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OVERCONFIDENCE IN INVESTMENT DECISIONS: AN EXPERIMENTAL APPROACH

Dennis Dittrich
Werner Güth
Boris Maciejovsky

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CESifo
Center for Economic Studies & Ifo Institute for Economic Research
Poschingerstr. 5, 81679 Munich, Germany
Phone: +49 (89) 9224-1410 - Fax: +49 (89) 9224-1409
e-mail: office@CESifo.de
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Abstract

We experimentally test overconfidence in investment decisions by offering participants the possibility to substitute their own for alternative investment choices. Overall, 149 subjects participated in two experiments, one with just one risky asset, the other with two risky assets. Overconfidence increases (i) with the absolute deviation from optimal choices, (ii) with task complexity, and (iii) decreases with uncertainty as indicated by the difference between willingness to pay and to accept.

JEL Classification: C91, D81, G11.

Keywords: risky decision making, behavioral finance, portfolio choice, experimental economics.

Dennis Dittrich
Max Planck Institute for Research into Economic Systems
Strategic Interaction Group
Kahlaischestr. 10
07745 Jena
Germany
Dittrich@mpiew-jena.mpg.de

Werner Güth
Max Planck Institute for Research into Economic Systems
Strategic Interaction Group
Kahlaischestr. 10
07745 Jena
Germany

Boris Maciejovsky
Max Planck Institute for Research into Economic Systems
Strategic Interaction Group
Kahlaischestr. 10
07745 Jena
Germany

1. Introduction

The evidence on decision biases and heuristics challenges the prescriptive validity of standard finance theory which is still the dominant paradigm in modern finance.[1] One such violation is the overconfidence bias in the sense of systematically overestimating the accuracy of one's decisions and the precision of one's knowledge.

Overconfidence has been observed in many professionals (for a survey see Yates (1990)). Most relevant for our study, overconfidence was found in entrepreneurs (Cooper et al. 1988), investment bankers (Stael von Holstein 1972) and managers (Russo and Schoemaker 1992). In particular, individuals were found to overestimate the precision of their knowledge (Fischhoff et al. 1977). Overconfidence was found to be strongest for questions of moderate to extreme difficulty (Griffin and Tversky 1992), and seems to increase with the personal importance of the task (Frank 1935). People were also more confident of their predictions in fields where they have self-declared expertise (Heath and Tversky 1991). Overconfidence has been explained by selective information searching strategies (e.g., Koriat et al. 1980), by motivational factors (e.g., Langer 1975), by imperfections in learning (e.g., Erev et al. 1994, Ferrell 1994), and, for instance, by the experimenters' tendency to choose harder-than-normal questions (e.g., Gigerenzer et al. 1991, Juslin 1993, 1994).

Other studies challenge the claim that people are generally overconfident (e.g., Erev et al. 1994). For an experimental asset market Maciejovsky and Kirchler (forthcoming) conclude that overconfidence depends on how it is operationalized, e.g. by comparing subjective confidence intervals to objective accuracy. Klayman et al. (1999) emphasize that overconfidence depends on (i) how the experimenter asks questions, (ii) what one asks for, and (iii) whom one asks indicating that individuals generally differ in their degree of biased responses. Experimentally alerting overconfident investors can eliminate overconfidence (Bloomfield et al. 1999). Likewise, Zacharakis and Shepherd (1999) recommend to reduce overconfidence by improving knowledge and thereby the decision quality of venture capitalists.

Exceptions to overconfidence are reported for tasks where (i) predictability is high, where (ii) swift and precise feedback about the accuracy of the judgments is provided, and (iii) for highly repetitive tasks (Kahneman and Riepe 1998). Correspondingly, expert bridge players (Keren 1987), race-track bettors (Dowie 1976, Hausch and Ziemba 1995), and meteorologists (Murphy and Winkler 1984) were found to be well-calibrated in their predictions.

Regarding financial decisions overconfidence was analytically (e.g., Barber and Odean 1999, Benos 1998, Caballé and Sákovics 2000) and experimentally (e.g., Adams et al. 1995, Benos and Tzafestas 1997, Camerer and Lovallo 1999) studied and also confirmed for field data (e.g., Barber and Odean 2000, Statman and Thorley 1999). Overconfident investors trade too much (Biais et al. 2000, Odean 1998, 1999), deviate from Bayes' rule when aggregating information (Nöth and Weber 2000), and overreact to private and underreact to public signals (Daniel et al. 1998). Though overconfident agents could thus be exploited by other market participants and driven out of the market, some studies show that overconfidence can persist (e.g., Bernardo and Welch forthcoming, Gervais and Odean 2001, Hirshleifer and Luo 2001, Kyle and Wang 1997, Wang 2001). Fellner et al. (2001) let first participants choose a portfolio which they then

[1] Although behavioral finance increasingly attracts attention (e.g., Hirshleifer 2001).

can substitute for an equally "good" alternative portfolio. Despite the identical payoffs their results indicate that most participants are willing to pay in order to keep their own portfolio.

In this paper we develop a formal model allowing us to unambiguously investigate whether participants exhibit overconfidence in investment decisions. We distinguish a one-risky and a two-risky assets case. To derive unambiguous optimal choices, we induce risk aversion by the binary lottery-method (Berg et al. 1986). In the experiments, the own investment choice can be substituted for (i) the optimal investment solution, (ii) a "risk averse" and (iii) a "risk loving" investment choice. We require a more systematic display of overconfidence by defining overconfidence as the consistent higher evaluation of the own investment choice with regard to all three investment alternatives.

The next section presents the one-asset and the two-assets model. In section 3, we introduce the two experiments by describing their procedure and design, and present our results. Section 4 summarizes our main findings and concludes.

