Stock Ownership and Learning from Financial Information

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We study whether people's prior investment choices influence their ability to learn from new financial information. In a sample of community participants who complete a portfolio selection task while undergoing functional magnetic resonance imaging, we find that prior portfolio choices bias participants' beliefs about the quality of investments available to them, and the process by which these individuals learn from new information about these investment options. Specifically, we find that people update more from information which is consistent with their prior portfolio choice. Moreover, we document that this behavioral effect is mirrored by a bias in activation in brain centers important for valuation, namely, that these centers are more responsive to new information about investment options which matches the participants' prior portfolio choice. These findings can help shed light on puzzling patterns in investor behavior, such as the low participation rate of households in equity markets and people's reluctance to sell losing stocks.

Motivation. One of the most puzzling patterns in household finance and a topic of current policy debates is that the majority of people in the U.S. and Europe do not invest in the stock market (*1*, *2*), which results in lower wealth accumulation and consumption over the life span (*3*). While in part the low participation rates in equity markets may be driven by insufficient provision of financial services to those willing to invest, it is also possible that some individuals are unable to process financial information and thus choose to avoid the stock market (*4*, *5*, *6*). Here, we test a specific mechanism that could lead people to have incorrect beliefs about the outcomes of stock investments, which in turn could change their willingness to participate in equity markets. In particular, using behavioral and brain imaging data, we test whether people's ability to learn from new financial information may mistakenly depend on their prior investment choices, in a manner that would make those not currently holding stocks to be more pessimistic about the potential outcomes of these risky assets, and thus less willing to invest.

An implicit assumption in the finance literature is that market participants are able to learn the same way from new information about available investments, irrespective of the composition of their portfolio. While theoretical work has shown that previous portfolio choices may influence investors' *utility function*, based on prospect theory (*7*) or realization theory (*8*), it is possible that these prior choices might also change investors' *beliefs* or the learning rules they use to incorporate financial market news. Experimental evidence from a sample of college students with limited financial expertise (*9*) suggests that people may update beliefs in a way to be consistent with their prior investment choices. However, it is important to determine whether this bias in beliefs induced by previous portfolio decisions generalizes to individuals who are responsible for household financial decisions and have available means to invest. If that is the case, functional MRI might shed light on the underlying brain processes driving this effect.

Thus, in this paper, we seek to understand whether indeed previous investment choices influence people's ability to use financial information correctly, and to uncover the brain mech-

anisms underlying this effect. In an experimental setting with working-age, highly educated and high-earning adults faced with real financial incentives, we find that prior investment decisions interfere with these individuals' ability to correctly update their beliefs about the quality of financial assets available to them. In particular, controlling for subjective beliefs prior to making an investment choice, when participants choose to hold a stock with risky payoffs, they subsequently form more optimistic beliefs about the quality of the stock, relative to when they choose to hold a safe bond. Moreover, stock holders update beliefs about the stock quality more after observing a high dividend of the stock, rather than a low dividend, whereas bond holders update their beliefs more after observing a low dividend of the stock, rather than a high one. This shows that people are more likely to learn from new information which ex-post justifies their prior investment choice. Importantly, in the financial investment task used in the study, it is optimal for participants to learn objectively from all new outcomes, as their prior choices do not constrain them from changing their portfolio going forward.

Furthermore, we show that this behavioral effect whereby prior choices interfere with people's ability to objectively learn from new information is accompanied by a bias induced by prior choices in the reactivity of certain brain regions – namely, the ventromedial prefrontal cortex (vmPFC), the posterior cingulate cortex (PCC) and the ventral striatum – to new information. We find that these areas preferentially encode new information which matches the participants' prior investment choice. Specifically, when participants choose to have the stock in their portfolio in a given trial, activation in these areas is significantly higher if the new dividend paid by the stock in that trial is high, relative to when they choose to hold the bond. We then show that this muted brain reactivity shown by bond holders in response to high stock outcomes can help predict the errors in beliefs subsequently expressed by these individuals regarding the quality of the stock's payoff distribution.

Experimental design.

