Investor Memory

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Abstract

How does memory shape individuals' financial decisions? We find experimental evidence of a self-serving memory bias. Subjects over-remember their positive investment outcomes and under-remember negative ones. In contrast, subjects who did not invest but merely observed the outcomes do not have this bias. The memory bias affects individual beliefs and decisions to re-invest. After investing, subjects form overly optimistic beliefs about their investment and re-invest even when doing so leads to a lower expected return. The memory bias is relevant for understanding how people learn from experiences in financial markets and has general implications for individual overconfidence and risk-taking.

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1 Introduction

How does memory shape individuals' financial decisions? While we all learn from experiences, our memories of those experiences can be both selective and distorted. Furthermore, the memories of personal experiences may be systematically biased relative to less subjective information. When you went to a fancy fish restaurant to eat with your friends, you may remember the nice company you had but forget that the food wasn't that good. Such memory limitations are largely ignored in economic research. While theory has recently integrated psychology-based facts about memory formation and retrieval into behavioral models, we are the first to provide evidence for a systematic memory bias in an important economic domain: financial decision-making. We document a self-serving memory bias for investment outcomes. People over-remember the positive and under-remember the negative outcomes from their prior choices. This finding changes the understanding of how people learn from experiences in financial markets and, more generally, proposes a unifying explanation for well documented phenomena in individuals' overconfident behavior and risk-taking.

Memory is not a neutral, accurate representation of past events, but is subject to errors and biases (Schacter, 1999). In this study, we focus on memory of outcomes people have personally experienced from prior investment choices, such as returns (Malmendier and Nagel, 2011). Experienced events are generally stored in episodic memory, the database of past experiences (Kahana, 2012; Tulving, 1972; Tulving and Murray, 1985).[1] Evidence in psychology suggests that episodic memory, in particular, tends to be biased in ways that maintain and enhance one's own positive self-image: People are more likely to remember personal successes than failures and to remember features of past options that are supportive of the choices they made (Mather and Johnson, 2000).[2] People are likely to rely on their subjective memory, rather than on records of historical data or information when making decisions. For instance, people might rely on their memory in situations when information is costly (e.g. due to search costs); when people actively avoid information (e.g. due to the ostrich effect (Karlsson, Loewenstein, and Seppi, 2009); or when people overestimate their memory accuracy (e.g. due to overconfidence).

We formalize a model in which memory of investment outcomes is systematically biased in a self-serving way and thereby distorts beliefs. We follow the intuition that selective recall might be

[1]The literature contrasts episodic memory of events to semantic memory of abstract knowledge. As an illustration for the different use of episodic and semantic memory in decision-making, consider people's judgements about the likelihood of future events. Applying Bayesian updating to base rate information needs the application of semantic knowledge. Yet, when frequencies of experienced events are incorporated into people's predictions, episodic memory leaks into their judgements.

[2]This is in line with the so-called Pollyanna principle, a general psychological principle which portrays the positive bias people have when thinking of the past (Matlin and Stang, 1978).

a potential mechanism for self-servingly biased beliefs (Bénabou and Tirole, 2002, 2004; Zimmermann, 2018). The memory bias stems from quasi-Bayesian belief updating with a probability of under-remembering specific previously observed signals. This probability depends on whether the signals are consistent with the decision maker's positive self-image. In the model, the agent observes outcomes of an asset in order to update her belief about the quality of the asset. She relatively under-remembers outcomes that are inconsistent with her positive self-image, and thus underweights them. If the agent invested in the asset, she under-remembers negative outcomes relative to positive ones and becomes over-optimistic about the quality of the asset. Our approach extends recent theoretical work by introducing a systematic memory bias, which is self-serving. This is distinct from previously considered memory-based mechanisms such as representativeness, similarity, or recency (Bordalo, Gennaioli, and Shleifer, 2019; Mullainathan, 2002; Nagel and Xu, 2018). We differentiate between memory of events with different levels of self-relevance (active experience versus passive observation).

We conduct an experiment in an investment context to test for the self-serving memory bias as well as its effect on beliefs and subsequent decisions. Subjects choose to invest either in a risky asset or a risk-free asset (Kuhnen, 2015). The risky asset is either a "good stock" or a "bad stock". A good stock is more likely to generate positive outcomes and a bad stock is more likely to generate negative outcomes. Subjects do not know whether their stock is good or bad. To identify memory bias, we let subjects observe a series of investment outcomes and elicit their memory of these outcomes either immediately following or one week after the observation. To relate subjects' memory bias to their beliefs and future investment behavior, we elicit their beliefs about the stock's chance of being the good stock and ask them to make another investment decision. The experiment has two key advantages. First, we can directly measure what people actually remember. Second, to explore behavioral deviations from standard theory, we can compare subjects' beliefs and choices to a Bayesian benchmark.

We have two main findings. First, subjects remember investment outcomes in a self-serving way. They relatively under-remember investment losses compared to gains, if they invested in the stock. In contrast, subjects who decided not to invest in the stock (i.e., chose the risk-free asset) do not display this memory bias. Second, the self-serving memory bias is related to subjects' belief formation and future investment choices. One week after the observation, subjects who invested in the stock form overly optimistic beliefs about the stock and are more likely to re-invest in the stock even when doing so leads to a lower expected return. Particularly, 54% of the subjects kept investing in the stock, although from a Bayesian perspective the risk-free asset was optimal. The results are consistent with our model in which image-concerns form the basis for how information is remembered and are robust to different measures of memory bias.

How past returns affect individual beliefs and financial decisions has been the focus of a rich strand of literature. There is extensive theoretical work (De Long, Shleifer, Summers, and Waldmann, 1990; Hong and Stein, 1999; Barberis, Greenwood, Jin, and Shleifer, 2015, 2018; Barberis and Vishny, 1998) as well as empirical evidence (De Bondt, 1993; Greenwood and Shleifer, 2014; Koijen, Schmeling, and Vrugt, 2015) suggesting that investors' expectations of future stock market returns are positively correlated with recent past returns. Furthermore, personal experiences of returns play an important role in financial behavior. Individuals' level of risk taking in financial markets is related to the returns they have experienced (Malmendier and Nagel, 2011; Knüpfer, Rantapuska, and Sarvimäki, 2017; Guiso, Sapienza, and Zingales, 2018; Andersen, Hanspal, and Nielsen, 2019). Other studies show that investors over-extrapolate from their personal experiences in savings decisions (Choi, Laibson, Madrian, and Metrick, 2009), IPO subscriptions (Kaustia and Knüpfer, 2008), and stock repurchasing decisions (Strahilevitz, Odean, and Barber, 2011). They tend to repeat actions that have generated favorable investment outcomes in the past.

The novel contribution of this paper is that we isolate memory as a channel through which experienced outcomes affect beliefs and behavior. We find that positive and negative outcomes, such as returns, are remembered differently, depending on whether people invested or not. This finding changes the understanding of how people learn from experiences in financial markets. The key implication of the experience hypothesis from prior literature is that experiencing high returns should be correlated with higher financial risk taking and experiencing low returns should be correlated with lower financial risk taking (Malmendier and Nagel, 2011). Yet, we find that this depends on whether people invested or not. People who invested can show high levels of risk taking despite experiencing low returns, because they form overly optimistic beliefs based on their biased memory. By contrast, those who did not invest but merely observe low returns can show unbiased memory and take less risk. Thus, we demonstrate that biased memory of own choice outcomes can lead to individual-level differences in experience effects beyond existing evidence of cohort-level experience effects (Malmendier and Nagel, 2011).

The memory mechanism we document could underlie overconfidence in financial markets. For instance, our results are in line with traders learning to be overconfident (Gervais and Odean, 2001). If investors under-remember their investment failures relative to successes, they become overconfident about private information quality or their ability to trade. This has important implications for investor learning in the long run if selectively forgotten information can no longer be retrieved. The memory bias may also be the source of why unsuccessful traders persist trading (Barber, Lee, Liu, Odean, and Zhang, 2017). If traders forget their own losses, they cannot learn from their failures.

Our paper further contributes to the economic literature on motivated beliefs. This line of work argues that people form and update beliefs in order to maintain a positive self-view (Bénabou and Tirole, 2002; Köszegi, 2006). Recent experimental work provides evidence for self-serving belief formation and updating about ego-relevant information on intelligence (Zimmermann, 2018), beauty (Eil and Rao, 2011), and generosity (Saucet and Villeval, 2018; Di Tella, Perez-Truglia, Babino, and Sigman, 2015; Carlson, Maréchal, Oud, Fehr, and Crockett, 2018). A key question in the literature remains how self-serving beliefs relate to behavior. We address this question by investigating the memory foundation of self-serving beliefs and its impact on future decisions. We look at whether people take their memories as accurate and use them to make decisions or whether they adjust their behavior for limitations of their memory. Our results suggest people's naiveté about the fallibility of their own memory.[3] Further, we extend the realm to a financial decision-making context which allows us to explore self-serving belief formation and updating from *choice outcomes* rather than from feedback on personal characteristics like intelligence, beauty, or generosity.

More generally, economics research has shown that prior outcomes affect subsequent risk taking (Thaler and Johnson, 1990; Imas, 2016; Suhonen and Saastamoinen, 2017). Our findings suggest that prior gains from own choices have a relatively larger impact on future risk taking compared to prior losses, because people forget their losses. Importantly, this effect increases significantly when time has passed. That is, the distinction in how individuals respond to prior gains versus losses depends on whether people make decisions immediately after experiencing the outcomes or after some delay. Such effects on individual risk taking are relevant in many economic domains, in particular for dynamic settings in which sequential risky choices are made. For example, the proposed self-serving memory bias might have implications for corporate investment decisions by CEOs, betting, or competitive behavior.

2 A Model of Memory-Based Belief Distortion

In this section, we present a simple behavioral mechanism for the self-serving memory bias and its effect on beliefs. In the model, the agent uses observed signals to update beliefs about an underlying state in a quasi-Bayesian way (e.g. Rabin, 2002). She behaves as a Bayesian updater, but places wrong weights on signals (e.g. Rabin and Schrag, 1999; Mobius, Niederle, Niehaus, and Rosenblat, 2011). In our setting, the biased signal weighting happens when the agent retrieves historical data,

[3] See Mullainathan (2002) for a naive model where people do not adjust for limitations of memory.

such as earnings surprises, returns, or dividends, from memory. The weights are biased in a self-serving way (e.g. Köszegi, 2006):[4] the agent relatively under-remembers signals that are inconsistent with her positive self-image, and becomes over-optimistic about more preferred states.

2.1 The Model

Suppose in each period t, a stock generates an outcome $d_t \in \mathcal{D}$, where $\mathcal{D}$ is a finite ordered set of outcomes. Outcomes in all periods are *i.i.d.* In a financial market, these outcomes can be thought of as earnings surprises, returns, or dividends. Which outcome is generated in each period is determined by the stock's underlying type. The agent's task is to observe the outcomes and to make inference about the stock's type. For simplicity and for the convenience in our subsequent experimental testing, we use binary outcomes and a binary type space. The outcomes are either positive or negative: $d_t \in \{0, 1\}$, where 0 represents a negative outcome and 1 represents a positive outcome.[5] The stock is of one of 2 different types good or bad, represented by G and B respectively. Each type corresponds to an underlying distribution from which outcomes are drawn. The probability of a positive outcome is θ_G for a good stock, and θ_B for a bad stock, with $0 < \theta_B < \theta_G < 1$. In other words, the good type has an outcome distribution that first-order stochastically dominates the bad type. Let μ_0^G and μ_0^B represent the prior belief about the good and bad type respectively.