2. The models

In this section, we present the one-risky asset model and the two-risky assets model and derive the optimal solution for the first model and the first-order conditions for the second model. In order to contrast observed behavior with optimal choices we induce risk aversion by the binary-lottery mechanism. In the following this mechanism is briefly introduced.

2.1. Inducing of risk aversion

The decision maker can win either a low ($\underline{M}$) or a high ($\overline{M}$) monetary prize with

$$0 < \underline{M} < \overline{M} \tag{1}$$

The decision maker is paid by the lottery

$$L = (\underline{M}|1 - W; \overline{M}|W) \tag{2}$$

offering the monetary reward $\underline{M}$ with probability $1-W$ and $\overline{M}$ with probability W. For given monetary rewards $\underline{M}$ and $\overline{M}$ satisfying (1) the lottery L is just a function of W, i.e. $L = L(W)$.

Decision behavior does not directly determine W but just the number of points P which one earns. This number P maps into $W = W(P)$ via

$$W = W(P) = P^{\alpha} \quad \text{with } 0 < \alpha < 1. \tag{3}$$

Due to $0 < \alpha < 1$ the function $W(P)$ is strictly concave so that the decision maker is risk averse with respect to investment success measured in points.

2.2. One risky asset

The decision maker is endowed with a positive number P_0, large enough to guarantee $P > 0$, and can invest any amount

$$0 \le i \le \bar{i} < P_0 \quad \text{with } 0 < \bar{i} < P_0 \tag{4}$$

into a risky asset A. This asset has a unit price 1 (in points) and pays dividends $\underline{d}$ and $\bar{d}$ with $\underline{d} < 0 < \bar{d}$ per unit (in points) with probability w and $1 - w$, respectively where $0 < w < 1$. If one buys i units, payments are $i\underline{d}$ with probability w and $i\bar{d}$ with probability $1 - w$. The remaining amount $P_0 - i$ is automatically invested in a riskless bond with an interest r satisfying

$$0 < r < w\underline{d} + (1 - w)\bar{d}. \tag{5}$$

Thus, compared to the bond the risky asset yields a higher expected return but is also more risky. For any given decision i satisfying (4) the number of points P earned is thus given by the lottery

$$P = [(P_0 - i)r + i\underline{d}|w; (P_0 - i)r + i\bar{d}|1 - w]. \tag{6}$$

The positive difference $P_0 - \bar{i}$ is chosen in such a way that P is positive, even in case of $\bar{i}\underline{d}$. Similarly, in case of $\bar{i}\bar{d}$ the number of points should yield a probability $W(P) = P^\alpha$ smaller than 1.

According to (3) the decision i is evaluated by the cardinal utility

$$W(i) = W[P(i)] = w[(P_0 - i)r + i\underline{d}]^\alpha + (1 - w)[(P_0 - i)r + i\bar{d}]^\alpha \tag{7}$$

This follows from two intuitive properties:[2]

(A.1) The decision maker prefers more ($\overline{M}$) to less ($\underline{M}$) money (and thus larger to smaller winning probabilities for the higher monetary prize $\overline{M}$)).

(A.2) The decision maker satisfies the reduction principle in probability calculation (when anticipating which probability W a certain investment level i implies).

Proposition 1 Under (A.1) and (A.2) the decision maker's cardinal utility $u[L(i)] = W[P(i)]$ can be expressed by $W(i)$ given in (7).

By the concavity of $W(i)$ an interior solution requires

$$\left[\left(\frac{w}{1-w}\right)\left(\frac{\underline{d} - r}{r - \bar{d}}\right)\right]^{1/1-\alpha} = \frac{(P_0 - i)r + i\underline{d}}{(P_0 - i)r + i\bar{d}} \tag{8}$$

[2]According to (A.1) the decision maker chooses i such that it maximizes W. By (3) and (A.2) the probability is, however, determined by (7). Denote by $u(\underline{M})$ the utility of earning $\underline{M}$ with certainty and by $u(\overline{M})$ the corresponding utility for $\overline{M}$. Due to (A.1), $u(\underline{M}) < u(\overline{M})$. Since cardinal utilities are only uniquely defined up to positively affine transformations, we can set $u(\underline{M}) = 0$ and $u(\overline{M}) = 1$.

Table 1: Probability Matrix of Repayments

	$\underline{d}_2$	$\overline{d}_2$
$\underline{d}_1$	a	b
$\overline{d}_1$	c	$1-a-b-c$

With the help of

$$R = \left[\left(\frac{w}{1-w} \right) \left(\frac{\underline{d}-r}{r-\bar{d}} \right) \right]^{1/1-\alpha} \tag{9}$$

an interior optimum $i^\star$ can be described as

$$i^\star = \frac{(1-R)rP_0}{R\bar{d} - \underline{d} + (1-R)r}. \tag{10}$$

Proposition 2 Under assumptions (A.1) and (A.2) and given the parameter restrictions guaranteeing $0 < i^\star < \bar{i}$ the optimal investment level $i^\star$ is given by equation (10).

The condition $0 < i^\star < \bar{i}$ will be checked numerically only for the experimentally chosen parameter constellations. In the experiment the decision maker first chooses his/her investment level i in the range (4) and then is offered successively to switch to three different predetermined alternative investment levels $\hat{i}$ of which one is the optimal choice $i^\star$.

2.3. Two risky assets

So far our analysis has been restricted to one riskless and one risky asset. However, over- and underconfidence, respectively may depend on cognitive capacity and effort. Introducing a second risky asset complicates the investment decision considerably. In line with previous empirical evidence indicating that overconfidence is positively related to task difficulty, we expect individual overconfidence to be more pronounced with the two risky assets.