Participants completed a financial decision making task based on the experimental protocol in (*10*). Each participant made 96 decisions, split into 16 separate blocks of six trials each, to invest in one of two securities: a stock with risky payoffs coming from one of two distributions (good and bad), one which was better than the other in the sense of first-order stochastic dominance, and a bond with a known payoff. In each trial, participants observed the dividend paid by the stock, after making their asset choice, and then were asked to provide an estimate of the probability that the stock was paying from the good distribution. The task included gain and loss blocks, as learning may differ across these domains (*10*). In gain blocks, the two securities provided positive payoffs only. The stock payoffs were + €10 or + €2 (gain & low variance condition), or €0 or + €12 (gain & high variance condition), while the bond payoff was + €6. In loss blocks, the two securities provided negative payoffs only. The stock payoffs were - €10 or - €2 (loss & low variance condition), or €0 or - €12 (loss & high variance condition), while the bond payoff was - €6 (see Table 1).

In either condition, the stock paid dividends from a good distribution or from a bad distribution. The good distribution is that where the high dividend occurs with 70% probability in each trial, while the low dividend occurs with 30% probability. The bad distribution is that where these probabilities are reversed: the high dividend occurs with 30% probability, and the low dividend occurs with 70% probability in each trial.

For each block of six trials, the participants' learning problem is the same. That is, participants know that the computer will either pay dividends from the good stock distribution in each of these six trials, or it will pay from the bad distribution in each of the six trials. At the beginning of each learning block, the computer randomly selected (with 50%-50% probabilities) whether the dividend distribution to be used in the following six trials would be the good or the bad one. Based on this 50% prior belief, as well as on the dividend revealed each

trial, participants were asked to provide a posterior probability estimate that the stock is paying from the good distribution in that block. In total, each subject faced 16 learning blocks, split equally in gain vs. loss, and high vs. low variance conditions. The order of the blocks was pseudo-randomized (see Figure 1 for trial examples).

Participants were paid based on their investment payoffs and the accuracy of the probability estimates provided. Specifically, they received the accumulated payoffs of the investments they chose throughout the task, plus ten Euro cents for each probability estimate within 5% of the correct answer, namely, the objective Bayesian posterior probability. Information regarding the accuracy of each subject's probability estimates and the corresponding payment was only provided at the end of the task. This was done to avoid feedback effects that could have changed the participants' strategy or answers during the progression of the task.

The value of the objective Bayesian posterior that the stock is paying from the good distribution can be easily calculated. Specifically, after observing t high outcomes in n trials so far, the Bayesian posterior that the stock is the good one is: $\frac{1}{1+\frac{1-p}{p}*(\frac{q}{1-q})^{n-2t}}$, where $p = 50\%$ is the prior that the stock is the good one (before any dividends are observed in that learning block) and $q = 70\%$ is the probability that a good stock pays the high (rather than the low) dividend in each trial. Table S1 in the Supplementary Materials section provides the value of the objective Bayesian posterior for all $\{n, t\}$ pairs possible in the experiment. This Bayesian posterior is our benchmark for measuring how close the subjects' expressed probability estimates are from the objectively correct beliefs.

The 46 participants in the study – all male (to avoid gender effects), age 40.08 $\pm$ sd. 6.53 years, age range 29-49 years – were recruited in Bonn, Germany. Participants gave written informed consent, as required by human subjects protection rules.

Importantly, the sample was purposely selected to be representative of educated, high-earning individuals across the age span: 78% of the participants have a college degree, 49%

are home owners, and 60% earn more than €4000 per month.

Behavioral results. We find that prior investment choices influence participants' posterior beliefs about the stock dividend distribution, and the manner they update from new dividend information. Panel (a) of Figure 2 shows that controlling for the beliefs expressed by subjects regarding the quality of the stock before the investment choice is made, individuals who choose the stock form more positive posterior beliefs about the stock dividend distribution compared to individuals who choose the bond ($p < 0.05$). Specifically, in trials where, before the choice, participants' prior belief that the stock is the good one was less than 50%, the average posterior belief that the stock is good is 41.25% for stock holders, and it is 33.60% for bond holders. In trials where participants' prior before the choice was greater or equal to 50%, the average posterior belief that the stock is the good one is 62.21% for stock holders, and 52.90% for bond holders. We find similar effects in a multivariate regression analysis which includes subject fixed effects and other experimental controls, as shown in Table S2 in the Supplementary Materials section. Thus, stock holders become more positive regarding the distribution of stock outcomes, compared to bond holders.