The true history of outcomes up to period t is represented by $h_t = (d_1, ..., d_t)$. The agent observes the history of outcomes h_t, stores the outcomes in memory as the history of remembered outcomes $h_t^R = (d_1^R, ..., d_t^R)$, and forms beliefs about the stock's type and future outcomes based on h_t^R. Up to period t, the total number of positive outcomes occurred is n_t^+, the total number of negative outcomes occurred is n_t^-. The total number of positive and negative outcomes sum up to t.[6] Let the number of remembered positive and negative outcomes be denoted as $n_t^{+,R}$ and $n_t^{-,R}$, respectively.

Assume that the agent always remembers the total number of periods correctly, thus $n_t^{+,R} + n_t^{-,R} = t$.[7] However, $n_t^{+,R}$ and $n_t^{-,R}$ may not be correct representations of n_t^+ and n_t^-. If the agent invests in the stock, she may relatively under-remember negative outcomes compared to positive outcomes.[8] This memory bias could emerge because obtaining negative outcomes might suggest that the initial investment decision was wrong and positive outcomes might justify the initial investment

[4] See Bénabou and Tirole (2016) for a review of this literature.

[5] This is without loss of generality, as long as the set of outcomes is ordered.

[6] Under the current notation, we also conveniently have $n_t^+ = \sum_0^t d_t$, and $n_t^- = t - \sum_0^t d_t$.

[7] This means if the agent relatively over-remembers positive outcomes, she must relatively under-remember negative outcomes. Of course the agent could also under-remember all outcomes in general, but that is not the type of memory bias we would like to capture.

[8] Relative mis-remembering a kind of outcome relative to the other is the phenomenon of interest here. Uniform mis-remembering of both positive and negative outcomes is not explored here.

decision. In other words, negative outcomes might be inconsistent with the agent's positive self-image and positive outcomes might align with the agent's positive self-image. In a similar vein, if the agent does not invest in the stock, she may relatively under-remember positive outcomes compared to negative outcomes. However, the effect does not have to be symmetric. For instance, the decision to invest could be of higher importance for the agent's self-image compared to the decision not to invest. Many studies document the power of action to alter self-views and provide evidence for an asymmetry between the influence of action and non-action on self-perception (Cioffi and Garner, 1996; Allison and Messick, 1988; Fazio, Chen, McDonel, and Sherman, 1982).

Suppose R_t represents the memory bias in period t, given the agent's initial choice to invest in the stock and dependent on whether the outcome is positive or negative:

$$R_t = I_t q^- + (1 - I_t)q^+, \tag{1}$$

where I_t is an indicator function that is equal to 1 if the agent invests in the stock in period t, and 0 otherwise. Additionally, $q^- \in [0,1]$ is the probability of under-remembering a negative outcome and $q^+ \in [0,1]$ is the probability of under-remembering a positive outcome. The assumption here is that if the agent invests, she faces a probability q^- of forgetting each negative outcome, but she does not mis-remember positive outcomes. Thus, she relatively under-remembers negative compared to positive outcomes. In case the agent invests (does not invest), if $q^- = 0$ ($q^+ = 0$) there is no memory bias, and if $q^- = 1$ ($q^+ = 1$) the memory bias is extreme, i.e., the outcomes are forgotten completely. It is possible that $q^- = q^+$, or $q^- \neq q^+$. That is, the agent may or may not have the same bias if she invests or if she does not. Further, it is possible that either q^- or q^+ is 0, which means the agent has a memory bias only if she invests in the stock, or only if she does not invest in the stock. When $q^- = q^+ = 0$, the model reverts to rational Bayesian updating.

If the agent invests in the stock in period 1 to t, then in period t, the remembered number of negative outcomes is expected to be $n_t^{-,R} = (1-q^-)n_t^- \leq n_t^-$, and the remembered number of positive outcomes is expected to be $n_t^{+,R} = t - n_t^{-,R} \geq n_t^+$. If the agent does not invest in the stock, then in period t, the remembered number of positive outcomes is expected to be $n_t^{+,R} = (1 - q^+)n_t^+ \leq n_t^+$, and the remembered number of negative outcomes is expected to be $n_t^{-,R} = t - n_t^{+,R} \geq n_t^-$. Note that equality holds if there is no outcome that contradicts with the agent's positive self-image. This is the case when $n_t^- = 0$ if the agent invests, and $n_t^+ = 0$ if the agent does not invest.

An unbiased agent uses the true history h_t to update her belief about the stock's type. The posterior belief that the stock's type is G of an unbiased agent is represented by:

$$\mu_t^{G,Bayesian}(h_t) = \frac{P(h_t|\theta_G)\mu_0^G}{\sum_{j=G,B} P(h_t|\theta_j)\mu_0^j}.$$

The likelihood ratio of type G relative to type B is given by:

$$\Lambda^{Bayesian}(h_t) = \frac{\theta_G^{n_t^+}(1-\theta_G)^{n_t^-}\mu_0^G}{\theta_B^{n_t^+}(1-\theta_B)^{n_t^-}\mu_0^B}. \tag{2}$$

A biased agent uses the history of remembered outcomes h_t^R to update her belief about the stock. The posterior belief that the stock's type is G of a biased agent is represented by:

$$\mu_t^{G,Biased}(h_t^R) = \frac{P(h_t^R|\theta_G)\mu_0^G}{\sum_{j=G,B} P(h_t^R|\theta_j)\mu_0^j}.$$

The likelihood ratio of type G relative to type B for a biased agent is

$$\Lambda^{Biased}(h_t^R) = \frac{\theta_G^{n_t^{+,R}}(1-\theta_G)^{n_t^{-,R}}\mu_0^G}{\theta_B^{n_t^{+,R}}(1-\theta_B)^{n_t^{-,R}}\mu_0^B}, \tag{3}$$

If the agent invests in the stock $n_t^{+,R} \geq n_t^+$, and thus $\Lambda^{Biased}(h_t^R) \geq \Lambda^{Bayesian}(h_t)$: the biased agent overestimates the good type relative to the bad type compared to a Bayesian agent. Conversely, if the agent does not invest in the stock $n_t^{+,R} \leq n_t^+$, and thus $\Lambda^{Biased}(h_t^R) \leq \Lambda^{Bayesian}(h_t)$. Again, the biased agent updates her beliefs like a Bayesian agent if there is actually no outcome that contradicts with her positive self-image.

In general, after a biased agent invests in the stock, her memory of observed outcomes will be biased. She relatively under-remembers less preferred outcomes, and thus when updating beliefs, she becomes overly optimistic about the underlying type of the stock. The opposite might happen if the biased agent does not invest in the stock. However, as stated before, the memory bias might not be symmetric for the cases in which the agent invests and does not invest. Note that when the probability of under-remembering (q^- or q^+) is zero, Equation (3) and Equation (2) coincide.

The agent with a self-serving memory bias can also be seen as placing biased weights on past outcomes when retrieving them from memory. If she invests in the stock, she relatively overweights positive outcomes, and overestimates the probability that the stock is of the good type. By contrast, if she does not invest in the stock, she relatively overweights negative outcomes, and overestimates the probability that the stock is of the bad type.

2.2 Signal Weighting

Without loss of generality, suppose that $\theta_G = \theta$, and $\theta_B = 1 - \theta$, where $\theta \in (0.5, 1)$. Additionally, the two types are equally likely, $\mu_0^G = \mu_0^B = \mu_0 = 0.5$.[9] This further simplifies matters and helps us to derive simple representations of biased signal weightings, which are testable in our experiment.

Rewriting Equation (2), an unbiased agent's posterior likelihood ratio of G relative to B is

$$\Lambda^{Bayesian}(h_t) = \frac{\theta^{n_t^+}(1-\theta)^{n_t^-}}{\theta^{n_t^-}(1-\theta)^{n_t^+}}$$

For a biased agent, if she invests in the stock, the posterior likelihood ratio of G relative to B is

$$\Lambda^{Biased,INV}(h_t^R) = \frac{\theta^{t-(1-q^-)n_t^-}(1-\theta)^{(1-q^-)n_t^-}}{\theta^{(1-q^-)n_t^-}(1-\theta)^{t-(1-q^-)n_t^-}} \geq \Lambda^{Bayesian}(h_t)$$

If the biased agent does not invest in the stock, the posterior likelihood ratio of G relative to B is

$$\Lambda^{Biased,NOT}(h_t^R) = \frac{\theta^{(1-q^+)n_t^+}(1-\theta)^{t-(1-q^+)n_t^+}}{\theta^{t-(1-q^+)n_t^+}(1-\theta)^{(1-q^+)n_t^+}} \leq \Lambda^{Bayesian}(h_t)$$

A Bayesian agent uses the correct number of occurred positive and negative outcomes to update her beliefs, placing equal weight on positive and negative outcomes. As in Equation (4), the weight should be exactly equal to $\ln(\frac{\theta}{1-\theta})$, which represents the informativeness of positive relative to negative signals.

$$\ln \Lambda^{Bayesian}(h_t) = \ln(\frac{\theta}{1-\theta})n_t^+ - \ln(\frac{\theta}{1-\theta})n_t^-. \tag{4}$$

However, the agent with a self-serving memory bias has the following log likelihood ratios

$$\ln \Lambda^{Biased,INV}(h_t^R) = \ln(\frac{\theta}{1-\theta})(n_t^+ + q^- n_t^-) - \ln(\frac{\theta}{1-\theta})(1-q^-)n_t^-;$$

$$\ln \Lambda^{Biased,NOT}(h_t^R) = \ln(\frac{\theta}{1-\theta})(1-q^+)n_t^+ - \ln(\frac{\theta}{1-\theta})(n_t^- + q^+ n_t^+).$$

It can be shown that the following equations characterize the difference between the log likelihood ratios of a biased agent and a Bayesian agent.

[9] In the experiment, we also have binary signals generated from the underlying distribution, either positive or negative outcomes. We used three positive and three negative outcomes, respectively, that are equally likely. However, this is irrelevant for a Bayesian updater when forming beliefs. Beliefs should be solely formed based on whether the signal is positive or negative.

$$\ln \Lambda^{Biased,INV}(h_t^R) - \ln \Lambda^{Bayesian}(h_t) = \ln(\frac{\theta}{1-\theta})2q^- n_t^-, \tag{5}$$

$$\ln \Lambda^{Biased,NOT}(h_t^R) - \ln \Lambda^{Bayesian}(h_t) = -\ln(\frac{\theta}{1-\theta})2q^+ n_t^+. \tag{6}$$

Hence, the belief distortion, measured as the log-likelihood deviation from the Bayesian belief, is positively correlated with θ, q^- (or q^+), and n_t^- (or n_t^+). The magnitude of the belief distortion is non-zero, when $q^- n_t^- \neq 0$ (or $q^+ n_t^+ \neq 0$), as $\theta \in (0.5, 1)$.

Equations (5) and (6) yield the following propositions.