Let $i = 1, 2$ denote the two risky assets whose repayments can assume just two levels $d_i \in \underline{d}_i, \overline{d}_i$ with $0 < \underline{d}_i < 1 < \overline{d}_i$. The stochastic process determining the repayment vector (d_1, d_2) is assumed to be governed by the probability matrix in Table 1 whose entries are assumed to satisfy $a, b, c > 0$ and $a + b + c < 1$. The case of independence with only two degrees of freedom can be captured by

$$a = (a+b)(a+c) \quad \text{or} \quad b = b(a,c) = a\frac{1-(a+c)}{a+c} \tag{11}$$

Due to parameter restrictions the level $b(a, c)$ is positive and smaller than 1. In our experiment we will distinguish a case of negatively correlated repayments ($a = 1/6, b = c = 1/3$) and one of independence ($a = b = 1/6, c = 1/3$).

Repayments are in points whose sum

$$P = P(i_1, i_2) = (P_0 - i_1 - i_2) + \begin{cases} \underline{d}_1 i_1 + \underline{d}_2 i_2 & \text{with probability } a \\ \underline{d}_1 i_1 + \overline{d}_2 i_2 & \text{with probability } b \\ \overline{d}_1 i_1 + \underline{d}_2 i_2 & \text{with probability } c \\ \overline{d}_1 i_1 + \overline{d}_2 i_2 & \text{with probability } 1 - a - b - c \end{cases} \tag{12}$$

is transformed via $W(P) = P^\alpha$ with $0 < \alpha < 1$ into the winning probability W for the large monetary reward. For a local optimum the two first order-conditions are

$$\left[aP(a)^{\alpha-1} + bP(b)^{\alpha-1}\right](1 - \underline{d}_1) = \left[cP(c)^{\alpha-1} + (1 - a - b - c)P(e)^{\alpha-1}\right](1 - \overline{d}_1) \tag{13}$$

and

$$\left[aP(a)^{\alpha-1} + cP(c)^{\alpha-1}\right](1 - \underline{d}_2) = \left[bP(b)^{\alpha-1} + (1 - a - b - c)P(e)^{\alpha-1}\right](1 - \overline{d}_2) \tag{14}$$

where

$$\begin{aligned} P(a) &= P_0 - i_1 - i_2 + \underline{d}_1 i_1 + \underline{d}_2 i_2 \\ P(b) &= P_0 - i_1 - i_2 + \underline{d}_1 i_1 + \overline{d}_2 i_2 \\ P(c) &= P_0 - i_1 - i_2 + \overline{d}_1 i_1 + \underline{d}_2 i_2 \\ P(e) &= P_0 - i_1 - i_2 + \overline{d}_1 i_1 + \overline{d}_2 i_2. \end{aligned} \tag{15}$$

The optimal solution $(i_1^\star, i_2^\star)$ for given parameters will be calculated numerically. For notational ease the vector (i_1, i_2) is denoted by i in the following.

2.4. Switching procedure and behavioral expectations

The willingness to switch from the own choice i to an alternative choice $\hat{i}$ is elicited by using the random price mechanism (Becker et al. 1964) with random prices (in probability) x from the interval

$$x \in [\underline{x}; \bar{x}] \quad \text{with } \underline{x} < 0 < \bar{x} \tag{16}$$

and some density φ with

$$\varphi(x) = \begin{cases} > 0 & \forall x \in [\underline{x}; \bar{x}] \\ = 0 & \text{otherwise.} \end{cases} \tag{17}$$

The bounderies $\underline{x}$ and $\overline{x}$ are chosen such that the optimal limit is always an interior point.

When eliciting the willingness to pay for keeping the own investment choice one, for instance, chooses a limit l in the sense that whenever $x \le l$ one would pay x points and keep the own investment i instead of $\hat{i}$, whereas for $x > l$ one would pay nothing and obtain the alternative investment $\hat{\imath}$. Thus, utility now depends on $i, \hat{\imath}, l$ and x via:

$$W = W(i, \hat{\imath}, l, x) = \begin{cases} W(i) - x & \text{for } x \leq l \\ W(\hat{\imath}) & \text{for } x > l. \end{cases} \quad (18)$$

Since the price x is independent of l, the optimal limit $l^\star$ is

$$l^\star(i, \hat{\imath}) = W(i) - W(\hat{\imath}). \quad (19)$$

Proposition 3 Rational switching requires $l^\star(i, \hat{\imath}) = W(i) - W(\hat{\imath})$.

Participants did not only confront the optimal alternative $i^\star$ but also alternative investment levels $\hat{\imath} = i_-$ and $\hat{\imath} = i_+$ satisfying

$$0 < i_- < i^\star < i_+ < \bar{\imath}. \quad (20)$$

If one has chosen optimally before, i.e. $i = i^\star$, and if $\hat{\imath} \neq i^\star$ one should choose a positive limit $l(i^\star, \hat{\imath})$. In view of the overconfidence hypothesis we expect positive limits even for $\hat{\imath} = i^\star$ and $i \neq i^\star$.