Panel (b) of Figure 2 shows that updating upon the release of new dividend information is different for stock holders relative to bond holders, even though in this task it is optimal for subjects to learn objectively from all new outcomes, as their prior choices do not constrain them from changing their portfolio going forward. To understand how people update their beliefs when given new information about the stock dividend distribution, we estimate regression models where the dependent variable is the change in a subject's probability estimate from the prior to the current trial, and the independent variable is their probability estimate from the prior trial. We estimate these regressions for trials where the stock dividend is low (left side of the panel), and for trials where the stock dividend is high (right side of the panel), separately for

bond holders and for stock holders. As expected, the figure shows that the average update regarding the probability that the stock is paying from the good distribution when a high dividend is revealed is positive, in accordance with Bayesian learning. However, this update is significantly greater for stock holders, relative to bond holders, on average by 10% (see Table S2), controlling for these individuals' beliefs about the stock quality prior to them making the asset choice ($p < 0.05$). The average update regarding the probability that the stock is paying from the good distribution when a low dividend is revealed is negative, in accordance to Bayesian learning, but it is more negative for bond holders (by 5% on average, $p < 0.05$, see Table S2), relative to stock holders. Therefore, the results in panel (b) of Figure 2 and in Table S2 indicate that investors update more from new information which ex-post justifies their prior investment choice. Importantly, this effect is different from the classic confirmation bias (*11*), which refers to people's tendency to choose information sources that can help confirm a particular hypothesis, instead of seeking sources that can help reject it. Our results suggest that when people obtain explicit falsifying information that does not match their prior choice, they fail to use it to reject incorrect hypotheses. Also, in the regression model in Table S2 we replicate the result in (*10*) that probability estimates are higher in the Gain domain than in the Loss domain (i.e., people are overly pessimistic when learning from negative financial outcomes). The same regression shows that whether the stock dividend distribution has high or low variance does not have a significant impact on subjective probability estimates.

Brain imaging results. We document that prior investment choices bias the brain response to new information. As shown in the analysis in Figure 3, stock holders are more likely than bond holders to experience an increase in activation in valuation-related brain areas when a high stock dividend is revealed. To conduct the analysis in Figure 3, we estimated a generalized linear regression that modeled the blood-oxygen-level dependent (BOLD) response at the time

of the stock outcome presentation separately by the prior investment (stock or bond) and the presented stock outcome (high or low dividend), while controlling for the prior probability that the stock is good (see Supplementary Materials). A two-by-two ANOVA of the whole-brain data revealed that a cluster extending in the ventromedial prefrontal cortex and the anterior cingulate cortex, the bilateral ventral striatum, the posterior cingulate cortex and a region in the inferior parietal lobule were sensitive to an interaction of the prior investment and the stock outcome ($p < 0.05$, FWE-corrected, see Table S3). To illustrate the nature of this interaction we plotted the mean beta parameters in anatomically defined region-of-interest (ROI) masks in Figure 3: if subjects had chosen the stock at the beginning of the trial they showed a stronger BOLD response to high stock dividends than if they had chosen the bond. Given the within-subject design of the experiment, a subject is considered a stock holder or a bond holder for a particular trial only, as he is free to switch his investment in the next trial.

As Figure 3 indicates, we find that activity in the ventromedial prefrontal cortex, ventral striatum and posterior cingulate cortex is greater for high stock dividends when the subject holds a stock than a bond. The left panel shows statistical parametric maps of the two-by-two ANOVA. The right panel shows the mean and standard error of the beta estimates for stock vs. bond holders, and for high and low stock dividends separately, in these three ROIs. These estimates indicate that these areas preferentially encode new information that matches the participants' prior investment choices, a finding that mirrors the behavioral effect of prior choices on participants' beliefs documented in Figure 2 and Table S2.

Predicting errors in beliefs. We also find that the brain response to new information that contradicts a participant's prior investment choice can help predict the person's ability to form correct beliefs about the quality of the stock. Specifically, when participants were faced with information contradicting their prior choice, higher activation in the vmPFC or the left ven-

tral striatum (but not other regions) during dividend presentation leads to a significantly lower probability estimation error in that trial (Table 2). These are situations when participants who chose the bond at the beginning of the trial subsequently observed that the stock paid a high dividend that trial. In those types of trials, the average probability estimation error is 15%. The coefficients in the table imply that a standard deviation increase in vmPFC activation, left ventral striatum activation, or in the common component of these two, leads to a reduction in the estimation error by 1%. This suggests that learning from financial information is improved if valuation-related brain centers are able to correctly encode new information, in spite of it being in conflict with the person's previous investment choice.