Proposition 1. *Given $q^- n_t^- \neq 0$ (or $q^+ n_t^+ \neq 0$), the magnitude of the belief distortion is positively correlated with the contrast between the underlying processes (θ).*

Proposition 2. *Given $q^- \neq 0$ (or $q^+ \neq 0$), the magnitude of the belief distortion is positively correlated with the number of signals inconsistent with one's self-image (n^- or n^+).*

Proposition 3. *Given $n_t^- \neq 0$ (or $n_t^+ \neq 0$), the magnitude of the belief distortion is positively correlated with the magnitude of the memory bias (q^- and q^+).*

The model serves two important purposes for our subsequent experimental testing. In the experiment, we fix θ but vary n_t^- and n_t^+. First, our model proposes interesting comparative statics. The model predicts that holding θ, q^- and q^+ constant, the belief distortion compared to the Bayesian posterior is larger if there are more true outcomes that are contradictory to the biased agent's self-image (Proposition 2). These are the negative outcomes if the agent invests and the positive outcomes when the agent does not invest. We will provide experimental evidence for this proposition.[10] Further, the model predicts that holding θ, n^- and n^+ constant, the belief distortion relative to the Bayesian posterior is larger for agents with a larger memory bias (Proposition 3). We will also provide evidence for this proposition.

Second, Equations (5) and (6) provide the foundation for our regression analysis with regard to memory-based belief distortion. With subjects' belief distortion as the dependent variable, $\ln(\frac{\theta}{1-\theta})2n_t^-$ or $-\ln(\frac{\theta}{1-\theta})2n_t^+$ as the independent variable, we can directly estimate the value of q^- and q^+, i.e., the memory bias, on average across subjects.

[10]Note that in our experiment, memory elicitation was a surprise task so we could not vary parameters within-subjects.

3 Experiment

3.1 Experimental Design

A setup to investigate a self-serving memory bias for investment outcomes and its effect on beliefs and choices requires (i) a meaningful investment decision that generates self-relevant outcomes, (ii) exogenous variation in investment outcomes (positive and negative outcomes), (iii) direct memory elicitation, and (iv) an experimental manipulation of the time span between observation of outcomes and tasks to isolate memory effects. In this section, we outline how our experimental setting meets these requirements (Table 1 summarizes our treatment conditions).[11]

Table 1: Experimental Conditions

Treatment	First investment choice and observation of outcomes	Memory elicitation	Belief elicitation and second investment choice
Delay	Week t	Week t+1	Week t+1
Immediate1	Week t	Week t	Week t
Immediate2	Week t+1	Week t+1	Week t+1
NoRecall	Week t	No	Week t+1

Notes: This table provides an overview of the treatment and control conditions of the experiment with different time spans between tasks.

First, subjects make an investment decision. They choose to invest either in a stock with risky outcomes (positive and negative outcomes) or in a bond with known safe outcomes (cf. Kuhnen, 2015). After that decision, investment outcomes are observed over the course of 12 periods. With equal probability, the stock may be good or bad. That is, the stock is either more likely to generate positive outcomes or more likely to generate negative outcomes. We choose $\theta = 0.6$. Good stocks have positive outcomes with a 60% probability and negative outcomes with a 40% probability each period. Bad stocks have positive outcomes with a 40% probability and negative outcomes with a 60% probability.[12] The positive outcomes of the stock are either 11, 13, or 15 EUR and the negative outcomes are either -5, -3, or -1 EUR. More precisely, given that the outcome in a period is positive, it is randomly drawn from $\{11, 13, 15\}$ with equal probability. Given that the outcome in a period is negative, it is randomly drawn from $\{-5, -3, -1\}$ with equal probability. The determination of the outcomes is independent across periods. The bond has a certain outcome of 3.10 EUR each period. Subjects start with an initial endowment of 60 EUR.[13] See Table 2 for an overview of subjects'

[11] The experiment instructions are provided in Appendix A.

[12] To make sure that subjects understand the distributions, we included a phase of experience sampling (for both the distribution of the good stock's and the bad stock's outcomes) which did not influence subjects payout.

[13] The incentive structure is described in detail in Section 3.2.

investment options.

To measure subjects' memory bias, we let subjects observe the generated stock outcomes and then elicit their memory of these outcomes. Subjects see the outcomes of the stock, irrespective of whether they chose to invest in the stock or bond. The outcome of each of the 12 periods is sequentially presented on a screen for 2 seconds. After subjects observe the outcomes, we ask them to recall how many positive and negative outcomes they observed and, more specifically, how often the stock paid 11, 13, 15, -5, -3, and -1 EUR. This memory task is not announced beforehand.[14]

Importantly, to clearly identify the effect memory has on subjects' recollection, we manipulate the time span between the observation phase and the memory elicitation, following a between-subject design. We randomly assign subjects to one of three experimental conditions for the whole experiment. In the *Delay* condition, subjects perform the memory task one week after the observation and in the *Immediate* condition, subjects perform the memory task immediately after they observed the investment outcomes (Table 1). Comparisons between the *Delay* and *Immediate* treatment allow us to isolate memory effects from other factors such as attention (Barber and Odean, 2008; DellaVigna and Pollet, 2009) or salience (Bordalo, Gennaioli, and Shleifer, 2012, 2013), which might influence subjects' recollection of outcomes, but are related to subjects' information acquisition and processing. Differences between the *Delay* and the *Immediate* condition cannot be caused by subjects' information acquisition or processing, but solely by the fact that subjects have to remember the stock's outcomes from last week.

A *NoRecall* condition, in which subjects do not perform a memory elicitation task, serves as a control condition. This treatment allows us to identify potential effects of simply asking subjects to recall investment outcomes. Note that we do not find a significant difference in subjects' beliefs or investment decisions between the *Delay* and *NoRecall* condition (T-test, $p = 0.714$ and $p = 0.343$, respectively), suggesting that simply asking subjects to recall the stock's outcomes does not drive our results. Please refer to Section 5.5 for a detailed description of the analyses.

Subjects in the *Delay* treatment observe investment outcomes in week t and perform the memory elicitation task in week $t + 1$. In contrast, subjects in the *Immediate* condition perform all experimental tasks in the course of one session. This could happen either in week t or in week $t + 1$. To rule out timing effects, we vary whether subjects perform the tasks in week t (*Immediate1* condition) or in week $t + 1$ (*Immediate2* condition). In half of the experimental sessions, subjects perform the tasks in week t and in the other half of the sessions in week $t + 1$ (Table 1). In our main analyses, we pool the data of the *Immediate1* condition and the *Immediate2* condition and control for the

[14] The instructions for the memory elicitation are provided in Appendix B.

Table 2: Overview of subjects' investment options

	Investment Option	Risk about Asset Type	Asset Type	Possible Outcome(s)	Probability of Outcome(s)	Expected Outcome
First Choice (Before Observation)	Stock	50% probability	Good Stock	11, 13, 15 EUR	60%	6.60 EUR
				-5, -3, -1 EUR	40%	
		50% probability	Bad Stock	11, 13, 15 EUR	40%	3.40 EUR
				-5, -3, -1 EUR	60%	
	Bond	No	-	3.10 EUR	100%	3.10 EUR
Second Choice (After Observation)	Stock	Based on Subjective posterior	Good Stock	11, 13, 15 EUR	60%	6.60 EUR
				-5, -3, -1 EUR	40%	
		Based on Subjective posterior	Bad Stock	-5, -3, -1 EUR	60%	3.40 EUR
				11, 13, 15 EUR	40%	
	Bond	No	-	5.10 EUR	100%	5.10 EUR

Notes: This table provides an overview of subjescts' investment options during the experiment.

session the subject participated in. In Section 5.4 we provide robustness checks for the timing.

Subjects had to sign up for and participated in two experimental sessions, with one week in between irrespective of whether they were randomly assigned to the *Delay* or *Immediate* treatments, to avoid selection effects. Further, in order to reduce attrition, (i) we made all payments from the experiment in the second session (in week $t + 1$), to maximize the incentive for subjects to show up to the second lab session, (ii) for each subject the first and the second lab session took place at the same day of the week and at the same time (only one week later), and (iii) subjects were reminded via email about the second lab session. Out of 239 subjects that participated in the first session, 229 participated in the second session, which is 96%.

To relate subjects' memory bias to their beliefs, we elicit subjects' beliefs about the stock's chance of paying a positive outcome after they observed the investment outcomes. Initially, subjects do not know the quality of the stock. They start with a prior that the stock is either good or bad with equal probability. After observing the outcomes, subjects make informed inferences about the stock's probability of paying from the good distribution of outcomes. A fully rational (Bayesian) subject counts the number of positive outcomes (11, 13, or 15 EUR) in the course of the 12 periods. The value of the objective Bayesian posterior can be calculated as:

$$\mu_t^G(h_t) = \frac{1}{1 + \frac{1-\mu_0^G}{\mu_0^G} * (\frac{\theta}{1-\theta})^{t-2n_t^+}} \tag{7}$$

where μ_0^G is 50% and indicates the prior that the stock is good; θ is 60%, the probability that a good stock generates the positive outcome in each period; t is the total number of observations; h_t represents the history of outcomes for t observations; n_t^+ represents the number of positive outcomes. This posterior serves as benchmark for objectively correct beliefs in our experimental setting.

To further investigate the consequence of a memory bias for subsequent investment behavior, we ask subjects to make a second investment decision after observing the outcomes. They choose to invest in the stock they have observed or another bond for further 12 periods (Table 2). Risk-neutral subjects should invest in the stock if it has a higher expected outcome than the bond. Note that for the post observation round of investment decisions, the bond pays 5.10 EUR per period. If the stock is good, the expected outcome of the stock is higher (6.60 EUR per period) than the expected outcome of the bond. Yet, if the stock is bad, the expected outcome is lower (3.40 EUR per period). Given these expected outcomes in our experimental setup, a risk-neutral Bayesian subject should always invest in the stock if there were more than 6 positive outcomes, which leads to a Bayesian posterior about the stock being good of 69.2% or greater.[15] Risk-averse subjects should require a higher posterior belief about the stock being a good stock in order to choose the stock. Since we are particularly interested in subjects' decision to invest in the stock despite an objectively low Bayesian posterior probability (Section 4.3), our results should hold for a range of reasonable risk attitude parameters.[16]

In the *Delay* condition, we elicit subjects' beliefs and second investment choice one week after the observation phase and in the *Immediate* condition immediately after the observation phase. Further, to avoid spill-over effects, the order in which subjects perform these tasks, i.e., the memory elicitation, belief elicitation, and the second investment task, is random.

3.2 Incentives and Procedures

The experimental sessions were organized in two parts. Subjects first made their decision to invest in the stock or bond, and observed the stock's outcomes, and afterwards participated in a memory elicitation, belief elicitation, and a second investment task.

Subjects were paid a show-up fee of 8 EUR for participating in the study.[17] Further, we randomly drew three participants from each session (with maximum 30 participants per session) who were paid based on their performance in one of the tasks. For each drawn subject, the computer

[15] In general, a risk-neutral subject should invest in the stock if the observed outcomes lead to a posterior belief of the stock being good above 53.1% and otherwise invest in the bond.

[16] Typically, people are risk-averse even at low payoff levels (Holt and Laury, 2002, 2005). However, note that the small stakes in the laboratory setting might lead subjects to behave in a risk-neutral manner (Rabin, 2000).