When classifying participants as over- and underconfident or neither one we use two approaches:

(i) The heuristic approach (HA) simply requires for over(under)confidence that $l(i, \hat{\imath}_-), l(i, \hat{\imath}^\star), l(i, \hat{\imath}_+) > 0 \, (< 0)$.[3]

(ii) The statistical approach (SA) demands for over(under)confidence that $l(i, \hat{\imath}_-), l(i, \hat{\imath}^\star), l(i, \hat{\imath}_+)$ are significantly larger (smaller) than their optimal counterparts $l^\star(i, \hat{\imath}_-), l^\star(i, \hat{\imath}^\star), l^\star(i, \hat{\imath}_+)$.[4]

Decision makers often display a large discrepancy between their willingness to accept (WTA) and their willingness to pay (WTP) (e.g., Bateman et al. 1997, Harless 1989, Kahneman et al. 1990). By eliciting both we can control for the endowment effect and test the correlation between over(under)confidence and the WTA/WTP disparity. We will refer to *consistent overconfidence* if and only if the decision maker is classified by both, the willingness to pay and the willingness to accept, as *overconfident* by either approach.

When for the decision maker the value of the object is less certain the WTA/WTP disparity should increase (Kolstadt and Guzman 1999, Mueser and Dow 1997). Since being less certain about something suggests a lower level of confidence, we expect the WTA/WTP disparity to be negatively correlated with the level of confidence.

[3] One will not want to switch from i to $\hat{\imath}$ if one considers i as better than $\hat{\imath}$. In such a case one wants to be rewarded for giving up i. On the other hand, one might regret one's choice and prefer $\hat{\imath}$ over i. In such a case one would be even willing to pay for switching from i to $\hat{\imath}$. Our test of over(under)confidence requires that all three limits $l(i, \hat{\imath}_-)$, $l(i, \hat{\imath}^\star)$ and $l(i, \hat{\imath}_+)$ are positive (negative).

[4] If $l^\star(i, \hat{\imath})$ is the optimal limit we classify a decision maker as *persistently overconfident* when $l(i, \hat{\imath})$ is significantly larger than $l^\star(i, \hat{\imath})$. Otherwise, we will speak of *persistent underconfidence* if $l(i, \hat{\imath})$ is significantly smaller than $l^\star(i, \hat{\imath})$.

Of course, we do not expect participants to engage in the proper (probability) calculus leading to $i^\star$ but rather to rely on aspiration levels, e.g. by a lower bound for $(P_0 - i)$ or for the sure interest $(P_0 - i)r$ which can be used to cover (hedge) the risk resulting from positive investments i. Most investment levels i should be, furthermore, prominent shares of P_0 (Albers 1997). If P_0 is a prominent number, e.g. $P_0 = 100$, prominence should not support rationality (which has been avoided by an appropriate specification of the model parameters).

3. The experiments

We conducted two experiments. The first one investigates individual investment behavior involving only one risky asset, whereas the second experiment involves two different risky assets.

3.1. Experiment I

Experiment I was conducted at the Humboldt-University of Berlin's experimental economics computer lab in June 2001 on three consecutive days with 72 participants in total. Twenty-eight participants were females and 44 males, studying business administration and economics with an average age of 23 years, ranging from 19 to 31. The low monetary prize $\underline{M}$ was DM 15 and the high monetary prize $\overline{M}$ DM 40 leading to an average payment of DM 26.81. Each session lasted for about 70 minutes.

3.1.1. Experimental design and procedure

While reading the instructions (see Appendix A) participants can privately ask questions. Afterwards they are asked to solve two problems related to the experiment. The problems are then solved by one experimenter in public to let participants learn how to calculate the probability of earning the high monetary prize. The instructions refer to lottery tickets and avoid the notion of probabilities. The probability of earning the high monetary prize $W(i)$ is transformed to a number of lottery tickets by multiplying it by 1000. Thus, each lottery ticket amounts to a 0.1 % chance of earning the high monetary prize $\overline{M}$.

The experiment was conducted computerized using z-Tree (Fischbacher 1999). After reading the instructions participants make four investment decisions for four different risky assets (see Table 2), whereby their endowment is always $P_0 = 100$. The upper limit for investments $\bar{i}$ is set to 80 so that $P > 0$ holds for all possible investments i. After each investment decision, participants successively confronted the alternative investment levels $\hat{i}_-, \hat{i}^\star$ and $\hat{i}_+$ in a randomized order and determined their limit for substituting their own choice i by the alternative $\hat{i}$ under consideration.[5] Participants are not told that one of the three alternative investment levels for each investment decision is the optimal one. The interval for the random price mechanism was set to $[-49; 50]$. Only one randomly selected decision is finally chosen to determine the participants' payoff.

[5]More specifically, we ask them: "How many lottery tickets are you willing to pay in order not to have to switch to the alternative investment level?" and "How many lottery tickets do we have to pay you so that you are willing to switch to the alternative investment level?"

Table 2: Parameters for the four different investment decisions

r	$\underline{d}$	$\bar{d}$	w	α	$i^\star$	$W(i^\star)$	i_-	$W(i_-)$	i_+	$W(i_+)$
0.0010	−0.0001	0.006	0.65	0.5	43	0.346	23	0.340	71	0.332
0.0010	−0.0001	0.006	0.67	0.5	38	0.340	21	0.330	63	0.335
0.0007	−0.0001	0.006	0.65	0.5	53	0.315	29	0.306	77	0.302
0.0010	−0.0001	0.007	0.70	0.5	37	0.341	19	0.336	74	0.317