Discussion. Overall, our results indicate that prior investment decisions influence people's ability to correctly form beliefs about the quality of financial assets. Specifically, controlling for prior beliefs, we find that if the participants' most recent choice is a stock, they will form more optimistic posterior beliefs about the dividend distribution of the stock, and will update their beliefs more after observing a high dividend, rather than a low one. If the participants' most recent choice is a bond, they will form less optimistic posterior beliefs about the quality of the stock, and will update their beliefs more after observing a low dividend, rather than a high one. This behavioral asymmetry in learning, induced by participants' prior investment choice is mirrored by an asymmetry in the response of valuation-related brain areas (vmPFC, PCC and ventral striatum) when new dividend information is presented. Specifically, activation in these areas increases significantly more when a high stock dividend is observed in trials where participants chose to hold the stock, rather than when they chose the bond. We also observe that the degree to which brain activation in the vmPFC and ventral striatum increases at the presentation of a high dividend to bond holders (which are situations where the new information contradicts the prior investment choice) predicts the accuracy of participants' estimates of the

probability that the stock is paying from the good distribution.

These findings can help shed light on the puzzling fact that a large share of households do not participate in the stock market (*1*, *2*), a behavior which is detrimental to wealth accumulation. Our findings suggest that one potential reason for this outcome may be that people who are not currently stock holders do not update their beliefs much if stocks perform well, and hence will be overly pessimistic about future payoffs in the stock market. These pessimistic beliefs will in turn deter these individuals from investing in equities, which will lead to limited stock market participation in the population. Our results may also help explain another puzzling aspect of investor behavior, namely, the disposition effect (*12*), which refers to the fact that investors seem to be reluctant to sell stocks that have not performed well. Our results suggest that a potential reason for this pattern is that these investors do not update sufficiently their beliefs after observing low outcomes of stocks they have previously chosen. This belief-related channel for the disposition effect complements the findings in (*13*), who find evidence suggesting that people's utility function is affected negatively by the realization of losses in their portfolio.

The brain imaging results in the paper contribute to the recent literature that identifies the vmPFC, ventral striatum and PCC as the key regions of a subjective value network (*14*, *15*). Here we show that they are critically involved in the updating of subjective probability estimates. This is in line with research associating the vmPFC and ventral striatum with the encoding of objective and subjective probability (*16*, *17*). Importantly, we document the novel result that the engagement of the vmPFC and ventral striatum at the time when new stock dividend information is presented is biased by irrelevant factors – namely, the subjects' prior portfolio choices, and this has detrimental consequences for people's ability to correctly assess their investment opportunities.

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18. Acknowledgements: Funding for this work was generously provided by the German Research Council (DFG; We 4427/3-1), the Frankfurt Institute of Risk Management and Regulation, and the Wells Fargo Center for Corporate Finance at the University of North Carolina at Chapel Hill. We thank participants at the 2014 meeting of the Society for Neuroeconomics for valuable comments and discussion.

