

# ASSOCIATIVE MEMORY AND BELIEF FORMATION<sup>\*</sup>

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## Abstract

Information is often embedded in memorable contexts, which may cue the asymmetric recall of similar past news through associative memory. Yet, direct evidence on the role of associations for belief formation and resulting choices is scarce. We design a simple theory-driven experiment, in which participants observe sequences of signals about hypothetical companies. Here, identical signal realizations are communicated with identical contexts: stories and images. Because participants predominantly remember those past signals that get cued by the current context, expectations and willingness-to-pay strongly overreact to recent news. Investigating comparative statics and limits of the role of associative memory, we find support for the model's predictions about how overreaction depends on the signal history; the correlation between signals and contexts; and the experimentally-induced scope for forgetting and associative memory. In model estimations, we quantify a large role of associative recall, and identify the conditions under which associations improve or worsen decision-making.

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# 1 Introduction

In economic textbook models of belief formation, memory imperfections play no role: agents combine prior knowledge with current information, and yesterday’s belief equals today’s prior. Our paper starts from the premise that people do not constantly have access to their beliefs about every potentially relevant state of the world. Rather, when people are prodded to act on or update their beliefs, they need to reconstruct their prior knowledge and beliefs from memory. This observation raises the empirical question how people retrieve prior information, and which features of news make it more or less likely for memory traces to be recollected.

The second observation that motivates our paper is that real-world information signals typically do not just consist of abstract information. Rather, information is often embedded in memorable contexts, by which we mean intrinsically uninformative environmental features that accompany information, such as stories and narratives, images, emotions, or sounds. Oftentimes, *similar news are embedded in similar contexts*. For example, when individuals receive negative feedback about their performance, these negative news are often associated with scolding and public shaming. Similarly, when good news prevail in the stock market, people are disproportionately exposed to bulls, upward-sloping trend lines, and good-times stories. To take yet another example, when immigration opponents relay negative information about the “typical” character traits of immigrants, then this often occurs through similar stories and images involving theft and other forms of violence.

The observations (i) that people may need to reconstruct prior information from memory and (ii) that similar news are often embedded in similar memorable contexts motivate the question about the role of *associative recall* for belief formation and choice. Associative recall refers to the idea that people are more likely to recollect items that are cued by current items (here: the current context). The associative nature of memory has recently received increased attention in the theory literature (Mullainathan, 2002; Bordalo et al., 2020b). A central prediction that emerges from this body of work is that asymmetric context-cued recall could lead to overreaction: after receipt of a piece of news, people reconstruct past knowledge from memory, yet predominantly remember those past news that appeared in similar contexts as today’s news. As a consequence, beliefs might *look like* they overreact to recent news, purely as a result of how prior knowledge is reconstructed. Indeed, in his influential writings on the role of narratives, Shiller (2017) appeals to the role of associative recall for economic expectation formation by observing that “[o]ne new narrative may remind of another that has been lying fairly dormant. . . there is cue-dependent forgetting.”

Despite this recent interest in the role of memory imperfections for economics, direct

empirical evidence on the role of associative memory for belief formation and resulting choices is scarce. This is a serious shortcoming for at least four reasons. First, associative recall is an (if not *the*) essential concept in psychological research on memory. Second, within economics, there is a clear gap between the blossoming of theoretical work on memory and a dearth of corresponding evidence. At this point, little is known about the qualitative and quantitative relevance of associations in shaping beliefs. Third, as we highlight below, understanding the origins of phenomena such as overreaction is important because memory-based distortions and canonical updating errors will frequently make different predictions. The reason is that the existence, direction and magnitude of memory-based distortions will depend on the precise structure of the signal history, while for canonical updating mistakes only their summary statistic (the current prior) matters. Fourth, from a normative perspective, associative recall can actually be both “good” (because it improves recall) and “bad” (because it does so in an asymmetric fashion), but there is no evidence on the conditions under which either effect will dominate.

An important challenge in studying the role of associative memory for beliefs empirically is that, in naturally-occurring data, the researcher does not have control over (and will usually not even be able to measure) the structure of past signals as well as the precise informational content of the contexts that may trigger associations. As a consequence, comparing observed beliefs to a normative benchmark and deriving clear-cut model predictions is difficult.

To circumvent this problem, we propose a novel theory-driven experimental paradigm that builds a bridge between quantitative, financially incentivized economic decision tasks and psychological paradigms on cued recall. With this new paradigm in hand, we make four contributions. First, we provide causal evidence that associative recall leads to overreaction in belief formation, in ways that predictably depend on the signal history. Second, we test and confirm various comparative statics predictions of a stylized version of existing memory models, and show that associative recall can also lead to predictable underreaction. Third, we contribute evidence on the potential limits of the role of associative recall for belief formation. Fourth, we use a combination of structural model estimates and empirical analyses to shed light on the conditions under which associative recall actually improves or worsens decision-making.

Our laboratory experiments are structured around the predictions of a simple formal framework that applies the idea of associative recall to belief formation, based on the formulations in Bordalo et al. (2020b) and Mullainathan (2002). In this model, decision-makers (i) have imperfect memory; (ii) are more likely to recollect a piece of news from the past if the context in which it is experienced is similar to today’s context; and (iii) are at least partially naïve about their memory imperfections. This stylized model predicts overreaction in beliefs. Importantly, in the model, this overreaction does not occur be-

cause people incorporate the current signal in some suboptimal way, but only because they asymmetrically retrieve past signals. The model makes various comparative statics predictions about how such overreaction depends on the signal history, the correlation structure between signals and contexts, the imperfection of memory, or the relevance of associative recall. Our treatments are tightly designed around these predictions.

We propose a new experimental paradigm to investigate the role of associative memory for belief formation in an economic decision context. Our paradigm builds a bridge between (i) the types of tightly-controlled, model-based, and financially incentivized designs that dominate modern experimental economics research on bounded rationality and (ii) psychological paradigms on cued recall problems. We aim to propose a setup that allows us both to provide a structured “existence proof” that associative recall matters, and to test various comparative statics predictions and potential limits.

In our experiment, participants predict the stock market value of multiple hypothetical companies. We adopt this particular framing for our experiment because it represents an intuitive environment for participants and allows for the straightforward implementation of contexts in which news are embedded, rather than because we primarily think of our paper as a finance application. The experiment comprises two distinct periods that we think of as “past” and “present.” Across both periods, a subject sequentially observes pieces of news about a company on their decision screen, where each piece of news takes on the value +10 or −10. The value of a company is deterministic and given by 100 plus the sum of all news that were shown up to a given point in time. As in the motivating examples, the news are embedded in a context, which consists of a story and an image that relate to the piece of news. For example, for one company, a positive signal would be shown with an (intrinsically uninformative) story about the company having launched a successful advertisement campaign with a celebrity, accompanied by a picture of that celebrity. In the baseline version of the experiment, as in the motivating examples, identical news are embedded in identical contexts: there is a one-to-one mapping between {Company × type of news} and context. That is, for each company, all positive news are communicated using the same context, and all negative news are communicated using the same context.

In the first period of the experiment, a subject sequentially observes a weakly positive number of news for a company and then states a first belief about the value of that company. This process is repeated for all companies. After the first period of the experiment, subjects work on an unrelated real effort task for 15 minutes to activate long-term memory. Then, in the second period, subjects observe up to one additional piece of news for a company and immediately after state their second-period belief about the value of that company. In addition, subjects explicitly indicate how many positive or negative signals they recall having seen throughout the experiment. Again, this procedure is repeated

for all companies. The basic intuition behind this experimental setup is that observing a particular piece of news in the second period might make it more likely for subjects to (asymmetrically) remember first-period news that were communicated in the same context. We think of this experimental paradigm as directly matching our opening examples (including Shiller's account on the role of narratives and cue-dependent forgetting) in that the experimental context in which information is presented reminds participants of a selected subset of the information that has been lying dormant in memory.

In this setup, our interest lies in evaluating the extent to which second-period beliefs overreact with respect to the second-period signal. Because of the simple deterministic structure of the experiment, the prediction of a rational model is that the OLS coefficient in a regression of second-period beliefs on second-period signals equals one. Likewise, a version of our model with imperfect but no associative memory also predicts a regression coefficient of one. In contrast, our framework predicts that, if context and news are positively correlated, (i) the OLS coefficient is larger than one, meaning that second-period beliefs overreact; (ii) overreaction increases in the number of first-period signals that take on the same realization as the second-period signal (because more first-period news can be cued); (iii) overreaction disappears if memory is manipulated to be perfect; and (iv) overreaction disappears if associative recall is exogenously shut down. All of these predictions hold when context and news are always linked in the same way. In contrast, when signals suddenly appear in a context that was previously associated with the opposite type of signal, our framework predicts that beliefs under- rather than overreact (prediction (v)). Our experiments with a total of 830 lab subjects were pre-registered to test these predictions, including a pre-analysis plan.

In our baseline treatment, we find that second-period beliefs strongly overreact with respect to the second-period signal: the aggregate OLS regression coefficient is 1.28, substantially larger than its rational or imperfect-but-no-associative-recall benchmark of one. Thus, our estimates reveal that the effect of the second-period signal on second-period beliefs is 28% larger than a model without associations would predict. In a follow-up treatment, we document that overreaction in beliefs also extends to economic choices: participants' willingness-to-pay for the hypothetical companies also strongly overreacts by 20% relative to a benchmark without associative recall.

Perhaps the most important prediction of our simple model is that overreaction should systematically depend on the signal history. In our data, the magnitude of overreaction indeed strongly increases in the number of first-period signals that get cued by the second-period signal. For instance, when subjects do not observe any first-period signals that match the second-period signal, their beliefs do not overreact at all. In contrast, when subjects previously observed two or three signals that match the second-period signal, 80% and 95% of all decisions reflect overreaction. These comparative

statics patterns are not just predicted by the model (and our pre-registration), they are also important in ruling out that overreaction is spurious and driven by recency bias or by subjects incorrectly believing that the data-generating process features positively autocorrelated signals.

To test the comparative statics predictions of our model with respect to the memory technology, we turn to testing predictions (iii) and (iv) on the roles of imperfect and associative recall. To this effect, we exogenously manipulate the relevance of both forgetting and associations in a series of experimental treatments. For instance, to exogenously manipulate the role of associative memory, we take as starting point that in our experiments associations operate via identical contexts. Thus, treatment *No Cue* follows the same structure as condition *Main*, except that each piece of news is communicated with a different context. That is, subjects never observe the same story or image twice, even if they receive the same signal for a given company twice. As predicted by the model, overreaction disappears entirely both when we shut down forgetting and when we eliminate the relevance of associations.

In all experiments reported above, types of news and contexts (stories and images) were connected through a one-to-one mapping: all positive signals for a given company appeared with the same context, and all negative signals appeared with the same (yet different) context. In treatment *Underreaction*, we modify this correlation structure between signals and contexts to test prediction (v) above. For example, in the second period of the experiment, positive signals are communicated with the context that was associated with negative signals for that same company in the first period. While prior theoretical work on associative memory has highlighted the prediction of overreaction, we show that, in this treatment, associative recall should produce underreaction. In our data, we indeed find that beliefs in *Underreaction* systematically underreact, where the magnitude of underreaction again depends on the signal history in ways predicted by the model.

All of our main results are derived from theoretically-motivated reduced-form regressions. In complementary analyses in the final part of the paper, we structurally estimate our stylized model to be able to quantitatively assess the importance of associative recall for stated beliefs, and to assess the payoff implications of associative memory. Our estimations reveal that, in our baseline experiments, associations imply an increase in the probability of remembering a signal of 27pp., or 48%. Moreover, in analogous experiments in which the time lag between the first and second period is three days, associative recall increases remembering by 137%. Thus, our structural estimates reveal that the effects of associative recall are large and persist over time.

Having established the quantitative importance of associative recall for belief formation, we use our model estimates to shed light on the conditions under which as-

sociations are actually “good” or “bad” for decision-making. Trivially, associative recall is inferior to a perfect recall technology. A perhaps more interesting benchmark is random, non-associative retrieval. As we work out in the context of our model, the relative (dis)advantage of associative recall strongly depends on the signal history, in particular the fraction of first-period signals that match the second-period signal. For instance, when the first-period signals all have the same realization and the second-period signal cues these first-period signals, then associations effectively provide a memory booster that unambiguously improves beliefs and earnings. On the other hand, when the first-period signals are mixed and the second-period signal selectively cues only a minority of them, associations boost memory in an asymmetric way, which makes beliefs biased and reduces profits. Using our model estimates and experimental data, we show that these theoretical predictions are confirmed empirically.

Our paper fits into an emerging literature that has argued for the importance of associative memory for economics. Mullainathan (2002) and Bordalo et al. (2020b) present models of how cued recall shapes economic decision-making across a broad set of domains. Models on cuing effects in consumption include Laibson (2001) and Bernheim and Rangel (2004). Related theoretical work has investigated the implications of associative recall in settings such as updating biases (Gennaioli and Shleifer, 2010; Noor, 2019), financial markets (Bodoh-Creed, 2019; Bordalo et al., 2019, 2020c; Wachter and Kahana, 2019), and self-esteem (Koszegi et al., 2019).<sup>1</sup> Thus far, this literature is theoretical in nature. As much of the simple formalism that structures our experiments directly draws from this literature, we view our experiments as providing some of the first direct evidence from tightly structured economic decision making tasks in relation to this emerging body of theoretical work.

Our work builds on a long psychology literature on episodic memory, which is the part of long-term memory that stores information about events and experiences. Psychological experiments on associative recall exhibit a different structure than the experiments that are presented here (see Kahana, 2012, for an overview). These typically consist of explicit cued recall problems (such as with words), rather than model-driven quantitative economic decision tasks. Also, psychological experiments do not focus on the implications of associative recall for belief formation or willingness-to-pay, or on identifying the history-dependent payoff implications of associations, as we do here. An important concept in psychological research, which we also leverage in our experimental design, is that of item similarity (Tversky, 1977; Evers and Imas, 2019). For example, Bordalo et al. (2020a) present an experiment on selective recall of abstract images that

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<sup>1</sup>Other research in economics on memory that does not focus on associative recall includes work on heuristics (Wilson, 2014) and motivated memory (Zimmermann, 2020; Carlson et al., 2018; Chew et al., forthcoming; Huffman et al., 2018).

shows a link between associative memory and the representativeness heuristic.

The remainder of the paper proceeds as follows. Section 2 offers a stylized formal framework that motivates the experimental design and structures the analysis. Section 3 describes the experimental design, implementation, and pre-registration. Sections 4–6 present the main results. Section 7 estimates the model and Section 8 concludes.

## 2 Theoretical Framework

### 2.1 Setup

This section presents a stylized model to guide the design of the experiments and structure the empirical analysis. The mechanics of the model directly build on some of the formulations in Mullainathan (2002) and Bordalo et al. (2020b). The framework rests on three key assumptions: (i) people may forget prior knowledge, so that they need to reconstruct it from memory; (ii) this recollection process is subject to associative recall, meaning that news are more likely to get remembered if they were observed in a context that is similar to the context in which today’s signal is observed; and (iii) people are (at least partially) naïve about their biased memory technology. In this model, decision-makers behave optimally conditional on what they recall. We abstract away from additional behavioral assumptions that the literature on associative memory has incorporated, such as salience or rehearsal.

Consider a decision-maker (DM) who forms beliefs about the state of a time-varying stochastic variable  $\theta_t$  with initial value  $v$ . We consider two periods that we will think of as “past” and “present.” In any given period  $t$ ,  $\theta_t$  is given by its initial value plus the sum of all news  $n_x$  that have accumulated up to this point, where  $n_x \in \{-q, q\}$ . News are equally likely and i.i.d. We will use the terms “news” and “signal” interchangeably.

A piece of news  $n_x$  is associated with a memorable context  $c_x \in \{L, H\}$ . In the “past”,  $k$  news arrive, so that  $\theta_1 = v + \sum_{x=1}^k n_x$ . In  $t = 1$ , there is a one-to-one mapping between type of news (positive or negative) and context (high or low):  $n_x = n_y \Leftrightarrow c_x = c_y$ .

In the “present” ( $t = 2$ ), the DM observes one final piece of news  $n_{k+1}$ . Thus:

$$\theta_2 = v + \sum_{x=1}^k n_x + n_{k+1} \quad (1)$$

Just as in  $t = 1$ , the piece of news is associated with a context. We will consider two regimes, though for any given DM the prevailing regime is known. In the first regime, second-period news and contexts are associated in the same way as in the first period: positive news appear in a “high” context and negative news in a “low” context. In the

second regime, the DM receives second-period news in a context opposite to what he was exposed to in the first period, meaning that he observes positive news in a “low” context and negative news in a “high” one. As a shorthand for this “correlation” between news and context, we define

$$\rho \equiv \begin{cases} 1 & \text{if } P(c_{k+1} = H | n_{k+1} = q) = P(c_{k+1} = L | n_{k+1} = -q) = 1 \\ -1 & \text{if } P(c_{k+1} = L | n_{k+1} = q) = P(c_{k+1} = H | n_{k+1} = -q) = 1 \end{cases}$$

## 2.2 Memory and Beliefs

Our object of interest is the extent to which the DM’s belief about  $\theta_2$  in  $t = 2$  responds to the latest piece of news  $n_{k+1}$ . A rational (or Bayesian, though there is no uncertainty here) DM would correctly predict  $\theta_2 = v + \sum_{x=1}^k n_x + n_{k+1}$ .

Suppose instead that the DM potentially forgets some of the news between  $t = 1$  and  $t = 2$ . Thus, his belief (after observing  $n_{k+1}$ ) is given by

$$b_2 = v + \sum_{x=1}^k m_x n_x + n_{k+1}, \quad (2)$$

where  $m_x \in \{0, 1\}$  denotes whether the DM remembers piece of news  $n_x$ .