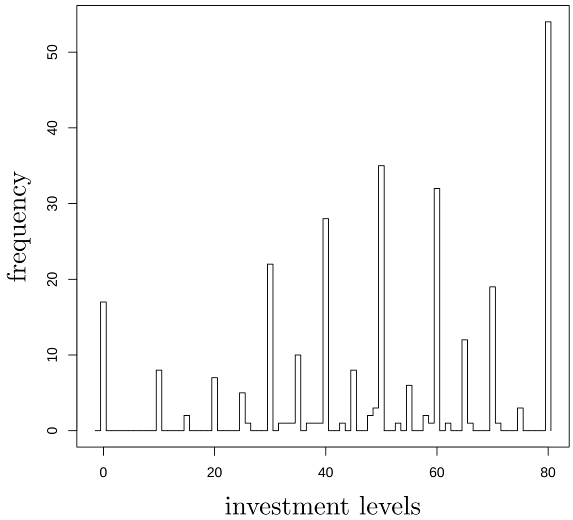

Figure 1: Participants' investment levels for all decisions

After all decisions are made participants are told which of their decisions has been randomly selected for payment and are asked to answer a short post-experimental questionnaire. The experimenters publicly determine whether the relevant risky asset yields a high or low dividend by using a ten-sided die, and apply the random price mechanism[6] for each participant individually. Final payment for each participant is determined by choosing a random number of points. A participant earns the high monetary prize if this number is less or equal to the number of lottery tickets, otherwise the participant earns the low monetary prize.

3.1.2. Results

Let us start by describing individual investment choices. From Figure 1 one can see that most investment levels i are prominent shares of 100 in the form of integer multiples of 10 or (less often) of 5. Only 20 out of 288 (6.9%) investment decisions are not prominent in this sense.

Average investments exceed the optimal ones (pairwise Wilcoxon rank sum test) with 7.5 as mean difference. Since for 61 of our participants we cannot reject optimal investment choices

[6]We have to subtract 50 from the number of points generated by two ten-sided dice to get the interval $[-49; 50]$.

Table 3: Number of participants classified as over- or nonconfident

	overconfident					nonconfident			
times	4	3	2	1	0	1	2	3	4
participants (WTP)[a]	8	12	12	13	20	3	0	1	0
participants (WTA)[b]	41	11	10	6	3	0	0	0	0

[a] Two participants were classified as once both over- and nonconfident. One participant was classified as twice overconfident and once nonconfident.
[b] One participant was once classified as nonconfident and three times as overconfident.

(pairwise Wilcoxon rank sum test at the 10% confidence level) risk aversion has been induced rather effectively.

The average optimal limit $l^\star$ equals -3.78, indicating that mostly investments i were not as good in terms of $W(i)$ as the alternatives. Our participants, however, valued their investments quite differently. First, we observe a significant WTA/WTP disparity (Wilcoxon rank sum test, $p < 0.001$). The mean limit resulting from the WTA question ($l_{\text{WTA}} = 29.34$) is well above the mean limit resulting from the WTP question ($l_{\text{WTP}} = 10.29$). Second, the median limit for each of the three alternative investments is positive.

We now focus on individual decisions and apply our confidence classification, with respect (i) to the heuristic approach, and (ii) to the statistically motivated one.

According to HA, a participant is classified as *overconfident* if all three limits are positive, and as *nonconfident* if all three limits are negative. Table 3 lists the frequency of participants who were classified as either overconfident or nonconfident for WTP and WTA limits. Since every participant is classified four times we can statistically test (Wilcoxon rank sum test) whether (s)he shows consistent behavior. If a participant is classified at least three times in either category this classification is statistically significant at the 10% level. This insistence on statistical significance makes our classification robust against small random deviations from induced risk preferences. As a result 20 out of 72 participants are overconfident in the sense of consistently overevaluating their own investment decision by their limits l_{WTP}. Using l_{WTA} for classification even 52 participants are overconfident.

With respect to SA, we focus on the difference between actual limits l and optimal limits $l^\star$ for each participant and apply the pairwise Wilcoxon rank sum test for classification. If these limits l are significantly larger at the 1 % level than the optimal levels $l^\star$ we classify the participant as *persistently overconfident* and if the limits l are significantly smaller than the optimal $l^\star$ as *persistently underconfident*. Applying this approach yields the following results: With respect to the limits l_{WTP} we classify 35 participants as persistently overconfident, and 37 as neither persistently over- nor underconfident. For the limits l_{WTA} 58 participants are persistently overconfident, and 14 are not classified in either category.

In view of the different numbers of overconfidence classifications we apply our definition of *consistent over-* and *underconfidence*. Now only those participants who are classified into the same category by both WTA and WTP data are called consistently over- and underconfident, respectively. This implies that a participant, classified as consistently overconfident by HA remains consistently overconfident in view of SA, but not vice versa.

Table 4: Probit Regression

Dependent Variable: consistent overconfidence classification
Method: ML - Binary Probit
QML (Huber/White) standard errors and covariance

Variable	Coefficient	Std. Error	z-Statistic	Prob.
constant	5.142057	2.507111	2.050990	0.0403
age	−0.059959	0.085218	−0.7035916	0.4817
sex	−0.879255	0.369041	−2.232540	0.0172
math mark	−0.258057	0.212001	−1.217241	0.2235
self-assessment	−0.069386	0.184353	−0.375156	0.7075
wta/wtp	−0.023176	0.012541	−1.848036	0.0646
mean absolute $i - i^\star$	0.083188	0.021081	3.946108	0.0001
time invest	−0.008515	0.007397	−1.151161	0.2497
time alternative	−0.001196	0.009603	−0.124544	0.9009
FKK-PC	−0.031202	0.018823	−1.657637	0.0974
FKK-SKI	−0.030307	0.019241	−1.575139	0.1152
Mean dependent var	0.416667	S.D. dependent var		0.496466
S.E. of regression	0.444725	Akaike info criterion		1.294803
Sum squared resid	12.06461	Schwarz criterion		1.642627
Log likelihood	-35.61291	Hannan-Quinn criter.		1.433273
Restr. log likelihood	-48.90192	Avg. log likelihood		-0.494624
LR statistic (10 df)	26.57802	McFadden R-squared		0.271748
Probability(LR stat)	0.003036			

Which features characterize an overconfident participant? We answer this question by running a binary probit regression (see Table 4). The dependent variable is the vector of consistent classifications by SA, i.e. a vector of "1s" for persistently overconfident participants and "0s" otherwise. The covariates are age, gender ("1": male,"0": female), math mark (of the university entrance qualification / high school exam) and self-assessment of being a good student. Since the post-experimental questionnaire asks for competence and control (Krampen 1989) resulting in 2 scales (generalized self-effectiveness (FKK-SKI) and generalized beliefs in external control (FKK-PC)), these scales will be covariates, too. Additionally, we include the vector of the WTA/WTP differences, the vector of the mean absolute differences of investments and optimal investments and a vector of the average time needed for investment decisions and trading investment alternatives.

