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## **THE PERCEPTION OF DEPENDENCE AND INVESTMENT DECISIONS**

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# THE PERCEPTION OF DEPENDENCE AND INVESTMENT DECISIONS

## Abstract

We study the perception of dependence between asset returns and its impact on investment decisions. Our findings suggest that, while changes in dependence are not neglected, correlation does not properly capture investors' perception of dependence. In several laboratory experiments we vary dependence between two assets. When dependence is linear, participants understand it and consistently diversify less at higher correlations. However, when we vary non-linear dependence---increasing dependence in extreme returns while decreasing dependence in moderate returns---most participants do not understand dependence in extreme returns. Consequently, they diversify less when dependence in moderate returns increases, even if overall correlation decreases due to less dependence in extreme returns. This finding suggests that investors could improve portfolio selection by taking into account biased beliefs about dependence.

JEL Classification: C91, G02, G11

Keywords: Biased Beliefs, Dependence, Investment Decisions, Correlation Neglect, Diversification, Risk Taking

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# 1 Introduction

We study the perception of dependence between asset returns and its impact on investment decisions. In many economic decisions, dependence between different sources of risk plays an important role. Particularly in finance, the impact of dependence on portfolio selection has been a focal topic since Markowitz (1952). As an illustration, investors need to decide how much of their savings to put into asset classes, such as stocks, bonds, and real estate. Empirically, the returns of these asset classes are dependent amongst each other. Investing into asset classes that increase in value when other asset classes in your portfolio decrease in value (negative dependence) reduces overall portfolio risk. As Markowitz, economists have mainly used Pearson correlation as the relevant measure of dependence in these diversification decisions. Asset classes which have low correlation with a portfolio provide an insurance for unexpectedly low or high portfolio returns, and thus decrease portfolio return variance. Hence, they should have a high weight in optimal portfolios. However, the behavioral finance literature shows that correlation is a concept which is hard to grasp for many investors. Starting with Kroll, Levy, and Rapoport (1988), experiments suggest that investors neglect correlation altogether. One reason for these findings may be that the way dependence is communicated in the experiments is unrealistic and difficult to understand for participants. Additionally, even with rational expectations about dependence, investors might care more about dependence in certain states—e.g. when it increases the risk of large losses (see Roy (1952))—so that correlation is not the relevant measure of dependence. The empirical asset pricing literature on the downside risk premium indicates that dependence matters to investors particularly when the market crashes (Ang, Chen, and Xing (2006); Chabi-Yo, Ruenzi, and Weigert (2015)).

We run four laboratory experiments to analyze how varying dependence between asset returns influences beliefs about dependence and investment decisions. We vary the dependence between two assets' returns across treatments, keeping marginal distributions (stock return means, volatilities etc.) constant. We then ask participants to invest their endowment into the two assets and elicit their beliefs about dependence. In our first experiment, we vary linear dependence.<sup>1</sup> We find that participants' beliefs are consistent with changes in dependence. Participants diversify less when dependence increases, in line with Markowitz (1952) and in contrast to previous studies' finding of correlation neglect. In our next experiments, we vary non-linear dependence, decreasing dependence in moderate returns while increasing dependence in extreme returns. We find that participants' beliefs are driven by dependence in moderate returns. They do not understand dependence in extreme returns and diversify less when dependence increases in moderate returns, even if correlation decreases due to

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<sup>1</sup>We use the term 'linear dependence' when the expected value of one asset's return is linear in the other asset's return, i.e.  $E(r_1|r_2) = a + b \cdot r_2$ . If this relation does not hold, we denote the dependence between two assets as 'non-linear'.

decreasing dependence in extreme returns. Thus their behavior is exactly opposite to what one would expect according to Markowitz (1952). In summary, while changes in dependence are taken into account by participants, correlation does not fully explain their beliefs and choices.

We contribute to the literature in several ways. First, we ask a new research question: In addition to analyzing the impact of linear dependence on investors' beliefs and choices, we analyze the impact of dependence in moderate versus extreme returns, i.e. we analyze variation in non-linear dependence. Second, we use a new, more ecologically valid research design: we communicate dependence between asset returns realistically by showing price paths and return series, where the returns are colored green if positive and red if negative. Specifically, participants click through a series of price paths and return series before making investment decisions and before answering questions about their beliefs. Third, we evaluate how well correlation captures investors' perception of dependence by asking detailed questions about participants' beliefs about dependence. Fourth, we ensure that any treatment effect we find stems from changes in dependence—not changes in average returns, volatility or other characteristics of marginal distributions—by keeping marginal distributions of asset returns (e.g. volatilities) the same across treatments.

The remainder of the paper is structured as follows: In Section 2 we relate our study to the literature and state our hypotheses. In Section 3 we describe the main features of our experimental design. We then report the results from an experiment where we vary linear dependence in Section 4. In a second experiment, described in Section 5, we keep correlation constant (at zero) and vary non-linear dependence, i.e. dependence in extreme vs. moderate returns. In Section 6, we describe results from a third experiment on non-linear dependence, where we increase dependence in moderate returns, while decreasing correlation. In a fourth experiment, we analyze how our results are influenced by the way we display information, see Section 7. Finally, we conclude in Section 8.

## 2 Literature and Hypotheses

Earlier studies on the impact of dependence on portfolio selection focus on varying linear dependence. In contrast, we analyze the impact of dependence *in general*, including non-linear dependence. We use the term 'linear dependence' when the expected value of one asset's return is linear in the other asset's return, i.e.  $E(r_2|r_1) = a + b \cdot r_1$ . If this relation does not hold, we denote the dependence between two assets as 'non-linear'. As an illustration, we display the conditional expectations for our treatments in experiments 1 and 2 in Figure 1. Treatments in experiment 1 exhibit linear dependence: The expectations for the return of one stock given the return of the other stock are located on the line  $E(r_2|r_1) = 4\% + \rho \cdot r_1$ , where  $\rho$  is the correlation between stock 1's return  $r_1$  and stock 2's return  $r_2$ . For instance, for

treatment 1 (3) correlation is negative (positive) at  $-0.6$  ( $+0.6$ ), so that  $E(r_2|r_1) = 4\% - 0.6 \cdot r_1$  ( $E(r_2|r_1) = 4\% + 0.6 \cdot r_1$ ). In contrast, the treatments in experiment 2 exhibit non-linear dependence: In particular, dependence in moderate returns is opposite to dependence in extreme returns. Although there is strong variation in dependence between the two treatments of experiment 2, correlation is zero in both treatments. Thus correlation does not capture these changes in non-linear dependence. To the best of our knowledge we are the first to experimentally test the perception of non-linear dependence and its impact on investment decisions.

[INSERT FIGURE 1 ABOUT HERE]

Furthermore, we communicate dependence via graphical information (price paths) and numerical information (sequences of returns), instead of relying on unrealistic direct statements about probabilities of joint events. We additionally avoid confounding effects of changes in volatility across treatments by keeping marginal distributions constant. An early experimental test of the impact of correlation on portfolio selection is Kroll, Levy, and Rapoport (1988). They find that investors neglect information on correlations in their portfolio decisions. Information is communicated via stating means, standard-deviations and correlations of jointly normally distributed returns with varying levels of correlation across treatments. In more current research, Kallir and Sonsino (2009) and Eyster and Weizsäcker (2011) also provide evidence in line with correlation neglect. Kallir and Sonsino (2009) vary the dependence for  $2 \times 2$  equally probable states (2-assets with 2 possible returns each) and communicate riskiness via probability statements as Kroll, Levy, and Rapoport (1988). In contrast to these two studies, Eyster and Weizsäcker (2011) do not vary the decision problem, but vary the framing of decisions by letting participants invest into two assets 1 and 2 in the first treatment and into assets 1 and 2' – where 2' is a linear combination of assets 1 and 2 – in the second treatment. This keeps the decision problem the same, while changing linear dependence and marginal distributions. Eyster and Weizsäcker (2011) also directly state the probabilities for all states.<sup>2</sup> Hence, by keeping marginal distributions constant, communicating dependence in a realistic manner, and additionally analyzing the impact of non-linear dependence we contribute to the experimental literature on portfolio selection.

Our study is also related to the literature on rare events. Whether investors focus on or neglect rare, extreme events becomes relevant when non-linear dependence is varied. Results in the literature are strongly dependent on the way risky choices are communicated. On the one hand, previous experiments find overweighting of rare observations when the probabilities of these events are communicated via description, i.e. when probabilities for

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<sup>2</sup>This is not supposed to be an exhaustive literature review, but rather a representative sample of the literature. Other studies on the impact of correlation on investment decisions include Kroll and Levy (1992), Benartzi and Thaler (2001), Hedesström, Svedsäter, and Gärling (2006), Klos and Weber (2006) Gubaydullina and Spiwoks (2009), Cornil and Bart (2013), and Reinholtz, Fernbach, and de Langhe (2016).

events are directly stated. This motivates the probability weighting function in the context of prospect theory, see Kahneman and Tversky (1979) and Tversky and Kahneman (1992). Based on these results, one could hypothesize that investors focus on dependence in salient extreme events. On the other hand, as shown by Hertwig, Barron, Weber, and Erev (2004), Abdellaoui, L’Haridon, and Paraschiv (2011), and Kaufmann, Weber, and Haisley (2013), experience sampling (the sequential drawing of potential outcomes) can lead to reduced overweighting or even underweighting of small probability events. Payzan-LeNestour (2015) finds that participants—even after being told about the underlying distribution—repeatedly agree to a bet with frequent positive outcomes, but extreme negative skewness and a negative expected value (‘picking up pennies in front of a steamroller’). Based on these results, one could hypothesize that investors focus on dependence in frequent events. We directly test these competing hypotheses by separately varying dependence in extreme (but rare) and frequent (but moderate) observations.

Another difference between the previous literature on correlation neglect and our experiments is our focus on beliefs about dependence. We directly ask for participants’ expectations about dependence in the domains of extreme and moderate returns, and thus differentiate between biased beliefs about dependence and over- or underweighting of observations in preferences. Barberis (2013) discusses the importance of disentangling biased beliefs and certain preferences with respect to rare tail events. As an illustration, the probability weighting in prospect theory is part of the preferences. Given objective beliefs about rare events’ probabilities, the prospect theory decision maker still overweights rare events. Relative to such preference-based overweighting, biased beliefs about the probability of rare (joint) events have very different implications for policy makers: Biased beliefs are irrational and ‘de-biasing’ agents should improve decisions, whereas the irrationality of a utility function with probability weighting is not that clear-cut.

We test the following hypotheses on the effects of changes in linear dependence ( $H_{11}$  and  $H_{12}$ ) and non-linear dependence ( $H_{21}$  and  $H_{22}$ ):

$H_{11}$ : Investors are able to perceive changes in linear dependence (Beliefs).

$H_{12}$ : Investors diversify more when linear dependence decreases (Choice).

$H_{21}$ : Investors are able to perceive changes in non-linear dependence. (Beliefs).

$H_{22}$ : Investors diversify more when perceived overall dependence decreases (Choice).

### 3 Experimental Setup

To determine how investment decisions (choices) and the perception of dependence (beliefs) are influenced by actual dependence, we conduct several experiments. In experiment 1 we

start with the relatively simple hypotheses  $H_{11}$  and  $H_{12}$  and test them by varying linear dependence. Varying linear dependence lets us compare our results to previous research, where the most common finding is 'correlation neglect'. In experiments 2, 3 and 4 we test hypotheses  $H_{21}$  and  $H_{22}$  by varying dependence in extreme versus moderate returns. In all experiments participants are asked to make portfolio selection decisions and to state their beliefs in situations with varying dependence between two stocks. We choose an allocation decision with only two stocks and no risk-free asset to keep the investment decision as simple as possible. There are several challenges that have to be met by the design of experiments on portfolio selection.

First, directly displaying probabilities for different states—although common in experiments that find correlation neglect—is unrealistic. Hence, we let participants see price paths (graphical display) and returns (numerical display) to present the risky choice they face. In experiment 4 (Section 7) we test the effects of the presentation mode by showing some of participants price paths only, and the other ones returns only. As is often done with real market data, returns are colored green if positive, and red if negative. Each participant gets to see a representative sample from the treatment's return distribution. Rare, extreme events have a probability of only 5% in all experiments, so that we need to show each participant 100 observations for a representative sample. Exponential growth makes it very hard to discern returns at the beginning of a typical 100-year sample.<sup>3</sup> Hence, we instead show  $10 \times 10$ -year subsamples, which participants click through.

Second, effects due to varying marginal distributions (e.g. volatilities) of each asset could drive the results. This problem is solved via using the same marginal distributions across treatments. Consequently means, standard-deviations and all other moments are equal across treatments. All that varies across the different decision situations is dependence. This approach is inspired by the concept of copula functions, which isolate structures of dependence between random variables from marginal distributions. Thus any measured effect between treatments must be a result of the varied dependence.

Third, it is likely that the order of observations each participant observes has a systematic influence on the participants' investment decisions. Asparouhova, Lemmon, and Hertz (2009) for instance show that participants expect reversals (continuation) after short (long) streaks when shown sequences of randomly generated *independent* numbers. Cohn, Engelmann, Fehr, and Maréchal (2015) find that risk aversion increases after participants are primed with bust scenarios. Mussweiler and Schneller (2003) report that extremely high (low) observations on price paths lead to a higher likelihood of purchases (sales). Using the same price path for all participants by treatment—even if it is a representative sam-

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<sup>3</sup>As an illustration: At an average return of 4% per year, 1 € grows to more than 50 € over 100 years, so that any return at the beginning of the sample is 50 times smaller on the usual linear scale relative to a similar return at the end of the sample. The analogue 10-year growth is 1.48-fold instead of 50-fold, so that this problem is negligible for 10-year samples.

ple of the treatment’s distribution—could thus lead to dependence of participants’ answers on a feature of the price path, which is not directly related to the dependence-treatment (e.g. whether it ends with a few positive returns of stock 1). We solve this problem by randomizing the order of pair-wise observations for each participant’s representative sample.

**Experimental tasks:** Participants are randomly assigned to one of the treatment sequences in a counterbalanced design.<sup>4</sup> After a short introduction, including instructions and a comprehension question, participants view  $10 \times 10$ -year price paths and return series for the two stocks. The 100 observations form a representative joint distribution for the treatment, but the order is randomized by participant. Then, they are asked how much of 10’000 € they want to invest into stocks 1 and 2. Finally, participants answer questions about the dependence between stocks 1 and 2.<sup>5</sup> Stock 1 offers an average return of 5%, whereas stock 2’s return distribution exhibits an average of only 4% achieved through a shift of stock 1’s distribution by 1%, so that all higher moments (e.g. volatility or skewness) are equal across stocks. Stock 2 should thus only be interesting because of its diversification potential. To incentivize participants, they get a fraction of  $\frac{1}{1000}$  of a simulated one-year payoff of their selected portfolio (payoffs range from 6.40 € to 13.50 € with an average of 10.47 € over all experiments; each session of the experiments took around one hour). To test our hypotheses on beliefs ( $H_{11}$  and  $H_{21}$ ) we directly ask for the dependence between stocks 1 and 2 (e.g. the overall dependence, dependence in extreme and moderate returns). To test our hypotheses on investors’ portfolio choice ( $H_{12}$  and  $H_{22}$ ), we check whether participants diversify more by investing more in stock 2—the stock with a lower return—when they perceive dependence between the stocks to be lower. The investment choice is made before questions about beliefs are asked.

**Control variables:** To improve the efficiency of some estimates, a number of control variables are collected at the end of the experiment (e.g. age, financial literacy and numeracy). Some of these variables (e.g. financial literacy) are additionally used as interaction variables with the main independent variable, i.e. the dependence treatment.<sup>6</sup>

## 4 Experiment 1: Varying Linear Dependence

**Stimuli:** In experiment 1, we test the effects of varying linear dependence on beliefs and diversification choices ( $H_{11}$  and  $H_{12}$ ). Correlation is -0.6 for treatment 1, 0.2 for treatment

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<sup>4</sup>In experiment, 1 there are 6 possible sequences for treatments 1, 2 and 3: 1-2-3, 1-3-2, 2-1-3, 2-3-1, 3-1-2, and 3-2-1. In experiments 2, 3 and 4, there are 2 possible sequences for treatments 1 and 2: 1-2 and 2-1.