Whether or not the DM remembers a piece of news is determined by both (i) imperfect and (ii) associative memory. First, by imperfect recall we mean that, irrespective of the piece of news, there is some probability  $r \in [0, 1]$  that the DM will remember. The reduced-form assumption of imperfect recall is a shorthand for different mechanisms that have been highlighted in the psychological literature. For now, we will assume that the parameter  $r$  is exogenously given, though our experimental design and results will shed some light on what induces imperfect memory in the first place.

Second, by associative recall we mean that the probability of recalling a piece of news from the past is higher if it is cued by today’s signal. That is, a past signal is more likely to get remembered if it occurred with the same context as today’s signal. Formally, there is an increase in the probability of recalling  $(1 - r)a$ ,  $a \in (0, 1]$ , if the context  $c_{k+1}$  that is associated with  $n_{k+1}$  is the same as the context that is associated with news  $n_x$ .<sup>2</sup>

We assume that the DM forms beliefs exclusively from what he recalls and is not aware of his biased memory technology. This implies naïveté about memory imperfec-

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<sup>2</sup>In a more general model, associativeness is formalized via a continuous similarity function on the unit interval (Bordalo et al., 2020b). The way we capture associativeness can be thought of as a shorthand for such a more general version where similarity is either 0 or 1.

tions as in Mullainathan (2002).<sup>3</sup> We have:

$$m_x = \begin{cases} 1 & \text{with probability } r + (1-r)\alpha \mathbb{1}_{c_x=c_{k+1}} \\ 0 & \text{else} \end{cases} \quad (3)$$

Denote by  $z \geq 0$  the number of news in  $t = 1$  that were observed in the same context as  $n_{k+1}$  and hence got “cued.” That is,  $z \equiv \sum_{x=1}^k \mathbb{1}_{c_x=c_{k+1}}$ . Doing straightforward algebra, the belief in period  $t = 2$  is given by:

$$\begin{aligned} b_2 &= v + n_{k+1} + \sum_{x=1}^k m_x n_x \\ &= v + n_{k+1} + \sum_{x=1}^k E[m_x | n_x, n_{k+1}] n_x + \underbrace{\sum_{x=1}^k (m_x - E[m_x | n_x, n_{k+1}]) n_x}_{\equiv \epsilon} \\ &= v + n_{k+1} + (1-r)\alpha \rho n_{k+1} \sum_{x=1}^k \mathbb{1}_{c_x=c_{k+1}} + r \sum_{x=1}^k n_x + \epsilon \\ &= v + n_{k+1} + [(1-r)\alpha \rho] (z n_{k+1}) + r \sum_{x=1}^k n_x + \epsilon \end{aligned} \quad (4)$$

$$= v + \underbrace{[1 + (1-r)\alpha \rho z]}_{\text{Object of interest}} n_{k+1} + r \sum_{x=1}^k n_x + \epsilon \quad (5)$$

Equations (4) and (5) are the core expressions that we subject to systematic experimental tests. Equation (4) clarifies that the second-period signal has two independent effects on second-period beliefs: the second term represents a direct mechanical effect according to which beliefs should move one-to-one with the signal. The third term is an indirect effect that captures the effect of the second-period signal on the recall of first-period signals. This third term is an interaction effect between the second-period signal and the number of first-period signals that get cued by the second-period signal ( $z$ ). This is intuitive: if no first-period signal gets cued by the second-period signal, then associative recall cannot generate overreaction. Due to the simple linear structure of the problem, the second and third terms in equation (4) can be combined. As a result, in equation (5),  $n_{k+1}$  shows up only once as a regressor.

This expression clarifies that, if the agent is rational ( $r = 1$ ), second-period beliefs will respond with a coefficient of one to variation in the second-period signal. Similarly,

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<sup>3</sup>In principle, naïveté could come in two forms: (i) the DM fails to realize that he sometimes forgets, i.e., that there are signals he does not recall; (ii) the DM realizes that he sometimes forgets, but he does not take into account that his recall is associative and hence asymmetric. In Appendix A.1, we formalize these types of naïveté and show that our predictions are robust to assuming partial naïveté.

if the agent exhibits imperfect ( $r < 1$ ) but no associative ( $a = 0$ ) recall, the bracketed term equals one. On the other hand, viewed through the lens of imperfect recall and associative memory, equation (5) suggests that beliefs will overreact if context and news are positively correlated ( $\rho = 1$ ). At the same time, the equation clarifies that overreaction does not occur because the agent incorporates the last signal in some suboptimal way, but only because he asymmetrically retrieves first-period signals.

In our experiments, we exogenously manipulate the components of the bracketed expression. Equations (4) and (5) will directly correspond to our econometric specification, where  $\epsilon$  reflects random noise in the memory technology. We state the following testable hypotheses, which we concretize for our experimental implementation in Section 3:

### Hypotheses.

1. *If the correlation between news and context is positive ( $\rho = 1$ ), expectations overreact to today's news, on average.*
2. *Overreaction increases in the number of past news that were communicated in the same context as today's news ( $z$ ).*
3. *Overreaction increases in the imperfection of memory ( $1 - r$ ).*
4. *Overreaction increases in the strength or relevance of associative recall ( $a$ ).*
5. *If the correlation between news and context is negative ( $\rho = -1$ ), expectations underreact to today's news, on average.*
6. *This underreaction increases in the number of past news that there were communicated in the same context as today's news ( $z$ ).*
7. *Underreaction increases in the imperfection of memory ( $1 - r$ ).*

It is worth highlighting that these predictions rely on the presence of associative recall  $a > 0$ . Models of recency bias (Fudenberg et al., 2014) or optimized responses to imperfect memory (Wilson, 2014) do not generate this joint set of predictions. For example, recency bias predicts overreaction, but not that overreaction depends on the history of news, or that it disappears once associative recall is shut down.

## 3 Experimental Design

An experimental analysis of the role of associative memory is challenging for several reasons. Perhaps most importantly, the researcher needs to have full control over past

and current information, as well as the contexts that trigger associations and the informational content they might convey. In addition, results should be clearly attributable to (associative) memory, rather than being conflated or noised up by subjects having to go through non-trivial Bayes'-rule-type calculations. Absent such a tightly controlled environment, deriving model predictions and comparing stated beliefs to a normative benchmark is difficult.

Our experimental design is designed around these challenges and builds a bridge between the tightly-controlled and quantitative designs that dominate modern experimental economics research on the one hand and psychological paradigms on cued recall problems on the other hand. We particularly focused on the following design objectives: (i) a decision setup that is closely tied to the model in Section 2; (ii) a task that is very simple, conditional on what is being recalled; (iii) a framed environment that is intuitive and allows for a straightforward implementation of contexts; (iv) exogenous variation in the key model parameters; and (v) incentive-compatible belief elicitation.

### 3.1 Experimental Setup

**Task.** To isolate the role of memory, we implemented a simple deterministic decision environment in which, absent potential memory constraints, behaving rationally is trivial. The experiment consisted of two periods, as summarized in Figure 1. In both periods, participants estimate the stock market value of hypothetical companies.

**First period.** Continuing the notation from Section 2, the value of company  $j$  in period  $t = 1$  is given by a baseline value,  $v = 100$ , plus the sum of all news about that company in  $t = 1$ :

$$\theta_1^j = 100 + \sum_{x=1}^{k_j} n_x^j. \quad (6)$$

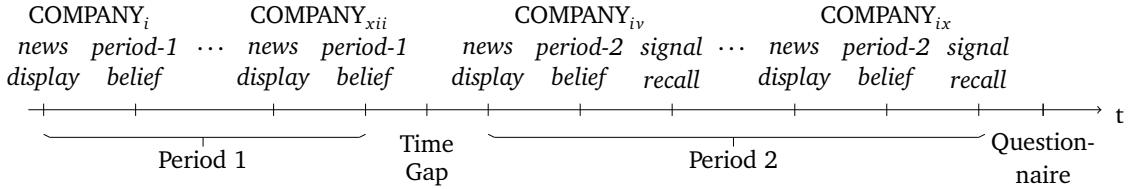
where  $k_j \in \{0, 1, 2, 3\}$  is the number of signals in  $t = 1$ .<sup>4</sup> News were equally likely to be positive,  $n_x = 10$ , or negative,  $n_x = -10$ , and were randomly and independently drawn by the computer. All of this was known to subjects.

Subjects sequentially observed news for a given company on their computer screens. Then, they were asked to estimate the company's current value. This procedure was repeated for all twelve companies. Thus, participants worked on the twelve companies strictly sequentially.

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<sup>4</sup>Each subject saw three companies with three pieces of news, three with two pieces of news, three with one piece of news and three with zero pieces of news.

Figure 1: Experimental Timeline



Beliefs in the first period allow us to verify whether subjects understood the basic information structure, had sufficient time to process the information, and were in principle able to determine correct estimates in our decision environment. As we will see below, first-period beliefs are indeed always very close to rational beliefs, which lends credence to our assumption that (absent memory constraints) subjects understood our design and were well-capable of behaving optimally.

After the first period, we implemented a time gap in which subjects worked on an unrelated real effort task, which required subjects to type multiple combinations of letters and numbers into the keyboard. Subjects had 15 minutes to type in as many combinations as they could. For each correctly solved task, they received 5 cents.

**Second period.** In the second period, for each company, subjects were shown up to one additional piece of news. The value of company  $j$  is given by:

$$\theta_2^j = \theta_1^j + n_{k+1}^j = 100 + \sum_{x=1}^{k_j} n_x^j + n_{k+1}^j. \quad (7)$$

For ten companies, subjects received an additional piece of news, while for two companies, there were no additional news. The experimental instructions and comprehension questions emphasized that first-period signals are also relevant for second-period guesses. We included two companies with no additional news because these allow us to directly assess whether subjects perfectly remember their first-period belief in the second period.

Immediately after observing the additional piece of news for a company, subjects were asked to state a second-period belief about the value of that company. Second-period beliefs constitute our main outcome of interest. In addition, on a subsequent decision screen, subjects were asked to recall the number of positive and negative news that were shown to them in the course of the entire experiment for that company. These recall measures were not financially incentivized. Again, this procedure was repeated for all twelve companies, so that participants worked on the 12 companies strictly sequentially within a given period.

To summarize, as depicted in Figure 1, the timeline of the experiment was as follows. First, a subject received all first-period signals for a company and immediately after stated a first-period belief. Then, the subject received all first-period signals for the next company and stated a first-period belief. This process was repeated for all twelve companies, after which a 15-minutes real effort task followed. Then, the subject received a second-period signal (if any) for a company and immediately after stated a second-period belief and indicated their recall of positive and negative signals. This procedure was then repeated for all twelve companies.

**Communication of news and context.** News were not only communicated as abstract numbers, but were shown on subjects' computer screens with what we refer to as a context. Neither our stylized model nor existing theoretical contributions define what exactly is part of a context. For the purposes of our experimental implementation, we use "context" as a shorthand for an image and a story that accompany a signal.

In treatment *Main*, each company is assigned two unique contexts, one for positive news and one for negative news. The story provides a rationale for why the value of the company had gone up or down, while the image encapsulated the content of the story. For one company, for instance, positive news are associated with successful hires on the job market and negative news with production problems. All stories were constructed to be of similar length and structure. Appendix G contains examples of these images and stories (see Figures 10 and 11).

The written instructions clarified to subjects that the images and stories of each context had no purpose other than to provide a rationale for the change in the value of the company. The signal, image and story were displayed on subjects' computer screens for 15 seconds. The time was calibrated such that subjects had sufficient time to process the news, as well as to fully grasp the content of the image and the story. An English tourist version of the computer program that communicates the sequence of first-period and second-period news and contexts in treatment *Main* can be accessed at [https://unikoelnwiso.eu.qualtrics.com/jfe/form/SV\\_0MrVD2rNNrKeLGt](https://unikoelnwiso.eu.qualtrics.com/jfe/form/SV_0MrVD2rNNrKeLGt). Screenshots of a full run-through are provided in Appendix H.

**Randomization and incentives.** The experiment was independently randomized across subjects across the following layers: (i) the order of companies in the first period; (ii) the order of companies in the second period; (iii) whether or not a company received a piece of news in the second period; and (iv) the actual signal realizations.

Beliefs were incentivized using a binarized scoring rule, which is incentive-compatible regardless of subjects' risk attitudes (Hossain and Okui, 2013). Under this scoring rule,

subjects could potentially earn a prize of 10 euros.<sup>5</sup> The probability of receiving the prize was given by 100 minus the squared distance between a subject's belief and the true value of the asset. In order to avoid hedging motives, at the end of the experiment one of the 24 beliefs was randomly selected for payment. Since second-period beliefs are our main outcome measure, we incentivized them more heavily, in expectation: with 90% probability a second-period belief was randomly selected for payment, and with 10% probability a first-period belief. To avoid extreme outliers due to typing mistakes, the computer program restricted beliefs to be in [50, 150].

### 3.2 Discussion of Design in Relation to Psychological Concepts

Given that ours is arguably the first structured economics experiment on associative recall, we deem it helpful to explain our design choices in light of the psychology literature. As discussed in the Introduction, associative recall is thought to be part of episodic memory, which is that part of long-term memory that stores past events. Our design builds on so-called A-B, A-C paradigms in the psychology literature and is based on the following concepts from memory research (Kahana, 2012).

First, because associative recall is believed to operate on long-term (rather than working) memory, we implemented a distraction task between the first and second period. The memory literature contains many demonstrations that sufficiently long distraction tasks activate long-term memory and corresponding memory imperfections.

Second, an important component of recent memory models in both economics and psychology is that of similarity (Tversky, 1977) and resulting interference (Kahana, 2012; Bordalo et al., 2020b). The key idea is that it is hard for people's memory to link a specific piece of past information to a particular variable if they have been exposed to similar information also for other variables. Based on this insight, we deliberately designed our experiment so as to include twelve companies with similar news.

Notice that both of these components could generate baseline forgetting. While the focus of our paper is an analysis of the role of associative memory *conditional on the existence of forgetting*, in Section 6, we shed light on the relative importance of the time lag and interference in generating forgetting in the first place.

### 3.3 Treatments and Sources of Exogenous Variation

Table 6 in Appendix B provides an overview of all treatments that we conducted for this paper, including information on subjects' average earnings.

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<sup>5</sup>Recent experimental work finds that the presence of cognitive biases is generally robust to the stake size employed (Enke et al., 2020).

**Treatments *Main* and *WTP*.** In treatment *Main*, every positive news for company A is communicated with the same context (image and story). Likewise, every negative news for company A is communicated with the same context (albeit a different one than the positive news). The same logic holds for all other companies. Thus, it can never happen that a context is communicated with news for different companies, or with both positive and negative news. Thus, treatment *Main* resembles our opening examples and implements a situation in which we hypothesize to observe overreaction.

Because the number and realizations of the signals vary across companies and subjects, the twelve tasks exhibit substantial variation in signal histories. We leverage this source of exogenous variation to test the within-treatment predictions derived in Section 2 about how the presence or quantitative magnitude of overreaction depends on the number of first-period signals that occurred in the same context as the second-period signal. 80 subjects participated in treatment *Main*.

Treatment *WTP* follows the same structure as *Main*, except that we do not elicit participants' beliefs about the value of the hypothetical companies. Neither do we elicit subjects' recall of positive and negative signals. Instead, the task was framed as decisions to purchase companies. In both the first and the second period of the experiment, subjects were endowed with 150 points for each company and then stated their willingness-to-pay (WTP) for a company. This treatment hence allows us to tie associative recall back to economic actions. To elicit WTP, we implemented a direct Becker-deGroot-Marschak elicitation mechanism, such that subjects directly entered the maximum number of points  $m$  that they would be willing to pay for an asset. We then randomly determined a price  $p \sim U[50, 150]$  and subjects received the asset if  $m \geq p$  and kept their endowment otherwise. Because we anticipated that participants' WTP would be a slightly noisier measure than pure beliefs data, 100 subjects participated in treatment *WTP*.

An important aspect of our experimental design is that signals are mutually independent, implying that subjects should not infer from the second-period signal about earlier signals. A potential concern is that subjects incorrectly believe that signals are positively autocorrelated. Such a belief (or heuristic) could also generate overreaction in our setup. Two design elements rule out that we spuriously pick up such an effect. First, an account of overreaction that is based on belief in positive autocorrelation does not generate the additional prediction – emphasized above – that overreaction increases in the number of cued first-period signals. This is because a belief in autocorrelation predicts that subjects always infer from a positive second-period signal that the first-period signals were likely also positive, irrespective of the realization of the first-period signals. In contrast, our model predicts that overreaction predictably depends on the *random realizations* of the first-period signals. Second, we implemented a comprehension question that directly asks participants whether a positive signal becomes more likely following

a positive signal. Across treatments, less than 1% of prospective participants answered this question incorrectly.

**Treatments *Reminder* and *WTP reminder*.** In treatments *Reminder* and *WTP reminder*, we seek to remove subjects' memory constraints, holding everything else constant. The setup in the reminder treatments was exactly the same as in the corresponding baseline conditions, except that at the beginning of the second period (i.e., before a subject observes the second-period signal for a company), subjects were reminded of their own first-period belief for that company. Conceptually, we think of this treatment as exogenously setting the parameter  $r = 1$  in the framework of Section 2 (meaning perfect memory). 50 subjects participated in treatment *Reminder* and 80 subjects in treatment *WTP reminder*.