As the likelihood ratio statistic shows, our regression model is indeed a significant improvement to the naïve assumption of constant probability classifications as *overconfident*. Neither age, math mark nor self-assessment are significant. The same is true for both, time variables and the scale of generalized self-effectiveness. According to our regression gender has a significant influence on overconfidence classifications, however, the sign contradicts previous evidence that males are more prone to overconfidence than females (e.g., Huberman and Rubinstein 2000, Lundeberg et al. 1994).

The further significant covariates are the WTA/WTP disparity, the mean deviation from optimal to actual investment and the scale of generalized beliefs in external control. A larger WTA/WTP difference leads to a smaller probability of overconfidence. Interpreting the WTA/WTP disparity as an indicator of uncertainty in evaluating own versus alternative in-

Table 5: Parameters for the four different investment decisions

$\underline{d}_1$	$\bar{d}_1$	$\underline{d}_2$	$\bar{d}_2$	a	b	c	$i^\star$	i_-	i_+
parameter sequence 1									
0.1	2.23	0.2	2.04	0.17	0.33	0.33	(36; 37)	(18; 18)	(53; 51)
0.1	1.94	0.2	2.16	0.17	0.17	0.33	(63; 26)	(31; 13)	(76; 34)
0.5	1.55	0.7	1.31	0.17	0.17	0.33	(129; 6)	(63; 3)	(144; 37)
0.3	1.94	0.3	1.78	0.17	0.33	0.33	(43; 27)	(23; 7)	(63; 47)
parameter sequence 2									
0.1	2.23	0.2	2.04	0.17	0.17	0.33	(79; 13)	(33; 7)	(87; 24)
0.1	1.94	0.2	2.16	0.17	0.33	0.33	(17; 43)	(9; 21)	(34; 73)
0.5	1.55	0.7	1.31	0.17	0.33	0.33	(23; 23)	(11; 12)	(51; 57)
0.3	1.94	0.3	1.78	0.17	0.17	0.33	(103; 6)	(63; 3)	(123; 17)

Note: Numbers in parentheses denote the alternative investments in risky assets 1 and 2, respectively.

vestments, participants are less likely overconfident the higher the degree of uncertainty. Furthermore, the larger the mean deviation from optimal to actual investment the more likely a participant is classified as overconfident. This confirms our intuition that those who performed poorly at the investment task do not recognize their non-competence (e.g., Kruger and Dunning 1999). Finally, participants believing more that their life is controlled by external factors are less likely classified as overconfident.

3.2. Experiment II

Experiment II was also conducted at the Humboldt-University of Berlin with 77 participants in total. Twenty-eight females and 49 males, all students of business administration or economics with an average age of 23 years, ranging from 19 to 28. The low monetary prize $\underline{M}$ was DM 10 and the high monetary prize $\overline{M}$ was DM 40 leading to an average payment of DM 26.36. Each session lasted for about 80 minutes.

3.2.1. Experimental design and procedure

The only difference to Experiment I is that instead of the opportunity to invest in just one risky asset, participants can now invest in two different risky assets (for instructions see Appendix B). We conducted two treatments using the same parameters except for changing the correlation structure of the risky assets, to test for differences between no correlation and negatively correlated risky assets (see Table 5).

3.2.2. Results

Overall, only 63 out of 616 (10.2%) investment choices do not qualify as prominent shares of 100. There are no significant differences between the sequences of uncorrelated ($a = b = 1/6$) and negatively correlated ($a = 1/6$, $b = 1/3$) assets regarding median investments, WTA/WTP levels and spread (Wilcoxon rank sum test, $\alpha = 0.05$). A few minor effects with respect to the two correlation structures of the assets are: First, the median difference between actual and optimal investment choices is 11, indicating that observed choices significantly exceed optimal

Table 6: Number of participants classified as over- or nonconfident

	overconfident						nonconfident		
times	4	3	2	1	0	1	2	3	4
participants (WTP)	21	12	16	12	12	1	1	0	1
participants (WTA)	43	17	8	3	5	0	0	0	0

choices (pairwise Wilcoxon rank sum test, $p < 0.0001$). Second, for uncorrelated risky assets this median difference is 30, whereas for negatively correlated risky assets it is -9, indicating over- and underinvestment respectively.

Since we cannot reject optimal investment choices (pairwise Wilcoxon rank sum test at the 10% confidence level) for 64 of our participants our results support like in Experiment I the intended induction of risk aversion.

The average optimal limit $l^\star$ is -8.08, indicating that investments i were not as good in terms of $W(i)$ as the alternatives. This holds for both, the uncorrelated and the negatively correlated risky assets, whose average optimal limits are -8.02 and -8.14, respectively. Like in Experiment I, we observe different evaluations with respect to mean limits $l_{WTA} = 29.35$ and $l_{WTP} = 12.34$. Again, the WTA/WTP disparity is highly significant ($p < 0.001$). However, the observed median limits do not depend on the correlation structure of the risky assets (Wilcoxon rank sum test for the differences of the median limits l between uncorrelated and negatively correlated investment tasks, $p = 0.175$).