<sup>5</sup>Appendix B shows an overview of the experiment. The exact instructions and questions from the experiment are reported in Appendix C.

<sup>6</sup>Appendix A shows an overview of the outcome variables (Panel A) and control variables (Panel B) collected in these experiments.

2 and 0.6 for treatment 3.<sup>7</sup> The conditional expectation of stock 1’s return is linear in stock 2’s return (i.e.  $E(r_1|r_2) = a + b \cdot r_2$ , see joint distributions in Table 2 and conditional expectations in Figure 1). The co-movement between returns increases from treatment 1 to treatment 3, regardless of whether participants focus on frequent, moderate returns or rare, extreme returns. Hence, we expect participants to perceive an increase in dependence from treatment 1 to treatment 3 ( $H_{11}$ ). Consequently, we expect participants to diversify less as correlation increases ( $H_{12}$ ). Figure 2 shows two of the  $10 \times 10$ -year draws sampled by participants for treatments 1 and 3, respectively. Note that the order of pairwise returns in the  $10 \times 10$ -year sample is randomized for each participant, so that it is uncertain how many of the other participants get to see exactly these price paths. Figure 3 shows the optimal investment in stock 2 for an expected utility maximizing investor with constant relative risk aversion (CRRA) at relative risk aversion from 0.5 to 10. The increase in correlation from treatment 1 to 3 leads to a lower optimal investment in stock 2. This can be expected as stock 2’s return distribution is just stock 1’s return distribution minus 1%, so that the main reason for a reasonably risk-averse CRRA investor to buy stock 2 is to diversify risk. Since the diversification potential of stock 2 decreases as correlation increases, the optimal investment in stock 2 decreases with correlation. Increased relative risk aversion leads to a higher optimal investment in stock 2. The return-difference of 1% between stocks 1 and 2 was selected so that only unreasonably low levels of relative risk aversion lead to the boundary solution of zero investment in stock 2.

[INSERT TABLE 1 ABOUT HERE]

[INSERT TABLE 2 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

[INSERT FIGURE 3 ABOUT HERE]

**Data and participants:** Experiment 1 was conducted at a lab for experimental economics with 127 participants. The participant pool consists mostly of university students. Summary statistics about the participants are reported in Panel A of Table 1. Note that there is considerable variation in financial literacy and numeracy scores. This enables us to test whether the perception of dependence and investment decisions change for more financially literate or numerate participants.<sup>8</sup>

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<sup>7</sup>The non-zero correlation (0.2) in treatment 2 is due to our requirement that probabilities for all states have integer percentage values, so that a representative distribution with  $10 \times 10 = 100$  observations can be used. We opted for a slightly positive correlation, instead of the also feasible slightly negative correlation of -0.2, since in financial markets positive correlations are more common.

<sup>8</sup>The authors wish to acknowledge the financial support of the University of Mannheim’s Area Banking, Finance & Insurance. The experiments were conducted in the Mannheim Lab for Experimental Economics (mLab) at the University of Mannheim. We would like to thank the mLab team, particularly Andrej Svorencik and Thomas Behles for their support. The software packages Orsee (Greiner (2003)) and z-Tree (Fischbacher (2007)) were used to conduct the experiment.

**Discussion of results:** Table 3 reports participants’ beliefs about dependence.<sup>9</sup> In summary, the findings lend support to hypothesis  $H_{11}$ : participants (correctly) believe dependence increases from treatment 1 to treatment 3. The exact questions asked are included in the tables and listed in Appendix C. Panel A shows that the majority (94 out of 127) of participants understand that stocks 1 and 2 move in opposite directions in treatment 1, where correlation is -0.6. In treatment 3, where correlation is +0.6, the majority (98 out of 127) understand that stocks 1 and 2 move together. Mean beliefs about dependence on a scale from 1 (Stocks 1 and 2 move ...in opposite directions) to 5 (...together) increase from 2.22 to 3.41 from treatment 1 to 2, and then to 3.86 for treatment 3. These increases are statistically significant. Panels B1 and B2 show that beliefs about the frequency of co-movement also change in accordance with the treatments’ true frequencies of co-movement: participants estimates for the frequency of co-movement significantly increase as correlation increases. For treatment 2 the average estimated frequency of co-movement (58% in B1 and 56% in B2) is relatively close to the treatment’s true frequency of co-movement (60%). For treatments 1 and 3 the estimated frequencies are biased towards 50%. In treatment 1 the true probability of co-movement is 20%, but participants’ average estimates are at 35% (Panel B1) and 38% (Panel B2). In treatment 3 the true probability of co-movement is 80%, but participants’ average estimates are at 69% (Panel B1) and 68% (Panel B2).

[INSERT TABLE 3 ABOUT HERE]

Participants’ beliefs about dependence in extreme versus moderate returns are reported in Panels C and D of Table 3. Again, participants seem to understand how dependence changes as correlation increases. Panels C1 and C2 show that the majority of participants believe that dependence in extreme returns is negative in treatment 1 and positive in treatment 3. Treatment effects on average beliefs about dependence in extreme returns are highly statistically significant for all pairwise comparisons. Panels D1 and D2 exhibit the same pattern for participants’ beliefs about dependence in moderate returns. Although effects are somewhat weaker they are still highly statistically significant. Note that from this experiment we cannot tell whether participants actually understood dependence in both domains, extreme and moderate returns. It may be that participants just understand dependence in one of the domains and project this belief onto the other domain. Since dependence is linear, this would not lead to biased beliefs. In experiment 2 we vary non-linear dependence to test whether participants understand both or just one of the two domains of dependence. All in all, the evidence in Table 3 is in line with  $H_{11}$ : Participants are able to perceive changes in linear dependence.

Next, we analyze whether linear dependence influences investment decisions. We would expect participants to diversify more when correlation decreases ( $H_{12}$ ). Hence we would

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<sup>9</sup>All outcome variables, which are not reported in the main tables are reported in Appendix D and discussed in Appendix E.

expect them to invest more in stock 2 in treatment 1 than in treatment 2, and more in treatment 2 than in treatment 3. Table 4 shows that this is indeed the case. Participants invest an average of 3'186 € out of 10'000 € into stock 2 in treatment 3, where correlation is at +0.6. For treatment 2 (correlation of +0.2) the investment in stock 2 increases by 707 € to 3'893 €. And for treatment 1 (correlation of -0.6) participants diversify the most at 4'112 €. The treatment effects from treatment 3 to treatments 1 and 2 are statistically significant at the 1%-level, whereas the treatment effect from treatment 2 to 1 is statistically insignificant.<sup>10</sup> Figure 3 shows that the average levels of investment in stock 2 are consistent with the optimal decision of a CRRA-investor with relative risk aversion between 2 and 5. Estimates of relative risk aversion from survey and field data regularly put it in this vicinity.<sup>11</sup> Note that these results are surprising, since previous research mostly found evidence in line with correlation neglect.

[INSERT TABLE 4 ABOUT HERE]

We now analyze some characteristics of participants that might be associated with the diversification decision. A variable we would expect to influence the diversification decision is risk aversion. More risk-aversion should lead to a higher level of investment in stock 2. In specification (2) of Table 4 we add participants' self-assessed risk aversion—standardized to have a mean of zero and standard-deviation of one—as an explanatory variable. Indeed a one standard-deviation increase in risk aversion is associated with a 503 € increase in diversification.<sup>12</sup> Other variables that might influence the diversification decision are financial literacy and numeracy. In specification (3) of Table 4 we add both (again standardized) to the regression. Whereas numeracy does not significantly influence the investment in stock 2, financial literacy seems to decrease the level of diversification. A one standard-deviation increase in financial literacy decreases the investment in stock 2 by 269 €. <sup>13</sup> This decrease in diversification might be driven by less 'naive diversification' (usage of the 1/N-heuristic) by financially literate participants. Incidentally, the treatment effects in our experiments

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<sup>10</sup>Regressing the investment in stock 2 on beliefs about dependence leads to qualitatively similar results. However, since these beliefs might co-vary with the investment decision independent of variation in dependence (they are endogenous), we rather analyze differences between treatments (the exogenous variation in dependence) directly.

<sup>11</sup>Friend and Blume (1975) use survey data on household asset holdings and find relative risk aversion 'probably in excess of two'. Metrick (1995) estimates risk aversion close to zero, using behavior on the game show 'Jeopardy!'. Kimball, Sahm, and Shapiro (2008) estimate a value of approximately eight based on hypothetical income gambles elicited through a survey. Aarbu and Schroyen (2014) use choices among hypothetical income lotteries in a Norwegian survey and arrive at a value of three to four. Paravisini, Rappoport, and Ravina (2015) use micro-lending data and get a relative risk aversion of close to three.

<sup>12</sup>Note that including characteristics of participants as additional variables does not change estimates for our treatment effects. This is because every participant goes through both treatments, so that the treatment dummies are orthogonal to characteristics of participants.

<sup>13</sup>In unreported robustness tests, we replace the financial literacy score by a dummy that indicates whether the one question related to diversification from the financial literacy test—item (5)—was answered correctly. Results do not qualitatively change.

cannot be explained by 'naive diversification', since a bias towards  $1/N$  should equally affect investment decisions in both treatments.

Even though financial literacy and numeracy do not have a robust influence on the level of diversification they could influence the treatment effects, i.e. the difference in diversification from treatment to treatment. To test this, we add interaction effects between our treatment dummies, financial literacy and numeracy (see specification (4) of Table 4). Even though there is strong variation in both variables (see summary statistics in Table 1), we do not find statistically significant interaction effects. A qualifier: confidence intervals include economically significant values.<sup>14</sup> All in all, the evidence in Table 4 is in line with  $H_{12}$ : Participants diversify more as linear dependence decreases.

## 5 Experiment 2: Varying Non-Linear Dependence I

**Stimuli:** In experiment 2, we test the effects of varying non-linear dependence on beliefs and diversification choices ( $H_{21}$  and  $H_{22}$ ), i.e. we test whether participants perceive dependence based on extreme (but rare) or frequent (but moderate) observations. Correlations between the two stocks are set to zero in both treatments. Although correlation is thus the same, a strong variation in dependence between extreme versus moderate returns across treatments is achieved: treatment 1 exhibits negative dependence in extreme returns and positive dependence in moderate returns, while treatment 2 exhibits positive dependence in extreme returns and negative dependence in moderate returns (see joint distributions in Table 5 and conditional expectations in Figure 6). Since dependence in the domain of extreme returns is positive when dependence in the domain of moderate returns is negative (and vice versa) we can differentiate participants who understand dependence in only one of these domains from those who understand it in only the other domain, even if they project their beliefs onto the domain they do not understand. If participants rather focus on dependence in extreme returns, we expect them to perceive an increase in overall dependence from treatment 1 to treatment 2, since dependence in extreme returns changes from perfectly negative to perfectly positive from treatment 1 to treatment 2. We particularly expect participants to correctly answer questions about dependence in extreme returns. In contrast, if participants rather focus on dependence in moderate returns, we expect them to perceive a decrease in overall dependence from treatment 1 to treatment 2, since dependence in moderate returns changes from perfectly positive to perfectly negative from treatment 1 to treatment 2. Participants should then be able to answer questions about dependence in moderate returns particularly well. Consequently, we expect participants to diversify less in

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<sup>14</sup>In unreported tests we find that adding control variables does not qualitatively change our results. We add: self-assessed statistics knowledge, age, gender, a dummy that is one if the participant owns stocks/equity-funds, a dummy for participants who indicate interest in financial markets and a dummy for having attended a university statistics course.

treatment 2, relative to treatment 1, if they focus on extreme returns. Vice versa, if they focus on moderate returns, we expect them to diversify more in treatment 2. As an illustration, Figure 4 shows two of the  $10 \times 10$ -year draws sampled by participants for treatments 1 and 2, respectively. Figure 5 shows the optimal investment in stock 2 for an expected utility maximizing investor with constant relative risk aversion (CRRA) at relative risk aversion from 0.5 to 10. Since correlation between returns and marginal distributions (means and variances) do not change from treatment 1 to treatment 2, the difference between optimal investments in stock 2 from treatment 1 to 2 is small relative to experiment 1.

[INSERT TABLE 5 ABOUT HERE]

[INSERT FIGURE 4 ABOUT HERE]

[INSERT FIGURE 5 ABOUT HERE]

**Data and participants:** Like experiment 1, experiment 2 was conducted at a lab for experimental economics. Summary statistics about the 94 participants are reported in Panel B of Table 1. They are similar to the summary statistics from experiment 1. There is no overlap between the sets of participants in experiments 1 and 2.

**Discussion of results (beliefs):** We first analyze participants' beliefs about dependence, i.e. we test whether participants' perception of dependence is influenced by changes in non-linear dependence ( $H_{21}$ ). In summary, the findings are in line with the hypothesis that participants correctly adjust their beliefs to changes of dependence in moderate returns, whereas they either do not understand dependence in extreme returns or even incorrectly project their beliefs about dependence in moderate returns onto extreme returns. Table 6 reports participants' beliefs about dependence. Participants believe overall dependence to decrease from treatment 1 to treatment 2. Dependence in extreme returns increases from treatment 1 to treatment 2, but dependence in moderate returns decreases. Panel A reports that—on a scale from 1 (Stocks 1 and 2 move ...in opposite directions) to 5 (...together)—participants expect stocks 1 and 2 to co-move (at an average of 3.55) in treatment 1, whereas they expect stocks 1 and 2 to move in opposite directions (at an average of 2.63) in treatment 2. The difference between average categories is statistically significant at the 1% level. Panel B shows that the estimated frequency of co-movement decreases from treatment 1 (72% in Panel B1 and 62% in Panel B2) to treatment 2 (37% in Panel B1 and 41% in Panel B2). The treatments' true frequencies of co-movement are 90% and 10%, respectively, so that there is a strong bias towards 50%. However, treatment effects have the hypothesized sign and are statistically significant at the 1% level.

[INSERT TABLE 6 ABOUT HERE]

Of course, the above results do not yet show that participants do not understand dependence in extreme returns. It might be that the question about overall dependence (Panel A of Table 6) is understood as a question about the frequency of co-movement (Panel B of Table 6), regardless of the magnitude of returns. Hence, we ask participants directly for their beliefs about dependence conditional on the magnitude of returns. Panels C and D of Table 6 show participants' beliefs about dependence in extreme versus moderate returns. Panel A reports the participants' beliefs about dependence in extreme returns. On the one hand, for treatment 1, stock 2 *always* moves in the *opposite* direction of stock 1 in extreme returns. On the other hand, for treatment 2, stock 2 *always* moves in the *same* direction as stock 1 in extreme returns. In spite of this clear, deterministic conditional dependence most participants cannot correctly answer the questions about dependence in extreme returns. In some cases the number of participants who select the category opposite to the correct one ('decrease' when 'increase' is correct and vice versa) is larger than the number of participants who select the correct category. There is no statistically significant treatment effect. In contrast, Panel B shows that participants' beliefs react correctly to the decrease of dependence in moderate returns from treatment 1 to treatment 2. Few participants (between 8 and 16 out of 94) wrongly believe dependence in moderate returns to be negative when it is actually positive or vice versa. Thus, whereas the average participant understands dependence in moderate returns, she does not understand dependence in extreme returns.