**Treatment *No Cue*.** Treatment *No Cue* was designed to manipulate the relevance of associative recall. The setup in this treatment was exactly the same as in *Main*, except that each piece of news was communicated with a different context. That is, a given context (image and story) never appears twice, even if the company and type of news is identical. As a consequence, stories and images can no longer trigger associations. At the same time, all other features of the environment remain unchanged. Comparing treatments *Main* and *No Cue* therefore allows us to cleanly identify the role of associative recall. 80 subjects participated in this treatment.

**Treatments *Underreaction* and *Underreaction reminder*.** All treatments described above rely on a design in which the observation of a positive piece of news in the second period cues the asymmetric recollection of positive first-period news (and analogously for negative news), which corresponds to  $\rho = 1$  in our formal framework. Treatment *Underreaction* corresponds to setting  $\rho = -1$ . Here, the first period proceeded exactly as in treatment *Main*. In the second period, however, news were communicated on subjects' decision screens along with the *opposite* story and image, relative to the first period. That is, a positive piece of news for company A was communicated along with the story and image that were associated with negative news for company A in the first period of the experiment. Analogously, a negative piece of news for company A was communicated along with the story and the image that were associated with positive news for company A in the first period of the experiment. The instructions in *Underreaction* emphasized that second-period news were communicated along with the opposite story and image, and control questions verified subjects' understanding of this aspect of the design. 80 subjects participated in this treatment.

A potential concern with this treatment is that it confuses subjects, or leads them to distrust the news in the second period. To account for this, we additionally conducted condition *Underreaction reminder*. This treatment was identical to *Underreaction*, except that subjects were reminded of their own first-period belief right before they received the second-period signal for a company. This treatment holds constant the potential confusion or distrust that could arise as a result of the change in the mapping between signals and contexts. In other words, if subjects did not perfectly trust second-period signals after the change in contexts, then this would generate underreaction in both *Underreaction* and *Underreaction reminder*. Thus, comparing the two treatments allows us to causally identify the role of memory for underreaction. 50 subjects took part in *Underreaction reminder*.

### 3.4 Predictions

Equation (5) in the conceptual framework directly suggests the following estimating equation for subject  $i$ 's second-period belief about the value of company  $j$ :

$$b_2^{i,j} = \alpha + \beta_1 n_{k+1}^{i,j} + \beta_2 \sum_{x=1}^k n_x^{i,j} + \epsilon^{i,j} \quad (8)$$

That is, we regress a subject's second-period belief on the value of the second-period signal as well as the first-period stock value (or the first-period belief). In those treatments in which we elicited WTPs rather than beliefs,  $b_2^{i,j}$  refers to the second-period WTP. Note that this specification corresponds to a textbook example for OLS.<sup>6</sup> Thus, under the model in Section 2, the regression coefficients are identified as  $E[\hat{\beta}_1] = 1 + \rho(1-r)a\bar{z} > 1$  and  $E[\hat{\beta}_2] = r < 1$ .

As clarified by equation (4) in the model, this reduced-form regression can equivalently be expressed as

$$b_2^{i,j} = \alpha + \beta_3 n_{k+1}^{i,j} + \beta_4 (n_{k+1}^{i,j} z^{i,j}) + \beta_5 \sum_{x=1}^k n_x^{i,j} + \epsilon^{i,j}, \quad (9)$$

where  $z^{i,j}$  is the number of first-period signals that got communicated in the same context as  $n_{k+1}^{i,j}$ . This shows that a potential over- (or under-) reaction with respect to the second-period signal  $n_{k+1}$  should depend on the signal history. In fact, the model

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<sup>6</sup>Note that, under our formal model in Section 2, the error term  $\epsilon^{i,j}$  is indeed orthogonal to  $n_{k+1}$ . To see this, recall that  $\epsilon = \sum_{x=1}^k (m_x - E[m_x])n_x$ . While both  $m_x$  and  $E[m_x | n_x, n_{k+1}]$  implicitly depend on  $n_{k+1}$ , this dependence is differenced out: the error term only captures the random difference between predicted and actual memory. In other words,  $n_{k+1}$  affects the systematic components of  $m_x$  and  $E[m_x | n_x, n_{k+1}]$  in identical ways, so that the difference between the two only reflects exogenous noise in the memory technology and is hence uncorrelated with  $n_{k+1}$ .

Table 1: Mapping from model predictions to experimental predictions

Abstract model prediction	Treatments	Experimental prediction
1. Overreaction if news and context positively corr.	Main, WTP	$\beta_1^{\text{Main}} > 1$
2. Overreaction increases in # identical past contexts	Main, WTP	$\beta_4^{\text{Main}} > 0$
3. Overreaction increases in imperfection of memory	Main, WTP, Reminder	$\beta_1^{\text{Main}} > \beta_1^{\text{Reminder}}$
4. Overreaction increases in relevance of associative recall	Main, No Cue	$\beta_1^{\text{Main}} > \beta_1^{\text{No Cue}}$
5. Underreaction if news and context negatively corr.	Underreaction	$\beta_1^{\text{Under.}} < 1$
6. Underreaction increases in # identical past contexts	Underreaction	$\beta_4^{\text{Under.}} < 0$
7. Underreaction increases in imperfection of memory	Under., Under. rem.	$\beta_1^{\text{Under.}} < \beta_1^{\text{Under. rem.}}$

predicts that  $E[\hat{\beta}_3] = 1$ , i.e., there is no overreaction at all once the interaction between  $n_{k+1}$  and  $z$  is included as a separate regressor. Here, associative memory predicts  $E[\hat{\beta}_4] = (1 - r)a\rho > 0$ . We will estimate (8) in Section 4.2 and (9) in Section 4.3.

By applying the abstract predictions derived in Section 2 to this experimental design and estimating equations, we are ready to state the following predictions:

### Predictions.

1. In treatments Main and WTP, there is overreaction:  $\beta_1 > 1$ .
2. In treatments Main and WTP, overreaction increases in the number of first-period signals that were observed in the same context as the second-period signal:  $\beta_4 > 0$ .
3. Overreaction is stronger in treatment Main than in Reminder, and stronger in WTP than in WTP reminder.
4. Overreaction is stronger in treatment Main than in No Cue.
5. In treatment Underreaction, we observe underreaction:  $\beta_1 < 1$ .
6. In treatment Underreaction, underreaction increases in the number of first-period signals that were observed in the same context as the second-period signal:  $\beta_4 < 0$ .
7. Underreaction is stronger in treatment Underreaction than in Underreaction reminder.

For clarity, Table 1 explicitly spells out which abstract model prediction from Section 2 maps into which specific experimental prediction, and which experimental treatments we use to test a given prediction.

### 3.5 Procedures and Logistics

Upon arrival in the lab, subjects received written instructions about the experiment. Appendix F contains the full set of paper-based instructions, translated into English.

Subjects were given unlimited time to read the instructions and could ask questions at any point in time. After all subjects had indicated that they had finished the instructions, they completed a total of seven computerized control questions to verify adequate comprehension. Whenever a subject did not solve a control question correctly, a computer screen pointed out the mistake and explained the correct solution. As we pre-registered (see below), we exclude subjects from the analysis that answered more than one control question incorrectly (7% of potential participants).

Treatments *Main*, *Reminder*, and *No Cue* were conducted in the BonnEconLab of the University of Bonn. Since we had exhausted the subject pool of the BonnEconLab, treatments *WTP*, *WTP reminder*, *Underreaction* and *Underreaction reminder* were conducted in the University of Cologne's Laboratory for Experimental Economics. Assignment to the relevant treatments was randomized within experimental sessions: *Baseline*, *Reminder*, and *No Cue* were all implemented in the same sessions, as were *Underreaction* and *Underreaction reminder*. In our statistical analyses, we only compare treatments that were randomized within experimental sessions, in the same location. The experiments were computerized using Qualtrics and lasted up to 90 minutes.

### 3.6 Pre-Registration

All experiments in this paper were pre-registered in the AEA RCT registry, including a pre-analysis plan. The different pre-registration files include (i) the design of all treatments reported in this paper; (ii) a heterogeneity analysis; (iii) the regression equation (8) through which we analyze all data; (iv) all predictions outlined in Section 3.4; (v) the sample size in each treatment; (vi) that subjects would be dropped from the sample (and replaced) if they answer more than one control question incorrectly; and (vii) the labs in which we ran the experiments. All pre-registration documents are available at <https://www.socialscienceregistry.org/trials/4247>.<sup>7</sup>

## 4 Baseline Results on Overreaction

### 4.1 Preliminaries

Before we present the results, we conduct two checks on our experimental data. First, we verify people's understanding of the experimental setup by investigating the accuracy of participants' first-period beliefs. The average percentage deviation between first-period

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<sup>7</sup>We report all analyses of our pre-analysis plan in Sections 4, 5, and 6. In addition, we provide analyses in Section 7 that are not part of our pre-analysis plan, though they are directly based on the theoretical framework that guided our pre-registered analyses.

beliefs and the truth is only 0.4%, while the median deviation is zero. This provides reassuring evidence that subjects appear to understand the decision task well.

Second, to show that subjects can no longer perfectly remember their first-period belief once the second period starts, we consider the relationship between subjects' second-period and first-period beliefs in those tasks in which a subject did not receive a second-period signal. In a regression of second-period on first-period beliefs, the OLS coefficient is only 0.56 and hence far from the perfect memory benchmark of one. This suggests that memory is indeed imperfect in our setup, hence opening up a potential role for associative recall.

## 4.2 Treatments *Main* and *WTP*: Overreaction in Beliefs and Choices

Our analysis begins by visually illustrating the result of overreaction in beliefs in treatment *Main*. Figure 2 plots average beliefs for different selected signal histories. The blue dots correspond to subjects that did not observe a second-period signal, while the red squares and green triangles correspond to second-period signals of 10 and  $-10$ . Without associative memory, the red and green dots would be equidistant from the blue dot. Our model, on the other hand, predicts that the red (green) dots are located further away from the blue dots than the green (red) dots if there are more positive (negative) first-period signals. The figure confirms this prediction. We further note here that this asymmetry appears to be increasing in the extremity of the first-signal history. We return to this observation (which is predicted by our model) below.

To provide a statistical test for overreaction, we present OLS regressions that correspond to variants of the estimating equation (8). Columns (1)–(4) of Table 2 present the results for treatment *Main*. In column (1), we regress second-period beliefs on the second-period signal (+10 or  $-10$ ), controlling for the first-period belief. In column (2), we show an analogous regression in which we control for experimental session fixed effects, first-period signal history fixed effects, company fixed effects, experimental order fixed effects, and subject fixed effects. In this second specification, controlling for first-period beliefs or company values is redundant as these are implicitly accounted for by the first-period signal history fixed effects. In each regression specification, an observation corresponds to a subject-task, for a total of ten tasks per subject.<sup>8</sup> Throughout, we cluster the standard errors at the subject level.

While the first two columns include all observations (as we pre-registered), column (3) shows the theoretically more appropriate case for which the number of first-period signals that match the second-period signal are strictly positive,  $z > 0$ . This specification

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<sup>8</sup>Naturally, and as specified in the pre-analysis plan, we restrict attention to those tasks in which a subject indeed received a signal in the second period.

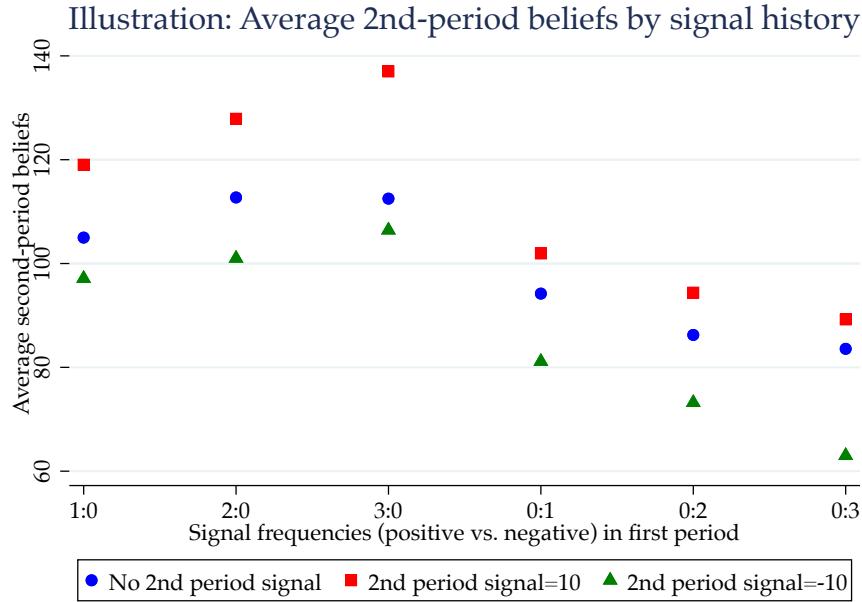


Figure 2: Average second-period beliefs as a function of the signal history in the first period. For example, “3:0” refers to three positive and zero negative signals in the first period. We suppress signal histories of “0:0”, “1:1”, “2:1” and “1:2” for the sake of ease of visibility. These signal histories are always included in regression analyses and statistical tests.

is conceptually more interesting because according to the model in Section 2, memory-based overreaction should only occur when  $z > 0$ .

The framework outlined in Section 2 predicts that the coefficient of first-period beliefs is less than one (due to imperfect memory) and that the coefficient of the second-period signal is greater than one (due to imperfect and associative memory). This is indeed what we find. In terms of magnitude, the OLS coefficient suggests that beliefs substantially overreact with respect to second-period signals, by 28 percent relative to the rational prediction of one when  $z > 0$ . In intuitive terms, this regression coefficient captures by how much the *difference* between second-period beliefs when the second-period signal is  $-10$  and  $10$  is amplified relative to rational beliefs. For a rational (or imperfect-but-no-associative-recall) agent, this difference should equal 20. The regression coefficient reveals that, on average, the difference in beliefs equals  $1.28 \times 20 = 25.6$ .<sup>9</sup> Regarding statistical tests, the last row of Table 2 reports the p-value for the null hypothesis that the coefficient of the second-period signal equals one. We reject this rational null hypothesis at all conventional levels of significance for all specifications.

<sup>9</sup>To investigate across-subject heterogeneity, we turn to three pre-registered heterogeneity analyses: (i) performance on a Raven matrices IQ test that was administered at the end of the experiment; (ii) a measure of the strength of memory that is estimated from the experimental recall data as a proxy for  $r$ ; and (iii) response times. Table 7 in Appendix D reports the results. We find that subjects with higher Raven scores and better non-cued recall exhibit less overreaction. The relationship between overreaction and response times is negative, but not statistically significant.

Table 2: Treatments *Main* and *WTP*

	Treatment <i>Main</i>				Treatment <i>WTP</i>			
	Dependent variable: 2nd period belief				2nd period WTP			
	Full (1)	Full (2)	$z > 0$ (3)	Full (4)	Full (5)	Full (6)	$z > 0$ (7)	Full (8)
2nd period signal	1.10*** (0.02)	1.11*** (0.03)	1.28*** (0.05)	0.87*** (0.04)	1.11*** (0.04)	1.13*** (0.04)	1.20*** (0.07)	0.98*** (0.07)
Belief in 1st period	0.75*** (0.03)							
2nd period signal $\times$ # 1st period signals in same context				0.31*** (0.05)			0.20*** (0.07)	
WTP in 1st period					0.51*** (0.04)			
Session FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
1st period signal history FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Company FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Order FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Subject FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Observations	800	800	416	800	1000	1000	515	1000
Adjusted $R^2$	0.80	0.80	0.90	0.81	0.61	0.72	0.80	0.73
p-value H0: $\beta$ (2nd period signal)=1	< 0.01	< 0.01	< 0.01	n/a	< 0.01	< 0.01	< 0.01	n/a

*Notes.* OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The sample includes all observations from treatments *Main* (columns (1)–(2) and (4)) and *WTP* (columns (5)–(6) and (8)) where subjects observed a second-period signal. In column (3) and (7), we exclude observations for which no first-period signal matches the second-period signal. Columns (4) and (8) suppress the coefficient of the number of first-period signals that match the second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Columns (5)–(7) of Table 2 report analogous analyses for treatment *WTP*, where the dependent variable is now a participant’s reported WTP. Note that because the decision problem in our setup is deterministic in nature, the prediction for a rational decision-maker is that the OLS coefficient of the second-period signal equals one, regardless of subjects’ risk attitudes. The results are very similar to those in treatment *Main*: we see overreaction with an aggregate OLS coefficient of 1.20.

**Result 1.** *Beliefs and choices overreact with respect to the second-period signal.*

### 4.3 Variation in the Signal History

The difference in regression coefficients between columns (1)–(2) and column (3) in Table 2 foreshadowed an analysis of the role of  $z$ : according to Prediction 2, overreaction increases in the number of cued first-period signals. This comparative statics prediction is a direct test of the role of associative memory because with either perfect memory

( $r = 1$  in the model) or imperfect-but-no-associative memory ( $a = 0$ ), this prediction would not hold, compare equation (4).

We now formally estimate equation (9) by including both  $n_{k+1}$  (the second-period signal) and  $n_{k+1}z$  (its interaction with the number of cued first-period signals) as separate regressors. Columns (4) and (8) of Table 2 therefore provide a formal and pre-registered test of Prediction 2 for both *Main* and *WTP*. The results show that the interaction term is positive and statistically highly significant, in line with the model predictions. The magnitude suggests that each additional first-period signal increases the responsiveness to the second-period signal by about 20–30%, on average.

Moreover, we see that the coefficient of the second-period signal  $n_{k+1}$  is now actually *less* than one. This coefficient captures the responsiveness of second-period beliefs to second-period signals when  $z = 0$ . It is reassuring that beliefs do not at all overreact in the case of zero positive and zero negative first-period signals because it shows that overreaction to the second-period is not an intrinsic feature of our experimental environment but indeed depends on the cueing effects described in the model. This underreaction is consistent with a large literature on belief updating that shows that in lab environments where the role of (associative) memory is shut down, people's belief updating typically exhibits underreaction or shading.<sup>10</sup> In our experiments, associative memory is sufficiently strong to turn such underreaction into overall overreaction.