Table 6 lists the frequency of participants who are classified as either overconfident or nonconfident according to HA. Insisting on statistically significant classifications, 33 out of 77 participants are overconfident with respect to their limits l_{WTP}, and even 60 participants are overconfident according to l_{WTA}.

According to SA, 60 participants are classified as persistently overconfident with respect to the limits l_{WTP}, one as persistently underconfident, and 16 as neither one. For the limits l_{WTA}, 72 participants are persistently overconfident and the remaining 5 participants are neither persistently over- nor underconfident.

Thus like in Experiment I, HA and SA lead to inconsistent classifications. We therefore again apply our definition of consistent overconfidence, reducing the disparity between the two approaches. Now only those participants who are classified into the same category by both WTA and WTP data are referred to as consistently under- and overconfident, respectively. All 32 participants who are classified as consistently overconfident by HA are consistently overconfident in the view of SA, too.

The results of the binary probit regression (see Table 7) yield three significant covariates: age, WTA/WTP disparity, and mean absolute deviation from optimal investment which is now measured as the euclidian distance between observed and optimal investment choice. First, age is negatively correlated with overconfidence, indicating that an older participant is less likely classified as overconfident. Second, the larger the WTA/WTP disparity the smaller is the probability of overconfidence. And third, a larger deviation from optimal investment leads to a higher probability of being classified as overconfident.

Table 7: Probit Regression

Dependent Variable: consistent overconfidence classification Method: ML - Binary Probit QML (Huber/White) standard errors and covariance				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
constant	−6.975185	3.573308	−1.952024	0.0509
age	0.237570	0.098072	2.422397	0.0154
sex	0.426292	0.374695	1.137702	0.2552
math mark	−0.280504	0.215306	−1.302813	0.1926
self-assessment	0.060838	0.197227	0.308465	0.7577
wta/wtp	−0.055053	0.013989	−3.935426	0.0001
mean absolute $i - i^{\star}$	0.054345	0.019024	2.856703	0.0043
time invest	−0.002163	0.002479	−0.872776	0.3828
time alternative	0.001734	0.001145	1.514132	0.1300
FKK-PC	−0.000073	0.020007	0.003675	0.9971
FKK-SKI	0.002815	0.022602	0.124547	0.9009
Mean dependent var	0.753247	S.D. dependent var		0.433949
S.E. of regression	0.397256	Akaike info criterion		1.069217
Sum squared resid	9.897914	Schwarz criterion		1.040475
Log likelihood	-30.16486	Hannan-Quinn criter.		1.203146
Restr. log likelihood	-43.02298	Avg. log likelihood		-0.391751
LR statistic (10 df)	25.71624	McFadden R-squared		0.298866
Probability(LR stat)	0.004141			

4. Discussion

We experimentally induced risk aversion and investigated overconfidence in an investment context by comparing actual investment choices with alternative ones. Overall, we conducted two different experiments, one with just one risky asset, the second one with two different risky assets. The residual endowment was automatically invested in a riskless bond. After selecting their own investment level participants confronted three alternative investment choices (including the optimal one) and were asked for their willingness to pay (WTP) and for their willingness to accept (WTA) for substituting the own for an alternative investment choice.

According to our results overconfidence (i) increases with the deviation of actual from optimal investments, indicating that the less accurate their investment decisions are the more prone are participants to exhibit overconfidence. We (ii) demonstrate that overconfidence increases with task complexity, that is overconfidence is more pronounced in the more complex two-assets case. The results (iii) indicate that overconfidence decreases with the WTA/WTP disparity. In at least one of the two experiments, we (iv) found that those participants who believe that their life is largely controlled by external factors are less often classified as overconfident, whereas, rather surprisingly, (v) males are less prone to overconfidence than females. Finally, we (vi) observed that age is negatively correlated with overconfidence.

One drawback of our study is the binary lottery mechanism for inducing risk aversion. There is experimental evidence questioning the reliability of the binary lottery mechanism (e.g., Selten et al. 1999) There is, however, also evidence supporting the notion of "general" risk aversion in experimental studies, even for low stakes and without experimentally inducing it (Holt and Laury 2001). Since we wanted to contrast actual with optimal investment choices, we had to control for risk attitudes in one way or another. As we have allowed for small random deviations from optimality, we feel confident that our tests yield a reliable classification.

Since our experimental approach focuses on individual investment, future research should further investigate overconfidence in the context of a competitive market environment in order to establish whether or not overconfidence survives the market. Also, further research on the relation between overconfidence and personality traits, such as attribution styles, is needed to learn when and why certain characteristics trigger overconfidence.