**Heterogeneous beliefs about extreme returns:** There are several potential reasons why there is no effect of this extreme switch in dependence of extreme returns on participants' *average* beliefs about them. Since our hypothesis on investment decisions ( $H_{22}$ ) depends on participants' perceived dependence, it is important to analyze these reasons. A first reason may be that none (or only very few) of the participants understand dependence in extreme returns. In this case, one would expect a large number of participants to check the middle category (between 'decrease' and 'increase') in their answers to the questions about extreme dependence. However, the patterns in Panel C of Table 6 show that many participants do not check the middle category. Actually, for 3 out of 4 questions, the middle category is selected less frequently than either one of the other categories. A second reason that could explain this v-pattern would be two counterbalancing types of participants in addition to the participants who have 'no idea' about dependence in extreme returns. Type 1 participants project their beliefs about moderate returns onto extreme returns and thus systematically select the category opposite to the correct one. Type 2 participants have no idea about dependence in extremes and tend to select the middle category. Type 3 participants understand dependence in extreme returns and systematically select the correct category. We empirically identify Type 1 participants as the ones who answer 'decrease' if the correct answer is 'increase' and vice versa in at least 3 out of 4 questions about dependence in extremes (18 out of 94 participants). Type 3 participants are identified as the ones who

correctly answer at least 3 out of 4 questions about dependence in extremes (16 out of 94 participants). The other participants are identified as Type 2 (60 out of 94 participants).<sup>15</sup>

**Discussion of results (choice):** Next, we analyze the impact of non-linear dependence on participants’ investment decisions, i.e. hypothesis  $H_{22}$ . This hypothesis depends on the participants’ beliefs about dependence. The perception of dependence for Type 1 and Type 2 participants is driven by moderate returns. Hence, for them (78 out of 94 participants) we expect the investment in stock 2 to increase as dependence in moderate returns decreases from treatment 1 to treatment 2. The perception of dependence for Type 3 participants may be driven by both moderate or extreme returns, so that it is not clear, how they should react to the treatment. Hence, the following analysis of participants’ investment decisions is done separately for Type 3 participants. Table 7 reports how participants’ investment decisions change as non-linear dependence changes. Specifications (1) and (2) show that Type 1 and 2 participants increase their investment in stock 2 from 3’619€ to 4’179€ as moderate dependence decreases from treatment 1 to treatment 2. The difference in investment of 561€ is statistically significant at the 5% level. In contrast, specifications (1) and (3) show that Type 3 participants decrease their investment in stock 2 from 3’531€ to 3’018€ as extreme dependence increases from treatment 1 to treatment 2. The treatment effect for Type 3 participants is not statistically significant, maybe owing to their low frequency (16 out of 94 participants). In specification (4) we check whether the treatment effect on Type 1 and 2 participants changes for participants with more financial literacy or numeracy. In spite of strong variation in financial literacy and numeracy (see summary statistics in Table 1), interaction effects are statistically insignificant.<sup>16</sup> All in all, the evidence in Table 7 is in line with  $H_{22}$ : Participants take perceived dependence into account in their portfolio selection decision.

[INSERT TABLE 7 ABOUT HERE]

## 6 Experiment 3: Varying Non-Linear Dependence II

**Stimuli:** In experiment 3, we check whether our insights from experiment 2—that participants focus on dependence in moderate returns when forming beliefs and making diversification choices—are robust under a more extreme treatment. We now let correlation increase with dependence in extreme returns from treatment 1 to treatment 2, while dependence in moderate returns decreases. This lets us pit the hypothesis that participants focus on moderate returns against the prediction from Markowitz (1952) that correlation matters.

<sup>15</sup>Note that an analogous classification for beliefs about moderate dependence is unnecessary, because hardly any participants systematically answer questions about moderate dependence incorrectly.

<sup>16</sup>In unreported robustness tests, we replace the financial literacy score by a dummy that indicates whether the one question related to diversification from the financial literacy test – item (5) – was answered correctly. Results do not change.

Specifically correlation increases from  $-0.21$  in treatment 1 to  $+0.21$  in treatment 2 while—as in experiment 2—dependence in moderate returns decreases from perfectly positive to perfectly negative, and dependence in extreme returns increases from perfectly negative to perfectly positive. We achieve this change in correlations by making both marginal distributions more extreme, shifting the extreme returns outwards by 7%. Figure 6 shows the change in conditional expectations from experiment 2 to experiment 3: The only difference between the two experiments is the outward shift of extreme returns (joint distributions are reported in Table 8). As an illustration, Figure 7 shows two of the  $10 \times 10$ -year draws sampled by participants for treatments 1 and 2, respectively. The extremeness of returns,  $-33\%$  ( $+42\%$ ) p.a. for the 5 out of 100 lowest (highest) returns, is now comparable to historical values. As an illustration, the average of S&P 500 returns in the worst (best) 5 years from 1928 to 2015 is  $-33.35\%$  ( $+47.36\%$ ). If our insights from experiment 2 hold, participants will still understand dependence in moderate returns while not understanding dependence in extreme returns. Consequently they should diversify less when moderate dependence increases from treatment 1 to treatment 2, even though correlation decreases. This would be a surprising result as it contradicts prescriptions for risk-averse investors under standard utility functions. Figure 8 shows the optimal investment in stock 2 for an expected utility maximizing investor with constant relative risk aversion (CRRA) at relative risk aversion from 0.5 to 10. In contrast to experiment 2, where correlation stayed constant at zero across treatments leading to hardly different optimal diversification choices, correlation now increases from treatment 1 to treatment 2. Therefore, a CRRA investor optimally diversifies less in treatment 2 compared to treatment 1. For instance at a relative risk aversion of 2, a CRRA investor’s investment goes from around 4000 € in treatment 1 to around 3200 € in treatment 2. Hence, the variation in correlation is large enough to warrant economically significant differences in diversification from a normative standpoint.

[INSERT FIGURE 6 ABOUT HERE]

[INSERT TABLE 8 ABOUT HERE]

[INSERT FIGURE 7 ABOUT HERE]

[INSERT FIGURE 8 ABOUT HERE]

**Data and participants:** Like experiments 1 and 2, experiment 3 was conducted at a lab for experimental economics. Summary statistics about the 107 participants are reported in Panel C of Table 1. They are similar to the summary statistics from experiments 1 and 2. There is no overlap between the sets of participants in experiments 1, 2 and 3.

**Discussion of results:** We first analyze participants’ beliefs about dependence, i.e. we test whether participants’ perception of dependence is influenced by changes in non-linear

dependence ( $H_{21}$ ). In summary, the findings are in line with results from experiment 2. Participants' beliefs about dependence in moderate returns are consistent with the treatments, whereas most participants do not understand dependence in extreme returns. Table 9 reports participants' beliefs about dependence. Participants believe overall dependence to decrease from treatment 1 to treatment 2. Dependence in extreme returns increases from treatment 1 to treatment 2, but dependence in moderate returns decreases. Panel A reports that—on a scale from 1 (Stocks 1 and 2 move ...in opposite directions) to 5 (...together)—participants expect stocks 1 and 2 to co-move (at an average of 3.39) in treatment 1, whereas they expect stocks 1 and 2 to move in opposite directions (at an average of 2.63) in treatment 2. The difference between average categories is statistically significant at the 1% level. Panel B shows that the average estimated frequency of co-movement decreases from treatment 1 (71% in Panel B1 and 61% in Panel B2) to treatment 2 (40% in Panel B1 and 44% in Panel B2). The treatments' true frequencies of co-movement are 90% and 10%, respectively, so that—as in experiment 2—there is a strong bias towards 50%. However treatment effects have the hypothesized sign and are statistically significant at the 1% level.

[INSERT TABLE 9 ABOUT HERE]

We then ask participants directly for their beliefs about dependence conditional on the magnitude of returns. Panels C and D of Table 9 show participants' beliefs about dependence in extreme versus moderate returns. Panel C reports the participants' beliefs about dependence in extreme returns. As in experiment 2, participants have trouble correctly answering questions about dependence in extreme returns, even though it is deterministically negative in treatment 1 and positive in treatment 2. For one of the two questions about dependence in extreme returns, there is a treatment effect with the correct sign, which is statistically significant at the 10% level. However, the magnitude of the effect is relatively small and this result cannot be confirmed in our second question on extreme returns. A large number of participants (between 26 and 42 out of 107) check the answer opposite to the correct one, again consistent with them projecting their (correct) beliefs about dependence in moderate returns onto extreme returns. In contrast, Panel D shows that participants' beliefs react correctly to the decrease of dependence in moderate returns from treatment 1 to treatment 2. Few participants (between 8 and 10 out of 107) wrongly believe dependence in moderate returns to be negative when it is actually positive or vice versa. Thus, whereas the average participant understands dependence in moderate returns, she does not understand dependence in extreme returns. All in all, the evidence from Table 9 is in line with our finding from experiment 2: Dependence is on average perceived based on frequent, moderate observations.

Next, we analyze the impact of our treatments on participants' investment choices. The results lend further support to our insights from experiment 2. Participants diversify more

as dependence in moderate returns decreases from treatment 1 to treatment 2, even though correlation and dependence in extreme returns increase. As in experiment 2 we split participants into two groups: those that do not understand dependence in extreme returns (Types 1 and 2: 86 out of 107 participants) and those that understand it (Type 3: 21 out of 107 participants). The prediction for Types 1 and 2 is clear. These participants do not understand dependence in extreme returns, but mostly do understand dependence in moderate returns, which decreases from treatment 1 to treatment 2. Hence, we expect them to diversify more in treatment 2. This is indeed the case: Specifications (1) and (2) of Table 10 show that Type 1 and 2 participants increase their investment in stock 2 from 3'154€ to 4'077€ as moderate dependence decreases from treatment 1 to treatment 2. The difference of 923€ is statistically significant at the 1% level. In contrast, the prediction for Type 3 participants is not straightforward. They seem to understand dependence in moderate and extreme returns, so that any of these could drive their decision. As discussed above, a CRRA investor would base her decision mostly on correlation and diversify less in treatment 2. On the other hand an investor with a strong preference to be well diversified most of the time would diversify more in treatment 2. Even though there are just 21 Type 3 participants, there is a statistically significant positive treatment effect from treatment 1 to treatment 2 (at the 5% level). Hence, these participants' diversification choice seems to also be driven by dependence in frequent, moderate returns. As for the previous experiments, Specification (4) shows that there is no significant interaction between our treatment effects and financial literacy or numeracy.<sup>17</sup> All in all, the evidence in Table 10 is in line with  $H_{22}$  and our insights from experiment 2: Participants take perceived dependence into account in their portfolio selection decision. However, they only understand dependence in moderate returns, not in extreme returns. In line with their perception of dependence, they diversify more as dependence in moderate returns decreases, even though correlation increases along with dependence in extreme returns. As discussed above, this goes against predictions under standard utility functions.

[INSERT TABLE 10 ABOUT HERE]

## 7 Experiment 4: Returns vs. Prices

**Stimuli:** In experiment 4, we analyze how our results are influenced by components of the information presentation. Both numerical returns and price paths are common pieces of information in realistic investment decisions. However, often only one of these is provided. In contrast to experiments 1 to 3 we display only return histories for one part of the

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<sup>17</sup>In unreported robustness tests, we replace the financial literacy score by a dummy that indicates whether the one question related to diversification from the financial literacy test – item (5) – was answered correctly. Results do not change.

participants (the return group), and only price paths for the other part (the price group; see examples in Figure 9). We use the same dependence treatments 1 and 2 as in experiment 3 (see Table 8). Hence correlation increases with dependence in extreme returns from treatment 1 (correlation of -0.21) to treatment 2 (correlation of +0.21), while dependence in moderate returns decreases. Since only the display of information is changed—not dependence treatments—the optimal investment in stock 2 for a CRRA investor does not change (see Figure 8). Optimally, participants should diversify less in treatment 2 compared to treatment 1, because diversification benefits decrease as correlation increases.

[INSERT FIGURE 9 ABOUT HERE]

**Data and participants:** Like experiments 1 to 3, experiment 4 was conducted at a lab for experimental economics. Summary statistics about the 205 participants are reported in Panel D of Table 1. They are similar to the summary statistics from the previous experiments.

**Discussion of results:** We first analyze participants’ beliefs about dependence, i.e. we test whether participants’ perception of dependence is influenced by changes in non-linear dependence ( $H_{21}$ ). Table 11 reports participants’ beliefs about dependence. The findings for the price group are in line with results from experiments 2 and 3: Participants’ beliefs about dependence in moderate returns are consistent with the treatments (see right-hand side of Panel D in Table 11), whereas most participants do not understand dependence in extreme returns (see right-hand side of Panel C). In contrast, participants from the return group are significantly more likely to also understand dependence in extreme returns (left-hand side of Panel C).<sup>18</sup> In spite of this better understanding of dependence in extreme returns, the return group’s overall dependence assessment is still driven by dependence in moderate, frequent returns: They believe overall dependence to decrease from treatment 1 to treatment 2 (see Panel A in Table 11). Hence, the evidence from Table 11 is in line with our finding from experiments 2 and 3 for both, the return and the price group: Dependence is on average perceived based on frequent, moderate observations.

Throughout Table 11 effect sizes are larger within the return group as compared to the price group. Furthermore the significantly better understanding of dependence in extreme returns compared to experiments 2 and 3 suggests that displaying return series without price paths (i.e. *less*) leads to a better understanding of dependence. Consistent with an objectively better understanding of dependence in experiment 4’s return group, these participants assess their subjective level of informedness and confidence in their decision as significantly higher.<sup>19</sup>

[INSERT TABLE 11 ABOUT HERE]

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<sup>18</sup>Framing effects related to prices vs. returns have been documented before, e.g. Glaser, Langer, Reynders, and Weber (2007) find that asking for return forecasts leads to significantly more optimistic forecasts than asking for price forecasts when prices trend upward.

<sup>19</sup>These further results are reported in Appendix D and discussed in Appendix E

Next, we analyze the impact of our treatments on participants' investment choices. Using the same method as in experiments 2 and 3 we split participants into two groups (see discussion of heterogeneous beliefs in Section 5): those that do not understand dependence in extreme returns (Types 1 and 2) and those that understand it (Type 3). The prediction for Types 1 and 2 is unambiguous. These participants do not understand dependence in extreme returns, but mostly do understand dependence in moderate returns. Dependence in moderate returns decreases from treatment 1 to treatment 2. Hence, we expect Type 1 and 2 participants to diversify more in treatment 2. This is indeed the case: For the return group, Specification (1) of Table 12 shows that Type 1 and 2 participants increase their investment in stock 2 from 3'494€ to 4'406€ as moderate dependence decreases from treatment 1 to treatment 2. The difference of 912€ is statistically significant at the 1% level. For the price group, the treatment effect for Types 1 and 2 is also positive at 441€ and statistically significant at the 10% level, see Specification (3). The prediction for Type 3 participants is ambiguous. They seem to understand dependence in moderate *and* extreme returns, so that any of these could drive their decision, depending on their preferences. The 41 participants of Type 3 in the return group diversify significantly more when dependence in frequent, moderate returns is lower (see Specification (2)). This is consistent with our results from experiment 3: In spite of understanding dependence in extreme returns, Type 3 participants seem to base their diversification decision on dependence in moderate returns, suggesting there is more than biased beliefs to our general result that dependence in frequent, moderate returns matters for diversification decisions. In contrast, the 25 participants of Type 3 in the price group diversify more when dependence in extreme, rare returns is lower. This effect is statistically insignificant (see Specification (4)). Hence, although beliefs about dependence are similar for all these Type 3 participants, the participants who view price paths choose to diversify away extreme, rare variations, whereas participants who view return series choose to diversify away frequent, moderate variations. As a consequence, the treatment effect from treatment 1 to treatment 2 (over all Types) increases by 722€ as we go from the price group to the return group. This effect is significant at the 5% level (see Specification (5)).

[INSERT TABLE 12 ABOUT HERE]

All in all, the evidence for the participants who view return series, and for the participants who view price paths *and* are subsequently unable to correctly answer questions about dependence in extreme returns is in line with hypothesis  $H_{22}$  and our results from experiments 2 and 3: Participants take perceived dependence into account in their portfolio selection decision. They diversify more as dependence in moderate returns decreases, even though correlation increases along with dependence in extreme returns. In contrast, the few participants who view price paths *and* are subsequently able to correctly answer questions about dependence in extreme returns diversify more as dependence in extreme returns decreases

along with correlation. The flipped sign of our treatment effect for these 25 (out of 112) participants in the price group is puzzling and warrants future research on presentation modes and investment decisions. It may be that the graphical display of a crash in a stock's price leads to a higher decision weight for this extreme state than the same information as a numerical return, e.g. '-33%'. In any case, the effect of dependence between asset returns on beliefs about dependence and investment decisions is influenced by the way information is presented. Given the choice of viewing price paths or return series (as in experiments 1, 2 and 3), participants' investment choices are similar to choices when they are only given return series. They seem to automatically use returns to make their investment decision, maybe because they find returns to be more informative. This would be consistent with the higher levels of informedness and confidence they state for their investment decision in the return group relative to the price group of experiment 4 (see discussion in Appendix E).