[17] In the first two sessions, subjects were paid 5 EUR for participating in the study. We increased this amount to 8 EUR after the first two sessions because the average duration of the experimental sessions was longer than expected.

randomly decided which task determined his or her payment.[18] In the first investment choice, subjects could earn an initial endowment of 60 EUR plus either 37.20 EUR from investing in the bond or accumulated outcomes over 12 periods from investing in the stock. In the belief elicitation task, subjects were paid according to the accuracy of their probability estimates. We paid them 120 EUR for a probability estimate within 5 percent of the objective Bayesian value. In the memory elicitation task, subjects could earn 12 EUR for each correct answer provided, which could add up to 120 EUR if they answered all memory questions correctly. In the second investment choice, subjects could earn an initial endowment of 60 EUR plus either 61.20 EUR from investing in the bond or accumulated outcomes over 12 periods from investing in the stock.

The experiment was followed by a questionnaire with background and control questions. We elicited subjects' general risk preferences (Dohmen, Falk, Huffman, Sunde, Schupp, and Wagner, 2011), financial literacy, stock market participation, as well as subjects' understanding of the risk-return relationship of investments. Further, subjects were asked to indicate their age, gender, and highest level of education. In addition, subjects were asked to solve three Raven matrices and we elicited their mood (Watson, Clark, and Tellegen, 1988).

A total of 229 subjects participated in the laboratory experiment, mostly business and economics students from one of the authors' universities.[19] On average, subjects earned 16.90 EUR. For each subject, both sessions took about 45 minutes each. The experiment is programmed and conducted with z-Tree (Fischbacher, 2007) and the experimental sessions were organized and administrated with the software hroot (Bock, Baetge, and Nicklisch, 2014).

4 Results

The results from our experiment document that subjects exhibit a self-serving memory bias for investment outcomes, which distorts their beliefs and drives subsequent investment decisions. The findings are consistent with our model in which image-concerns form the basis for how information is remembered.

[18] It has been shown that paying a subset of participants is an effective payment scheme for economic experiments (Charness, Gneezy, and Halladay, 2016) and that random incentive systems do not bias risk-taking behavior in experiments (Starmer and Sugden, 1991; Cubitt, Starmer, and Sugden, 1998; Hey and Lee, 2005).

[19] The experiment and its procedure were ethically approved by the University Experimental Laboratory Committee. We obtained subjects' consent orally before participating in the experiment.

4.1 Memory Bias

We find that (i) subjects' memory of investment outcomes is systematically inaccurate; (ii) subjects' memory bias differs for positive and negative outcomes; and (iii) subjects' memory bias depends on whether they invested or not. Together, these results provide evidence for a self-serving memory bias for own investment gains and losses.

Result 1. After investing, subjects recall significantly more positive and less negative outcomes than actually occurred. Subjects who did not invest recall the correct number of occurred positive and negative outcomes.

Based on our direct memory elicitation, memory bias is estimated at the individual level by taking the difference between each subject's recalled number of positive and negative outcomes in the memory elicitation task and the actual observed number of outcomes. If subjects had perfect memory, their memory bias would be zero. A memory bias above zero means that subjects recollect a higher number of outcomes than actually observed and a memory bias below zero means that subjects remember a lower number of outcomes than observed. Importantly, to isolate memory effects from other factors related to subjects' information acquisition or processing, we compare subjects' recollection in our two treatment conditions, *Immediate* and *Delay*.

Table 3 provides an overview of subjects' memory bias and reports results from T-tests against the null hypothesis that the memory bias is zero (column 2, column 4, column 6, and column 8). We first focus on the *Delay* condition, in which people had time to form inaccurate memory in the week between observing the stock's outcomes and recollecting them. Column 1 illustrates that subjects have inaccurate memory of the stock's outcomes in the *Delay* condition, as implied by a self-serving memory bias: If they invested in the stock, they remember significantly more positive outcomes (T-test, $p < 0.001$) and significantly less negative outcomes (T-test, $p < 0.001$) than actually observed. On average, subjects over-remember the number of gains by 0.9 and under-remember the number of losses by 0.7. This corresponds to a deviation from the average number of observed outcomes of +15.3% and -11.4%, respectively. Moreover, the first columns (columns 1-4) illustrate that while subjects who invested in the stock show a significant memory bias for investment outcomes, subjects who did not invest do not display a memory bias. This is in line with studies suggesting that the decision to do something is of higher importance for one's self-image compared to the decision not to do something (Cioffi and Garner, 1996; Allison and Messick, 1988; Fazio, Chen, McDonel, and

Table 3: Subjective Memory Bias

Observed outcomes	*Delay*				*Immediate*				Difference (if invested)
	Invested (N = 74)	T-test	Not invested (N = 18)	T-test	Invested (N = 78)	T-test	Not invested (N = 18)	T-test	T-test
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Positive outcomes	0.89	p = 0.001	-0.06	p = 0.918	0.27	p = 0.058	-0.11	p = 0.668	p = 0.018
Negative outcomes	-0.73	p = 0.000	-0.22	p = 0.664	-0.28	p = 0.037	-0.06	p = 0.875	p = 0.038

Notes: This table displays subjects' memory bias in the *Delay* and *Immediate* condition, seperately for subjects who invested in the stock and subjects who did not invest in the stock, i.e., invested in the bond. Memory bias is estimated at the individual level by subtracting the actual individually observed number of positive (negative) outcomes from subject's recalled number of the stock's positive (negative) outcomes. The table reports mean values and T-test results against the null hypothesis that the memory bias is zero (columns 1-8) and T-test results of the difference in means between our conditions *Delay* and *Immediate* for subjects who invested in the stock (column 9).

Sherman, 1982).

Further, our results suggest a memory effect on subjects' recollection beyond factors that might be related to subjects' information acquisition or processing capacities. The comparison of subjects' recollection between the *Immediate* and *Delay* condition isolates the effect of memory from these alternative explanations. We indeed find that the self-serving memory bias is significantly larger in the *Delay* treatment than in the *Immediate* treatment, both for positive and for negative outcomes (T-test, $p < 0.05$).

These results provide supportive evidence for the essential notion of our model, a self-serving memory bias for investment outcomes. Our findings are robust to different estimations of memory bias. Please refer to Section 5.1 for robustness of these findings to using estimations based on the relative fraction of the recalled number of positive and negative outcomes as well as the difference between the number of recalled positive and negative outcomes.

4.2 Memory-Based Beliefs

In this section, we show that the memory bias is associated with overly optimistic subjective beliefs. First, our results document that subjects' elicited memory bias is significantly correlated with too optimistic beliefs about the stock. Second, in accordance with our model, we test for subjects' memory bias based on how they weight observed outcomes when forming beliefs about the stock. In line with the model propositions, we find that subjects who invested in the stock relatively underweight negative compared to positive outcomes, resulting in overly optimistic beliefs. This supports our finding of a memory bias without relying on a specific memory elicitation method. Moreover, we show that the belief distortion of subjects who invested in the stock is larger if more negative outcomes occurred, which is consistent with the self-serving mechanism we propose.

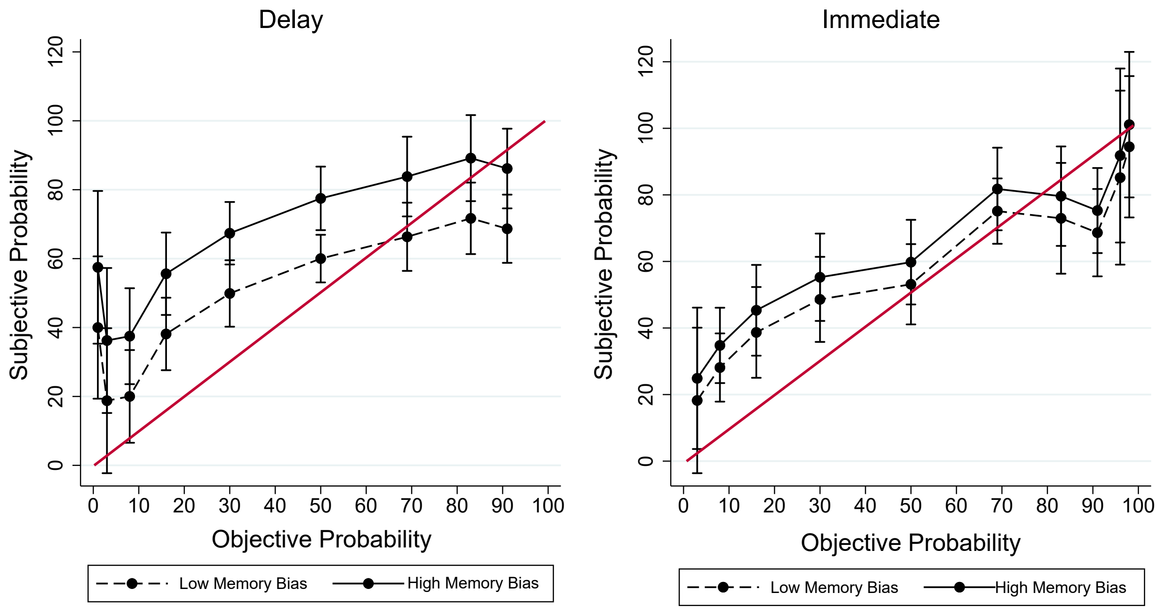
Result 2. Subjects with a larger memory bias form significantly more optimistic beliefs about their investment.

First, Figure 1 gives a graphical presentation of subjects' beliefs in our experiment if they chose to invest. The figure displays subjects' beliefs relative to the objective Bayesian probabilities. The x-axis indicates the value of each possible objective Bayesian posterior belief, i.e., the objective probability that the stock is good, and the y-axis represents the average belief indicated by the subject, i.e., the subjective probability that the stock is good. If subjects indicated the objectively correct probability, their subjective posteriors would line up along the 45° reference line. The figure suggests that subjective beliefs deviate from the objective posteriors in a systematic way and are associated with subjects' memory. In the *Delay* condition (left panel) subjective beliefs are overly optimistic regarding the likelihood that the stock is good. Moreover, the belief of subjects with an above average memory bias (solid line) is further away from Bayesian objective posteriors relative to the belief of subjects with a below average memory bias (dashed line).

In accordance with this graphical display, we find that subjects' elicited memory bias predicts subjective beliefs. We focus our analysis on subjects in the *Delay* treatment. The regression models in Table 4 indicate that subjects' memory bias for positive and negative outcomes is significantly correlated with their beliefs. We use subjects' belief that the stock is the good stock (columns 1 and 2) and their belief distortion compared to the Bayesian posterior (columns 3 and 4) as dependent variables. Subjects' belief distortion is the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities. The elicited memory bias for positive and negative outcomes serve as independent variables. In our first two models, we control for the correct Bayesian probability that the stock is good, given the information seen by the subject. In all models we control for session fixed effects. Column 1 shows that subjects' beliefs are on average 4.89% higher for each positive outcome they over-remember ($p < 0.001$). That is, subjects who recollect a higher number of positive outcomes than observed form more optimistic beliefs about the stock. We find the opposite direction for negative investment outcomes (column 2). Subjects' beliefs are on average 6.94% lower for every loss they over-remember ($p < 0.001$). This also means that subjects who remember a lower number of losses than observed

Figure 1: Subjective Beliefs

This figure displays the average subjective posterior that the stock is the good stock, as a function of the correct objective Bayesian probability. The sample is limited to subjects who invested in the stock (first choice). If subjective estimates were Bayesian, they would line up on the 45° line. The left panel presents subjective beliefs from the *Delay* condition and the right panel presents subjective beliefs from the *Immediate* condition. Subjects' probability estimates for each level of the objectively correct Bayesian posterior are shown on solid lines for subjects with a high memory bias, and on dashed lines for subjects with a low memory bias. *High Memory Bias* is a dummy variable equal to 1 if the subject has a memory bias that is larger than the mean memory bias in its treatment condition. *Low Memory Bias* is a dummy variable equal to 1 if the subject has a memory bias that is smaller than the mean memory bias in its treatment condition.



form also more optimistic beliefs about the stock.[20] Similarly, results in column 3 and 4 document that subjects' elicited memory bias is significantly correlated with their actual deviation from the objective Bayesian probability. Subjects who remember a higher number of positive outcomes (or a lower number of negative outcomes) than observed, form overly optimistic beliefs compared to the Bayesian benchmark.