To visually illustrate the dependence of overreaction on the signal history, it is instructive to compute the magnitude of overreaction that is implied in each individual decision. In the model, overreaction is defined relative to the counterfactual of not having received a second-period signal, which is unobservable. However, we can estimate overreaction by computing the amount of overreaction  $x_i^h$  implied in each belief  $b_i^h$  relative to the average belief of other subjects that did not receive a second-period signal but were exposed to the same first-period signal history  $h$ .<sup>11</sup> Figure 3 shows the distribution of decision-level overreaction. As the model predicts, we again see that overreaction strongly increases in  $z$ . Moreover, overreaction is present for the vast majority of decisions. For  $z = 2$ , 80% of decisions reflect overreaction, and for  $z = 3$ , 95% of decisions.

**Result 2.** *Overreaction increases in the number of cued first-period signals.*

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<sup>10</sup>As suggested in recent work by Enke and Graeber (2019), such shading at least partly reflects a response to cognitive uncertainty: people's subjective uncertainty about what the rational belief is. Here, cognitive uncertainty plausibly arises because subjects know that they might forget some first-period signals. This could induce subjects to state estimates that are regressive towards 100 (the prior), so that signals of  $-10$  and  $+10$  would not generate a difference in beliefs of 20 and, hence, a second-period coefficient of less than one.

<sup>11</sup>Formally,  $x_i^h = \text{sign}(n_{i,k+1})[b_i^h - \bar{b}_{\text{no signal}}^h - n_{i,k+1}]$ , where  $\bar{b}_{\text{no signal}}^h$  is the average belief of subjects that observed the same first-period signals but no second-period signal.

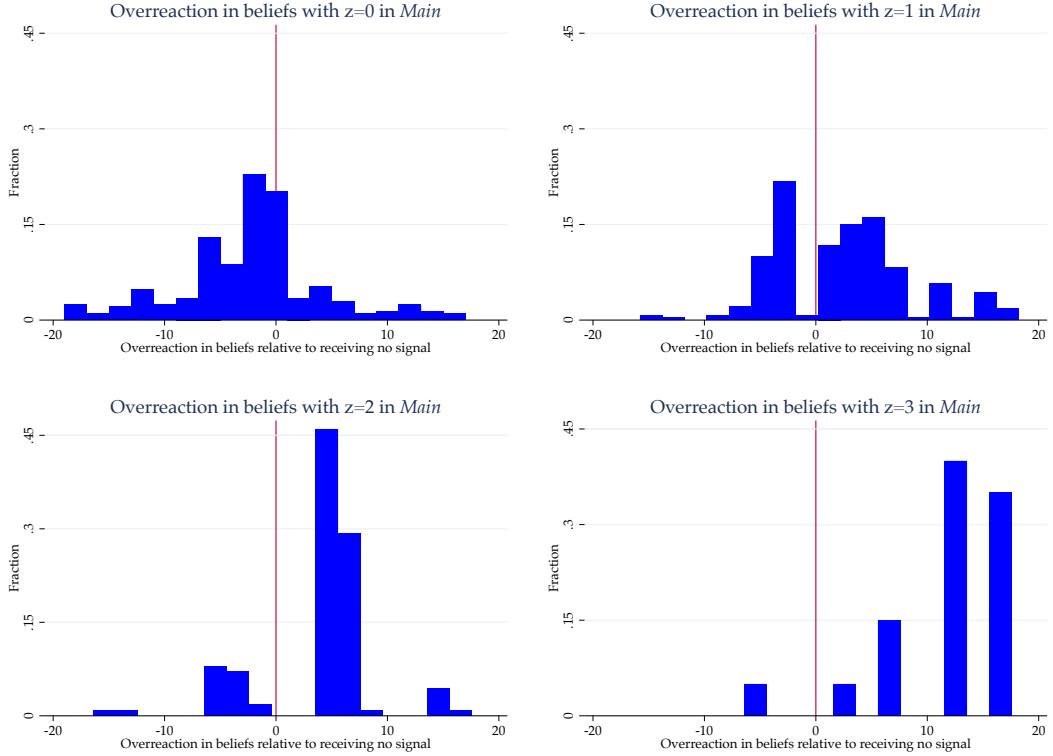


Figure 3: Overreaction in beliefs by signal history. Each histogram plots the distribution of overreaction  $x$  implied in each belief *relative to the average belief* of other subjects that did not receive a second-period signal but were exposed to the same first-period signal history. In the histograms, an observation is an individual decision by an individual subject. To ease visibility, we trim the sample at  $|x| > 20$ . This affects 11 out of 800 observations.

#### 4.4 Direct Evidence on Associative Recall

Our model asserts that the patterns documented above arise because subjects are more likely to recall first-period signals that are cued by the second-period context than those that are not. We can directly test this assumption using our unincentivized recall data. Figure 4 shows average levels of reported recall of first-period signals in condition *Main*, as a function of whether or not these first-period signals were cued by the second-period context. The figure shows that the recall of cued signals is very accurate, on average. In contrast, the recall of non-cued signals is more compressed.<sup>12</sup>

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<sup>12</sup>A potential concern is that the recall data do not have independent informational content but are constructed by subjects through ex post reasoning to match their stated beliefs. The data do not seem to support such a consistency-based interpretation. To see why, note that Figure 4 reveals very accurate recall of cued signals. Such accurate recall would not be predicted by a simple consistency account because there are often multiple combinations of positive and negative signals that would rationalize a given belief. For example, if a subject stated a belief of 110, then there are two combinations of recall data that rationalize such a belief: one positive / zero negative signals, and two positive / one negative signals.

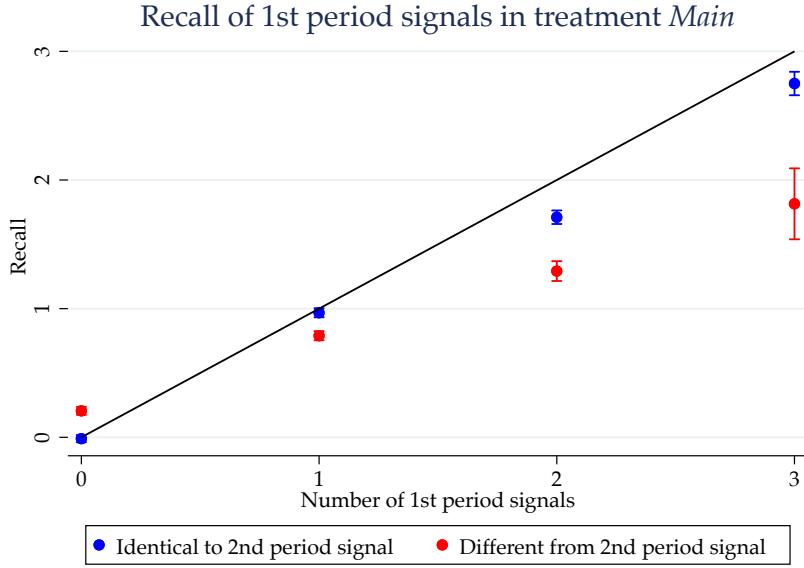


Figure 4: Recall of first-period signals in Treatment *Main*, depending on whether the second-period signal was identical to or different from the first-period signals. In the case of recall of signals that are different from the second-period signal, we use the reported recall quantity. In the case of recall of signals that are identical to the second-period signal, we use the reported recall minus one. That is, we make the arguably very plausible assumption that subjects always remember the value of the second-period signal that they just saw a few seconds ago.

## 5 Exogenous Variation in Other Model Parameters

### 5.1 The Role of Forgetting

To provide causal evidence for the role of imperfect memory in belief overreaction, we manipulate whether participants actually need to reconstruct prior knowledge from memory. Conceptually, treatment *Reminder* is designed to set  $r = 1$ . To this effect, we reminded participants of their first-period belief immediately before they received the second-period signal.

Columns (1)–(2) of Table 3 formally compare treatments *Main* and *Reminder*. As specified in the pre-registration, we again analyze our data by means of OLS regressions in which we relate subjects' second-period beliefs to the value of the second-period signal, except that now we also interact the second-period signal with a treatment dummy. Our prediction, spelled out in Sections 2 and 3.4, is that the value of the second-period signal should matter more in treatment *Main* than in *Reminder*. The results provide supporting evidence for this prediction. The interaction term is quantitatively large and statistically significant at all conventional levels. In *Main*, subjects respond 12–14% more to the value of the second-period signal than subjects in *Reminder*. Indeed, we see that the coefficient of the second-period signal (which, in this interaction regression, just captures the coefficient within treatment *Reminder*), equals almost exactly one. Thus, in

Table 3: Treatments *Main* vs. *Reminder* and *No Cue*

Treatments	Dependent variable:					
	2nd period belief		2nd period WTP		2nd period belief	
	<i>Main</i> vs. <i>Reminder</i>		<i>WTP</i> vs. <i>WTP reminder</i>		<i>Main</i> vs. <i>No Cue</i>	
	(1)	(2)	(3)	(4)	(5)	(6)
2nd period signal	0.99*** (0.01)	0.98*** (0.01)	0.97*** (0.04)	0.96*** (0.05)	0.89*** (0.04)	0.88*** (0.04)
2nd period signal × 1 if <i>Main</i> , 0 if <i>Reminder</i>	0.12*** (0.03)	0.14*** (0.03)				
2nd period signal × 1 if <i>WTP</i> , 0 if <i>Reminder WTP</i>			0.14** (0.06)	0.17** (0.07)		
2nd period signal × 1 if <i>Main</i> , 0 if <i>No Cue</i>					0.21*** (0.04)	0.22*** (0.05)
Belief in 1st period	0.84*** (0.02)				0.62*** (0.03)	
WTP in 1st period			0.66*** (0.04)			
Treatment FE	Yes	Yes	Yes	Yes	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes
1st period signal history FE	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	Yes
Observations	1300	1300	1800	1800	1600	1600
Adjusted $R^2$	0.86	0.86	0.69	0.74	0.68	0.67

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. In columns (1)–(2), the sample includes treatments *Main* and *Reminder*. In columns (3)–(4), the sample includes treatments *WTP* and *WTP reminder*. In columns (5)–(6), the sample includes treatments *Main* and *No Cue*. In all columns, the sample only includes subjects who observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

the presence of a reminder, there is no overreaction to recent news. Again, this pattern is a specific prediction of our framework, but not of an account of recency effects.

Columns (3)–(4) present analogous analyses for actions (willingness-to-pay) by comparing treatments *WTP* and *WTP reminder*. Again, overreaction is substantially stronger in the presence of memory imperfections. Again, the coefficient of the second-period signal suggests that in treatment *WTP reminder* there is again no overreaction at all.

**Result 3.** *Overreaction disappears once forgetting is shut down.*

## 5.2 The Role of Associations

We proceed by experimentally manipulating the relevance of associative memory. According to equation (5), if there is no associative recall, there should be no overreaction. As a direct test of this hypothesis, we compare treatments *Main* and *No Cue*. Recall that in treatment *No Cue*, each signal realization was communicated with a different context, so that the current context cannot cue identical past contexts.

Columns (5)–(6) of Table 3 present a formal comparison of treatments *Main* and *No Cue*. As specified in the pre-analysis plan, we link participants' second-period beliefs to the second-period signal, interacted with a treatment dummy. As predicted, the interaction term shows that subjects respond significantly more to the second-period signal in *Main* than in *No Cue*. Moreover, as predicted, there is no overreaction in treatment *No Cue* (which can again be inferred from the coefficient of the second-period signal). If anything, the data reveal slight underreaction. As discussed above, this underreaction result is consistent with a large set of findings from belief updating experiments in which associative recall cannot play a role by design. In combination, the results from treatments *Main* and *No Cue* again suggest that associative recall is so strong that it turns the traditional shading result into overreaction. Figure 6 in Appendix C visually illustrates these results by plotting the distribution of overreaction, akin to Figure 3 above.

**Result 4.** *Overreaction disappears once associative recall is shut down.*

## 5.3 Over- vs. Underreaction

Next, we turn to investigating predictions 5–7 in Section 3.4, which conceptually correspond to setting the parameter  $\rho = -1$  in the simple model. For this purpose, as discussed in Section 3, we implemented treatments *Underreaction* and *Underreaction reminder*. Here, a second-period signal cues the recollection of the opposite past signals. To verify that potential underreaction in treatment *Underreaction* is not driven by some form of confusion that could arise from the change in the mapping from news to contexts after the first period, treatment *Underreaction reminder* serves as a control treatment. That is, if subjects were somehow confused by the change in the association between signals and contexts between the first and second period, then this should also be present in the control treatment. Thus, the treatment difference identifies the role of associative memory.

Table 4 presents the regression results. Columns (1) and (2) show that, within treatment *Underreaction*, the coefficient of the second-period signal is 0.74–0.76, substantially smaller than one. Importantly, columns (3) and (4) show that, as posited in Prediction 6, underreaction strongly increases in the number of first-period signals that

Table 4: Treatments *Underreaction* and *Underreaction reminder*

	Dependent variable: 2nd period belief					
	Treatments:					
	<i>Underreaction</i>			+ <i>Reminder</i>		
	(1)	(2)	(3)	(4)	(5)	(6)
2nd period signal	0.76*** (0.04)	0.74*** (0.04)	0.99*** (0.04)	0.95*** (0.05)	1.01*** (0.02)	1.01*** (0.02)
Belief in 1st period	0.65*** (0.04)		0.50*** (0.05)		0.77*** (0.03)	
2nd period signal × # 1st period signals in same context			-0.31*** (0.06)	-0.28*** (0.07)		
2nd period signal × 1 if <i>Underr.</i> , 0 if <i>Reminder underr.</i>					-0.25*** (0.04)	-0.28*** (0.05)
Treatment FE	No	No	No	No	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes
Signal history FE	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	Yes
Observations	800	800	800	800	1300	1300
Adjusted $R^2$	0.67	0.68	0.68	0.70	0.79	0.79

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. In columns (3)–(4), the table suppresses the coefficients of the number of first-period signals that were communicated in the same context as the second-period signal. The sample includes all observations from treatments *Underreaction* and *Underreaction reminder* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

were communicated in the same context as the second-period signal, see the statistically significant interaction term. These interaction results are not only predicted by our model, they are also difficult to rationalize by an account of subject confusion: in columns (3)–(4), the coefficient of the second-period signals by construction captures the responsiveness of beliefs to the second-period signal for the case of  $z = 0$ . We can see that, when no first-period signal gets cued, the regression coefficient is almost exactly “rational.”

Finally, columns (5) and (6) compare treatments *Underreaction* and *Underreaction reminder*. Again, the coefficient of interest is the interaction term between the second-period signal and a treatment dummy. The dummy is statistically highly significant and suggests that underreaction is 25–28% stronger in *Underreaction*.<sup>13</sup> In contrast, as we

<sup>13</sup>Comparing the magnitude of these treatment effects with the corresponding estimates in treatment *Main*, we see more underreaction in *Underreaction* than overreaction in *Main*. As we document when we structurally estimate our model in Section 7, at least part of this difference can be attributed to a higher level of forgetting (lower  $r$  in the model) in *Underreaction*, see the estimates in Table 5.

can infer from the coefficient of the second-period signal, there is no underreaction in treatment *Underreaction reminder*, with a coefficient of 1.01, statistically indistinguishable from one. The evidence hence points to asymmetric recall as mechanism behind underreaction in the same way as it produced overreaction when  $\rho = 1$ .

Finally, to further corroborate the claim that underreaction is generated by asymmetric recall rather than subject confusion, Figure 7 in Appendix C analyzes the self-reported recall patterns in treatment *Underreaction* as a function of the signal history, akin to Figure 4 in Section 4. Here, we see that subjects' recall is much more precise for those first-period signals that *differ* from the second-period signal than for those that equal the second-period signal. This pattern corresponds to associative recall because those first-period signals that differ from the second-period signal now get cued by the second-period context.

**Result 5.** *When the correlation between context and news is negative, beliefs underreact with respect to the second-period signal.*

**Result 6.** *Underreaction increases in the number of cued first-period signals.*

**Result 7.** *Underreaction disappears once memory imperfections are shut down.*

## 5.4 Robustness

**Recall data.** As specified in the pre-analysis plan, we analyze our experimental predictions by looking at both incentivized beliefs (these are the main analyses above) and unincentivized reports of recall of positive and negative signals. As pre-registered, our corresponding outcome variable is the difference between recall of positive and recall of negative news, multiplied by ten, so that the variable has the same scale as the beliefs data. This summary statistic of a subject's recall is highly correlated with actual second-period beliefs ( $\rho = 0.95$ ), suggesting that the recall data are meaningful. Tables 8, 9 and 10 in Appendix D show that the results using this measure are very similar.

**Recency bias.** A prominent principle of memory is recency. The more recently information has been received, the more likely is its recall from memory. While recency bias could generate overreaction to news when the most recent past information matches current information, it does not predict overreaction when only non-recent past information matches current information. In addition, recency bias does not predict that overreaction increases in the number of cued first-period signals, or that it disappears when the role of associations is shut down in treatment *No Cue*, or that overreaction even reverses in *Underreaction*. Since we provide evidence for these features of memory-based overre-

action, our findings cannot be explained by recency bias. Associative recall hence plays an important role relative to other important principles of memory.