## 8 Conclusion

We run several laboratory experiments to analyze how varying dependence between asset returns influences the perception of dependence and investment decisions. We find that participants correctly adjust their beliefs to changes in linear dependence. They diversify more when correlation decreases, which is in line with Markowitz (1952). Thus, presenting information realistically, using price paths and return series, we do not find correlation neglect. This is in contrast to the previous literature (e.g. Kroll, Levy, and Rapoport (1988)), where information was mostly given in the form of description, with direct statements about probabilities of events. However, our findings suggest that correlation does not properly capture participants' perception of dependence. When we increase dependence in moderate returns while decreasing dependence in extreme returns, only few participants correctly adjust their beliefs about dependence in extreme returns. In contrast they do understand dependence in frequent, moderate returns. Consequently, they diversify less when dependence in moderate returns increases, even if correlation decreases due to less dependence in extreme returns. This choice is opposite to the prediction of Markowitz (1952). To sum up, while changes in dependence are taken into account by participants, correlation does not properly explain their beliefs and choices.

This study has implications for individual investors' portfolio selection. Our findings suggest that investors can improve diversification decisions by debiasing beliefs about dependence in extremes, for instance via viewing information about past returns in a format they better understand. In particular in contexts, where non-linear dependence is large—e.g. structured financial products with embedded options—the neglect of dependence in extreme events may lead to unintentional risk taking. Henderson and Pearson (2011) analyze structured equity products and find evidence in line with the 'hypothesis that banks

and investment banks design financial products to exploit investors' misunderstandings of financial markets, cognitive biases in evaluating probabilistic information, and framing effects.' In the light of such risks, our findings should be of interest to policy makers, since the financial industry could have an incentive to use investors' neglect of dependence in crashes to unload downside risks via offering structured products with embedded out-of-the money put options.

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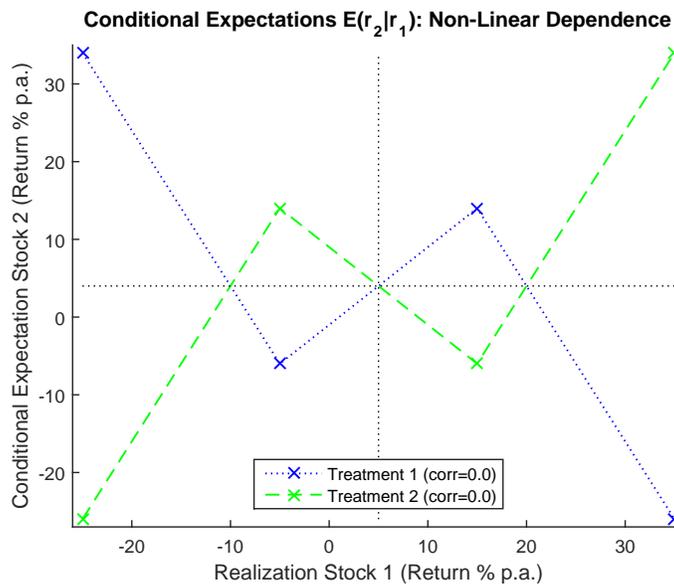
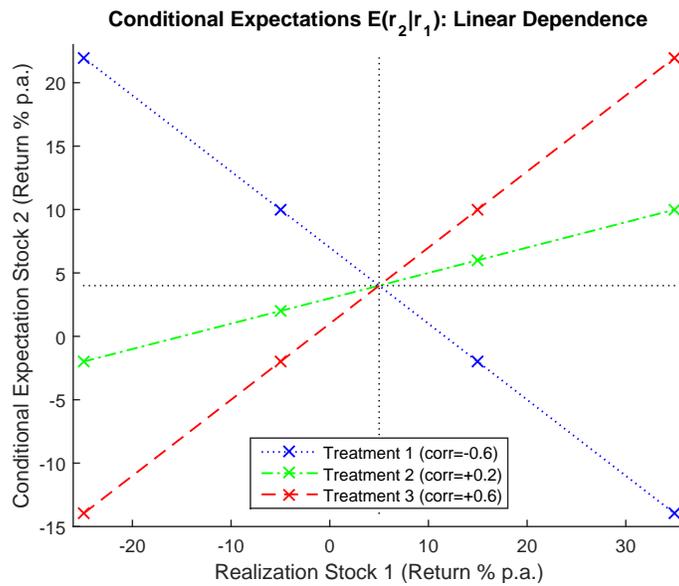
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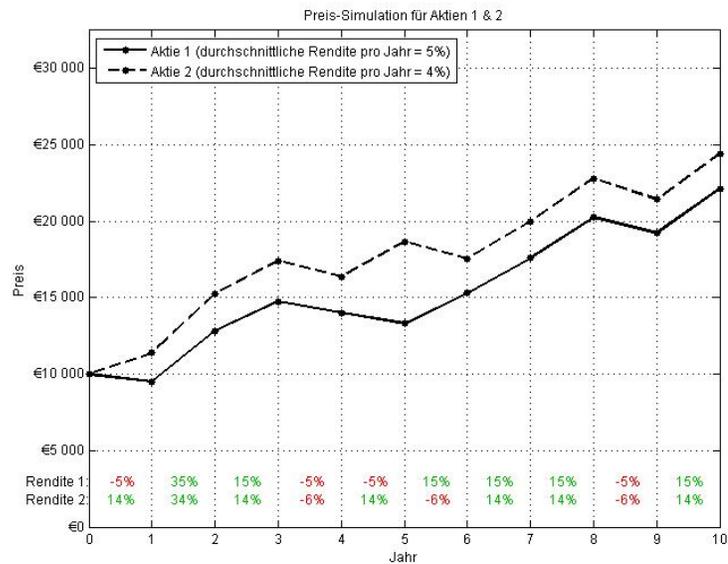
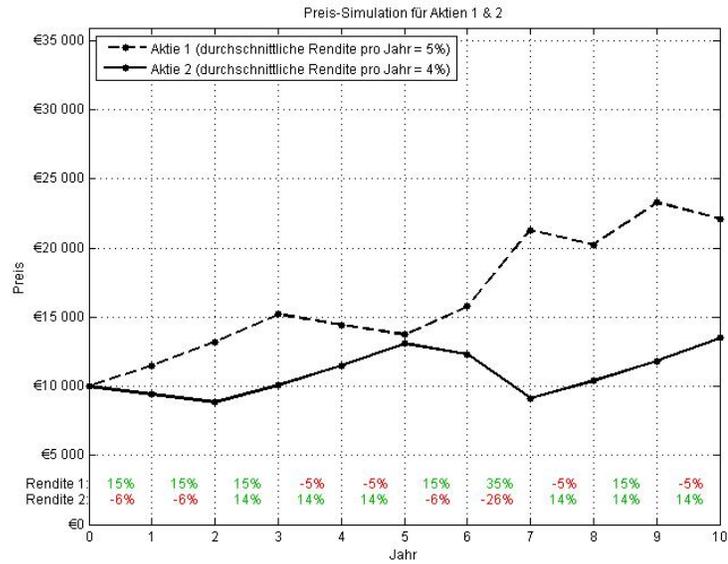
**Figure 1:** Experiment 1 vs. 2: Linear vs. Non-Linear Dependence

These graphs display the expectation for the return of stock 2 conditional on each of the four possible realized returns of stock 1, i.e.  $E(r_2|r_1)$ . The first graph displays conditional expectations for experiment 1's three treatments. Dependence is linear, i.e. all four conditional expectations are located on one line. The second graph displays conditional expectations for experiment 2's two treatments. Dependence is non-linear. In particular, dependence in moderate returns is opposite to dependence in extreme returns. We also display the expected values for stock 1's (2's) return as the vertical (horizontal) dotted line at 5% (4%).



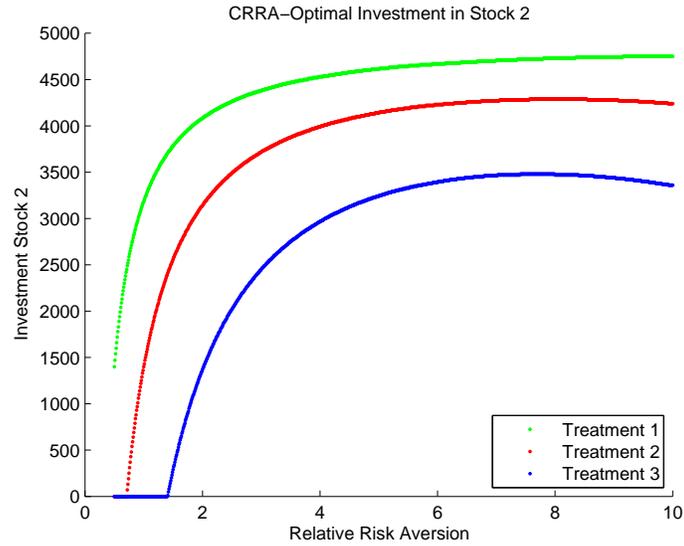
**Figure 2:** Experiment 1 – Illustrative Price Paths Treatments 1 and 3

These price paths are illustrative examples for the information shown to participants in experiment 1. The first path is an example from treatment 1 (correlation of -0.6) and the second path is from treatment 3 (correlation of +0.6). Returns are displayed in green (red) when positive (negative). The labels are in German. Translations: 'Preis-Simulation für Aktie 1 & 2' means 'Price-Simulation for Stocks 1 & 2'. 'Aktie X (durchschnittliche Rendite pro Jahr = y%)' means 'Stock X (average return per year = y%)'. 'Jahr' and 'Preis' mean 'Year' and 'Price' respectively.



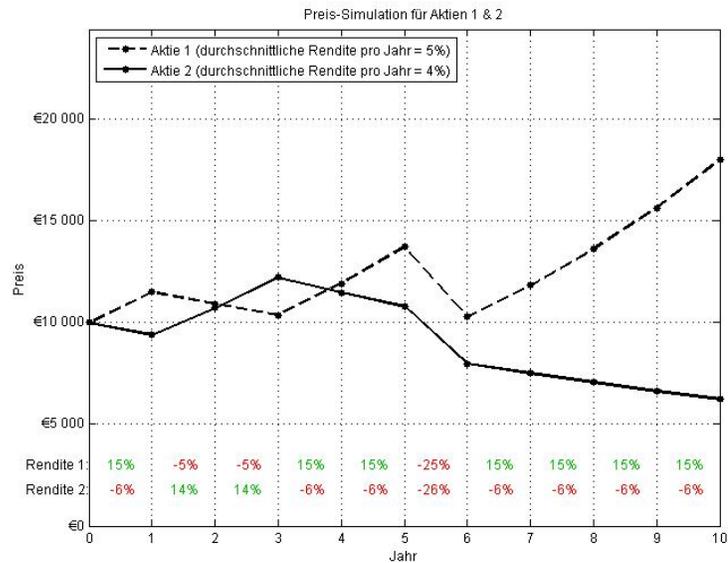
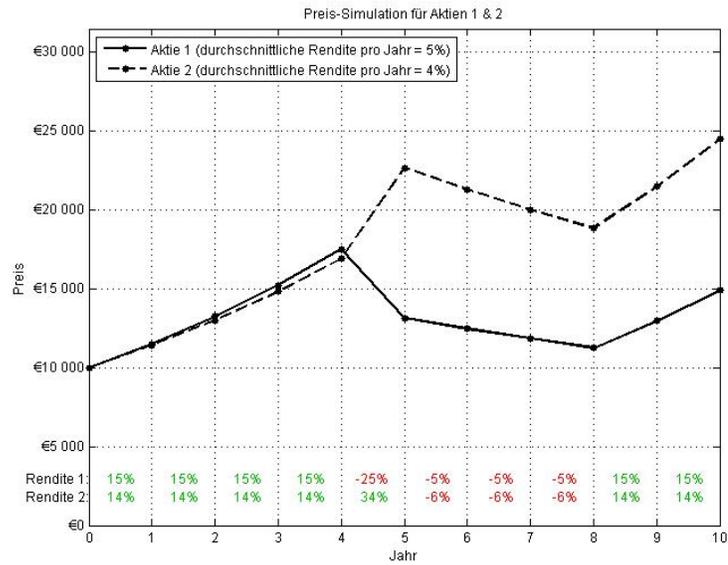
**Figure 3:** Experiment 1: CRRA-Optimal Investment in Stock 2

For each of the treatments, this figure displays the investment in stock 2 out of 10'000 € that maximizes the expected CRRA-utility at levels of relative risk aversion between 0.5 and 10. Treatment 1, 2 and 3 exhibit correlations between the two stocks of -0.6, 0.2, and 0.6, respectively. The investment is restricted to be in the closed interval between 0 and 1 and it is assumed that the remaining funds are invested in stock 1.



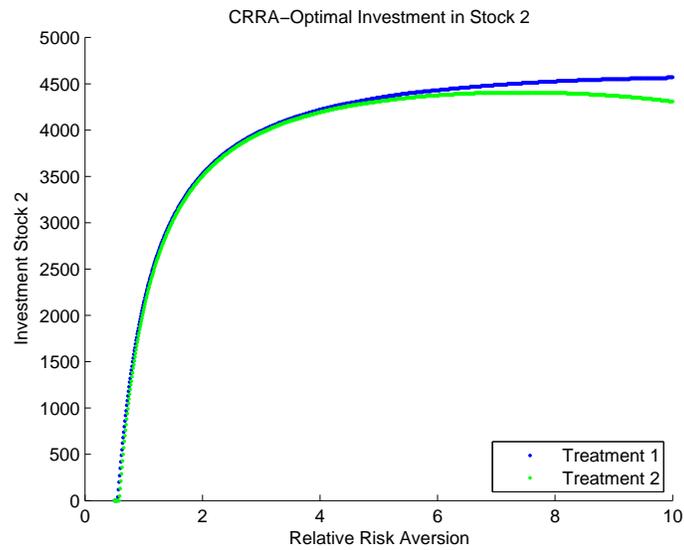
**Figure 4:** Experiment 2 – Illustrative Price Path Treatments 1 and 2

These price paths are illustrative examples for the information shown to participants in experiment 2. The first path is an example from treatment 1 (positive dependence in moderate returns, negative in extremes) and the second path is from treatment 2 (negative dependence in moderate returns, positive in extremes). Returns are displayed in green (red) when positive (negative). The labels are in German. Translations: 'Preis-Simulation für Aktie 1 & 2' means 'Price-Simulation for Stocks 1 & 2'. 'Aktie X (durchschnittliche Rendite pro Jahr =  $y\%$ )' means 'Stock X (average return per year =  $y\%$ )'. 'Jahr' and 'Preis' mean 'Year' and 'Price' respectively.



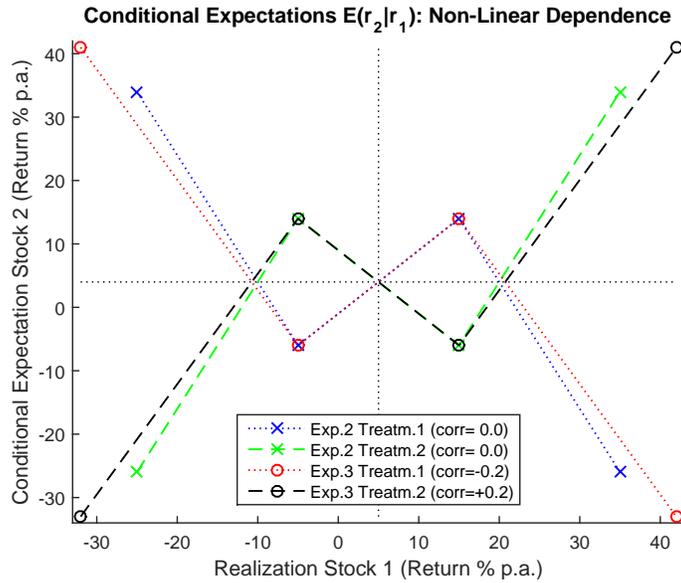
**Figure 5:** Experiment 2: CRRA-Optimal Investment in Stock 2

For each of the treatments, this figure displays the investment in stock 2 out of 10'000 € that maximizes the expected CRRA-utility at levels of relative risk aversion between 0.5 and 10. Both treatments exhibit zero correlation between the two stocks. Treatment 1 exhibits positive dependence in moderate returns, and negative dependence in extremes. Treatment 2 exhibits negative dependence in moderate returns, and positive dependence in extremes. The investment is restricted to be in the closed interval between 0 and 1 and it is assumed that the remaining funds are invested in stock 1.