Second, we show that subjects' weighting of observed outcomes when forming beliefs is consistent with our model and supports our finding of a self-serving memory bias without relying on a specific memory elicitation method. To begin with, we find that subjects' belief distortion is positively correlated with the number of observed signals that might be inconsistent with their self-image, as indicated in Proposition 2. Figure 2 displays this finding for subjects who invested in the stock. The bars represent the mean value of subjects' belief distortion for different numbers of observed negative

[20]Note that the magnitude of the regression coefficients for the objective probability as well as the constant are similar to previous results reported by Kuhnen (2015).

Table 4: Memory-Based Beliefs

This table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variable is the subjective posterior belief that the stock is the good stock (from 1 to 100), *Subjective Probability*, or subjects' belief distortion measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities, *Belief Distortion*. The sample is limited to subjects in the *Delay* treatment. *Memory Bias (for Pos. Outcomes)* represents subject's memory bias for observed positive outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of positive stock outcomes from subject's recalled number of the stock's positive outcomes. *Memory Bias (for Neg. Outcomes)* represents subject's memory bias for observed negative outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of negative stock outcomes from subject's recalled number of the stock's negative outcomes. *Objective Probability* is the value of the objective Bayesian probability that the stock is the good stock (from 1 to 100). *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

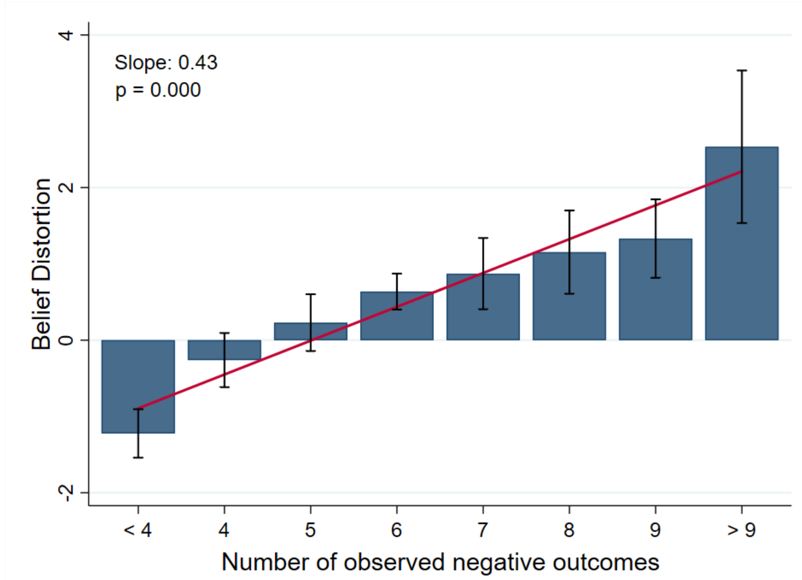
	(1) Subjective Probability	(2) Subjective Probability	(3) Belief Distortion	(4) Belief Distortion
Memory Bias (for Pos. Outcomes)	4.891***		0.343***	
	(4.47)		(5.32)	
Memory Bias (for Neg. Outcomes)		-6.939***		-0.466***
		(-5.21)		(-5.88)
Objective Probability	0.612***	0.637***		
	(7.91)	(8.45)		
Constant	12.090	11.341	-0.847**	-0.786**
	(1.55)	(1.51)	(-2.27)	(-2.16)
Session	Yes	Yes	Yes	Yes
N	92	92	91	91
R^2	0.48	0.51	0.38	0.42

outcomes (n^-). The red line indicates the prediction for a linear regression. The figure illustrates a significant positive trend ($p < 0.001$), in line with our Proposition 2. The magnitude of the belief distortion of subjects who invested in the stock is positive as soon as subjects observed more than four negative outcomes. Further, the belief distortion increases significantly with a growing number of observed negative outcomes.

Moreover, we are interested in subjects' memory bias parameters from our model, q^- and q^+. In the model, q^- is the probability of under-remembering a negative outcome of invested in the stock and q^+ is the probability of under-remembering a positive outcome if not invested. If q^- or q^+ equals zero, the probability of under-remembering an outcome is zero and if it equals one, the probability of under-remembering an outcome is 100%. Regressions in Table 5 estimate q^- and q^+. The table reports results from regressions with subject's belief distortion as dependent variable. As independent variable, we use a combination of the informativeness of evidence (the log likelihood ratio $\ln \frac{\theta}{1-\theta}$) and the strength of evidence (n^- or n^+) in our experimental situation, according to Equations (5) and (6) and control for session fixed effects. Thus, the regression coefficients represent our estimations for q^- and q^+ from our model based on subjects' relative underweighting

Figure 2: Belief Distortion and Observed Outcomes

This figure displays mean values of subjects' belief distortion measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities (*Belief Distortion*). The sample is limited to subjects who invested in the stock (first choice). The bars represent the mean values for different numbers of individually observed negative outcomes by subjects (n^-). Error bars indicate 95% confidence intervals. The red line represents the prediction for a linear regression of *Belief Distortion* on a Dummy variable for different numbers of n^-.



of negative and positive outcomes n^- and n^+ when forming beliefs about the stock. The regressions are reported separately for subjects who invested and for those who did not invest as well as across our two treatments *Delay* and *Immediate*. Our results show that subjects who invested in the stock (columns 1 and 3) are likely to underweight negative relative to positive outcomes when forming beliefs ($p > 0.001$), while subjects who did not invest in the stock (columns 2 and 4), do not display a significant probability to underweight outcomes in a systematic way. This is consistent with the proposed behavioral mechanism in our model as well as our previous results based on subjects' directly elicited memory bias (Table 3). Here, q^- can be interpreted as the magnitude of subjects' memory bias when updating beliefs. We find that subjects who invested in the stock show a higher belief distortion when their memory bias (q^-) is higher. After observing a negative outcome in the *Delay* condition, subjects who invested in the stock forget this outcome with a probability of 59.9% ($p < 0.001$). Moreover, this probability is larger for subjects in the *Delay* condition than for subjects in the *Immediate* condition (47.3%, $p < 0.001$). Thus, we find that subjects' belief distortion stems from relatively underweighting negative outcomes when forming beliefs about the stock. This finding is consistent with our proposed self-serving memory bias and does not rely on a specific memory elicitation method. This finding and the observation that subjects' elicited memory bias is significantly correlated with their belief distortion (Table 4) is supportive of our Proposition 3.

Table 5: Estimated Memory Bias Based on Relative Weighting of Observed Outcomes

This table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variable is subjects' belief distortion, *Belief Distortion* (*Belief Dist.*), measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities. As independent variables, we use the combination of the informativeness of evidence (the log likelihood ratio $\ln \frac{\theta}{1-\theta}$) and the strength of evidence (n^- or n^+) in our experimental situation, according to Equations (5) and (6). *Session* is a dummy variable representing the different sessions of the experiment. Regression coefficients represent parameters q^- and q^+. We present the regression models for our treatments *Delay* (*Del.*) and *Immediate* (*Imm.*) as well as for subjects who invested and who did not invest separately. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Belief Dist. (*Del.*, inv.)	(2) Belief Dist. (*Del.*, not inv.)	(3) Belief Dist. (*Imm.*, inv.)	(4) Belief Dist. (*Imm.*, not inv.)
$ln(\frac{\theta}{1-\theta})2{n_t}^-$	0.599***		0.473***	
	(8.10)		(6.64)	
$-ln(\frac{\theta}{1-\theta})2{n_t}^+$		0.341		0.147
		(1.26)		(0.41)
Constant	-3.189***	0.686	-1.880***	1.830
	(-5.93)	(0.38)	(-3.73)	(0.91)
Session	Yes	Yes	Yes	Yes
N	73	18	73	19
R^2	0.55	0.58	0.46	0.40

4.3 Consequences for Investment Decisions

The evidence so far shows that subjects relatively under-remember negative outcomes compared to positive outcomes if they invested in the stock. This self-serving memory bias is associated with overly optimistic beliefs about the investment. In this section, we show that subjects' memory is related to future investment choices. We find that subjects in the *Delay* condition invest significantly more in the observed stock compared to subjects in the *Immediate* condition, even in cases when this is objectively a mistake. This investment mistake is strongly related to subjects' elicited memory bias.

Result 3. Subjects with a larger memory bias are significantly more likely to re-invest suboptimally.

Table 6 shows the proportion of subjects who chose to invest in the stock after observing the investment outcomes and T-tests for differences in means across our treatments. In the *Immediate* condition, subjects were asked to decide immediately after the observation and in the *Delay* condition

Table 6: Memory-Based Investment Decisions

	First choice		Second choice			
	Investment in stock	N	Investment in stock	N	Investment in stock (suboptimal)	N
	(1)		(2)		(3)	
Immediate	80.41	97	40.21	97	29.82	75
Delay	80.43	92	56.52	92	54.39	69
Difference (T-test)	p = 0.997		p = 0.025		p = 0.008	

Notes: This table displays subjects' investment decisions before (first choice) and after (second choice) observing the stock's outcomes in the *Delay* and *Immediate* condition. *Investment in stock* is a dummy variable equal to one if the subjects chose to invest in the stock. The table reports mean values and T-tests for differences in group means between our conditions *Delay* and *Immediate*. *Investment in stock (suboptimal)* is a dummy variable equal to one if the subject invested in the stock with a lower expected outcome than the bond after the observation phase (second choice).

with a one week delay. Comparing the results in columns 1 and 2 illustrates that subjects decide differently in the two conditions, although they show the same preferences for investing in the risky stock before the treatment (first choice in the experiment). An important question is whether this effect is associated with the quality of subjects' choices. Therefore, column 3 reports results for subjects who made a suboptimal choice from a Bayesian perspective, assuming risk neutrality. Given the individual outcomes subjects observed, they invested in the stock, although the stock's expected outcome was lower than the bond's outcome. The results show that more than half of the subjects in the *Delay* condition (54.39%) invest in the stock despite its lower expected outcome, while in the *Immediate* condition only 29.82% of the subjects invest in such a manner. The difference between the two treatments is significant at the 1% level. Thus, subjects seem to be more likely to avoid suboptimal decisions when immediately deciding whether to invest or not (*Immediate* condition), whereas subjects who have to rely on their memory from last week (*Delay* condition) are likely to invest, although the decision is suboptimal. Note that we assume risk-neutral subjects. If instead some subjects were risk averse, the fraction of subjects investing suboptimally would be even larger. Hence, our estimates are rather conservative.