**False belief in serial dependence.** An important component of our design is that the signals are serially independent. In principle, the baseline result of overreaction could also result from subjects incorrectly believing that signals are positively autocorrelated. Three observations point against such an interpretation. (i) As discussed in Section 3, we took special care in explaining to subjects that signals are serially independent, and we verified their understanding of this through a comprehension check that less than 1% of prospective participants failed. (ii) An account of belief in autocorrelation does not explain why overreaction increases in the number of cued first-period signals. A belief in autocorrelation would lead participants to infer from a positive second-period that the first-period signals were probably also positive, yet the resulting overreaction would not depend on the specific random *realizations* of the first-period signals. (iii) An account of incorrect belief in autocorrelation would predict overreaction also in those cases in which a subject did not observe any first-period signals that match the second-period signal (e.g., two positive signals in the first period and a negative signal in the second period). In contrast, associative recall predicts no overreaction in this case. When we re-run our baseline regression from Table 2 only using those observations for which  $z = 0$ , we find an OLS coefficient of the second-period signal of 0.82 ( $s.e. = 0.05$ ) for beliefs and of 0.92 ( $s.e. = 0.07$ ) for WTP, both of which actually reflect underreaction. Thus, these results are also inconsistent with an account of false belief in autocorrelation.

## 6 Extension: Potential Limits of Associative Recall

In our model, memory is governed by the parameters  $r$  and  $a$ , which we assumed to be exogenous. In reality, however, their magnitude may depend on features of the problem, such as the length of the time lag between different piece of news, or the presence of what memory researchers refer to as “interference.” Given that economic predictions may depend on understanding in which settings associative memory is more or less likely to matter, this section investigates potential limits or boundaries of effects that are based on associative recall.

**Length of Time Lag.** A natural candidate for a limit of associative recall is the length of the time lag between the first and second period. If it was true that associativeness would stop operating already after a few days, then it would likely be of less interest to economists. Treatment *Extended time lag* followed the same procedure as treatment *Main*, except that the time lag between the first and second period of the experiment

was three days.<sup>14</sup> Due to the substantially increased time lag, we conducted treatment *Extended time lag reminder* as an additional benchmark condition, which is identical to treatment *Reminder*, except for the increased time lag. These two treatments were also pre-registered in the original pre-registration. 80 subjects participated in treatment *Extended time lag* and 50 in treatment *Extended time lag reminder*. Attrition was negligible (5%). Table 11 in Appendix D summarizes the results, which are very similar to those in treatments *Main* and *Reminder*: we see (i) overreaction; (ii) stronger overreaction when more first-period signals get cued by the second-period signal; and (iii) stronger overreaction relative to a treatment with a reminder. If anything, we find that overreaction is even stronger with a time lag of three days rather than 15 minutes: in the baseline regression, the OLS coefficient of the second-period signal increases from 1.10 in *Baseline* to 1.17 in *Extended time lag*.

**Interference.** Memory researchers highlight that forgetting (which is a prerequisite for associative recall to matter) is largely driven by similarity-based interference. To study the boundaries of associative recall based on interference, we introduce treatment *No interference*. In this treatment, there is only one company. In addition to this one company, subjects also completed eleven recall tasks that were designed to be similar to the main experimental task, without introducing interference via similarity. To this effect, we introduced eleven “groups” of colored shapes, where each group consisted of two shapes. For each of the groups, participants sequentially observed shapes on their decision screen and were then asked how many times they had seen shapes that belong to a particular group. We implemented this treatment with 60 additional subjects, randomized within session along with a replication of treatment *Main*. We find that, for the one company, overreaction disappears: the OLS coefficient of the second-period signal is 1.01 and statistically indistinguishable from the rational benchmark of one. Moreover, overreaction in *No interference* is significantly smaller than in treatment *Main replication*, see Table 13 in Appendix D. In fact, as Figure 8 in Appendix C shows, subjects’ recall of first-period signals is close to perfect once there is no interference. These results suggest that the strength of memory  $r$  decreases in the degree of similarity-based interference, consistent with recent theoretical work in both economics (Bordalo et al., 2020b) and psychology (Kahana, 2012).

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<sup>14</sup>In a further treatment, *No time lag*, we omit the 15-minutes time lag between the first and second period. Of course, for any given company, the time lag is not zero because participants also receive news for other companies. 60 subjects participated in this treatment, which was randomized within experimental sessions with a replication of treatment *Main*. Table 13 in Appendix D shows corresponding regression analyses. We find that the OLS coefficient of the second-period signal is 1.11 in both *Main replication* and *No time lag*. This suggest that the time lag of 15 minutes is inessential.

## 7 Model Estimations and Payoff Implications

All analyses reported up to this point are motivated and structured through the formal framework laid out in Section 2. To supplement these reduced-form analyses, we now explicitly estimate this model. This will serve two main purposes: (i) to shed light on the quantitative importance that associative recall plays in generating observed beliefs, relative to the importance of baseline forgetting, and (ii) to assess whether (and when) associations are on balance “good” or “bad” for beliefs and decision-making.

### 7.1 Quantitative Relevance

We estimate the parameters  $\hat{\gamma}$ ,  $\hat{r}$ , and  $\hat{a}$  by minimizing the sum of squared residuals for the non-linear regression equation (9) through maximum likelihood:

$$b_2^{i,j} = 100 + \gamma n_{k+1}^{i,j} + r \sum_{x=1}^k n_x^{i,j} + (1-r)a \sum_{x=1}^z n_x^{i,j} + \epsilon^{i,j}, \quad (10)$$

where  $\gamma$  measures an individual’s intrinsic responsiveness to the second-period signal. We estimate this equation by pooling the data across subjects, separately for each treatment.<sup>15</sup> In these estimations, the parameters are separately identified: (i)  $\gamma$  is identified by comparing second-period beliefs across realizations of the second-period signal, when there is no first-period signal; (ii)  $r$  is identified from observations where the second-period signal does not match any first-period signals; and (iii)  $a$  is identified by comparing (ii) with observations where the second-period signal matches some first-period signals.

Table 5 summarizes the results, where our focus is on understanding the quantitative importance of associative recall. In treatment *Main*, the baseline probability of recall is estimated to be  $\hat{r} = 0.56$ . On the other hand, when the second-period signal equals the first-period signal, associative memory implies a recall probability of  $\hat{r} + (1-\hat{r})\hat{a} = 0.83$ . Thus, associativeness implies an increase in the probability of remembering of 27pp., or 48%. Analogous calculations reveal that in treatment *Extended time lag*, where the time lag between the first and second period was three days, associative recall increases remembering from 32% to 76% – an increase of 137%. Thus, the effects of associative recall are large and persist over time.

In treatment *Reminder*, we confirm that imperfect memory entirely disappears (by construction of the treatment), so that associative recall cannot be identified with reasonable precision (compare the huge standard error). Analogously, we see that in treatment

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<sup>15</sup>In Appendix E, we present analogous estimates at the level of individual subjects.

Table 5: Estimates of model parameters across treatments

Treatment	Forgetting ( $1 - \hat{r}$ )	Associative recall $\hat{\alpha}$	Responsiveness $\hat{\gamma}$
<i>Main</i> *	0.44*** (0.03)	0.62*** (0.05)	0.91*** (0.02)
<i>Reminder</i>	0.01 (0.01)	-1.59 (4.83)	1.00*** (0.01)
<i>No Cue</i>	0.51*** (0.05)	0.01 (0.11)	0.88*** (0.05)
<i>Underreaction</i>	0.51*** (0.06)	0.61*** (0.08)	0.98*** (0.04)
<i>Extended time lag</i>	0.68*** (0.05)	0.65*** (0.06)	0.85*** (0.05)
<i>No interference</i>	0.04 (0.04)	0.64 (1.04)	0.99*** (0.05)

*Notes.* Maximum likelihood estimates of (10). Standard errors (in parentheses) are computed from a sandwich variance matrix estimate that controls for clustering at the subject level. The model is estimated by pooling the data across subjects in a given treatment. \*The estimates for treatment *Main* also include data from *Main replication* and *No time lag*. The estimates are almost identical for *Main* alone. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

*No Cue*, associative recall collapses to zero, again by construction of the treatment.<sup>16</sup>

## 7.2 Payoff Implications of Associative Recall

Associative recall provides a context-specific memory “booster.” Intuitively, such a booster can have both positive and negative effects, depending on the signal history. On the one hand, associations improve recall. On the other hand, such improved recall can be asymmetric, which in turn could lead to beliefs that are *more biased* than if people forgot nearly everything. To formally investigate this in the framework of our model, we compare expected payoffs with and without associative recall. Taking into account the binarized scoring rule used in the experiment and setting  $\rho = 1$ , we get:

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<sup>16</sup>Moreover, we see that subjects’ intrinsic responsiveness to the second-period signal  $\gamma$  (conditional on memory parameters) is usually estimated to be less than one, unless there are no memory imperfections. This again resonates with a large body of experimental work on belief formation: intrinsically, subjects usually *underreact* to current news. However, in our setup, the effects of associative recall are sufficiently strong to turn such intrinsic underreaction into overall overreaction.

$$\begin{aligned}
\Delta\pi &\equiv E[\pi(b, \theta)|a > 0] - E[\pi(b, \theta)|a = 0] \\
&= - \left\{ [1 + (1 - r)az]n_{k+1} + r \sum_{x=1}^k n_x - \theta \right\}^2 + \left\{ n_{k+1} + r \sum_{x=1}^k n_x - \theta \right\}^2 \\
&= (1 - r)^2 n_{k+1}^2 az(4z - az - 2k)
\end{aligned}$$

This implies that earnings will be higher with associations if  $\frac{z}{k} > \frac{2}{4-a}$ . In words, associations will have (i) a positive effect on beliefs and resulting payoffs if the fraction of first-period signals that gets cued by the second-period signal is large; (ii) a negative effect when the fraction of cued signals is small but strictly positive, and (iii) no effect when no first-period signals get cued. Intuitively, the negative effect in (ii) arises because asymmetrically remembering those first-period signals that were relatively less frequent pushes the second-period belief even further away from the truth than complete forgetting would.

To empirically test this prediction, we compare the (average) expected earnings in treatment *Main* (where associations are present) with those in *No Cue* (where they are not). Because the cutoff for the hypothesized earnings difference depends on  $a$ , we use the parameter estimates in Table 5 to generate predicted beliefs and resulting predicted earnings as a benchmark. Because we estimate  $\hat{a}^{Main} = 0.62$ , earnings should be higher with associations if and only if  $z/k > 0.59$ .

Figure 5 shows the results. We see that, as predicted, the payoff implications of associative recall strongly depend on the signal history: when the fraction of first-period signals that gets cued is small but strictly positive, associations harm. On the other hand, when that same fraction is large, associations improve stated beliefs. These patterns further highlight the need to distinguish between memory-driven belief errors and those that result from canonical biases in information-processing, as the latter typically induce lower earnings.

As a final remark, it is worth pointing out that the reason for the quantitative divergence between model predictions and observed earnings in the far right of Figure 5 is driven by extreme first-period signal histories such as three positive and zero negative. Intuitively, the reason is likely that when subjects are cued with, e.g., a positive second-period signal, they remember that they have observed that same signal before but they may be unsure of how often exactly they have seen it. Because this psychological mechanism is absent from our model, our simulations generate predictions that are too extreme. However, note that this only happens for extreme signal histories. In general, the simple three-parameter model fits the data very well: even though we estimate parameters at the population level (rather than for each subject separately), the predicted

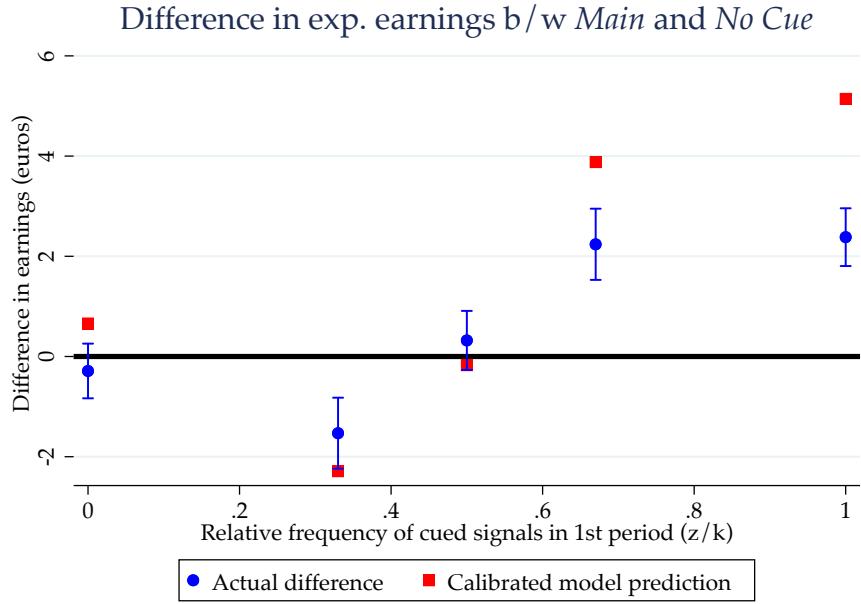


Figure 5: Difference in average expected earnings between treatments with associations (*Main*, *Main replication* and *No time lag*) and treatment *No Cue*. The model predictions are computed by applying the parameter estimates in Table 5 to equation (10) to predict beliefs, and then applying the binarized scoring rule described in Section 3. The x-axis captures the ratio between first-period signals that get cued by the second-period signal ( $z$ ) and the overall number of first-period signals ( $k$ ). Error bars show  $\pm 1$  SE.

beliefs that are implied by (10) and  $\hat{a}$ ,  $\hat{r}$  and  $\hat{\gamma}$ , are very highly correlated with observed individual-level beliefs. For instance, in treatment *Main*, the correlation is  $\rho = 0.88$ .

## 8 Discussion

Associative recall is one of the most important principles underlying psychological research on memory. Despite growing theoretical interest, experimental and empirical behavioral economists have so far largely neglected the potential role of associative memory and memory imperfections more broadly in shaping decision-making. This paper has provided an experimental analysis of the role of associative memory for belief formation and willingness-to-pay. We present the first set of theory-driven experiments that build a bridge between psychological paradigms on cued recall and structured, quantitative economic decision tasks. In doing so, we have both provided an existence proof that associative recall can matter for belief formation and choice, and investigated relevant comparative statics effects, potential limits and quantitative relevance. Our experiments and estimations suggest a predictable and quantitatively meaningful role for associative memory in belief formation, and that associations can be either a “net positive” or a “net negative” in terms of payoffs, depending on the signal history.

We believe that by offering a new experimental paradigm in which questions related

to associative memory can be studied, our paper provides a stepping stone for further experimental research in an agenda on memory imperfections and belief formation. We highlight two broad avenues and open questions.

A first broad avenue – linked to existing theoretical work – could empirically investigate further *implications* of associative recall for choice and belief formation. First, our experiments are potentially related to an active literature that documents overreaction in survey expectations about economic variables (e.g., Bordalo et al., 2020c). The result of overreaction in field data is often considered to be a slight puzzle from the perspective of laboratory research on belief formation. This is because structured laboratory belief updating problems almost always find underreaction, at least partly due to participants' cognitive uncertainty (Enke and Graeber, 2019). However, in these laboratory experiments, memory imperfections are by design ruled out. We do not intend to claim that associative recall can explain the entire pattern of over- and underreaction identified in the literature. However, it is conceivable that *part* of the reason why the laboratory and field literatures identify such different patterns is that memory constraints and memorable contexts likely play a more important role in the field, as exemplified by Shiller's (2017; 2019) discussion of the role of memorable narratives and "cue-dependent forgetting." As a second economic application, future research could investigate "optimal cue design:" given the positive and negative effects of associations on earnings, which combination of cues is optimal from the perspective of a designer? Third, experimental work could use techniques similar to ours to elucidate empirically how associations shape valuation and choice among consumed goods. Fourth, an interesting potential agenda could link associative recall to marketing and advertising, which in many ways builds on the idea of generating positive associations. Fifth, political economy applications appear ripe for exploration, where highly valent narratives about immigrants or the costs of taxation could induce people to asymmetrically remember past information that is congruent with current news, and therefore to overreact.

A second broad avenue could delve into the *mechanics of associative recall*. First, our results emphasize that associative recall can be good or bad (compared to random retrieval), depending on the signal history. But it remains to be explored more generally to what extent associative recall is adaptive and how the possibly beneficial consequences of associativeness depend on features of the updating environment. Second, in our experiments, the contexts that link signals in the first and second period are kept identical. An open question is how more granular variation in similarity would affect recall, such as when the images or stories are similar but not identical. This discussion links to the important role that the concept of interference plays in psychological research. Third, our experimental contexts always include two dimensions: images and stories. Future research could delve into the importance of either of these two, or potentially add ad-

ditional dimensions. For example, if dozens of dimensions are added, it is conceivable that people get overburdened and associative recall severely attenuates. Fourth, in our experiments, subjects only receive one second-period signal that potentially cues first-period news; an interesting question is what would happen in a more dynamic setup, in which people receive both positive and negative current news.

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# ONLINE APPENDIX

## A Additional Derivations

### A.1 Partial Naïveté

#### A.1.1 Type I naïveté

The main text assumes that decision-makers are fully naïve about their memory imperfections. We now verify robustness against assuming partial naïveté. Suppose the DM to some extent (captured by naïveté parameter  $\mu$  such that  $\mu = 0$  for full naïveté and  $\mu = 1$  for full sophistication) fails to realize that he sometimes forgets. When he does realize that he forgot a past signal  $n_x$ , however, then he correctly (in a Bayesian sense) infers the realization of the information based on memory parameters  $r$  and  $a$ .

We have that  $Pr(n_x = n_{k+1} | \text{no recall}, n_{k+1}) = \frac{(1-r)-(1-r)a}{(1-r)-(1-r)a+(1-r)} = \frac{1-a}{2-a}$ . Accordingly, we have that  $E(n_x | \text{no recall}, n_{k+1}) = n_{k+1} \frac{1-a}{2-a} - n_{k+1} \frac{1}{2-a} = \frac{-a}{2-a} n_{k+1}$ .