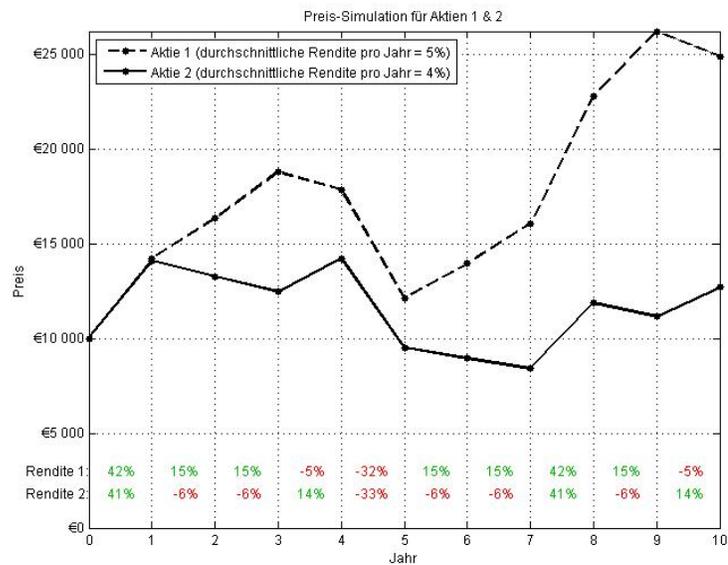
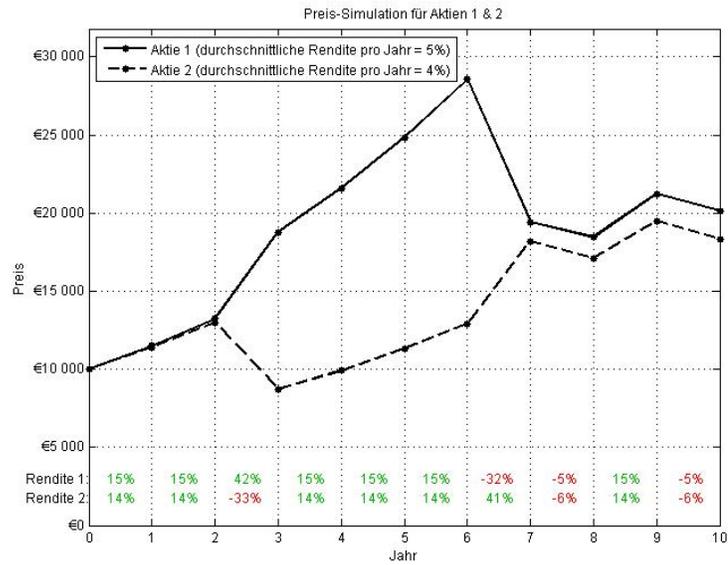
**Figure 6:** Experiment 2 vs. 3: Conditional Expectations

This graph displays the expectation for the return of stock 2 conditional on each of the four possible realized returns of stock 1, i.e.  $E(r_2|r_1)$ . We plot conditional expectations for experiment 2's (marked by 'x') and experiment 3's (marked by 'o') treatments in one graph. Dependence is non-linear in all four cases. In particular, dependence in moderate returns is opposite to dependence in extreme returns. In experiment 2 correlations between the returns of stock 1 and stock 2 are zero in both treatments. In contrast, experiment 3's treatments 1 and 2 exhibit correlations of -0.2 and +0.2, respectively. The differing correlations in experiment 3 are achieved via an outward shift of the extreme returns. We also display the expected values for stock 1's (2's) return as the vertical (horizontal) dotted line at 5% (4%).



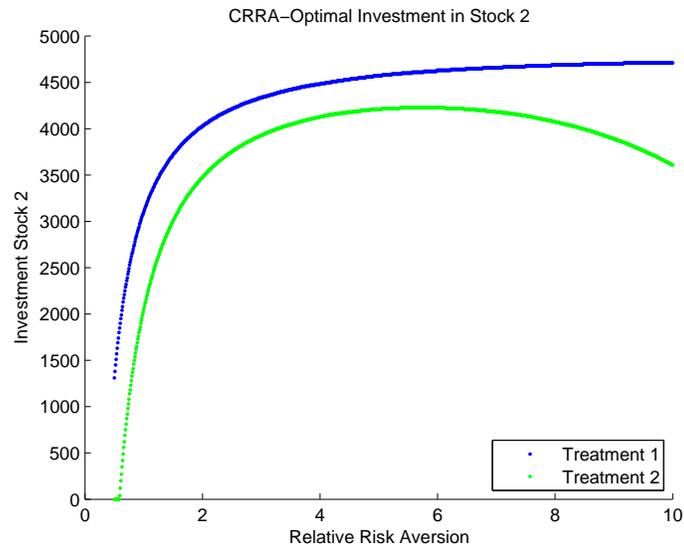
**Figure 7:** Experiment 3 – Illustrative Price Path Treatments 1 and 2

These price paths are illustrative examples for the information shown to participants in experiment 3. The first path is an example from treatment 1 (positive dependence in moderate returns, negative in extremes) and the second path is from treatment 2 (negative dependence in moderate returns, positive in extremes). Returns are displayed in green (red) when positive (negative). The labels are in German. Translations: 'Preis-Simulation für Aktie 1 & 2' means 'Price-Simulation for Stocks 1 & 2'. 'Aktie X (durchschnittliche Rendite pro Jahr = y%)' means 'Stock X (average return per year = y%)'. 'Jahr' and 'Preis' mean 'Year' and 'Price' respectively.



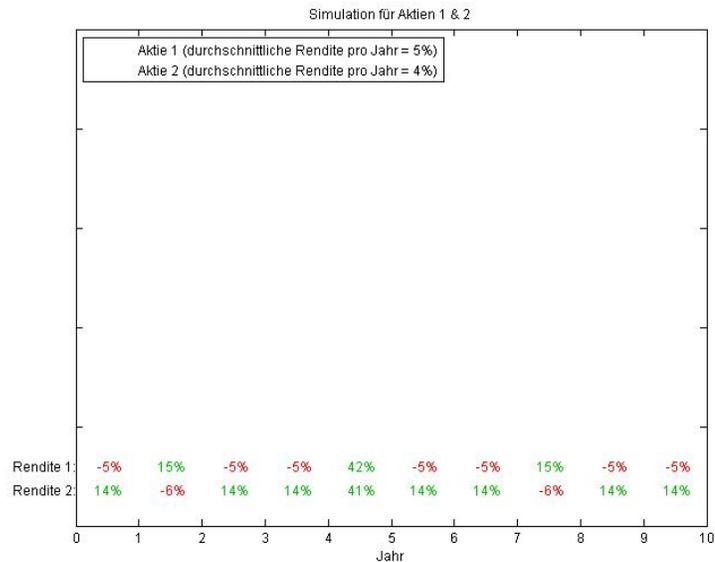
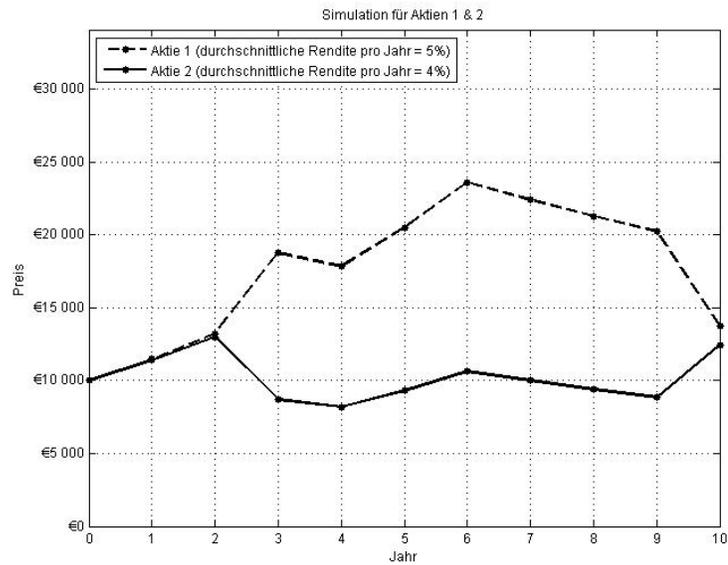
**Figure 8:** Experiments 3 & 4: CRRA-Optimal Investment in Stock 2

For each of the treatments, this figure displays the investment in stock 2 out of 10'000 € that maximizes the expected CRRA-utility at levels of relative risk aversion between 0.5 and 10. Treatment 1 exhibits a correlation between stock returns of -0.21, positive dependence in moderate returns, and negative dependence in extremes. Treatment 2 exhibits a correlation between stock returns of 0.21, negative dependence in moderate returns, and positive dependence in extremes. The investment is restricted to be in the closed interval between 0 and 1 and it is assumed that the remaining funds are invested in stock 1.



**Figure 9:** Experiment 4 – Illustrative Price Path Treatments 1 (Price) and 2 (Return)

These price paths and return series are illustrative examples for the information shown to participants in experiment 4. The first path is an example from treatment 1 with price paths (positive dependence in moderate returns, negative in extremes) and the second path is from treatment 2 with return series (negative dependence in moderate returns, positive in extremes). Returns are displayed in green (red) when positive (negative). The labels are in German. Translations: 'Preis-Simulation für Aktie 1 & 2' means 'Price-Simulation for Stocks 1 & 2'. 'Aktie X (durchschnittliche Rendite pro Jahr = y%)' means 'Stock X (average return per year = y%)'. 'Jahr' and 'Preis' mean 'Year' and 'Price' respectively.



**Table 1: Summary Statistics**

Numbers in brackets indicate the range of possible values, e.g. values 1-4 for self-assessed knowledge on statistics. Financial literacy is measured as the number of correctly answered questions in the test proposed by Fernandes, Lynch, and Netemeyer (2014). Numeracy is measured as the number of correctly answered questions in the test proposed by Cokely, Galesic, Schulz, and Ghazal (2012).

	Mean	Std.Dev.	10%ile	50%ile	90%ile
Panel A: Experiment 1 (127 participants)					
Age	21.87	4.31	18	21	26
Fraction Male	0.55	0.50	0	1	1
Owns Stocks or Equity Funds	0.20	0.40	0	0	1
Interested in Financial Markets	0.69	0.47	0	1	1
Willingness to Take Risks (1-5)	2.87	1.15	1	3	4
Has Taken Statistics Course	0.36	0.48	0	0	1
Statistics Knowledge (1-4)	2.83	0.96	1	3	4
Financial Literacy (0-12)	8.31	2.71	5	9	11
Numeracy (0-4)	1.89	1.25	0	2	4
Panel B: Experiment 2 (94 participants)					
Age	24.10	5.14	19	23	30
Fraction Male	0.43	0.50	0	0	1
Owns Stocks or Equity Funds	0.21	0.41	0	0	1
Interested in Financial Markets	0.59	0.50	0	1	1
Willingness to Take Risks (1-5)	2.51	1.14	1	2	4
Has Taken Statistics Course	0.63	0.49	0	1	1
Statistics Knowledge (1-4)	2.68	1.04	1	3	4
Financial Literacy (0-12)	7.85	2.98	3	8	11
Numeracy (0-4)	1.97	1.28	0	2	4
Panel C: Experiment 3 (107 participants)					
Age	22.32	3.83	19	21	26
Fraction Male	0.47	0.50	0	0	1
Owns Stocks or Equity Funds	0.15	0.36	0	0	1
Interested in Financial Markets	0.56	0.50	0	1	1
Willingness to Take Risks (1-5)	2.61	1.01	1	2	4
Has Taken Statistics Course	0.78	0.42	0	1	1
Statistics Knowledge (1-4)	2.60	0.92	1	3	4
Financial Literacy (0-12)	8.38	2.59	5	9	11
Numeracy (0-4)	2.33	1.28	1	2	4
Panel D: Experiment 4 (205 participants)					
Age	23.33	5.59	19	22	27
Fraction Male	0.59	0.49	0	1	1
Owns Stocks or Equity Funds	0.26	0.44	0	0	1
Interested in Financial Markets	0.66	0.47	0	1	1
Willingness to Take Risks (1-5)	2.78	1.09	2	3	4
Has Taken Statistics Course	0.64	0.48	0	1	1
Statistics Knowledge (1-4)	2.54	1.02	1	2	4
Financial Literacy (0-12)	8.58	2.66	5	9	12
Numeracy (0-4)	2.15	1.29	0	2	4

**Table 2:** Experiment 1 – Treatments: Probability Distributions

Tables show the joint distribution for stock 1 (returns in first row) and stock 2 (returns in first column) for all treatments. Marginal distributions are kept constant across treatments and experiments. Means are 5.0% for stock 1 and 4.0% for stock 2. Standard-deviations are 13.0% for both stocks. In experiment 1 correlation varies across treatments and dependence is linear.

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<b>Treatment 1:</b> Pearson-Correlation of $-0.6$					
return	-25%	-5%	15%	35%	sum
-26%	1%	0%	0%	4%	5%
-6%	0%	9%	36%	0%	45%
14%	0%	36%	9%	0%	45%
34%	4%	0%	0%	1%	5%
sum	5%	45%	45%	5%	100%

<b>Treatment 2:</b> Pearson-Correlation of $+0.2$					
return	-25%	-5%	15%	35%	sum
-26%	3%	0%	0%	2%	5%
-6%	0%	27%	18%	0%	45%
14%	0%	18%	27%	0%	45%
34%	2%	0%	0%	3%	5%
sum	5%	45%	45%	5%	100%

<b>Treatment 3:</b> Pearson-Correlation of $+0.6$					
return	-25%	-5%	15%	35%	sum
-26%	4%	0%	0%	1%	5%
-6%	0%	36%	9%	0%	45%
14%	0%	9%	36%	0%	45%
34%	1%	0%	0%	4%	5%
sum	5%	45%	45%	5%	100%

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**Table 3:** Experiment 1 – Perception of Dependence

The panels show the frequency of each answer-category for questions on beliefs about dependence. Boxes around numbers indicate correct answers (based on data shown to participants; panel A does not have one correct answer). Below panels A, C and D, you will find the mean category for each treatment and differences between these means. Below panel B you will find mean probability estimates and differences between these mean estimates. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Treatment 1 Correlation=-0.6	Treatment 2 Correlation=+0.2	Treatment 3 Correlation=+0.6
Panel A (Overall Dependence): Stocks 1 and 2 move...			
in opposite directions 1	<b>13</b>	1	0
2	<b>81</b>	14	7
3	26	<b>46</b>	22
4	6	<b>64</b>	<b>80</b>
together 5	1	2	<b>18</b>
mean	2.22	3.41	3.86
-Treatment 1	-	1.19*** (0.09)	1.64*** (0.09)
-Treatment 2	-	-	0.45*** (0.09)
Panel B1 (Frequency of Co-Movement): Given stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)			
[0,20)	3	12	45
20	1	21	<b>25</b>
(20,40)	3	26	14
40	8	<b>15</b>	10
(40,60)	23	20	9
60	15	12	5
(60,80)	30	11	8
80	<b>27</b>	7	8
(80,100]	17	3	3
mean	65.36	41.59	31.45
-Treatment 1	-	-23.77*** (2.69)	-33.91*** (2.69)
-Treatment 2	-	-	-10.14*** (2.69)
Panel B2 (Frequency of Co-Movement): Given stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)			
[0,20)	25	5	6
20	<b>19</b>	7	4
(20,40)	24	15	2
40	10	8	9
(40,60)	19	22	11
60	8	<b>18</b>	7
(60,80)	11	26	21
80	4	17	<b>35</b>
(80,100]	7	9	32
mean	38.48	56.12	68.41
-Treatment 1	-	17.64*** (2.84)	29.93*** (2.84)
-Treatment 2	-	-	12.29*** (2.84)