Furthermore, regression analyses in Table 7 show that subjects' suboptimal investment decisions are correlated with their elicited individual memory bias. The table reports results from Probit regressions with a dummy variable equal to one for subjects who chose to invest in the stock with a lower expected outcome than the bond after observing the outcomes as dependent variable (second choice). We use subjects' memory bias for positive and negative outcomes as independent variables

Table 7: Subjective Memory Bias and Suboptimal Investment Decisions

This table contains the coefficients and t-statistics (in parentheses) of Probit regressions in which the dependent variable is a dummy variable which is equal to one if the subject invested in the stock with a lower expected outcome than the bond after the observation phase (second choice). *Memory Bias (for Pos. Outcomes)* represents subject's memory bias for observed positive outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of positive stock outcomes from subject's recalled number of the stock's positive outcomes. *Memory Bias (for Neg. Outcomes)* represents subject's memory bias for observed negative outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of negative stock outcomes from subject's recalled number of the stock's negative outcomes. *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Investment in Stock (Suboptimal)	(2) Investment in Stock (Suboptimal)
Memory Bias (for Pos. Outcomes)	0.258***	
	(3.78)	
Memory Bias (for Neg. Outcomes)		-0.233***
		(-3.19)
Constant	-1.701***	-1.732***
	(-3.44)	(-3.50)
Session	Yes	Yes
N	188	188
Pseudo R^2	0.12	0.10

and control for session fixed effects. Column 1 indicates that subjects' probability to invest in the stock with a lower expected outcome than the bond increases by 25.8% with each positive outcome they over-remember ($p < 0.001$). In other words, subjects who recollect a higher number of positive outcomes than actually observed have a significantly higher probability to invest in the stock with a lower expected outcome. We find the opposite direction for negative investment outcomes (column 2). Subjects' probability to invest in the stock with the lower expected outcome is on average 23.3% lower for every loss they over-remember ($p < 0.01$). Note that the average subject remembers a lower number of negative outcomes than actually occurred (Table 3). In this regard, our results indicate that subjects who remember a lower number of losses than actually observed have a higher probability to invest in the stock with a lower expected outcome. Together, these findings document that subjects' memory bias is related to suboptimal investment choices.

5 Robustness of Results

Our results are robust to different measures of memory bias as well as to differences in subjects' risk preferences and financial literacy. Remarkably, better financial knowledge does not alleviate the memory bias. Further, neither different timing of the experimental tasks in the *Immediate* condition nor the mere fact that we asked subjects to recall outcomes changed their beliefs or subsequent investment decisions.

5.1 Different Measures of Memory Bias

This section presents the robustness of our main findings in Table 3 of Section 4.1 to different measures of subjects' memory bias. Table 8 uses a memory bias measure based on the fraction of recalled positive or negative outcomes among all observed outcomes and Table 9 shows results for a memory bias of the absolute difference between recalled positive and negative outcomes. Our results are qualitatively unchanged.

Table 8: Subjective Memory Bias based on the Recalled Fraction

	Delay				*Immediate*				Difference (if invested)
	Invested (N = 74)	T-test	Not invested (N = 18)	T-test	Invested (N = 78)	T-test	Not invested (N = 18)	T-test	T-test
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Positive outcomes	0.07	p = 0.000	0.01	p = 0.846	0.02	p = 0.042	-0.00	p = 0.953	p = 0.015
Negative outcomes	-0.07	p = 0.000	-0.01	p = 0.846	-0.02	p = 0.042	0.00	p = 0.953	p = 0.015

Notes: This table displays subjects' memory bias in the *Delay* and *Immediate* condition, seperately for subjects who invested in the stock and subjects who did not invest in the stock, i.e., invested in the bond. Memory bias is estimated at the individual level by subtracting the actual individually observed fraction of positive (negative) outcomes relative to the 12 observed outcomes from subject's recalled fraction of the stock's positive (negative) outcomes relative to the 12 observed outcomes. The table reports mean values and T-tests against the null hypothesis that the memory bias is zero (columns 1-8) and of differences in group means between our conditions *Delay* and *Immediate* (column 9).

Table 8 displays the results for the memory bias measured based on the fraction of remembered positive and negative outcomes. It reports a self-serving memory bias of positive and negative outcomes for subjects who invested in the stock. They significantly over-remember the fraction of gains and under-remember the fraction of losses (column 1, column 2, column 5, and column 6). Similar to our main results, there is no significant memory bias for subjects who did not invest in the stock (column 3, column 4, column 7, and column 8). In line with our previous results, Table 8 indicates a significant difference in subjects' memory bias, if they invested, between our *Delay* and *Immediate* condition, suggesting a memory effect.

Table 9 documents results for the memory bias based on the absolute difference between recalled positive and negative outcomes. The table reports similar results as we have shown previously. If subjects invested in the stock, they significantly over-remember positive outcomes and under-remember negative outcomes (columns 1, column 2, column 5, and column 6). Subjects incorrectly

Table 9: Subjective Memory Bias based on the Recalled Absolute Difference

	Delay				*Immediate*				Difference (if invested)
	Invested (N = 74)	T-test	Not invested (N = 18)	T-test	Invested (N = 78)	T-test	Not invested (N = 18)	T-test	T-test
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Difference between positive and negative outcomes	1.62	p = 0.000	0.16	p = 0.871	0.55	p = 0.045	-0.06	p = 0.927	p = 0.013

Notes: This table displays subjects' memory bias in the *Delay* and *Immediate* condition, seperately for subjects who invested in the stock and subjects who did not invest in the stock, i.e., invested in the bond. Memory bias is estimated at the individual level by subtracting the actual difference between observed positive and negative outcomes from subject's recalled difference between the stock's positive and negative outcomes. The table reports mean values and T-tests for differences in group means between our conditions *Delay* and *Immediate* (column 9).

remember 1.62 more positive than negative outcomes compared to the actually observed outcomes ($p < 0.001$) in the *Delay* treatment (column 1 and column 2). However, if they did not invest, they do not show a memory bias (column 3 and column 4). In line with our previous results, the table indicates a significant difference in subjects' memory bias, if they invested, between our *Delay* and *Immediate* condition, suggesting a memory effect (column 9).

5.2 Subjects' Risk Preferences

Next, we report the robustness of our findings to differences in subjects' risk preferences. First, as displayed in Table 6, the proportion of subjects who chose to invest in the stock *before* observing the investment outcomes (first choice) is the same across our treatments. In both conditions, the *Delay* and the *Immediate* condition, 80.4% of subjects invested in the stock. This suggests that before treatment, the random assignment of subjects was effective in that individual characteristics were balanced and could not drive differences in investment decisions, nor in the memory bias.

Second, in order to control for a potential effect of risk preferences, we directly elicited subjects' risk preferences in our experiment. We measure self-stated general risk preferences on a validated scale (Dohmen, Falk, Huffman, Sunde, Schupp, and Wagner, 2011). Table 10 reports that subjects' memory bias is not correlated with their risk preferences. The table shows results from linear regressions with subjects' memory bias for positive (column 1) and negative outcomes (column 2) as dependent variable. We use subjects' risk preferences as independent variable and control for session fixed effects. The results indicate that neither the memory bias for positive outcomes (column 1) nor the memory bias for negative outcomes (column 2) is significantly correlated with subjects' risk preferences.

Table 10: Subjective Memory Bias and Individual Risk Preferences

This table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variables are subject's memory bias for observed positive and negative outcomes. Both variables, *Memory Bias (for Pos. Outcomes)* and *Memory Bias (for Neg. Outcomes)*, are estimated at the individual level by subtracting the actual individually observed number of positive (negative) stock outcomes from subject's recalled number of the stock's positive (negative) outcomes. *Risk Tolerance* represents subjects' self-stated general risk preferences on a 10-point scale from 0 (lowest) to 10 (highest) (Dohmen, Falk, Huffman, Sunde, Schupp, and Wagner, 2011). *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Memory Bias (for Pos. Outcomes)	(2) Memory Bias (for Neg. Outcomes)
Risk Tolerance	-0.003	0.030
	(-0.06)	(0.68)
Constant	-0.136	-0.082
	(-0.31)	(-0.22)
Session	Yes	Yes
N	187	187
R^2	0.06	0.03

Additionally, we report our main findings of Section 4.2 and 4.3 controlling for subjects' risk preferences (Table 11). The table reports results from linear regressions with subjects' belief distortion relative to the Bayesian posterior as dependent variable (columns 1 and 2) as well as Probit regressions with a dummy variable equal to one for suboptimal investment in the observed stock as dependent variable (columns 3 and 4). We use subjects' memory bias for positive and negative outcomes as independent variables and control for subjects' risk preferences as well as session fixed effects.

In line with our previous results, the memory bias for positive outcomes is positively correlated and the memory bias for negative outcomes is negatively correlated with subjects' belief distortion ($p < 0.001$). Thus, our main finding is robust to controlling for risk preferences. Subjects who remember a higher number of positive outcomes (or a lower number of negative outcomes) than observed, form overly optimistic beliefs compared to the Bayesian benchmark. Moreover, subjects' memory bias is correlated with their probability to invest suboptimally, i.e. to invest in the stock with a lower expected outcome ($p < 0.005$). Hence, our finding that subjects who recollect a higher number of positive outcomes (and a lower number of negative outcomes) than actually observed have a significantly higher probability to invest suboptimally, holds when controlling for subjects' risk preferences. Again, controlling for risk preferences did not affect this result. Further, subjects' risk preferences are not associated with their belief distortion (columns 1 and 2) or with suboptimal investment decisions (columns 3 and 4).

Table 11: Robustness of Main Results to Individual Risk Preferences

In columns 1 and 2 this table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variable is subjects' belief distortion measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities, *Belief Distortion*. In columns 3 and 4 this tables contains the coefficients and t-statistics (in parentheses) of Probit regressions in which the dependent variable is a dummy variable which is equal to one if the subject invested in the stock with a lower expected outcome than the bond after the observation phase (second choice), *Investment (Subopt.)*. *Memory Bias (for Pos. Outcomes)* represents subject's memory bias for observed positive outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of positive stock outcomes from subject's recalled number of the stock's positive outcomes. *Memory Bias (for Neg. Outcomes)* represents subject's memory bias for observed negative outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of negative stock outcomes from subject's recalled number of the stock's negative outcomes. *Risk Tolerance* represents subjects' self-stated general risk preferences on a 10-point scale from 0 (lowest) to 10 (highest) (Dohmen, Falk, Huffman, Sunde, Schupp, and Wagner, 2011). *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Belief Distortion	(2) Belief Distortion	(3) Investment (Subopt.)	(4) Investment (Subopt.)
Memory Bias (for Pos. Outcomes)	0.424***		0.269***	
	(7.78)		(3.84)	
Memory Bias (for Neg. Outcomes)		-0.524***		-0.244***
		(-8.62)		(-3.29)
Risk Tolerance	-0.020	-0.004	0.052	0.052
	(-0.52)	(-0.10)	(1.16)	(1.18)
Constant	-0.100	-0.206	-1.970***	-2.010***
	(-0.32)	(-0.68)	(-3.53)	(-3.58)
Session	Yes	Yes	Yes	Yes
N	181	181	187	187
R^2	0.31	0.35		
Pseudo R^2			0.13	0.10

5.3 Subjects' Financial Literacy

Here, we present the robustness of our findings to differences in subjects' financial literacy. To measure subjects' financial literacy, we asked them to calculate the expected value of an investment allocated between a stock and a savings account at the end of the session (Kuhnen, 2015). First, Table 12 reports the robustness of our findings in Table 3 of Section 4.1, by separately testing the significance of memory bias for subjects with different levels of financial literacy. Columns 1 to 4 display results for subjects who indicated the correct answer to the financial literacy question and columns 5 to 8 display the results for subjects who indicated an incorrect answer. The sample is limited to subjects who invested in the stock before the observation of outcomes (first choice). We find that subjects show a self-serving memory bias, irrespective of their financial literacy. They remember significantly more positive and significantly less negative outcomes than actually observed in the *Delay* treatment. Thus, higher financial knowledge does not alleviate the memory bias.