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Appendix

A. Instructions of Experiment I

In this experiment you will make several decisions. Your final payoff does not depend on the decisions of other participants. Instead, payoff will be determined for each participant individually solely on basis of his/her own decisions.
You will have to make a total of four investment decisions. You can choose between a risky asset and a riskless bond. The risky asset can yield negative and positive payoffs. You will be informed about the corresponding probabilities later in the experiment. The positive payoff of the risky asset exceeds the payoff of the riskless asset.
Your endowment is 100 Guilders, out of which you can invest at most 80 Guilders in the risky asset (in order to avoid losses). The amount of Guilders which is not invested in the risky asset is automatically invested in the riskless bond.
The payoff will not be made in monetary units, but in lottery tickets. The better your decisions the more lottery tickets you get. Overall, there are 1,000 lottery tickets. The high payoff of the lottery is DM 40.-, whereas the low payoff is DM 15.- With your choices you can influence the number of lottery tickets yielding the high payoff.
After your investment decision you will be presented alternative investment choices, and you are asked under which conditions you accept to switch.
Whether you can keep your initial investment choice will be determined by throwing two dice. If L is the amount of lottery tickets, which you are willing to pay in order not to switch, you can keep your investment decision if the dice yields a number smaller or equal to L. However, you have to pay the number shown by the dice. If the dice show a number larger than L, you will have to switch to the alternative investment choice. If you want to switch from your initial investment decision to the alternative choice you can also state a negative amount. L must be in the interval from -49 to 50.
You also have to state your minimum price at which you accept to switch from your initial investment decision to the alternative one. Again this will be determined by throwing two dice. If L is the amount of lottery tickets, which you require for switching, you have to switch if the dice yield a number which is higher to L. In this case you will get the number shown by the dice. You keep your initial investment choice if the dice yield a number which is smaller or equal to L. If you want to switch from your initial investment choice you can even state a negative amount. L must be in the interval from -49 to 50.
We will randomly determine which of your decisions will be relevant for your payoff. Please note that each of your decisions can be randomly selected.
By using the dice we will randomly decide whether the risky asset yields a high or a low payoff which determines the number of lottery tickets you get. Then we will randomly select the winning lottery ticket. Finally, you will paid out your resulting prize.

Decision sheet

Code-No.: ________ Date: ________ Time: ________

May P be your possible payoff given your investment choice. You then get $1000 * \sqrt{P}$ lottery tickets. The risky asset yields a dividend of 0.006 per unit with a probability of 35%, and a dividend of -0.0001 per unit with a probability of 65%. The possible number of lottery tickets given an investment level of i Guilders is:
$1000 * \sqrt{(100 - i) * 0.001 + i * 0.006}$ with probability 35%
or $1000 * \sqrt{(100 - i) * 0.001 - i * 0.0001}$ with probability 65%.

How many lottery tickets will you get in case of the high dividend of 0.006, if you invest 100 Guilders? ______

How many lottery tickets will you get in case of the negative dividend of -0.0001, if you do not invest any Guilders in the risky asset? ______

B. Instructions of Experiment II

In this experiment you will make several decisions. Your final payoff does not depend on the decisions of other participants. Instead, payoff will be determined for each participant individually solely on basis of his/her own decisions.
You will have to make a total of four investment decisions. You can choose between two risky assets and a riskless bond. The risky assets can low and high payoffs. You will be informed about the corresponding probabilities later in the experiment. The high payoff of the risky asset exceeds the payoff of the riskless asset.
Your endowment is 100 Guilders, however it is also possible to invest more, since we are granting you a costless credit. Nevertheless we guarantee that even in case of the low dividends you can meet your obligations. The amount of Guilders which is not invested in the risky assets is automatically invested in the riskless bond.
The payoff will not be made in monetary units, but in lottery tickets. The better your decisions the more lottery tickets you get. Overall, there are 1,000 lottery tickets. The high payoff of the lottery is DM 40.-, whereas the low payoff is DM 10.- With your choices you can influence the number of lottery tickets yielding the high payoff.
After your investment decision you will be presented alternative investment choices, and you are asked under which conditions you accept to switch.
Whether you can keep your initial investment choice will be determined by throwing two dice. If L is the amount of lottery tickets, which you are willing to pay in order not to switch, you can keep your investment decision if the dice yields a number smaller or equal to L. However, you have to pay the number shown by the dice. If the dice show a number larger than L, you will have to switch to the alternative investment choice. If you want to switch from your initial investment decision to the alternative choice you can also state a negative amount. L must be in the interval from -49 to 50.
You also have to state your minimum price at which you accept to switch from your initial investment decision to the alternative one. Again this will be determined by throwing two dice. If L is the amount of lottery tickets, which you require for switching, you have to switch if the dice yield a number which is higher to L. In this case you will get the number shown by the dice. You keep your initial investment choice if the dice yield a number which is smaller or equal to L. If you want to switch from your initial investment choice you can even state a negative amount. L must be in the interval from -49 to 50.
We will randomly determine which of your decisions will be relevant for your payoff. Please note that each of your decisions can be randomly selected.
By using the dice we will randomly decide whether the risky asset yields a high or a low payoff which determines the number of lottery tickets you get. Then we will randomly select the winning lottery ticket. Finally, you will paid out your resulting prize.

Decision sheet

Code-No.: ____________ Date: ____________ Time: ____________

May P be your possible payoff given your investment choice. You then get $30 * \sqrt{P}$ lottery tickets. Asset A yields either a dividend of -90% or a high dividend of 100%. Asset B yields either a dividend of -50% or a high dividend of 50%.
The probability for both assets to yield a high dividend is 1/3, whereas the probability for both assets to yield a low dividend is 1/6. The probability for asset A to yield a high dividend is and asset B to yield a low dividend is 1/3, whereas the probability for asset B to yield a high dividend and for asset A to yield a low dividend is 1/6.
The possible payoffs in lottery tickets given you invested i in asset A and j in asset B are:

$$30\sqrt{100 - i - j + 2i + 1.5j} \tag{21}$$
$$30\sqrt{100 - i - j + 0.1i + 0.5j} \tag{22}$$
$$30\sqrt{100 - i - j + 2i + 0.5j} \tag{23}$$
$$30\sqrt{100 - i - j + 0.1i + 1.5j} \tag{24}$$

How many lottery tickets will you get, if you invest 20 Guilders in each of the risky assets and both yield the high dividend? ______
How many lottery tickets will you get, if you invest 20 Guilders in each of the risky assets and both yield the low dividend? ______