	Treatment 1 Correlation=-0.6	Treatment 2 Correlation=+0.2	Treatment 3 Correlation=+0.6
Panel C1 (Extreme Dependence): Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...			
decrease 1	9	46	82
2	15	36	22
increase 3	103	45	23
mean	2.74	1.99	1.54
-Treatment 1	-	-0.75 <sup>***</sup> (0.09)	-1.20 <sup>***</sup> (0.09)
-Treatment 2	-	-	-0.45 <sup>***</sup> (0.09)
Panel C2 (Extreme Dependence): Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...			
decrease 1	91	41	23
2	26	40	25
increase 3	10	46	79
mean	1.36	2.04	2.44
-Treatment 1	-	0.68 <sup>***</sup> (0.09)	1.08 <sup>***</sup> (0.09)
-Treatment 2	-	-	0.40 <sup>***</sup> (0.09)
Panel D1 (Moderate Dependence): Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...			
decrease 1	16	49	68
2	66	63	47
increase 3	45	15	12
mean	2.23	1.73	1.56
-Treatment 1	-	-0.50 <sup>***</sup> (0.08)	-0.67 <sup>***</sup> (0.08)
-Treatment 2	-	-	-0.17 <sup>**</sup> (0.08)
Panel D2 (Moderate Dependence): Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...			
decrease 1	48	16	7
2	64	42	50
increase 3	15	49	70
mean	1.74	2.26	2.50
-Treatment 1	-	0.52 <sup>***</sup> (0.08)	0.76 <sup>***</sup> (0.08)
-Treatment 2	-	-	0.24 <sup>***</sup> (0.08)

**Table 4:** Experiment 1 – Investment Decision

Inv<sub>2</sub> is the investment in stock 2. I<sub>ti</sub> is a dummy for treatment i. The subscript N denotes normalization to a mean of zero and standard deviation of one. RA is self-assessed riskaversion (=  $-1 \times$  willingness to take risk). FL is the financial literacy score according to Fernandes, Lynch, and Netemeyer (2014). NUM is the numeracy score according to Cokely, Galesic, Schulz, and Ghazal (2012). We run random effects regressions to take account of participant-specific effects. Since the treatment is orthogonal to participant characteristics, random effects—as opposed to fixed effects—regressions are justified. This is also why adding control variables does not change treatment effect estimates. Treatments 1, 2, and 3 exhibit correlations between stock returns of -0.6, 0.2, and 0.6, respectively. Standard-errors are reported in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Inv <sub>2</sub> (1)	Inv <sub>2</sub> (2)	Inv <sub>2</sub> (3)	Inv <sub>2</sub> (4)
Constant	3186.31*** (171.57)	3186.31*** (165.93)	3186.31*** (163.90)	3186.31*** (164.09)
I <sub>t1</sub>	926.02*** (212.28)	926.02*** (212.28)	926.02*** (212.28)	926.02*** (212.72)
I <sub>t2</sub>	707.00*** (212.28)	707.00*** (212.28)	707.00*** (212.28)	707.00*** (212.72)
RA <sub>N</sub>		503.25*** (112.00)	425.77*** (112.32)	425.77*** (112.32)
FL <sub>N</sub>			-268.91** (121.04)	-292.94 (181.83)
NUM <sub>N</sub>			-118.99 (121.61)	-284.62 (182.21)
FL <sub>N</sub> *I <sub>t1</sub>				138.02 (235.03)
FL <sub>N</sub> *I <sub>t2</sub>				-65.93 (235.03)
NUM <sub>N</sub> *I <sub>t1</sub>				244.50 (235.03)
NUM <sub>N</sub> *I <sub>t2</sub>				252.40 (235.03)
Random Effects	YES	YES	YES	YES
No. obs.	381	381	381	381

**Table 5:** Experiment 2 – Treatments: Probability Distributions

Tables show the joint distribution for stock 1 (returns in first row) and stock 2 (returns in first column) for all treatments. Marginal distributions are kept constant across treatments and experiments. Means are 5.0% for stock 1 and 4.0% for stock 2. Standard-deviations are 13.0% for both stocks. In experiment 2 correlation is kept at zero and non-linear dependence in extreme vs. moderate returns is varied. Treatment 1 exhibits negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive dependence in extreme returns and negative dependence in moderate returns.

---

**Treatment 1: Pearson-Correlation of 0.0**

return	-25%	-5%	15%	35%	sum
-26%	0%	0%	0%	5%	5%
-6%	0%	45%	0%	0%	45%
14%	0%	0%	45%	0%	45%
34%	5%	0%	0%	0%	5%
sum	5%	45%	45%	5%	100%

**Treatment 2: Pearson-Correlation of 0.0**

return	-25%	-5%	15%	35%	sum
-26%	5%	0%	0%	0%	5%
-6%	0%	0%	45%	0%	45%
14%	0%	45%	0%	0%	45%
34%	0%	0%	0%	5%	5%
sum	5%	45%	45%	5%	100%

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**Table 6:** Experiment 2 – Perception of Dependence

The panels show the frequency of each answer-category for questions on beliefs about dependence. Boxes around numbers indicate correct answers (based on data shown to participants; panel A does not have one correct answer). Treatment 1 exhibits negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive dependence in extreme returns and negative dependence in moderate returns. Below panels A, C and D, you will find the mean category for each treatment and differences between these means. Below panel B you will find mean probability estimates and differences between these mean estimates. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Treatment 1	Treatment 2
Panel A (Overall Dependence): Stocks 1 and 2 move...		
in opposite directions		
1	1	7
2	5	43
3	31	24
4	55	18
together	2	2
mean	3.55	2.63
-Treatment 1	-	-0.93*** (0.12)
Panel B1 (Frequency of Co-Movement): Given stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)		
[0,10)	8	3
10	10	0
(10,50)	42	20
50	11	12
(50,90)	18	40
90	2	14
(90,100]	3	3
mean	38.00	62.83
-Treatment 1	-	24.83*** (3.76)
Panel B2 (Frequency of Co-Movement): Given stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)		
[0,10)	4	10
10	4	12
(10,50)	12	30
50	16	15
(50,90)	42	23
90	9	2
(90,100]	7	2
mean	62.12	40.69
-Treatment 1	-	-21.43*** (3.85)

	Treatment 1	Treatment 2
Panel C1 (Extreme Dependence): Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...		
decrease 1	26	<u>31</u>
2	27	22
increase 3	<u>41</u>	41
mean	2.16	2.11
-Treatment 1	-	-0.05 (0.12)
Panel C2 (Extreme Dependence): Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...		
decrease 1	<u>37</u>	41
2	27	24
increase 3	30	<u>29</u>
mean	1.93	1.87
-Treatment 1	-	-0.05 (0.12)
Panel D1 (Moderate Dependence): Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...		
decrease 1	<u>48</u>	8
2	36	41
increase 3	10	<u>45</u>
mean	1.60	2.39
-Treatment 1	-	0.80*** (0.10)
Panel D2 (Moderate Dependence): Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...		
decrease 1	9	<u>41</u>
2	34	37
increase 3	<u>51</u>	16
mean	2.45	1.73
-Treatment 1	-	-0.71*** (0.10)

**Table 7:** Experiment 2 – Investment Decision

$Inv_2$  is the investment in stock 2.  $I_{ti}$  is a dummy for treatment  $i$ . Treatment 1 exhibits negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive dependence in extreme returns and negative dependence in moderate returns.  $I_c$  is a dummy, which is 1 for type 3 participants, i.e. participants that get  $\geq 3$  out of 4 questions about extreme dependence right. The subscript  $N$  denotes normalization to a mean of zero and standard deviation of one.  $FL$  is the financial literacy score according to Fernandes, Lynch, and Netemeyer (2014).  $NUM$  is the numeracy score according to Cokely, Galesic, Schulz, and Ghazal (2012). We run random effects regressions to take account of participant-specific effects. Since the treatment is orthogonal to participant characteristics, random effects—as opposed to fixed effects—regressions are justified. This is also why adding control variables does not change treatment effect estimates. Standard errors are reported in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	$Inv_2$ All Types (1)	$Inv_2$ Types 1 & 2 (2)	$Inv_2$ Type 3 (3)	$Inv_2$ Types 1 & 2 (4)
Constant	3618.77*** (212.09)	3618.77*** (212.10)	3531.25*** (468.19)	3618.77*** (213.20)
$I_{t2}$	560.72** (279.50)	560.72* (295.55)	-512.50 (386.96)	560.72* (298.00)
$I_{t2} * I_c$	-1073.22 (677.45)			
$I_c$	-87.52 (514.08)			
$FL_N$				-210.56 (248.44)
$NUM_N$				53.67 (248.44)
$FL_N * I_{t2}$				161.88 (347.25)
$NUM_N * I_{t2}$				-298.73 (347.25)
Random Effects	YES	YES	YES	YES
No. obs.	188	156	32	156

**Table 8:** Experiments 3 & 4 – Treatments: Probability Distributions

Tables show the joint distribution for stock 1 (returns in first row) and stock 2 (returns in first column) for all treatments. Marginal distributions are kept constant across treatments and experiments. Means are 5.0% for stock 1 and 4.0% for stock 2. Standard-deviations are 15.14% for both stocks. In experiments 3 and 4 correlation and dependence in extreme returns increase, while dependence in moderate returns decreases from treatment 1 to treatment 2. Treatment 1 exhibits a correlation between stock returns of -0.21, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits a correlation between stock returns of +0.21, positive dependence in extreme returns and negative dependence in moderate returns.

---

<b>Treatment 1:</b> Pearson-Correlation of $-0.21$					
return	-32%	-5%	15%	42%	sum
-33%	0%	0%	0%	5%	5%
-6%	0%	45%	0%	0%	45%
14%	0%	0%	45%	0%	45%
41%	5%	0%	0%	0%	5%
sum	5%	45%	45%	5%	100%

<b>Treatment 2:</b> Pearson-Correlation of $+0.21$					
return	-32%	-5%	15%	42%	sum
-33%	5%	0%	0%	0%	5%
-6%	0%	0%	45%	0%	45%
14%	0%	45%	0%	0%	45%
41%	0%	0%	0%	5%	5%
sum	5%	45%	45%	5%	100%

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**Table 9:** Experiment 3 – Perception of Dependence

The panels show the frequency of each answer-category for questions on beliefs about dependence. Boxes around numbers indicate correct answers (based on data shown to participants; panel A does not have one correct answer). Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns. Below panels A, C and D, you will find the mean category for each treatment and differences between these means. Below panel B you will find mean probability estimates and differences between these mean estimates. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Treatment 1	Treatment 2
Panel A (Overall Dependence): Stocks 1 and 2 move...		
in opposite directions 1	0	3
2	16	56
3	36	27
4	52	20
together 5	3	1
mean	3.39	2.63
-Treatment 1	-	-0.77*** (0.11)
Panel B1 (Frequency of Co-Movement): Given stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)		
[0,10)	10	1
10	6	1
(10,50)	50	29
50	14	12
(50,90)	25	53
90	2	9
(90,100]	0	2
mean	38.58	59.35
-Treatment 1	-	20.77*** (3.25)
Panel B2 (Frequency of Co-Movement): Given stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)		
[0,10)	2	5
10	2	7
(10,50)	22	45
50	13	16
(50,90)	56	29
90	6	4
(90,100]	6	1
mean	60.58	43.98
-Treatment 1	-	-16.60*** (3.27)

	Treatment 1	Treatment 2
Panel C1 (Extreme Dependence): Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...		
decrease 1	26	<a href="#">34</a>
2	24	31
increase 3	<a href="#">57</a>	42
mean	2.29	2.07
-Treatment 1	-	-0.21* (0.11)
Panel C2 (Extreme Dependence): Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...		
decrease 1	<a href="#">48</a>	41
2	28	28
increase 3	31	<a href="#">38</a>
mean	1.84	1.97
-Treatment 1	-	0.13 (0.12)
Panel D1 (Moderate Dependence): Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...		
decrease 1	<a href="#">58</a>	8
2	41	43
increase 3	8	<a href="#">56</a>
mean	1.53	2.45
-Treatment 1	-	0.92*** (0.09)
Panel D2 (Moderate Dependence): Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...		
decrease 1	10	<a href="#">52</a>
2	43	47
increase 3	<a href="#">54</a>	8
mean	2.41	1.59
-Treatment 1	-	-0.82*** (0.09)

**Table 10:** Experiment 3 – Investment Decision

$Inv_2$  is the investment in stock 2.  $I_{ti}$  is a dummy for treatment  $i$ . Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns.  $I_c$  is a dummy, which is 1 for type 3 participants, i.e. participants that get  $\geq 3$  out of 4 questions about extreme dependence right. The subscript N denotes normalization to a mean of zero and standard deviation of one. FL is the financial literacy score according to Fernandes, Lynch, and Netemeyer (2014). NUM is the numeracy score according to Cokely, Galesic, Schulz, and Ghazal (2012). We run random effects regressions to take account of participant-specific effects. Since the treatment is orthogonal to participant characteristics, random effects—as opposed to fixed effects—regressions are justified. This is also why adding control variables does not change treatment effect estimates. Standard errors are reported in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Inv <sub>2</sub> All Types (1)	Inv <sub>2</sub> Types 1 & 2 (2)	Inv <sub>2</sub> Type 3 (3)	Inv <sub>2</sub> Types 1 & 2 (4)
Constant	3154.42*** (192.56)	3154.42*** (199.66)	3250.00*** (321.51)	3154.42*** (197.12)
I <sub>t2</sub>	923.02*** (259.41)	923.02*** (273.30)	952.38** (383.15)	923.02*** (275.49)
I <sub>t2</sub> *I <sub>c</sub>	29.36 (585.56)			
I <sub>c</sub>	95.58 (434.66)			
FL <sub>N</sub>				-271.80 (241.32)
NUM <sub>N</sub>				-293.26 (241.32)
FL <sub>N</sub> *I <sub>t2</sub>				140.65 (337.27)
NUM <sub>N</sub> *I <sub>t2</sub>				111.32 (337.27)
Random Effects	YES	YES	YES	YES
No. obs.	214	172	42	172

**Table 11:** Experiment 4 – Perception of Dependence

The panels show the frequency of each answer-category for questions on beliefs about dependence. Boxes around numbers indicate correct answers (based on data shown to participants; panel A does not have one correct answer). Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns. Below panels A, C and D, you will find the mean category for each treatment and differences between these means. Below panel B you will find mean probability estimates and differences between these mean estimates. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Return Group		Price Group	
	1	2	1	2
Panel A (Overall Dependence): Stocks 1 and 2 move...				
in opposite directions	1	3	1	7
	2	66	10	56
	3	18	41	22
	4	6	59	27
together	5	0	1	0
mean	3.75	2.29	3.44	2.62
-Treatment 1	-	-1.46 <sup>***</sup> (0.10)	-	-0.82 <sup>***</sup> (0.11)
Panel B1 (Frequency of Co-Movement): Given stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)				
[0,10)	15	0	4	2
10	<span style="border: 1px solid green; padding: 2px;">18</span>	2	<span style="border: 1px solid green; padding: 2px;">7</span>	3
(10,50)	36	9	65	31
50	5	11	13	13
(50,90)	16	48	21	50
90	2	<span style="border: 1px solid green; padding: 2px;">14</span>	2	<span style="border: 1px solid green; padding: 2px;">11</span>
(90,100]	1	9	0	2
mean	30.27	69.34	35.63	56.87
-Treatment 1	-	39.08 <sup>***</sup> (3.53)	-	21.23 <sup>***</sup> (3.08)
Panel B2 (Frequency of Co-Movement): Given stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases. (Any answer from 0 to 100 was allowed.)				
[0,10)	4	11	0	3
10	0	<span style="border: 1px solid green; padding: 2px;">11</span>	2	<span style="border: 1px solid green; padding: 2px;">8</span>
(10,50)	18	30	33	39
50	7	12	14	18
(50,90)	40	23	53	39
90	<span style="border: 1px solid green; padding: 2px;">15</span>	4	<span style="border: 1px solid green; padding: 2px;">10</span>	5
(90,100]	9	2	0	0
mean	66.46	40.41	57.21	47.44
-Treatment 1	-	-26.05 <sup>***</sup> (4.05)	-	-9.78 <sup>***</sup> (3.18)