Further, Table 13 reports that subjects' memory bias is not correlated with their financial knowl-

Table 12: Subjective Memory Bias and Individual Financial Literacy

	Financial Literacy Question Correct				*Financial Literacy Question Incorrect*			
	Delay (N = 23)	T-test	Immediate (N = 15)	T-test	Delay (N = 51)	T-test	Immediate (N = 62)	T-test
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Positive outcomes	1.04	p = 0.013	0.60	p = 0.108	0.82	p = 0.004	0.17	p = 0.252
Negative outcomes	-0.78	p = 0.005	-0.6	p = 0.108	-0.71	p = 0.002	-0.19	p = 0.182

Notes: This table displays subjects' memory bias in the *Delay* and *Immediate* condition, separated by subjects' financial literacy measured in the post-questionnaire Kuhnen (2015). Memory bias is estimated at the individual level by subtracting the actual individually observed number of positive (negative) outcomes from subject's recalled number of the stock's positive (negative) outcomes. The table reports mean values and T-tests against the null hypothesis that the memory bias is zero.

edge. The table shows results from linear regressions with subjects' memory bias for positive (column 1) and negative outcomes (column 2) as dependent variable. We use subjects' measure of financial literacy as independent variable and control for session fixed effects. The results indicate that neither the memory bias for positive outcomes (column 1) nor the memory bias for negative outcomes (column 2) is significantly correlated with subjects' financial knowledge.

Table 13: Subjective Memory Bias and Individual Financial Literacy

This table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variables are subject's memory bias for observed positive and negative outcomes. Both variables, *Memory Bias (for Pos. Outcomes)* and *Memory Bias (for Neg. Outcomes)*, are estimated at the individual level by subtracting the actual individually observed number of positive (negative) stock outcomes from subject's recalled number of the stock's positive (negative) outcomes. *Financial Literacy* is a dummy variable equal to one for subjects who indicated the correct answer to a financial literacy question used in Kuhnen (2015). *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Memory Bias (for Pos. Outcomes)	(2) Memory Bias (for Neg. Outcomes)
Financial Literacy	0.248	-0.217
	(0.86)	(-0.86)
Constant	-0.237	0.126
	(-0.62)	(0.38)
Session	Yes	Yes
N	187	187
R^2	0.06	0.03

Table 14 shows the robustness of our main findings of Section 4.2 and 4.3 to differences in subjects' financial literacy. The table reports results from linear regressions with subjects' belief distortion compared to the Bayesian posterior as dependent variable (columns 1 and 2) as well as

Table 14: Robustness of Main Results to Individual Financial Literacy

In columns 1 and 2 this table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variable is subjects' belief distortion measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities, *Belief Distortion.* In columns 3 and 4 this tables contains the coefficients and t-statistics (in parentheses) of Probit regressions in which the dependent variable is a dummy variable which is equal to one if the subject invested in the stock with a lower expected outcome than the bond after the observation phase (second choice), *Investment (Subopt.)*. *Memory Bias (for Pos. Outcomes)* represents subject's memory bias for observed positive outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of positive stock outcomes from subject's recalled number of the stock's positive outcomes. *Memory Bias (for Neg. Outcomes)* represents subject's memory bias for observed negative outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of negative stock outcomes from subject's recalled number of the stock's negative outcomes. *Financial Literacy* is a dummy variable equal to one for subjects who indicated the correct answer to a financial literacy question used in Kuhnen (2015). *Session* is a dummy variable representing the different sessions of the experiment. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Belief Distortion	(2) Belief Distortion	(3) Investment (Subopt.)	(4) Investment (Subopt.)
Memory Bias (for Pos. Outcomes)	0.427***		0.257***	
	(7.83)		(3.76)	
Memory Bias (for Neg. Outcomes)		-0.528***		-0.233***
		(-8.70)		(-3.17)
Financial Literacy	-0.156	-0.166	0.196	0.212
	(-0.74)	(-0.81)	(0.78)	(0.86)
Constant	-0.130	-0.164	-1.803***	-1.840***
	(-0.47)	(-0.61)	(-3.46)	(-3.53)
Session	Yes	Yes	Yes	Yes
N	181	181	187	187
R^2	0.31	0.35		
Pseudo R^2			0.13	0.10

Probit regressions with a dummy variable equal to one for suboptimal investment in the observed stock as dependent variable (columns 3 and 4). We use subjects' memory bias for positive and negative outcomes as independent variables and control for subjects' financial literacy as well as session fixed effects. Subjects' financial literacy is a dummy variable equal to one for subjects who indicated a correct answer to the financial literacy question.

The results are qualitatively unchanged. Subjects' memory bias for positive outcomes is positively correlated and subjects' memory bias for negative outcomes is negatively correlated with their belief distortion ($p < 0.001$). Hence, when controlling for subjects' financial literacy, our main finding that subjects who remember a higher number of positive outcomes (or a lower number of negative outcomes) than observed, form overly optimistic beliefs, remains. In addition, subjects' memory bias is correlated with their probability to invest in the stock with a lower expected outcome ($p < 0.005$). Thus, our finding that subjects who remember a higher number of positive outcomes (and a lower number of negative outcomes) than actually occurred, have a significantly higher probability to invest suboptimally, holds. In addition, financial literacy is correlated neither with subjects' belief distortion (columns 1 and 2) nor with suboptimal investment decisions (columns 3 and 4).

5.4 Timing of Experimental Tasks

Subjects in the *Immediate* condition perform all experimental tasks in the course of one session. This could happen either in week t or in week $t+1$. In half of the experimental sessions, subjects perform the tasks in week t and in the other half of the sessions in week $t+1$. Here, we show the robustness of our findings to differences in timing of the experimental tasks for our main findings of Section 4.2 and 4.3. Table 15 reports results from linear regressions with subjects' belief distortion compared to the Bayesian posterior as dependent variable (columns 1 and 2) as well as Probit regressions with a dummy variable equal to one for suboptimal investment in the observed stock as dependent variable (columns 3 and 4). We use subjects' memory bias for positive and negative outcomes as independent variables and control for timing as well as session fixed effects. Timing is a dummy variable equal to one for sessions in which subjects in the *Immediate* condition perform the tasks in week t and zero for sessions in which subjects in the *Immediate* condition perform the tasks in week $t+1$.

Our main results hold. Again, subjects' memory bias for positive outcomes is positively correlated and subjects' memory bias for negative outcomes is negatively correlated with their belief distortion ($p < 0.001$). Thus, when controlling for the timing of experimental tasks in the *Immediate* condition, our main finding that subjects who remember a higher number of positive outcomes (or a lower number of negative outcomes) than observed, form overly optimistic beliefs, remains. In addition, subjects' memory bias is correlated with their probability to invest in the stock with a lower expected outcome ($p < 0.005$). Our finding that subjects who remember a higher number of positive outcomes (and a lower number of negative outcomes) than actually occurred have a significantly higher probability to invest suboptimally, remains unchanged.

5.5 No Memory Elicitation

We included a *NoRecall* condition, in which subjects do not perform a memory elicitation task as a control condition. This control condition allows us to identify potential effects of simply asking subjects to recall investment outcomes. Table 16 indicates no significant difference in subjects' beliefs or investment decisions between the *Delay* and *NoRecall* condition (T-test, $p = 0.714$ and $p = 0.343$, respectively). This holds for the subsample of subjects who invested in the stock with a lower expected return ($p = 0.383$). Thus, simply asking subjects to recall investment outcomes seems to have no effect on their subjective beliefs or choices afterwards.

Table 15: Robustness of Main Results to Timing in Immediate Condition

This table contains the coefficients and t-statistics (in parentheses) of OLS regressions in which the dependent variable is the subjective posterior belief that the stock is the good stock (from 1 to 100), *Subjective Probability*, or subjects' belief distortion measured by the difference between the posterior log-likelihood ratios of subjects' elicited probabilities and the objective Bayesian probabilities, *Belief Distortion*. The sample is limited to subjects in the *Delay* treatment. *Memory Bias (for Pos. Outcomes)* represents subject's memory bias for observed positive outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of positive stock outcomes from subject's recalled number of the stock's positive outcomes. *Memory Bias (for Neg. Outcomes)* represents subject's memory bias for observed negative outcomes. This variable is estimated at the individual level by subtracting the actual individually observed number of negative stock outcomes from subject's recalled number of the stock's negative outcomes. *Objective Probability* is the value of the objective Bayesian probability that the stock is the good stock (from 1 to 100). *Session* is a dummy variable representing the different sessions of the experiment. *Timing* is a dummy variable equal to one for sessions in which subjects in the *Immediate* condition perform the tasks in week t and zero for sessions in which subjects in the *Immediate* condition perform the tasks in week $t+1$. *, **, and *** denote significance at the 10%, the 5%, and the 1% level, respectively.

	(1) Belief Distortion	(2) Belief Distortion	(3) Investment (Subopt.)	(4) Investment (Subopt.)
main				
Memory Bias (for Pos. Outcomes)	0.424***		0.258***	
	(7.83)		(3.78)	
Memory Bias (for Neg. Outcomes)		-0.525***		-0.233***
		(-8.70)		(-3.19)
Timing	-0.401	-0.544	-1.071*	-1.098**
	(-1.11)	(-1.57)	(-1.93)	(-1.98)
Constant	0.216	0.322	-0.630**	-0.634**
	(0.89)	(1.40)	(-2.44)	(-2.43)
Session	Yes	Yes	Yes	Yes
N	182	182	188	188
R^2	0.31	0.35		
Pseudo R^2			0.12	0.10

6 Conclusion

This paper investigates how memory shapes individuals' financial decisions. We find a self-serving memory bias for investment gains and losses. A key characteristic of the self-serving memory bias is the distinction between memory of events with different levels of self-relevance. Our results show that subjects relatively under-remember investment losses compared to gains, if they actively invested in the stock. By contrast, subjects who decided not to invest in the stock do not display this memory bias.

The self-serving memory bias is related to subjective beliefs and subsequent investment decisions. We find that subjects who invested in the stock relatively underweight negative compared to positive outcomes from memory, resulting in overly optimistic beliefs. This belief distortion increases with the number of observed negative outcomes. These findings are consistent with our model in which image-concerns form the basis for how information is remembered and robust to different measures of memory bias. We further show that those subjects do not adjust their behavior to account for

Table 16: Comparison of Subjective Beliefs and Choices between *Delay* and *NoRecall*

	Delay		*NoRecall*		Differences
	Mean	N	Mean	N	T-test
	(1)		(2)		(3)
Subjective Probability	58.011	92	59.725	40	p = 0.714
Investment in stock (second choice)	0.565	92	0.475	40	p = 0.343
Investment in stock (second choice, suboptimal)	0.544	92	0.435	40	p = 0.383

Notes: This table displays subjective beliefs as well as subjects' investment choice after the observation phase (second choice) in the *Delay* and *NoRecall* condition. Subjective beliefs are subject's indicated probability that the observed stock is the good stock (1 to 100). Investment in stock is a dummy variable which is equal to one if the subject invested in the stock after the observation phase (second choice); Investment in stock (suboptimal) is a dummy variable which is equal to one if the subject invested in the stock with a lower expected outcome than the bond after the observation phase (second choice). The table reports mean values and T-tests for differences in group means between our conditions *Delay* and *NoRecall* (column 3).

the fallibility of their memory when making investment choices, which leads to investment mistakes in our experiment. They are likely to re-invest in the stock even when doing so leads to a lower expected return. More than half of the subjects in our treatment condition (54%) – one week after the observation of investment outcomes – invest in the asset despite its lower expected outcome.

