents the same lottery. Sure payments of option Y vary from decision to decision. Such a choice list could look like the following:



In the example above option X always represents a lottery which results in earnings of either € 5 with 50% probability or € 10 with 50% probability. Option Y starts with a sure payment of € 5 and ends with a sure payment of € 10.
For each row you have to choose between option X and option Y. The first decision in a list is always predetermined: Instead of getting a sure payment of € 5 with certainty it is always better to receive a lottery with an outcome of either € 5 or € 10. Thus, **Option X is always predetermined for the first decision**. The last decision in a list is also predetermined. Instead of getting a lottery with an outcome of either € 5 or € 10 it is always better to receive a sure payment of € 10. Thus, **Option Y is always predetermined for the last decision**.
Between these two extremes you have to make choices for 19 option pairs. Since sure payments of option Y are continuously increasing in a list, it is **consistent to switch only once** from option X to option Y.

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[16] For the control experiment, i.e the choice list.

Altogether you will have to fill in **11 choice lists**. The lotteries of option X and the range of the sure amounts will differ from list to list. At the end of the experiment, one choice list is randomly chosen by the computer. From this list the computer **randomly** chooses **one decision to determine your payoffs** for part 1 of the experiment. If for this option pair you chose option X, you will gamble and receive the outcome of the chosen lottery. More precisely, the experimenter comes to your desk at the end of the experiment and you **roll a six-sided dice**. For the example above you would receive € 5 if you roll the numbers 1, 2 or 3 or € 10 if you roll the numbers 4, 5 or 6. If for this option pair you chose option Y, you receive the sure amount of option Y.
Since you don't know which choice will be payoff relevant, it is in your own interest to **consider carefully all your decisions**.

Example 1: Let's assume the computer randomly selects the choice list shown above. From this list choice 2 is randomly selected to determine payoffs. Let's further assume you picked option X in this decision task. In this case you have to gamble. More precisely, you have to roll the dice. With numbers 1, 2 or 3 you receive € 5, and with numbers 4, 5 and 6 you receive € 10.

Example 2: Let's again assume the computer randomly selects the choice list above. From this list choice 20 is randomly selected to determine payoffs. Let's assume you picked option Y for this decision task. In this case you receive the sure amount of option Y in decision 20, namely € 9.75.
At the top right corner you will find a timer which gives you some temporal orientation for your decision. You can exceed this time limit (especially for the initial decisions, this might often be the case).