	Return Group		Price Group	
	1	2	1	2
Panel C1 (Extreme Dependence): Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...				
decrease 1	20	53	24	26
2	15	12	27	26
increase 3	58	28	61	60
mean	2.41	1.73	2.33	2.30
-Treatment 1	-	-0.68*** (0.13)	-	-0.03 (0.11)
Panel C2 (Extreme Dependence): Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...				
decrease 1	58	28	54	53
2	13	16	24	28
increase 3	22	49	34	31
mean	1.61	2.23	1.82	1.80
-Treatment 1	-	0.61*** (0.13)	-	-0.02 (0.11)
Panel D1 (Moderate Dependence): Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...				
decrease 1	64	7	55	13
2	25	27	44	45
increase 3	4	59	13	54
mean	1.35	2.56	1.63	2.37
-Treatment 1	-	1.20*** (0.09)	-	0.74*** (0.09)
Panel D2 (Moderate Dependence): Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...				
decrease 1	6	56	9	52
2	20	26	43	43
increase 3	67	11	60	17
mean	2.66	1.52	2.46	1.69
-Treatment 1	-	-1.14*** (0.10)	-	-0.77*** (0.09)

**Table 12:** Experiment 4 – Investment Decision

$Inv_2$  is the investment in stock 2.  $I_{ti}$  is a dummy for treatment  $i$ . Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns.  $I_p$  is a dummy, which is 1 for price treatments, i.e. the participants that are shown price paths (not return series). Since the treatment is orthogonal to participant characteristics, random effects—as opposed to fixed effects—regressions are justified. This is also why adding control variables would not change treatment effect estimates. Standard errors are reported in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Return Group		Price Group		Both Groups
	$Inv_2$ Types 1 & 2 (1)	$Inv_2$ Type 3 (2)	$Inv_2$ Types 1 & 2 (3)	$Inv_2$ Type 3 (4)	$Inv_2$ All Types (5)
Constant	3494.23*** (280.90)	2973.02*** (277.67)	3487.36*** (193.20)	4167.60*** (453.59)	3264.45*** (199.19)
$I_{t2}$	911.65*** (318.38)	992.26*** (318.49)	440.69* (234.30)	-524.08 (575.32)	947.19*** (237.26)
$I_{t2} * I_p$					-721.85** (320.98)
$I_p$					374.74 (269.48)
Random Effects	YES	YES	YES	YES	YES
No. obs.	104	82	174	50	410

## A Appendix: Overview of Variables

The following table briefly defines the main variables collected in our experiments.

Panel A: Outcome Variables	
Variable Name	Description
Viewing Time	The number of seconds a participant looks at each of the $10 \times 10$ -year price paths.
Investment in Stock 2	'You have an endowment of 10'000 €. Your task is to invest this money in two stocks. How much do you invest into stock 2? (Note: The rest is invested in stock 1.)' (Any numerical answer between 0 and 10'000 could be typed in.)
Overall Dependence	'Stocks 1 and 2 move ...' (Three radiobuttons from 'in opposite directions' to 'together'.)
Downside Frequency of Comovement	'Given that stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases.' (Any numerical answer from 0 to 100 was allowed.)
Upside Frequency of Comovement	'Given that stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases.' (Any numerical answer from 0 to 100 was allowed.)
Downside Dependence in Extreme Returns	'Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...'. (Three radiobuttons from 'decrease' to 'increase'.)
Upside Dependence in Extreme Returns	'Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...'. (Three radiobuttons from 'decrease' to 'increase'.)
Downside Dependence in Moderate Returns	'Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...'. (Three radiobuttons from 'decrease' to 'increase'.)
Upside Dependence in Moderate Returns	'Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...'. (Three radiobuttons from 'decrease' to 'increase'.)

Portfolio Value	'Given your investment decision, what do you expect your portfolio value to be in one year?' (Any numerical answer $\geq 0$ was allowed.)
Loss Frequency	'In how many out of 100 cases do you expect to lose money (a final portfolio value of less than 10'000€ in one year)?' (Any numerical answer between 0 and 100 was allowed.)
Large Loss Frequency	'In how many out of 100 cases do you expect your final portfolio value to be less than 8'000€ in one year?' (Any numerical answer between 0 and 100 was allowed.)
Large Gain Frequency	'In how many out of 100 cases do you expect your final portfolio value to be more than 12'000€ in one year?' (Any numerical answer between 0 and 100 was allowed.)
Portfolio Risk	'How risky do you perceive your portfolio to be?' (Seven radiobuttons from 'risk-free' to 'very risky'.)
Confidence	'How confident are you about your investment decision?' (Seven radiobuttons from 'not confident at all' to 'very confident'.)
Informedness	'How informed do you feel when making this investment decision?' (Seven radiobuttons from 'not at all informed' to 'completely informed'.)

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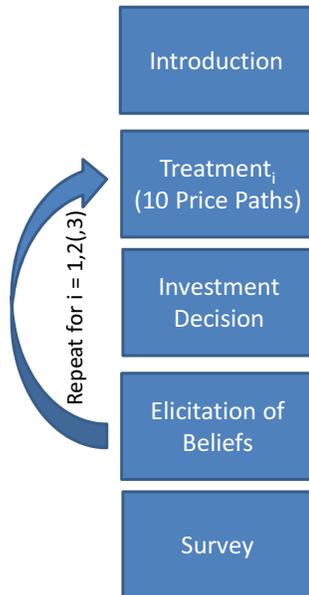
Panel B: Control Variables

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Variable Name	Description
Age	Age of the participant.
Gender	Gender of the participant.
Stock-Ownership	'Do you own stocks or an equity mutual fund?' (Answer: Yes or no.)
Financial Market Interest	'Are you generally interested in stock or financial markets?' (Answer: Yes or no.)
Risk Attitude	Self-reported: 'Please estimate your willingness to take financial risk.' (Five radiobuttons from 'not willing to accept any risk' to 'willing to accept substantial risk to potentially earn a greater return'.)
Statistics Course	'Have you attended a university statistics course?' (Answer: Yes or no.)
Statistics Knowledge	'How would you describe your knowledge about statistics?' (Four radiobuttons from 'good' to 'bad'.)
Financial Literacy	Financial Literacy Score between 0 and 12: The number of correct answers to twelve financial literacy questions from Fernandes, Lynch, and Netemeyer (2014). Item (8) from the original test was left out since the experiments were conducted in Germany (it is a question related to 401(k) plans and therefore specific to the US setting).
Numeracy	Numeracy Score between 0 and 4: The number of correct answers to the traditional format version of the Berlin Numeracy Test from Cokely, Galesic, Schulz, and Ghazal (2012).

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## B Appendix: Overview of Experimental Setup



## C Appendix: Instructions and Questions

All instructions and questions, translated from German into English.

### Introduction:

#### Screen 1 (Welcome Screen):

Dear participant,

the aim of this experiment is to better understand decision making of investors. The experiment consists of two sections. In section 1, an experiment is conducted, in the course of which you have to make 2 investment decisions. Section 2 is a survey.

For your participation in this experiment, you will receive a performance-based compensation, which depends on your 2 investment decisions in section 1 of the experiment. After the experiment, we will randomly select whether you will receive the compensation based on your first or

second investment decision. You will receive your compensation after completing the survey.

The experiment will take (including time for reading of instructions, the survey, and the payout of your compensation) around 1 hour. We politely ask you to not communicate with other participants during the experiment. As soon as you leave this screen, section 1 of the experiment begins.

If you have any questions, please put your hand up.

### **Screen 2 (Instructions):**

On the following screens, you will see simulated price paths of two stocks. Subsequently, you are supposed to split your fictive wealth of 10'000 € between the two stocks. The average return per year of stocks 1 and 2 is known:

Average return stock 1: 5% per year    Average return stock 2: 4% per year

You will receive a compensation that is based on your investment decision. We calculate this compensation based on a simulation of a one-year stock return for each of the two stocks, according to the following formula:

$$[\text{Investment\_Stock1} * (1 + \text{Return\_Stock1}) + \text{Investment\_Stock2} * (1 + \text{Return\_Stock2})] / 1'000$$

Example: Assume you have split your wealth evenly between stocks 1 and 2. The simulation results in a yearly return of -10% for stock 1 and +20% for stock 2. Your fictive wealth is then  $5'000 \text{ €} * (1 - 10\%) + 5'000 \text{ €} * (1 + 20\%) = 5'000 \text{ €} * 0.9 + 5'000 \text{ €} * 1.2 = 10'500 \text{ €}$ . Your performance-based compensation is therefore  $10'500 \text{ €} / 1'000 = 10,50 \text{ €}$

Comprehension questions: Assume you have invested 2'000 € of your wealth into stock 2. The simulation results in a return of +25% for stock 1 and -25% for stock 2. What is your fictive wealth at the end of this investment round?

As soon as you click 'Continue', the experiment will begin.

### **Treatment<sub>i</sub> (10 Price Paths):**

#### **Screen 3 (Introduction to Treatment i):**

Round i of the experiment starts now.

After this screen, you will see simulated price paths of two stocks. Based on these price paths you can get an idea of possible joint realizations for these stocks. Subsequently, you are supposed to split your fictive wealth of 10'000 € between the two stocks. Your compensation at the end of the

experiment depends on this investment decision and newly simulated returns of both stocks.

### Screens 4-13 (Treatment i):

[Participants view  $10 \times 10$ -year price paths for the current treatment. Participants determine themselves how long to view each path and click 'continue to next price path' (paths 1-9) or 'continue to investment decision' (path 10) to continue. After moving on from each price path, they cannot go back. The heading of each screen shows the number of price paths already viewed, e.g. 'price path 5 out of 10'.]

### Investment Decision:

#### Screen 14:

Your have 10'000€ at your disposal. Your task is to split this wealth between the two stocks. How much do you want to invest in stock 2? (Note: The remainder will automatically be invested in stock 1.)

Investment in stock 2 (in €):

### Elicitation of Beliefs:

#### Screen 15 (Dependence):

- 'Stocks 1 and 2 move ...' (Three radiobuttons from 'in opposite directions' to 'together'.)
- 'Given that stock 1's price decreases strongly (by more than 20%), I expect stock 2 to...'  
(Three radiobuttons from 'decrease' to 'increase'.)
- 'Given that stock 1's price increases strongly (by more than 20%), I expect stock 2 to...'  
(Three radiobuttons from 'decrease' to 'increase'.)
- 'Given that stock 1's price decreases moderately (by less than 20%), I expect stock 2 to...'  
(Three radiobuttons from 'decrease' to 'increase'.)
- 'Given that stock 1's price increases moderately (by less than 20%), I expect stock 2 to...'  
(Three radiobuttons from 'decrease' to 'increase'.)
- 'Given that stock 1's price decreases, I expect stock 2's price to increase in ... out of 100 cases.' (Any numerical answer from 0 to 100 was allowed.)
- 'Given that stock 1's price increases, I expect stock 2's price to increase in ... out of 100 cases.' (Any numerical answer from 0 to 100 was allowed.)

### Screen 16 (Portfolio Characteristics):

- 'Given your investment decision, what do you expect your portfolio value to be in one year?' (Any numerical answer  $\geq 0$  was allowed.)
- 'In how many out of 100 cases do you expect to lose money (a final portfolio value of less than 10'000 € in one year)?' (Any numerical answer between 0 and 100 was allowed.)
- 'In how many out of 100 cases do you expect your final portfolio value to be more than 12'000 € in one year?' (Any numerical answer between 0 and 100 was allowed.)
- 'In how many out of 100 cases do you expect your final portfolio value to be less than 8'000 € in one year?' (Any numerical answer between 0 and 100 was allowed.)
- 'How risky do you perceive your portfolio to be?' (Seven radiobuttons from 'risk-free' to 'very risky'.)
- 'How confident are you about your investment decision?' (Seven radiobuttons from 'not confident at all' to 'very confident'.)
- 'How informed do you feel when making this investment decision?' (Seven radiobuttons from 'not at all informed' to 'completely informed'.)

### Survey:

#### Screen 17 (Basic Characteristics):

- Self-reported: 'Please estimate your willingness to take financial risk.' (Five radiobuttons from 'not willing to accept any risk' to 'willing to accept substantial risk to potentially earn a greater return'.)
- 'Do you own stocks or an equity mutual fund?' (Answer: 'yes' or 'no'.)
- 'Are you generally interested in stock or financial markets?' (Answer: 'yes' or 'no'.)
- 'Do you own stocks or an equity mutual fund?' (Answer: 'yes' or 'no'.)
- 'Have you attended a university statistics course?' (Answer: 'yes' or 'no'.)
- 'How would you describe your knowledge about statistics?' (Four radiobuttons from 'good' to 'bad'.)
- 'What's your age?' (Answer: Any numerical answer between 16 and 80 was allowed.)
- 'Are you male or female?' (Answer: 'male' or 'female'.)

## Screen 18 (Financial Literacy I):

- Imagine that the interest rate on your savings account was 1% per year and inflation was 2% per year. After 1 year, would you be able to buy:
  - More than today with the money in this account
  - Exactly the same as today with the money in this account
  - *Less than today with the money in this account*
  - Don't know
  - Refuse to answer

(Item (1) from Fernandes, Lynch, and Netemeyer (2014).)

- Do you think that the following statement is true or false? 'Bonds are normally riskier than stocks.'
  - True
  - *False*
  - Don't know
  - Refuse to answer

(Item (2) from Fernandes, Lynch, and Netemeyer (2014).)

- Considering a long time period (for example, 10 or 20 years), which asset described below normally gives the highest return?
  - Savings accounts
  - *Stocks*
  - Bonds
  - Don't know
  - Refuse to answer

(Item (3) from Fernandes, Lynch, and Netemeyer (2014).)

- Normally, which asset described below displays the highest fluctuations over time?
  - Savings accounts
  - *Stocks*
  - Bonds
  - Don't know

- Refuse to answer

(Item (4) from Fernandes, Lynch, and Netemeyer (2014).)

**Screen 19 (Financial Literacy II):**

- When an investor spreads his money among different assets, does the risk of losing a lot of money:
  - Increase
  - *Decrease*
  - Stay the same
  - Don't know
  - Refuse to answer

(Item (5) from Fernandes, Lynch, and Netemeyer (2014).)

- Do you think that the following statement is true or false? 'If you were to invest 10'000 € in a stock mutual fund, it would be possible to have less than 10'000 € when you withdraw your money.'
  - *True*
  - False
  - Don't know
  - Refuse to answer

(Item (6) from Fernandes, Lynch, and Netemeyer (2014).)

- Do you think that the following statement is true or false? 'A stock mutual fund combines the money of many investors to buy a variety of stocks.'
  - *True*
  - False
  - Don't know
  - Refuse to answer

(Item (7) from Fernandes, Lynch, and Netemeyer (2014).)

- Do you think that the following statement is true or false? 'A 15-year mortgage typically requires higher monthly payments than a 30-year mortgage, but the total interest paid over the life of the loan will be less.'
  - *True*

- False
- Don't know
- Refuse to answer

(Item (9) from Fernandes, Lynch, and Netemeyer (2014).)

**Screen 20 (Financial Literacy III):**

- Suppose you have 100 € in a savings account and the interest rate is 20% per year and you never withdraw money or interest payments. After 5 years, how much would you have in this account in total?
  - *More than 200 €*
  - Exactly 200 €
  - Less than 200 €
  - Don't know
  - Refuse to answer

(Item (10) from Fernandes, Lynch, and Netemeyer (2014).)