These results provide experimental evidence of a systematic memory bias in financial decision-making and thereby complement important theoretical work that has emphasized the role of selective recall in how people deal with ego-threatening information (Bénabou and Tirole, 2002, 2004) and has formalized consequences of memory limitations for economic choices (Mullainathan, 2002)).

The findings of this paper enhance the understanding of how people learn from experiences in financial markets. We explicitly designed an experiment in which subjects have to rely on their recollection of financial information and we directly elicit subjects' memory of this information at different points in time. This allows us to isolate biased memory as a microfoundation of subjective beliefs and choices, which can have important implications for financial decision-making. People are likely to rely on their memory, rather than on records of historical data or information when making decisions; in situations when information is costly; when people actively avoid information; or when people overestimate their memory accuracy. Our results suggest that in such cases relying on biased memory is likely to result in suboptimal decisions.

The memory bias documented in this paper opens several avenues for further research. First, we study self-serving memory bias, whereas Bordalo, Coffman, Gennaioli, Schwerter, and Shleifer (2019) find experimental evidence for selective memory based on representativeness. Future work can study the relative importance and potential interaction of different kinds of memory bias in economic decision making.

Second, we provide evidence for past experiences affecting memory and future behavior in a setting without extreme outcomes. Yet, market-wide shocks, such as a depression investigated in Malmendier and Nagel (2011), are often extreme. Psychologists have shown that people can exhibit enhanced memory for extreme emotional events (Phelps, LaBar, Anderson, O'Connor, Fulbright, and Spencer, 1998; Hamann, Ely, Grafton, and Kilts, 1999; Hamann, 2001). An interesting avenue for future research is to explore the memory bias with regard to extreme experiences.

Third, our experiment studied the effect of biased memory one week after the initial investment decision and observation of outcomes. Future work can explore the degree and dynamics of biased memory over longer time horizons.

Fourth, self-image concerns and the fundamental tendency to maintain and enhance self-esteem (Bénabou and Tirole, 2002) are used to explain how investment ideas spread in financial markets (Han, Hirshleifer, and Walden, 2018; Shiller, 2017). It has been suggested that investors have a self-enhancing bias in conversations, i.e. they talk more about good than about bad returns, which influences the popularity and thus pricing of particular investment strategies. Future work can explore the interplay between memory bias and social interaction in financial markets.

Fifth, we decided to conduct a laboratory experiment that provides tight identification of biased memory and an objectively correct benchmark for subjects' beliefs and choices. A promising avenue for future research is to explore the effects of memory bias in the field.

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Appendices

A Experimental Instructions

A.1 Introduction

Welcome to our financial decision making study

For the duration of the study, we ask you to follow a few rules. Should there be questions, please raise your hand and an experimenter will answer your question privately. We ask you not to communicate with each other or use a calculator during the study.

We also ask you to turn off your cell phones and other devices, or at least to put them on silent, and to pack them away with your bag or belongings. We do not want you or other participants to be disturbed or distracted. If you do not adhere to these rules, this will lead to an automatic exclusion from the study and from payment.

The study consists of 3 stages and will last approximately 1.5 hours. You will perform different tasks of the study at different points in time, which last about 45 min today and 45 min next week.

After the study, you will receive a payout for your participation. The actual amount will depend on your decisions in the experiment and luck.

Everyone will earn 8 EUR for participating in this study. In addition, the computer will randomly pick three out of the present participants who get paid his or her earnings from one of the study's tasks.

Please press 'proceed' to continue with the general instructions.

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A.2 General Instructions

In this study you complete investment tasks, related to two securities: a risky security (i.e., a stock with risky payoffs) and a riskless security (i.e., a bond with a known payoff), and will provide estimates as to how good an investment in the risky security is.

Please click 'proceed' to continue with the detailed instructions for the tasks. Take your time to read the instructions carefully. Note that you cannot go back to previous pages. Please let us know if you have any questions.

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A.3 Stage 1 of the Study

Investment task 1

First, you will decide to invest in one of two securities for 12 periods: a risky security (i.e., a stock with risky payoffs) and a riskless security (i.e., a bond with a known payoff).

Either way, you start with an endowment of 60 EUR. In addition to this endowment, you will get payoffs from investing.

If you choose to invest in the bond, you get a payoff of 3.10 EUR for sure in each period.

If you choose to invest in the stock, you will receive a dividend in every period, which can be either positive or negative. A positive dividend is either 11, 13, or 15 EUR with equal probability. A negative dividend is either -1, -3, or -5 EUR with equal probability.

The stock can either be good or bad, and this will determine the likelihood of its dividend being positive or negative. If the stock is good then the probability of receiving a positive dividend is 60% and the probability of receiving a negative dividend is 40%. If the stock is bad then the probability of receiving a positive dividend is 40% and the probability of receiving a negative dividend is 60%.

If you decide to invest in the stock, you will have the possibility to choose between two stocks, Stock BLUE and Stock YELLOW. One of the stocks is good and one is bad. You will not know which type of stock you chose. You may be facing the good stock, or the bad stock, with equal probability.

The dividends of the stock are independent from period to period, but come from the same distribution. In other words, once you decided for a stock (BLUE or YELLOW) and it is a good stock, then in each period the odds of the dividend being positive are 60%, and the odds of it being negative are 40%. If the chosen stock is a bad stock then the probability of receiving the positive dividend is 40% and the probability of receiving the negative dividend is 60% in each period.

If you decide to invest in a stock you accumulate the dividends paid by the stock over 12 periods and if you invest in the riskless security you accumulate the known payoff over 12 periods, i.e. you earn 37.20 EUR for sure.

At the end of the task, you will be told how much you have accumulated. Your task earnings will be your accumulated payoffs plus your initial endowment of 60 EUR.

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Stock evaluation task

You will then see the dividends of the stock, no matter if you chose to invest in the stock or the bond. You will see either the dividends paid by the stock you chose, or – if you decided to invest in the bond – by one of the stocks randomly picked by the computer.

After that, we will ask you to tell us two things:

(1) what you think is the probability that the stock is the good one (the answer must be a number between 0 and 100);

(2) how much you trust your ability to come up with the correct probability estimate that the stock is good. In other words, we want to know how confident you are that the probability you estimated is correct.

There is always an objective, correct, probability that the stock is good, which depends on the history of dividends paid by the stock already. For instance, at the beginning of the task, the probability that the stock is good is exactly 50%, and there is no doubt about this value.

As you observe the dividends of the stock, you will update your belief whether or not the stock is good. It may be that after a series of good dividends, you think the probability of the stock being good is 75%. However, how much you trust your ability to calculate this probability could vary. Sometimes you may not be too confident in the probability estimate you calculated and sometimes you may be highly confident in this estimate. For instance, at the very beginning of the task, the probability of the stock being good is 50% and you should be highly confident in this number because nothing else has happened since then.

If you provide us with a probability estimate that is within 5% of the correct value (e.g., correct probability is 80% and you say 84%, or 75%) you will earn 120 EUR in this task.

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Investment task 2

Further, you will again decide to invest in the stock you observed (Stock BLUE/Stock YELLOW) or in another bond for the next 12 periods.

Either way, you start with an endowment of 60 EUR. In addition to this endowment, you will get payoffs from investing.

If you choose to invest in the bond, you get a payoff of 5.10 EUR for sure in each period.

Again, if you choose to invest in the stock, you will receive a dividend in every period, which can be either positive or negative. A positive dividend is either 11, 13, or 15 EUR with equal probability. A negative dividend is either -1, -3, or -5 EUR with equal probability.

The dividends of the stock are independent from period to period, but **come from the same distribution as in Investment Task 1**. In other words, once you decided for a stock (BLUE or YELLOW) and it is a good stock, then in each period the odds of the dividend being positive are 60%, and the odds of it being negative are 40%. If the chosen stock is a bad stock then the probability of receiving the positive dividend is 40% and the probability of receiving the negative dividend is 60% in each period.

As in the Investment Task 1, if you decide to invest in the stock you accumulate the dividends of the stock over 12 periods and if you invest in the riskless security you accumulate the known payoff over 12 periods, i.e. you earn 61.20 EUR for sure.

At the end of the task, you will be told how much you have accumulated. Your task earnings will be your accumulated payoffs plus your initial endowment of 60 EUR.

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A.4 Stage 2 of the study

We will then ask you to complete three IQ test questions. The more questions you answer correctly, the more you earn in this task. For each correct answer you earn 40 EUR. For example, if you answer all three questions correctly, you earn 3 x 40 EUR i.e., 120 EUR. If you don't answer any question correctly, you will earn nothing.

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Your final payment at the end of the study
Your final payment will be:

You will get paid 8 EUR for participating in our study regardless of your task earnings.

In addition, your earnings in one of the experimental tasks can determine your payment. We will randomly draw three participants out of each session (with maximum 30 participants) who will get paid one of her or his task earnings. The computer will randomly decide which of the above-described tasks will determine the participants' payment. Remember, your task earnings depend on your decisions and answers:

Investment Task 1: Your initial endowment of 60 EUR and either 37.20 EUR from investing in the bond or accumulated dividends over 12 periods from investing the stock.

Stock Evaluation Task: Either 120 EUR if you provide us with a probability estimate that is within 5% of the correct value or nothing.

Investment Task 2: Your initial endowment of 60 EUR and either 61.20 EUR from investing in the bond or accumulated dividends over 12 periods from investing the stock.

IQ Test: Between 120 EUR and nothing; dependent on how many questions you answer correctly (40 EUR for each correct answer).

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A.5 Stage 3: Post-questionnaire

At the end of the experiment, we will ask you some personal questions. Note that all answers will be treated confidentially and will be analyzed anonymously.

B Memory Elicitation

The memory elicitation task was not announced beforehand. We randomized the order of the specific recall questions, i.e. whether we first asked to recall positive or negative outcomes.

B.1 Instructions

Before we proceed to the next part, we ask you to complete a Recall Task, related to information you observed [last week]. Similar to the other experimental tasks, your answers can determine your final payment. This Recall Task can as well be selected by the computer for additional payment, which three of you will receive.

We will ask you 10 questions. The more questions you answer correctly, the more you earn in this task. For each correct answer, you earn 12 EUR. For example, if you answer all ten questions correctly, you earn 10 x 12 EUR i.e., 120 EUR. If you don't answer any question correctly, you will earn nothing.

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B.2 Questions for positive and negative outcomes

First, your task consists of recalling the stock dividends from last week. You observed 12 dividends of the stock.

How many positive dividends (11, 13, or 15) did you observe? ☐

... and how many negative dividends (-1, -3, or -5) did you observe? ☐

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B.3 Questions for specific outcomes

How often did the stock pay a dividend of -1 EUR? ☐

How often did the stock pay a dividend of -3 EUR? ☐

How often did the stock pay a dividend of -5 EUR? ☐

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How often did the stock pay a dividend of 11 EUR? ☐

How often did the stock pay a dividend of 13 EUR? ☐

How often did the stock pay a dividend of 15 EUR? ☐