The expected belief in period  $t = 2$  is then given by:

$$\begin{aligned} E[b_2 | n_x, n_{k+1}] &= v + n_{k+1} + \sum_{x=1}^k m_x n_x + \mu \sum_{x=1}^k (1-m_x) \frac{-a}{2-a} n_{k+1} \\ &= v + n_{k+1} + \sum_{x=1}^k r n_x + \sum_{x=1}^z (1-r)a n_x \\ &\quad + \mu \sum_{x=1}^k (1-r) \frac{-a}{2-a} n_{k+1} + \mu \sum_{x=1}^z (1-r)a \frac{-a}{2-a} n_{k+1} \end{aligned} \tag{11}$$

$$= v + [1 + \rho(1-r)a(z + \mu z \frac{a}{2-a} - \mu k \frac{1}{2-a})] n_{k+1} + r \sum_{x=1}^k n_x \tag{12}$$

Note that equation (12) mirrors equation (5) from Section 2. Equation (12) allows us to directly analyze the implications of allowing for partial naïveté.

We first note that if  $\mu$  is small ( $\mu \rightarrow 0$ ), then equation (12) converges to equation (5).

Second, we note that “on average” (across possible signal histories), equation (12) still predicts overreaction for all levels of  $\mu < 1$  and  $\rho = 1$ . To see this, note that there is overreaction as long as  $z + \mu z \frac{a}{2-a} - \mu k \frac{1}{2-a} > 0$ . For a given  $k$ ,  $z$  is randomly and symmetrically distributed with mean  $\frac{k}{2}$ . Due to the linear structure of equation (12), it therefore suffices to note that  $z + \mu z \frac{a}{2-a} - \mu k \frac{1}{2-a} > 0$  for  $z = \frac{k}{2}$  and  $\mu < 1$ .

### A.1.2 Type II naïveté

According to type II naïveté, the DM fully realizes that he sometimes forgets, but is naïve in how she infers what he forgot. This form of naïveté is captured by the DM's belief  $\hat{a}$  about memory parameter  $a$ ,  $\hat{a} \leq a$ . Here,  $\hat{a} = 0$  captures full naïveté, meaning that the DM is aware of imperfect memory but not of the associative nature of recall.  $\hat{a} = 1$  captures full sophistication, meaning that the DM fully takes into account that he is more likely to retrieve information that is cued by the current context.

The DM's inference would then be as outlined in the previous section, except that it would use  $\hat{a}$ . The DM's forecast would thus be given by  $f = v + n_{k+1} + \sum_{x=1}^k m_x n_x + \sum_{x=1}^k (1 - m_x) \frac{-\hat{a}}{2 - \hat{a}} n_{k+1}$ .

Analogous to type I naïveté, the expected belief in period  $t = 2$  is given by:

$$\begin{aligned} E[b_2 | n_x, n_{k+1}] &= v + n_{k+1} + \sum_{x=1}^k m_x n_x + \sum_{x=1}^k (1 - m_x) \frac{-\hat{a}}{2 - \hat{a}} n_{k+1} \\ &= v + n_{k+1} + \sum_{x=1}^k r n_x + \sum_{x=1}^z (1 - r) a n_x \\ &\quad + \sum_{x=1}^k (1 - r) \frac{-\hat{a}}{2 - \hat{a}} n_{k+1} + \sum_{x=1}^z (1 - r) a \frac{-\hat{a}}{2 - \hat{a}} n_{k+1} \end{aligned} \quad (13)$$

$$= v + [1 + \rho(1 - r)(az + az \frac{\hat{a}}{2 - \hat{a}} - k \frac{\hat{a}}{2 - \hat{a}})] n_{k+1} + r \sum_{x=1}^k n_x \quad (14)$$

As above, we first note that if  $\hat{a}$  is small ( $\hat{a} \rightarrow 0$ ), then equation (14) converges to equation (5).

Moreover, by an analogous argument to the previous section, there would again be overreaction as long as  $\hat{a} < 1$ . To see this, note that there is overreaction as long as  $az + az \frac{\hat{a}}{2 - \hat{a}} - k \frac{\hat{a}}{2 - \hat{a}} > 0$ . For a given  $k$ ,  $z$  is randomly and symmetrically distributed with mean  $\frac{k}{2}$ . Due to the linear structure of equation (14), it therefore suffices to note that  $az + az \frac{\hat{a}}{2 - \hat{a}} - k \frac{\hat{a}}{2 - \hat{a}} > 0$  for  $z = \frac{k}{2}$  and  $\hat{a} < 1$ .

## B Overview of Experimental Treatments

Table 6: Treatment overview

Treatment	# of subjects	Ave. earnings (euros)	Pre-registration document
<i>Main</i>	80	15.20	1
<i>Reminder</i>	50	17.80	1
<i>No Cue</i>	80	14.00	1
<i>Extended time lag</i>	80	24.00	1
<i>Extended time lag reminder</i>	50	27.50	1
<i>Underreaction</i>	80	14.70	2
<i>Underreaction reminder</i>	50	18.00	2
<i>WTP</i>	100	19.10	3
<i>WTP reminder</i>	80	18.80	3
<i>Main replication</i>	60	13.40	4
<i>No time lag</i>	60	12.40	4
<i>No interference</i>	60	19.20	4

Notes. Horizontal lines indicate which treatments were randomized within the same experimental sessions. Payments included a show-up fee of € 15 in *Extended time lag / Extended time lag reminder* and of € 5 in all other treatments.

## C Additional Figures

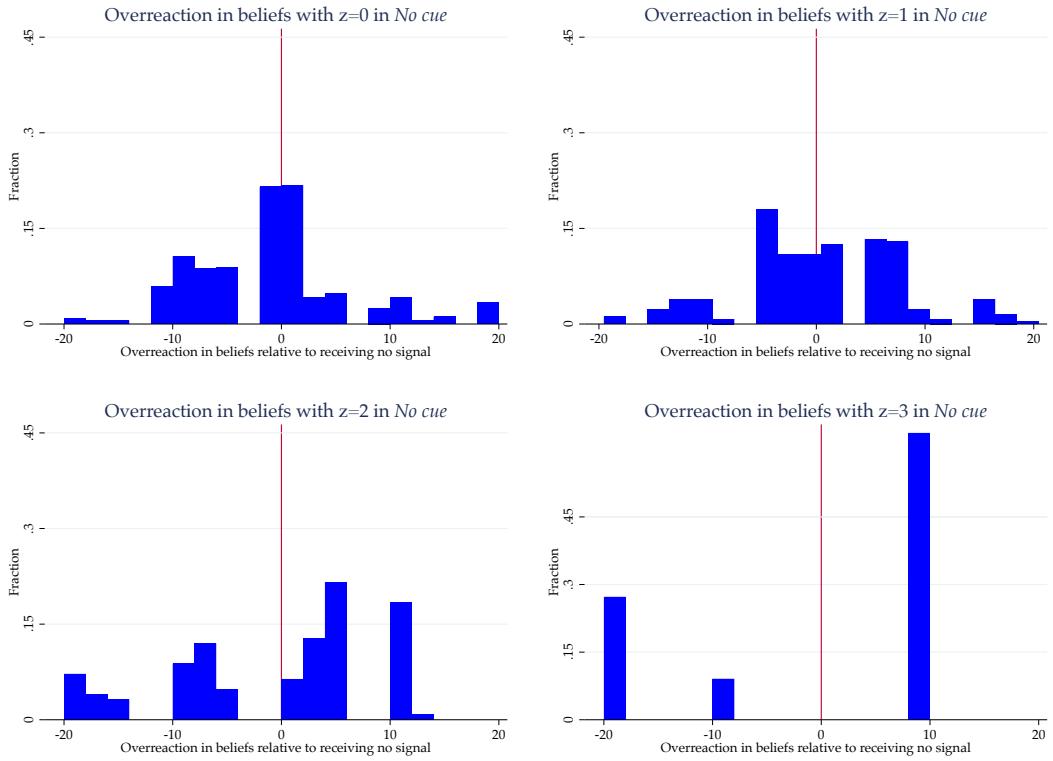


Figure 6: Overreaction in beliefs by signal history. Each histogram plots the distribution of overreaction  $x$  implied in each belief  $i$  relative to the average belief of other subjects that did not receive a second-period signal but were exposed to the same first-period signal history  $h$ . In the histograms, an observation is an individual decision by an individual subject. To ease visibility, we trim the sample at  $|x| > 20$ . This affects 11 out of 800 observations.

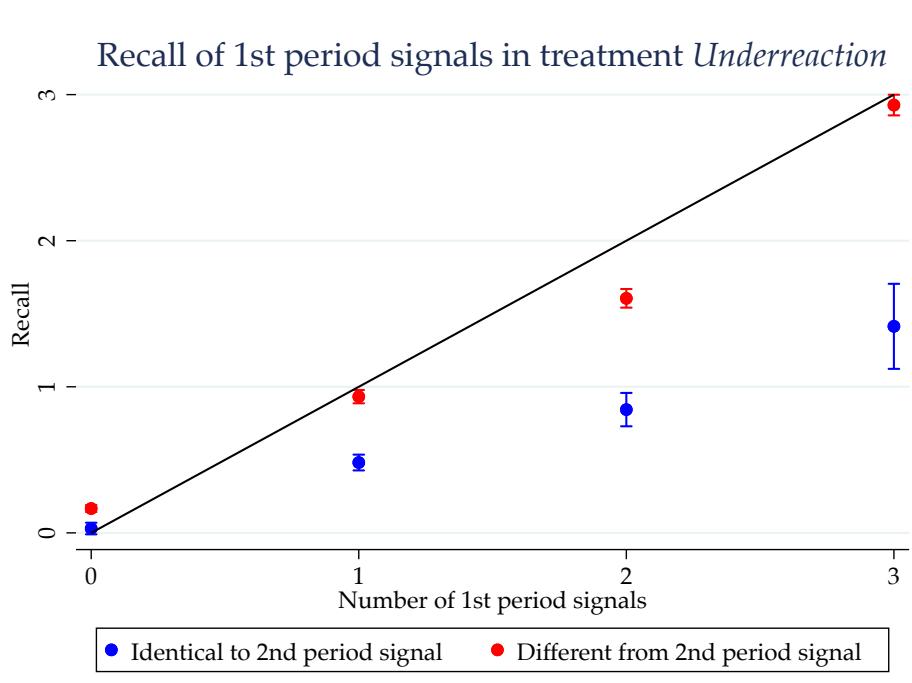


Figure 7: Recall of first-period signals in Treatment *Underreaction*, depending on whether the second-period signal was identical to or different from the first-period signals. We construct the recall variables as follows. In the case of recall of signals that are different from the second-period signal, we use the reported recall quantity. In the case of recall of signals that are identical to the second-period signal, we use the reported recall minus one. That is, we make the arguably very plausible assumption that subjects always remember the value of the second-period signal that they just saw a few seconds ago.

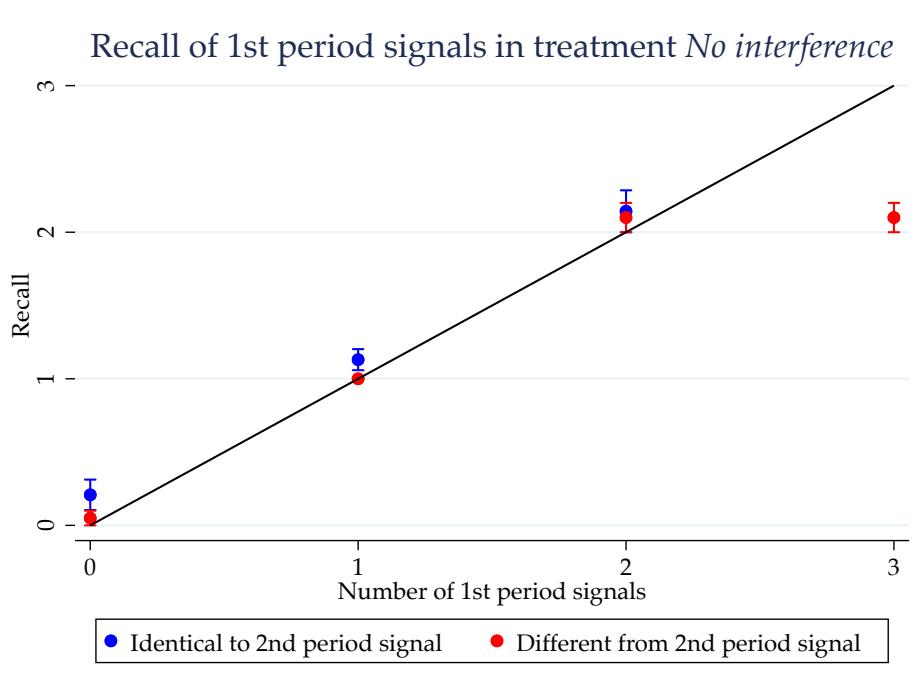


Figure 8: Recall of first-period signals in Treatment *No interference*, depending on whether the second-period signal was identical to or different from the first-period signals. We construct the recall variables as follows. In the case of recall of signals that are different from the second-period signal, we use the reported recall quantity. In the case of recall of signals that are identical to the second-period signal, we use the reported recall minus one. That is, we make the arguably very plausible assumption that subjects always remember the value of the second-period signal that they just saw a few seconds ago.

## D Additional Tables

Table 7: Treatment *Main*: Heterogeneity analysis

	<i>Dependent variable:</i> 2nd period belief					
	(1)	(2)	(3)	(4)	(5)	(6)
2nd period signal	1.26*** (0.08)	1.25*** (0.09)	1.23*** (0.04)	1.21*** (0.04)	1.14*** (0.04)	1.14*** (0.04)
2nd period signal × Raven score	-0.030** (0.01)	-0.028* (0.01)				
2nd period signal × Memory for non-cued signals			-0.23*** (0.06)	-0.20*** (0.06)		
2nd period signal × Response time					-0.37 (0.29)	-0.35 (0.24)
Belief in 1st period	0.75*** (0.03)		0.75*** (0.03)		0.75*** (0.03)	
Session FE	No	Yes	No	Yes	No	Yes
1st period signal history FE	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	Yes
Observations	800	800	800	800	800	800
Adjusted $R^2$	0.80	0.80	0.80	0.80	0.80	0.80

*Notes.* OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The table suppresses the coefficients of Raven score (columns (1)–(2)), memory for non-cued signals (columns (3) –(4)), and response time (columns (5)–(6)). Response times are measured in minutes. The sample includes all observations from treatment *Main* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 8: Treatment Main: Recall data

	Dependent variable: $\Delta$ Recall [Pos. – Neg.]				
	(1)	(2)	(3)	(4)	(5)
2nd period signal	1.05*** (0.04)	1.06*** (0.03)	1.07*** (0.04)	0.79*** (0.05)	0.83*** (0.05)
Belief in 1st period		0.74*** (0.03)		0.57*** (0.05)	
Company value in 1st period			0.74*** (0.03)		
2nd period signal × # 1st period signals in same context				0.36*** (0.05)	0.31*** (0.05)
Session FE	No	No	Yes	No	Yes
1st period signal history FE	No	No	Yes	No	Yes
Company FE	No	No	Yes	No	Yes
Order FE	No	No	Yes	No	Yes
Subject FE	No	No	Yes	No	Yes
Observations	800	800	800	800	800
Adjusted $R^2$	0.76	0.77	0.77	0.78	0.78

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The  $\Delta$  recall variable is constructed as difference between reported recall of positive and negative signals. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 9: Treatments *Main* vs. *Reminder* and *No Cue*: Recall data

	Dependent variable: $\Delta$ Recall [Pos. – Neg.]					
	Main vs. Reminder			Main vs. No Cue		
	(1)	(2)	(3)	(4)	(5)	(6)
2nd period signal	0.95*** (0.02)	0.95*** (0.02)	0.94*** (0.02)	0.76*** (0.05)	0.75*** (0.05)	0.77*** (0.06)
2nd period signal $\times$ 1 if <i>Main</i> , 0 if <i>Reminder</i>	0.11** (0.04)	0.12*** (0.04)	0.13*** (0.04)			
2nd period signal $\times$ 1 if <i>Main</i> , 0 if <i>No Cue</i>				0.29*** (0.06)	0.29*** (0.06)	0.30*** (0.07)
Belief in 1st period	0.83*** (0.02)			0.60*** (0.03)		
Company value in 1st period		0.83*** (0.02)			0.61*** (0.03)	
Treatment FE	Yes	Yes	Yes	Yes	Yes	Yes
Session FE	No	No	Yes	No	No	Yes
1st period signal history FE	No	No	Yes	No	No	Yes
Company FE	No	No	Yes	No	No	Yes
Order FE	No	No	Yes	No	No	Yes
Subject FE	No	No	Yes	No	No	Yes
Observations	1300	1300	1300	1600	1600	1600
Adjusted $R^2$	0.82	0.83	0.83	0.62	0.63	0.63

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. In columns (1)–(3), the sample includes all observations from treatments *Main* and *Reminder* where subjects observed a second-period signal. In columns (4)–(6), the sample includes all observations from treatments *Main* and *No Cue* where subjects observed a second-period signal. The  $\Delta$  recall variable is constructed as difference between reported recall of positive and negative signals. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 10: Treatments *Underreaction* and *Underreaction reminder*: Recall data