- Which of the following statements is correct?
  - Once one invests in a mutual fund, one cannot withdraw the money in the first year
  - *Mutual funds can invest in several assets, for example in both stocks and bonds*
  - Mutual funds pay a guaranteed rate of return which depends on their past performance
  - None of the above
  - Don't know
  - Refuse to answer

(Item (11) from Fernandes, Lynch, and Netemeyer (2014).)

- Which of the following statements is correct? If somebody buys a bond of firm B:
  - He owns a part of firm B
  - *He has lent money to firm B*
  - He is liable for firm B's debts
  - None of the above
  - Don't know
  - Refuse to answer

(Item (12) from Fernandes, Lynch, and Netemeyer (2014).)

- Suppose you owe 3'000€ on your credit card. You pay 30€ each month. At an annual percentage rate of 12% (or 1% per month), how many years would it take to eliminate your credit card debt if you made no additional new charges?
  - Less than 5 years
  - Between 5 and 10 years
  - Between 10 and 15 years
  - *Never*
  - Don't know
  - Refuse to answer

(Item (13) from Fernandes, Lynch, and Netemeyer (2014).)

Note: This test is an adapted version of the financial literacy test in Fernandes, Lynch, and Netemeyer (2014). Item (8) from the original test was left out since the experiments were conducted in Germany (it is a question related to 401(k) plans and therefore specific to the US setting).

### Screen 21 (Numeracy):

- 'Out of 1,000 people in a small town 500 are members of a choir. Out of these 500 members in a choir 100 are men. Out of the 500 inhabitants that are not in a choir 300 are men. What is the probability that a randomly drawn man is a member of the choir? Please indicate the probability in percent. This means that you should not use any commas or dots.' (Numerical answer between 0 and 100. Correct answer: 25)
- 'Imagine we are throwing a five-sided die 50 times. On average, out of these 50 throws how many times would this five-sided die show an odd number (1, 3 or 5)?' (Numerical answer between 0 and 50. Correct answer: 30)
- 'Imagine we are throwing a loaded die (6 sides). The probability that the die shows a 6 is twice as high as the probability of each of the other numbers. On average, out of these 70 throws how many times would the die show the number 6?' (Numerical answer between 0 and 70. Correct answer: 20)
- 'In a forest 20% of mushrooms are red, 50% brown and 30% white. A red mushroom is poisonous with a probability of 20%. A mushroom that is not red is poisonous with a probability of 5%. What is the probability that a poisonous mushroom in the forest is red?' (Numerical answer between 0 and 100. Correct answer: 50)

Note: This test is the traditional format version of the Berlin Numeracy Test from Cokely, Galesic, Schulz, and Ghazal (2012).

## D Appendix: Additional Tables

**Table D1:** Experiment 1 – Other Portfolio Outcomes

Panel A shows participants' beliefs about the return characteristics of their selected portfolios. Additionally, for each statistic, the estimation error relative to the value based on the true portfolio return distribution is given. Panel B shows participants' subjective assessment of their portfolio selection. In addition to the respective variable's average value, the difference between the treatment two and one (2m1), three and two (3m2), and three and one (3m1) averages is reported. Treatments 1, 2, and 3 exhibit correlations between stock returns of -0.6, 0.2, and 0.6, respectively. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Treatment					
	1	2	3	2m1	3m2	3m1
Panel A: Portfolio Beliefs						
E(Value)	11549.50 <sup>***</sup> (271.61)	11743.35 <sup>***</sup> (393.11)	12050.89 <sup>***</sup> (240.26)	193.86 (436.68)	307.54 (436.68)	501.39 (436.68)
Error	1090.62 <sup>***</sup> (271.63)	1282.29 <sup>***</sup> (393.23)	1582.75 <sup>***</sup> (240.46)	191.67 (436.84)	300.47 (436.84)	492.13 (436.84)
P(return < 0%)	31.14 <sup>***</sup> (1.39)	28.84 <sup>***</sup> (1.43)	28.24 <sup>***</sup> (1.31)	-2.30 (1.95)	-0.60 (1.95)	-2.90 (1.95)
Error	9.11 <sup>***</sup> (2.05)	-8.12 <sup>***</sup> (1.62)	-16.35 <sup>***</sup> (1.39)	-17.23 <sup>***</sup> (2.41)	-8.23 <sup>***</sup> (2.41)	-25.46 <sup>***</sup> (2.41)
P(return < -20%)	14.84 <sup>***</sup> (1.34)	11.91 <sup>***</sup> (1.00)	12.11 <sup>***</sup> (1.00)	-2.94 <sup>*</sup> (1.59)	0.20 (1.59)	-2.73 <sup>*</sup> (1.59)
Error	13.59 <sup>***</sup> (1.35)	8.78 <sup>***</sup> (1.00)	8.02 <sup>***</sup> (1.00)	-4.81 <sup>***</sup> (1.60)	-0.76 (1.60)	-5.57 <sup>***</sup> (1.60)
P(return > 20%)	28.69 <sup>***</sup> (1.88)	30.96 <sup>***</sup> (2.09)	32.47 <sup>***</sup> (2.19)	2.27 (2.91)	1.51 (2.91)	3.78 (2.91)
Error	26.84 <sup>***</sup> (1.86)	27.52 <sup>***</sup> (2.08)	28.09 <sup>***</sup> (2.19)	0.68 (2.90)	0.57 (2.90)	1.24 (2.90)
Panel B: Subjective Assessment of Portfolio Selection						
Portfolio Risk (1-7)	4.30 <sup>***</sup> (0.12)	4.05 <sup>***</sup> (0.13)	3.98 <sup>***</sup> (0.13)	-0.25 (0.18)	-0.07 (0.18)	-0.32 <sup>*</sup> (0.18)
Confidence (1-7)	4.22 <sup>***</sup> (0.13)	4.45 <sup>***</sup> (0.13)	4.61 <sup>***</sup> (0.12)	0.23 (0.18)	0.17 (0.18)	0.39 <sup>**</sup> (0.18)
Informedness (1-7)	3.50 <sup>***</sup> (0.13)	3.43 <sup>***</sup> (0.13)	3.51 <sup>***</sup> (0.14)	-0.06 (0.19)	0.08 (0.19)	0.02 (0.19)

**Table D2:** Experiment 2 – Other Portfolio Outcomes

Panel A shows participants' beliefs about the return characteristics of their selected portfolios. Additionally, for each statistic, the estimation error relative to the value based on the true portfolio return distribution is given. Panel B shows participants' subjective assessment of their portfolio selection. In addition to the respective variable's average value, the difference between the treatment two and one (2m1) averages is reported. Treatment 1 exhibits negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive dependence in extreme returns and negative dependence in moderate returns. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	1	Treatment 2	2m1
<b>Panel A: Portfolio Beliefs</b>			
E(Value)	11398.16 <sup>***</sup> (356.83)	11481.13 <sup>***</sup> (396.52)	82.97 (533.44)
Error	934.20 <sup>**</sup> (357.29)	1020.95 <sup>**</sup> (396.63)	86.75 (533.83)
P(return < 0%)	29.26 <sup>***</sup> (1.63)	30.79 <sup>***</sup> (1.56)	1.53 (2.26)
Error	-19.63 <sup>***</sup> (1.62)	14.78 <sup>***</sup> (2.48)	34.40 <sup>***</sup> (2.96)
P(return < -20%)	13.44 <sup>***</sup> (1.36)	13.73 <sup>***</sup> (1.15)	0.30 (1.78)
Error	12.90 <sup>***</sup> (1.39)	8.73 <sup>***</sup> (1.15)	-4.17 <sup>**</sup> (1.81)
P(return > 20%)	31.06 <sup>***</sup> (2.35)	27.90 <sup>***</sup> (2.27)	-3.15 (3.27)
Error	29.68 <sup>***</sup> (2.39)	22.90 <sup>***</sup> (2.27)	-6.78 <sup>**</sup> (3.30)
<b>Panel B: Subjective Assessment of Portfolio Selection</b>			
Portfolio Risk (1-7)	4.28 <sup>***</sup> (0.15)	4.29 <sup>***</sup> (0.16)	0.01 (0.22)
Confidence (1-7)	4.17 <sup>***</sup> (0.15)	4.01 <sup>***</sup> (0.16)	-0.16 (0.22)
Informedness (1-7)	3.24 <sup>***</sup> (0.15)	3.03 <sup>***</sup> (0.14)	-0.21 (0.21)

**Table D3:** Experiment 3 – Other Portfolio Outcomes

Panel A shows participants' beliefs about the return characteristics of their selected portfolios. Additionally, for each statistic, the estimation error relative to the value based on the true portfolio return distribution is given. Panel B shows participants' subjective assessment of their portfolio selection. In addition to the respective variable's average value, the difference between the treatment two and one (2m1) averages is reported. Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	1	Treatment 2	2m1
Panel A: Portfolio Beliefs			
E(Value)	11116.78 <sup>***</sup> (248.09)	11132.28 <sup>***</sup> (248.66)	15.50 (351.25)
Error	648.51 <sup>**</sup> (247.82)	673.30 <sup>***</sup> (248.53)	24.79 (350.97)
P(return < 0%)	27.50 <sup>***</sup> (1.56)	28.43 <sup>***</sup> (1.46)	0.93 (2.14)
Error	-21.57 <sup>***</sup> (1.59)	6.61 <sup>***</sup> (2.35)	28.18 <sup>***</sup> (2.84)
P(return < -20%)	14.11 <sup>***</sup> (1.41)	14.20 <sup>***</sup> (1.30)	0.08 (1.92)
Error	13.18 <sup>***</sup> (1.46)	8.78 <sup>***</sup> (1.37)	-4.40 <sup>**</sup> (2.00)
P(return > 20%)	27.99 <sup>***</sup> (2.24)	28.11 <sup>***</sup> (2.09)	0.12 (3.06)
Error	26.12 <sup>***</sup> (2.20)	15.12 <sup>***</sup> (2.73)	-11.00 <sup>**</sup> (3.51)
Panel B: Subjective Assessment of Portfolio Selection			
Portfolio Risk (1-7)	4.21 <sup>***</sup> (0.14)	4.13 <sup>***</sup> (0.13)	-0.07 (0.17)
Confidence (1-7)	4.09 <sup>***</sup> (0.15)	4.13 <sup>***</sup> (0.14)	0.04 (0.12)
Informedness (1-7)	3.34 <sup>***</sup> (0.13)	3.39 <sup>***</sup> (0.14)	0.06 (0.13)

**Table D4:** Experiment 4 – Other Portfolio Outcomes

Panel A shows participants' beliefs about the return characteristics of their selected portfolios. Additionally, for each statistic, the estimation error relative to the value based on the true portfolio return distribution is given. Panel B shows participants' subjective assessment of their portfolio selection. In addition to the respective variable's average value, the difference between the treatment two and one (2m1) averages is reported. Treatment 1 exhibits negative correlation, negative dependence in extreme returns and positive dependence in moderate returns. Treatment 2 exhibits positive correlation, positive dependence in extreme returns and negative dependence in moderate returns. Standard errors are in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Return-Treatment			Price-Treatment		
	1	2	2m1	1	2	2m1
<b>Panel A: Portfolio Beliefs</b>						
E(Value)	10989.57*** (229.94)	10832.35*** (194.42)	-157.22 (296.43)	10943.11*** (320.33)	11380.47*** (285.71)	437.37 (429.24)
Error	522.02*** (229.72)	374.27* (194.37)	-147.75 (300.91)	479.50** (320.49)	919.12*** (285.45)	439.62 (429.17)
P(return < 0%)	29.14*** (1.68)	29.88*** (1.68)	0.74 (2.38)	27.12*** (1.34)	29.20*** (1.63)	2.08 (2.11)
Error	-20.22*** (1.68)	6.49** (2.63)	26.71*** (3.12)	-22.17*** (1.39)	4.51*** (2.86)	26.68*** (3.18)
P(return < -20%)	12.16*** (1.24)	11.88*** (1.15)	-0.28 (1.61)	12.25*** (1.03)	12.44*** (1.04)	0.19 (1.47)
Error	10.98*** (1.29)	6.88*** (1.15)	-4.10** (1.73)	11.40*** (1.05)	6.63*** (1.26)	-4.77*** (1.64)
P(return > 20%)	18.47*** (1.81)	20.14*** (1.90)	1.67 (2.62)	28.13*** (2.07)	28.89*** (2.24)	0.76 (3.05)
Error	16.54*** (1.83)	5.95** (2.80)	-10.59*** (3.35)	26.57*** (2.11)	11.44*** (2.82)	-15.13*** (3.52)
<b>Panel B: Subjective Assessment of Portfolio Selection</b>						
Portfolio Risk (1-7)	4.19*** (0.15)	3.89*** (0.16)	-0.30 (0.18)	4.13*** (0.13)	4.04*** (0.15)	-0.09 (0.14)
Confidence (1-7)	4.54*** (0.14)	4.49*** (0.15)	-0.04 (0.15)	3.97*** (0.15)	4.13*** (0.15)	0.16 (0.12)
Informedness (1-7)	3.80*** (0.14)	3.69*** (0.15)	-0.12 (0.16)	2.84*** (0.13)	2.98*** (0.14)	0.14 (0.11)

**Table D5:** Viewing Time of Extreme Events

$\ln(\text{Viewing Time})$  is the log of viewing time in seconds for each price path. The independent variable is the number of extreme events for each path. FEs are fixed effects, the coefficients of which are not reported. Standard-errors are reported in brackets. 1/2/3 stars denote significance at the 10/5/1%-level.

	Experiment				
	1	2	3	4 (Returns)	4 (Prices)
	$\ln(\text{Viewing Time})$				
	(1)	(2)	(3)	(4)	(5)
Number of Extreme Events	0.0578*** (0.0114)	0.1215*** (0.0172)	0.0909*** (0.0319)	0.1570*** (0.0172)	0.0998*** (0.0144)
Path FEs	YES	YES	YES	YES	YES
Round FEs	YES	YES	YES	YES	YES
Treatment FEs	YES	YES	YES	YES	YES
Participant FEs	YES	YES	YES	YES	YES
R <sup>2</sup>	0.63	0.68	0.67	0.63	0.68
No. obs.	3810	1900	2140	1860	2240

## E Appendix: Discussion of Additional Tables

Tables D1 through D4 in Appendix D report further outcome variables, which show that participants do not correctly answer questions about the riskiness of their portfolio returns. We collect participants' beliefs about portfolio characteristics (panel A) and their subjective assessment of the portfolio selection decision (panel B). Their beliefs about aggregate portfolio characteristics do not react significantly to the treatments, even though actual portfolio characteristics change a lot. As an illustration, the probability of a negative portfolio return for the average participant in experiment 1 (Table D1) increases by around 22% (from 22% to 44%) as correlation increases from treatment 1 to treatment 3. However, participants' estimate for the probability of negative returns does not change significantly, staying between 28% and 32%. Subjective assessments of the portfolio selection decision do not change strongly over the treatments either. Hence, even though our main analysis shows that participants' beliefs and choices react to changes in dependence over treatments, these results indicate that participants cannot properly aggregate their beliefs about dependence to make reasonable statements about the riskiness of portfolio returns.

Table D4 reports further outcome variables separately for participants who see return series and those who see price paths. As for experiments 1, 2 and 3, participants' beliefs about aggregate portfolio characteristics do not react significantly to the treatments, even though actual portfolio characteristics change a lot. Subjective assessments of the portfolio selection decision do not change significantly over the treatments either. However, participants state significantly higher levels of confidence and informedness in the return series group (statistical significance of 5% for confidence and 1% for informedness). These assessments are consistent with participants' stronger treatment effects in the return group.

Table D5 reports the reaction of log-viewing times to the number of extreme events in a price path. One might argue that a reason for missing influence of extreme returns on beliefs and the investment decision is that extreme states—although in line with historical extreme observations (see Section 7)—are not salient enough. We can provide evidence against this argument. For all four experiments, paths with more extreme events are viewed significantly longer than paths with less extreme events. The mean differences in viewing times for each additional extreme event per 10-year path are 6% (experiment 1), 12% (experiment 2), 9% (experiment 3), 16% (experiment 4 with returns), and 10% (experiment 4 with price paths).