	Dependent variable: 2nd period belief					
	Treatments:					
	<i>Underreaction</i>				+ Reminder	
	(1)	(2)	(3)	(4)	(5)	(6)
2nd period signal	0.62*** (0.05)	0.60*** (0.05)	0.86*** (0.05)	0.81*** (0.06)	0.89*** (0.03)	0.91*** (0.04)
Belief in 1st period		0.66*** (0.04)		0.49*** (0.05)		0.76*** (0.03)
2nd period signal × # 1st period signals in same context			-0.33*** (0.06)	-0.28*** (0.06)		
2nd period signal × 1 if <i>Underr.</i> , 0 if <i>Reminder underr.</i>					-0.28*** (0.06)	-0.32*** (0.06)
Treatment FE	No	No	No	No	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes
Signal history FE	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	Yes
Observations	800	800	800	800	1300	1300
Adjusted $R^2$	0.59	0.61	0.61	0.63	0.71	0.72

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The  $\Delta$  recall variable is constructed as difference between reported recall of positive and negative signals. In columns (3)–(4), the table suppresses the coefficient of the number of first-period signals that were communicated with the same context as the second-period signal. The sample includes all observations from treatments *Underreaction* and *Reminder underreaction* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 11: Treatments *Extended time lag* and *Extended time lag reminder*

	Dependent variable:											
	2nd period belief						Δ Recall [Pos. – Neg.]					
	Time lag		+ Reminder time lag		Treatments:		Time lag		+ Reminder time lag		+ Reminder time lag	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
2nd period signal	1.17*** (0.04)	1.16*** (0.04)	0.85*** (0.05)	0.84*** (0.06)	1.02*** (0.02)	1.03*** (0.02)	0.97*** (0.05)	0.96*** (0.06)	0.66*** (0.05)	0.66*** (0.06)	0.97*** (0.06)	0.98*** (0.03)
Belief in 1st period	0.52*** (0.04)		0.33*** (0.05)		0.71*** (0.03)		0.52*** (0.04)		0.33*** (0.05)		0.70*** (0.03)	
2nd period signal × # 1st period signals in same context			0.44*** (0.05)	0.45*** (0.07)					0.43*** (0.06)	0.43*** (0.07)		
2nd period signal × 1 if Time lag, 0 if Reminder t.l.					0.18*** (0.04)	0.15*** (0.05)					0.022 (0.06)	-0.0011 (0.06)
Treatment FE	No	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Signal history FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	800	800	800	800	1300	1300	800	800	800	800	1300	1300
Adjusted $R^2$	0.68	0.67	0.70	0.70	0.77	0.77	0.57	0.57	0.60	0.60	0.70	0.70

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. In columns (3)–(4) and (9)–(10), the table suppresses the coefficient of the number of first-period signals that were communicated with the same context as the second-period signal. The sample includes all observations from treatments *Extended time lag* and *Extended time lag reminder* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 12: Treatments *Main repl.*, *No time lag*, and *No interf.*

Dependent variable: 2nd period belief									
Treatments:									
	<i>Main repl.</i>		<i>No time lag</i>		<i>No interference</i>		<i>Main repl. + No time lag</i>		<i>Main repl. + No interf.</i>
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2nd period signal	1.11 *** (0.03)	1.14 *** (0.04)	1.11 *** (0.03)	1.11 *** (0.04)	1.01 *** (0.04)	0.92 *** (0.06)	1.11 *** (0.03)	1.12 *** (0.04)	1.11 *** (0.03)
Belief in 1st period	0.65 *** (0.05)		0.67 *** (0.05)		0.98 *** (0.03)		0.66 *** (0.04)		0.68 *** (0.05)
2nd period signal × 1 if <i>No time lag</i> , 0 if <i>Main repl.</i>					-0.0011 (0.05)		-0.0058 (0.05)		
2nd period signal × 1 if <i>No interf.</i> , 0 if <i>Main repl.</i>								-0.16 ** (0.07)	-0.33 *** (0.08)
Treatment FE	No	No	No	No	No	Yes	Yes	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes	Yes	No	Yes
Signal history FE	No	Yes	No	Yes	No	Yes	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	No	Yes	No	No
Observations	600	600	600	600	60	1200	1200	660	660
Adjusted $R^2$	0.76	0.76	0.74	0.76	0.95	0.95	0.75	0.76	0.77

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The sample includes all observations from treatments *Main replication*, *No time lag*, and *No interf.* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 13: Treatment *Main repl.*, *No time lag*, and *No interf.*: Recall data

	Dependent variable: $\Delta$ Recall [Pos. - Neg.]									
	Treatments:									
	<i>Main repl.</i>		<i>No time lag</i>		<i>No interference</i>		<i>Main repl. + No time lag</i>		<i>Main repl. + No interf.</i>	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2nd period signal	1.06*** (0.04)	1.07*** (0.04)	1.04*** (0.05)	1.03*** (0.05)	1.07*** (0.05)	1.03 *** (0.04)	1.06*** (0.04)	1.06*** (0.05)	1.06*** (0.04)	1.08*** (0.04)
Belief in 1st period	0.68*** (0.05)		0.69*** (0.04)		1.00*** (0.03)		0.68*** (0.03)		0.70*** (0.04)	
2nd period signal $\times$ 1 if <i>No time lag</i> , 0 if <i>Main repl.</i>								-0.020 (0.06)	-0.031 (0.07)	
2nd period signal $\times$ 1 if <i>No interf.</i> , 0 if <i>Main repl.</i>									-0.050 (0.08)	-0.17* (0.09)
Treatment FE	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Session FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Signal history FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Company FE	No	Yes	No	Yes	No	No	No	Yes	No	Yes
Order FE	No	Yes	No	Yes	No	No	No	Yes	No	Yes
Subject FE	No	Yes	No	Yes	No	No	No	Yes	No	No
Observations	600	600	600	600	60	60	1200	1200	660	660
Adjusted $R^2$	0.73	0.73	0.71	0.71	0.94	0.97	0.72	0.72	0.74	0.74

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The  $\Delta$  recall variable is constructed as difference between reported recall of positive and negative signals. The sample includes all observations from treatments *Main replication*, *No time lag*, and *No interf* where subjects observed a second-period signal. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 14: Treatment *No interference*: Associative memory in recall of colored shapes

	<i>Dependent variable:</i> Recall of shapes in group		
	(1)	(2)	(3)
# 1st period shapes in same context	0.74*** (0.05)	0.68*** (0.11)	0.70*** (0.10)
# 1st period shapes in different context	0.60*** (0.06)	0.53*** (0.12)	0.56*** (0.11)
Session FE	No	Yes	Yes
Shape history FE	No	Yes	Yes
Group FE	No	Yes	Yes
Order FE	No	Yes	Yes
Subject FE	No	No	Yes
Observations	540	540	540
Adjusted $R^2$	0.45	0.46	0.55

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The sample includes all observations from treatment *No interference* where subjects reported the recall of the number of shapes in a given group. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

## E Individual-Level Estimation of Model

In this section, we estimate the same model as in Section 7, yet separately for each individual. To assess the fit of the model at the individual level, we use the individual-level estimates of  $\hat{r}_i$  and  $\hat{a}_i$  to predict participant  $i$ 's reported recall of those first-period news that did ( $q_i^c$ ) or did not ( $q_i^n$ ) get cued by the second-period signal:

$$\hat{q}_i^n = \hat{r}_i * (k - z) \quad (15)$$

$$\hat{q}_i^c = [\hat{r}_i + (1 - \hat{r}_i)\hat{a}_i] * z \quad (16)$$

where  $z$  again denotes the number of first-period signals that were communicated in the same context as the second-period signal, and  $k$  the total number of first-period signals. Note that the recall data do not enter the estimation and prediction procedure because the memory parameters are estimated only from the beliefs data. Thus, comparing *predicted* with *actual* recall allows for an assessment of model fit.

We find that, within treatment *Main*, the correlation between predicted and actual recall of those signals that got cued by the second-period signal is  $\rho = 0.82$ . The correlation between predicted and actual recall of those signals that did not get cued is  $\rho = 0.67$ , see Figure 9. We interpret these results as encouraging evidence that our simple two-parameter memory model fits the observed data well.

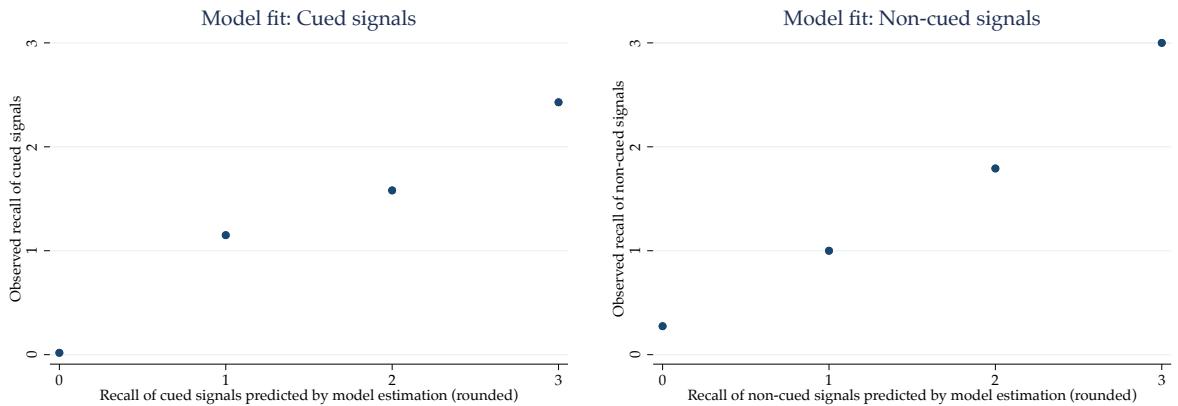


Figure 9: Relationship between recall as predicted by the model estimates and actual recall. The figures represent binned scatter plots that average observed recall for a given level of (rounded) predicted recall. Predicted recall is computed by first estimating equation (10) at the subject level and then applying equations (15) and (16).

## F Experimental Instructions

We provide translations of the paper-based instructions here. An English version of the computer program for treatment *Main* (where subjects observe news and enter their guesses) can be accessed at [https://unikoelnwiso.eu.qualtrics.com/jfe/form/SV\\_0MrVD2rNNrKeLGt](https://unikoelnwiso.eu.qualtrics.com/jfe/form/SV_0MrVD2rNNrKeLGt). Screenshots of this tourist version are provided in Section H.

### F.1 Treatment *Main*

Welcome to the Experiment!

We ask you to remain quiet throughout the experiment, and to refrain from talking to or disturbing other participants. Should you have any questions, please notify one of the experimenters. Please do so quietly in order to avoid disturbing other participants.

As is the case in all experiments in the BonnEconLab, you are free to leave the experiment at any time without explanation.

The main part of the experiment consists of two parts that belong together. Below you will receive the instructions for both parts. Please read the instructions carefully. At the end of the instructions, you will be asked a series of control questions in order to test your understanding of the instructions. You may only take part in the experiment if you answer these control questions correctly.

For your participation you will receive a participation fee of 5 euros. Depending on your decisions, you can earn additional money.

#### PART 1 OF THE EXPERIMENT

In this experiment, there are twelve hypothetical firms. We have invented twelve firms that are in no way related to real firms. These firms have the following names:

- Firm X
- Firm I
- Firm K
- Firm N
- Firm J

- Firm M
- Firm D
- Firm U
- Firm P
- Firm G
- Firm R
- Firm T

Each firm has a stock price that is determined by a simple formula: The stock price is given by the so-called base price plus the sum of all news you receive about the respective firm over the course of the entire experiment.

For example, suppose that there are two pieces of news for a firm. Then, the stock price of that firm is calculated as follows:

$$\text{Stock price} = \text{Base price} + \text{News 1} + \text{News 2}$$

This is just an example. In the actual experiment, you will not receive two pieces of news for each firm. Instead, the number of news varies from firm to firm. You will thus receive more news about some firms than about others. It is also possible that you receive no news at all for some firms. It is just important for you to understand that the stock price is calculated as the sum of the base price and all news. In this experiment, you can hence simply calculate the stock price of a firm by adding up the base price of a firm and all news about this firm. Other factors do not play a role in determining the stock price.

### **The Base Price**

The base prices of the firms are known and identical across firms: the base price of each firm is 100.

### **The News**

In this experiment, there are two types of news for each firm, where one type of news is positive and the other type of news is negative. Positive news have a value of +10, which means that the stock price of the respective firm increases by 10. Negative news have a value of -10, which means that the stock price of the respective firm decreases

by 10. You can see that positive and negative news each have exactly the same value, except that one is positive and one negative.

Once the experiment begins, you will see the news for the different firms in sequential order. First, on a separate screen, you will be informed about which firm the upcoming news concern. In case you receive no news for that firm, you will be informed about this on your screen. In case you do receive news, these will be displayed one after another on your screen (one piece of news per screen). How many news you receive for a particular firm is determined randomly by the computer and does not depend on the value of the news for the firm.

The computer determines randomly whether the news for a particular firm are positive or negative. You can think of this as the computer tossing a fair coin each time:

- Heads means positive news (Probability 50%)
- Tails means negative news (Probability 50%)

Importantly, it can happen that the same type of news occurs several times. In this case, you also have to incorporate the news several times.

Example 1: The base price of a firm is 100 and you receive news  $-10$  twice for this firm, and news  $+10$  once (because the three coin tosses of the computer turned out that way). Then, the correct stock price is given by  $100 - 10 - 10 + 10 = 90$ .

Example 2: The base price of a firm is 100 and you receive no news about this firm. Then, the correct stock price is 100.

Example 3: The base price of a firm is 100 and you receive one news  $+10$  for the firm (because the coin toss of the computer happened to land that way). The correct stock price in this case is given by  $100 + 10 = 110$ .

Please note that the computer independently tosses a coin for each firm and each piece of news, such that each coin toss is completely independent of the others. This means that the development of the stock price of a firm is completely random and does not follow systematic trends. Just because the first piece of news was positive does not mean that the second piece will also be positive. Rather, the probability for positive news is again exactly 50%, because the coin tosses are completely independent of each other.

Please also note that this implies that for every firm the expected value of the news is exactly zero: positive and negative news have the same value and the probability for

each is 50:50. Thus, in case you don't know the news for a firm, you know that the news is on average zero and thus no change in the stock price occurs.

### **Communication of the News**

As already mentioned, in this experiment you will receive news about the stock prices of twelve firms. In case you receive news for a firm, the news will appear sequentially on separate screens. However, the news appear separately for each firm. This means that you will first observe all news for one company, then all the news for another company, and so on. It will be important for you to distinguish which news belong to which firm.

The news will be communicated to you on your screen. Each piece of news is communicated along with two features:

1. Each type of news is accompanied by a particular "story", that explains to you why this particular type of news occurred.
2. Each type of news is accompanied by a particular image that will be displayed on your screen. This image will roughly reflect the story.

In this experiment, there are 24 types of news in total: one positive and one negative type of news for each of the twelve firms. As explained above, each of these 24 types of news is accompanied by a specific image and a specific story:

- The positive news about firm X will only be communicated with story 1 and image 1.
- The negative news about firm X will only be communicated with story 2 and image 2.
- The positive news about firm I will only be communicated with story 3 and image 3.
- The negative news about firm I will only be communicated with story 4 and image 4.
- Etc.

Please note: As mentioned above, it can happen that you receive the same news several times. For example, it can happen that you receive the positive news +10 twice for a given firm. The two pieces of news would then be accompanied by exactly the same

story and image. When you determine a company's stock price, you would then have to take both of these positive news into account.

Importantly, please note that it can never happen that a story accompanies different types of news, or even belongs to different firms. Each story only belongs to one type of news for one particular firm. Likewise, it can never happen that an image is associated with different types of news. Each image and each story are assigned to only one type of news for one particular firm.

If you now enter the code "1108" on your screen, you will see an example of a piece of news. Please note that the accompanying story and image are only an example and do not correspond to those in the actual experiment.

### **Your Task: Determine the Stock Prices of the Twelve Firms**

After you will have seen the news for a firm, you will be asked to provide an estimate of the stock price of that firm. In doing so, you can earn 10 Euros. The closer your estimate is to the actual stock price of the firm, the higher the probability that you actually receive the 10 Euros. This is determined using the following formula:

$$\text{Probability of winning 10 Euros (in percent)} = 100 - (\text{Estimate} - \text{True price})^2$$

This means that the difference between your estimate and the true value is squared. This number is then subtracted from the maximum possible probability of 100%. While this formula might seem complicated, the underlying principle is very simple: the smaller the difference between your estimate and the true value, the higher the likelihood that you win 10 Euros. Notice that the probability of winning only depends on the absolute difference. Thus, it doesn't matter for your payment whether you overestimate the true value by, say, 5 or underestimate it by 5.

### **PART 2 OF THE EXPERIMENT**

As explained above, in the first part of the experiment your task is to provide an estimate of the stock price of each firm. In the second part, we will again ask you to estimate the stock price of each firm.

You will receive up to one additional piece of news for each company. For some companies, there will be no further news. Whether or not you receive an additional piece of news for a particular company is randomly determined by the computer and does not depend on the value of the previous news for this company.

Afterwards, you will again be asked provide an estimate of the stock price of that firms.

As in the first part of the experiment, the stock price is determined by the base price (100) plus the sum of all news for the firm. Please note that the stock price of a firm is determined by all news that you have seen for that company over the course of the entire experiment, i.e., all news from the first and all news from the second part.

As in the first part, the closer your estimate is to the actual stock price of the firm, the higher your probability of winning 10 Euros. This is determined by the same formula as in the first part of the experiment:

$$\text{Probability of winning 10 Euros (in percent)} = 100 - (\text{Estimate} - \text{True Price})^2$$

## **PROCEDURE OF THE EXPERIMENT**

1. You will first answer a set of control questions on the computer.
2. You complete the first part of the experiment:
  - We will first inform you about which of the twelve hypothetical firms is next.
  - You will sequentially receive pieces of news for this firm. In case you receive no news for a firm, you will be informed about this on your screen.
  - Afterwards, you will be asked to enter an estimate of the stock price of this firm.
  - We will repeat this procedure for each of the twelve firms.
3. You complete several other tasks.
4. You complete the second part of the experiment:
  - We will first inform you about which of the twelve hypothetical firms you are dealing with.
  - Then, you will potentially receive an additional piece of news for this firm. For some firms, you will receive no further news.
  - Afterwards, you will be asked to enter an estimate of the stock price of this firm. The actual stock price of the firm is given by the base price plus all news that you received over the course of the experiment (i.e., part 1 and part 2).
  - We will repeat this procedure for each of the twelve firms.

## **YOUR PAYMENT**

In addition to the 5 Euro participation fee, you can earn money with your estimates as described above. In total, you will provide 24 estimates in this experiment: two for each

of the 12 firms. At the end of the experiment, the computer randomly selects one of the twelve firms as well as one of your two estimates for this firm. The probability that the estimate from part 2 of the experiment gets selected is 90% and the probability that the estimate from part 1 gets selected is 10%. You will then be paid according to your earnings from your estimate for this firm. Thus, every decision is potentially relevant for your payments. However, only one decision will actually be paid out, so there is no point in strategizing by, for example, alternating between high and low answers. In order to maximize your earnings, you should always enter the best estimate that you have in mind for the task at hand.

As soon as all participants have read the instructions, we will provide you with another code to start the control questions.

## F.2 Treatment Reminder

*Instructions for treatment Reminder were identical to treatment Main, except that we informed subjects in the instructions for part 2 that they would be reminded of their part 1 estimates in part 2. For completeness, we display the relevant parts below.*

### PART 2 OF THE EXPERIMENT

As explained above, in the first part of the experiment your task is to provide an estimate of the stock price of each firm. In the second part, we will again ask you to estimate the stock price of each firm.

For each company, we will first remind you of your estimate of the stock price for this company from part 1.

You will receive up to one additional piece of news for each company. For some companies, there will be no further news. Whether or not you receive an additional piece of news for a particular company is randomly determined by the computer and does not depend on the value of the previous news for this company.

Afterwards, you will again be asked provide an estimate of the stock price of that firms.

As in the first part of the experiment, the stock price is determined by the base price (100) plus the sum of all news for the firm. Please note that the stock price of a firm is determined by all news that you have seen for that company over the course of the entire experiment, i.e., all news from the first and all news from the second part.

As in the first part, the closer your estimate is to the actual stock price of the firm, the higher your probability of winning 10 Euros. This is determined by the same formula as in the first part of the experiment:

$$\text{Probability of winning 10 Euros (in percent)} = 100 - (\text{Estimate} - \text{True Price})^2$$

### **PROCEDURE OF THE EXPERIMENTS**

1. You will first answer a set of control questions on the computer.
2. You complete the first part of the experiment:
  - We will first inform you about which of the twelve hypothetical firms is next.
  - You will sequentially receive pieces of news for this firm. In case you receive no news for a firm, you will be informed about this on your screen.
  - Afterwards, you will be asked to enter an estimate of the stock price of this firm.
  - We will repeat this procedure for each of the twelve firms.
3. You complete several other tasks.
4. You complete the second part of the experiment:
  - We will first inform you about which of the twelve hypothetical firms you are dealing with.
  - We will then remind you of your part 1 estimate of the stock price for this company.
  - Then, you will potentially receive an additional piece of news for this firm. For some firms, you will receive no further news.
  - Afterwards, you will be asked to enter an estimate of the stock price of this firm. The actual stock price of the firm is given by the base price plus all news that you received over the course of the experiment (i.e., part 1 and part 2).
  - We will repeat this procedure for each of the twelve firms.

### **F.3 Treatment No Cue**

*Instructions for treatment No Cue were again identical to treatment Main, except for the description of news and stories. For completeness, we display the relevant parts below.*

## **Communication of the News**

As already mentioned, in this experiment you will receive news about the stock prices of twelve firms. In case you receive news for a firm, the news will appear sequentially on separate screens. However, the news appear separately for each firm. This means that you will first observe all news for one company, then all the news for another company, and so on. It will be important for you to distinguish which news belong to which firm.

The news will be communicated to you on your screen. Each piece of news is communicated along with two features:

1. Each type of news is accompanied by a particular “story”, that explains to you why this particular type of news occurred.
2. Each type of news is accompanied by a particular image that will be displayed on your screen. This image will roughly reflect the story.

Every single piece of news is attached to its own image and its own story.

- The first piece of news for company X (should you receive one) will be communicated with an separate story and a separate image.
- The second piece of news for company X (should you receive one) will be communicated with an separate story and a separate image.
- The first piece of news for company I (should you receive one) will be communicated with a separate story and a separate image.
- The second piece of news for company I (should you receive one) will be communicated with a separate story and a separate image.
- Etc.

Please note: As mentioned above, it can happen that you receive the same news several times. For example, it can happen that you receive the positive news +10 twice for a given firm. The two pieces of news would then be accompanied by exactly two different stories and two different images. When you determine a company's stock price, you would then have to take both of these positive news into account.

Importantly, please note that it can never happen that a story accompanies multiple news, or even belongs to different firms. Each story only belongs to one piece of news for one particular firm. Likewise, it can never happen that an image is associated with

multiple news. Each image and each story are assigned to only one piece of news for one particular firm.

If you now enter the code “1108” on your screen, you will see an example of a piece of news. Please note that the accompanying story and image are only an example and do not correspond to those in the actual experiment.

## G Example screenshots of signal, story and image presentation

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Company N tries to advertise its products through commercials with German celebrities, like, for instance, Boris Becker, Helene Fischer or Til Schweiger. Recently, a new advertisement campaign with a celebrity worked extremely well.

**The value of the company increased by 10 points.**

Figure 10: Example screenshot of how a piece of positive news for Company N is communicated to subjects. The signal is displayed in the last line of the text. A story and an image accompany the signal.



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The head of sales of Company K is a choleric. Every once in a while, he engages in temper tantrums during which he yells at customers of Company K and insults them. These customers hence take their business elsewhere. Just now, another temper tantrum occurred.

**The value of the company decreased by 10 points.**

Figure 11: Example screenshot of how a piece of negative news for Company K is communicated to subjects. The signal is displayed in the last line of the text. A story and an image accompany the signal.

## H Screenshots of Tourist Version

Each of the following pages depict screenshots from the tourist version of treatment *Main* with the following order:

1 2  
3 4

{The following shows Part 1 and Part 2 of treatment MAIN of Enke, Schwerter and Zimmermann, Associative Memory and Belief Formation. Text in curly brackets indicates text that was not part of the original experiment, but was added for expositional purposes}



Please read the printed instructions now.

Please enter the code {1108} found in the instructions in order to start with the example.



  
Firm B employs award-winning marketing chief Tom Stark. In the newest marketing campaign, everything that can be done to appeal to ecologically conscious customers was done. These customers react to the advances of firm B in large numbers.

The stock price of firm B increases by 10 points.

The example is now completed. Please now finish reading the instructions. As soon as all participants are finished with reading the instructions, the experimenter will give you a new code {4711}. You can enter this in the field below in order to start with the control questions.



{In between reading the instructions, seeing the example and the beginning of Part 1, subjects completed the 7 control questions concerning the content of the instructions}



#### Part 1

You will now receive the news for the firms sequentially, where one firm is handled after the other. The news will be shared with you on your screen, along with the accompanying story and picture. First you will see the news for one firm. After you have seen all the news for this firm, you are asked to state your estimate of the stock price of the firm. Then, the same procedure is repeated with another company, etc.



The presentation of the news will begin momentarily

The following concerns firm G



Firm G is always spied on by a competitor. These spies steal important know-how, which then only benefits the competitor. Recently, spies have struck again, causing significant damage to firm G.

The stock price of firm G decreases by 10 points.

What is the stock price of firm G?



The following concerns firm P

There is no news for firm P

What is the stock price of firm P?



The following concerns firm X

There is no news for firm X

What is the stock price of firm X?



The following concerns firm M



Firm M has been engaged in sports promotion for some time now. Recently the local handball club, whose home games are always sold out, was also promoted. As a result, firm M now counts more and more handball fans among its customers

**The stock price of firm M increases by 10 points.**



Firm M has been engaged in sports promotion for some time now. Recently the local handball club, whose home games are always sold out, was also promoted. As a result, firm M now counts more and more handball fans among its customers

**The stock price of firm M increases by 10 points.**

**What is the stock price of firm M?**



The following concerns firm U



Firm U incidentally discovered an archive with old writings from Albert Einstein in its warehouse. These sometimes contain ingenious and also profitable ideas. Recently an employee of firm U discovered another ingenious idea.

**The stock price of firm U increases by 10 points.**



Firm U has many salesmen who are active in the local volunteer firefighting service. Whenever there is a firefighting assignment, firm U must forgo almost all of its salesmen for several hours. There has been another local fire.

**The stock price of firm U decreases by 10 points.**



Firm U incidentally discovered an archive with old writings from Albert Einstein in its warehouse. These sometimes contain ingenious and also profitable ideas. Recently an employee of firm U discovered another ingenious idea.

**The stock price of firm U increases by 10 points.**

What is the stock price of firm U?



The following concerns firm D

There is no news for firm D

What is the stock price of firm D?



The following concerns firm K



Firm K is located near a popular petting zoo. Entire school classes frequently visit the petting zoo, which in turn generates enormous sales for firm K. Recently, a class visited the petting zoo again.

**The stock price of firm K increases by 10 points.**



Firm K is located near a popular petting zoo. Entire school classes frequently visit the petting zoo, which in turn generates enormous sales for firm K. Recently, a class visited the petting zoo again.

**The stock price of firm K increases by 10 points.**

**What is the stock price of firm K?**



The following concerns firm R



Firm R employs a staff member who helps out weekly in a nursing home and thus often comes to work with the flu. Because he showed up to work sick again, a flu epidemic causes significant losses in the workforce of company R.

**The stock price of firm R decreases by 10 points.**



Firm R is adored by a special customer who is extremely wealthy and lives in an enormous villa on the outskirts of the city. The older woman is so excited that she just paid a premium price for a product from firm R again.

**The stock price of firm R increases by 10 points.**



Firm R employs a staff member who helps out weekly in a nursing home and thus often comes to work with the flu. Because he showed up to work sick again, a flu epidemic causes significant losses in the workforce of company R.

**The stock price of firm R decreases by 10 points.**

What is the stock price of firm R?



The following concerns firm I



Firm I transports its means of production primarily via a maritime route to Europe. In doing so, the supply ships of firm I are sometimes captured by pirates, who then demand ransom money. Recently, another ship has been captured by pirates.

**The stock price of firm I decreases by 10 points.**

What is the stock price of firm I?



The following concerns firm T



The sales leader of firm T is a member of the local carnival club.  
Important local politicians are also in the club, which means firm T  
always has good prospects when new public contracts are awarded. Yet  
another public contract has been awarded.

**The stock price of firm T increases by 10 points.**



The sales leader of firm T is a member of the local carnival club.  
Important local politicians are also in the club, which means firm T  
always has good prospects when new public contracts are awarded.  
Another public contract is now grabbed again.

**The stock price of firm T increases by 10 points.**



The sales rooms of firm T are located near a river that every once in a  
while overflows, flooding the sales rooms of firm T and halting sales.  
The sales rooms are under water yet again.

**The stock price of firm T decreases by 10 points.**

What is the stock price of firm T?



The following concerns firm N



Firm N has an employee who repeatedly sells marijuana to the staff.  
Whenever this happens, almost the entire staff is intoxicated and production halts. Today the employee of firm N sold marijuana yet again.

**The stock price of firm N decreases by 10 points.**



Firm N has an employee who repeatedly sells marijuana to the staff.  
Whenever this happens, almost the entire staff is intoxicated and production halts. Today the employee of firm N sold marijuana yet again.

**The stock price of firm N decreases by 10 points.**

What is the stock price of firm N?



The following concerns firm J



Firm J operates in an area where the mafia is widespread. Whenever the mafia godfather comes by, firm J must pay a large sum of protection money. The godfather just came by again.

**The stock price of firm J decreases by 10 points.**

What is the stock price of firm J?



{In between Part 1 and Part 2, subjects participated in a real effort task that lasted  
for 15min in treatment MAIN}



## Part 2

In what follows, for each firm you will first learn the name of a firm. Then you will hear a last news item for this firm, which for some randomly selected ones, there will be no further news. At the end, you must estimate the stock price of the firm.

### As a reminder:

Every news item is associated with exactly one story and exactly one picture.

The stock price of a firm is determined as the basis price plus the sum of all news for a respective firm that you hear over the course of the experiment. Therefore, it doesn't matter if you receive this news now or have received it previously.

The basis price of all firms is 100. Each piece of news implies a stock price change of either +10 or -10 points.

### Example:

Suppose that the last news you received for a particular firm is a price change of +10 points. Earlier, you received a news item of +10 points and a news item with -10 points for the same firm. Then, the stock price of the firm in this example is:

Example stock price = 100 (Basis price) + 10 (last news) + 10 (previous, positive news)  
- 10 (previous, negative news) = 110



## Part 2

### We proceed as follows:

In what follows, for each firm you will first learn the name of a firm. Then you will hear a last news item for this firm, which for some randomly selected ones, there will be no further news. At the end, you must estimate the stock price of the firm. Thereby, the closer your estimate is to the true price of the stock, the more money you will earn.



The following concerns firm D



Firm D employs many salespeople who must predominantly travel to customers by plane. On the last flight to a major customer, the plane needed to land unscheduled. A drunk passenger had smoked in the bathroom. Because of this, firm D lost the order.

The stock price of firm D decreases by 10 points.

What is the stock price of firm D?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm D?

Positive (+10) news for firm D:

Negative (-10) news for firm D:



The following concerns firm M



Firm M produces many of its products in the wild. This leads to many clashes with wildlife. Now another cat ran into the manufacturing plant. This halts the production of firm M for several days.

The stock price of firm M decreases by 10 points.

What is the stock price of firm M?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm M?

Positive (+10) news for firm M:

Negative (-10) news for firm M:



The following concerns firm R



Firm R is adored by a special customer who is extremely wealthy and lives in an enormous villa on the outskirts of the city. The older woman is so excited that she just paid a premium price for a product from firm R again.

**The stock price of firm R increases by 10 points.**

What is the stock price of firm R?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm R?

Positive (+10) news for firm R:

Negative (-10) news for firm R:



The following concerns firm N



Firm N tries to advertise its products through commercials with German celebrities like, for instance, Boris Becker, Helene Fischer or Til Schweiger. Recently a new advertisement campaign from firm N with a celebrity has worked extremely well.

**The stock price of firm N increases by 10 points.**

What is the stock price of firm N?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm N?

Positive (+10) news for firm N:

Negative (-10) news for firm N:



The following concerns firm T

There is no news for firm T

What is the stock price of firm T?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm T?

Positive (+10) news for firm T:

Negative (-10) news for firm T:



The following concerns firm I

There is no news for firm I

What is the stock price of firm I?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm I?

Positive (+10) news for firm I:

Negative (-10) news for firm I:



The following concerns firm K



The head sales of firm K is a choleric. Every once in a while, he engages in temper tantrums during which he yells at customers of firm K. These customers hence take their business elsewhere. Just now, another temper tantrum occurred.

**The stock price of firm K decreases by 10 points.**

What is the stock price of firm K?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm K in total?

Positive (+10) news for firm K:

Negative (-10) news for firm K:



The following concerns firm G



Firm G has its headquarters near the "Alien Friends" NGO. Alien Friends NGO regularly organizes events where visitors from all over the world come on site and look for aliens. Recently one such event provided firm G with a lot of customers.

The stock price of firm G increases by 10 points.

What is the stock price of firm G?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm G?

Positive (+10) news for firm G:

Negative (-10) news for firm G:



The following concerns firm J



Firm J operates in an area where the mafia is widespread. Whenever the mafia godfather comes by, firm J must pay a large sum of protection money. The godfather just came by again.

The stock price of firm J decreases by 10 points.

What is the stock price of firm J?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm J?

Positive (+10) news for firm J:

Negative (-10) news for firm J:



The following concerns firm U



Firm U has many salesmen who are active in the local volunteer firefighting service. Whenever there is a firefighting assignment, firm U must forgo almost all of its salesmen for several hours. There has been another local fire.

The stock price of firm U decreases by 10 points.

What is the stock price of firm U?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm U?

Positive (+10) news for firm U:

Negative (-10) news for firm U:



The following concerns firm X



Firm X has introduced a "Mojito Happy Hour". On one Friday after 4:00pm there was a nice gathering with mojitos and other drinks for the employees. Of course, this makes firm X extremely popular among its employees.

**The stock price of firm X increases by 10 points.**

What is the stock price of firm X?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm X?

Positive (+10) news for firm X:

Negative (-10) news for firm X:



The following concerns firm P



Firm P is located very close to a large harbor. Whenever a giant ship from Asia docks at the harbor, firm P is in peak season and sales shoot through the roof. Now a huge Asian ship has arrived again.

The stock price of firm P increases by 10 points.

What is the stock price of firm P?



How many positive (+10) and negative (-10) news items (including the last news item) are you able to remember for firm P?

Positive (+10) news for firm P:

Negative (-10) news for firm P:



(After Part 2, subjects had 5min to complete as many Raven Matrices as possible (out of 10) and completed demographic information)



{The following shows Part 1 and Part 2 of treatment MAIN of Enke, Schwerter and Zimmermann, Associative Memory and Belief Formation. Text in curly brackets indicates text that was not part of the original experiment, but was added for expositional purposes}