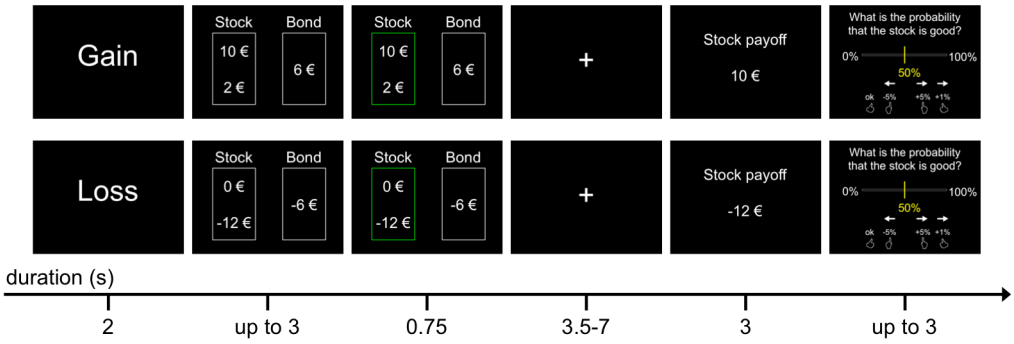
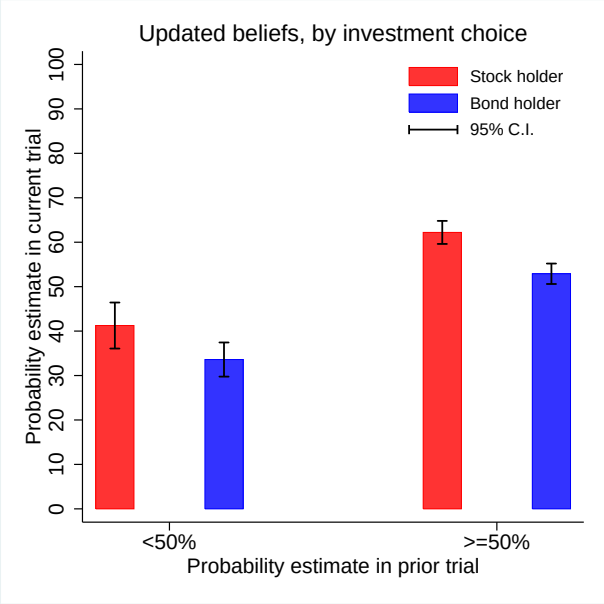
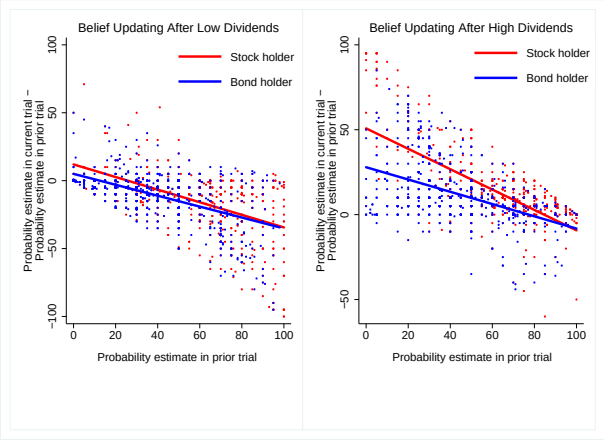


Figure 1: Timeline of trials. At the beginning of each block, the condition (gain or loss) is displayed for 2s, followed by a jittered interstimulus interval (ISI) of 1-3s (not shown). Then, the first choice screen is presented and the subject has 3s to make a choice. After the subject has made a choice, a green frame is presented around the chosen option for 0.75s, followed by an anticipation period during which a fixation cross is presented for a jittered period of 3.5-7s (M 6.02 $\pm$ SD 0.41s). Next, irrespective of the subject's choice, the stock dividend is shown for 3s, followed by an ISI. Then, the subject is asked to estimate the probability that the current stock is a good stock. The estimation is self-paced (RTs $<=$ 3s) and followed by an ISI. Finally, the subject's updated balance is presented for 3s (not shown). After a final ISI, the next trial begins. Each learning block consisted of 6 trials and could be a gain or loss block, with high or low variance in the dividend distribution, rendering four task conditions. The figure shows one example of a gain block with a low variance stock (upper panel) and one example of a loss block with a high variance stock (lower panel). For each block, the stock was randomly assigned to be good or bad. If the stock was good (bad), it paid the high outcome with 70% (30%) probability and the low outcome with 30% (70%) probability. To make optimal investment choices, subjects need to update their beliefs about the stock's dividend distribution after observing each dividend paid by the stock.



(a) Investment choices influence posterior beliefs.



(b) Investment choices influence the updating process.

Figure 2: Panel (a) shows that controlling for the beliefs held before the investment choice is made, individuals who choose the stock form more positive posterior beliefs about the stock dividend distribution compared to individuals who choose the bond. Panel (b) shows that updating upon the release of new dividend information is different for stock holders relative to bond holders. The solid lines represent lines of best fit for regressions where the dependent variable is the change in the subject's probability estimate from the prior to the current trial, and the independent variable is their probability estimate from the prior trial. For each value of prior belief expressed by subjects, these linear predictions indicate the average belief update produced across all subjects, either after observing a low dividend in the current trial (left side of Panel (b)), or after observing a high dividend in the current trial (right side of Panel (b)), separately for those who chose the bond in the current trial (blue line) or for those who chose the stock in the current trial (red line).

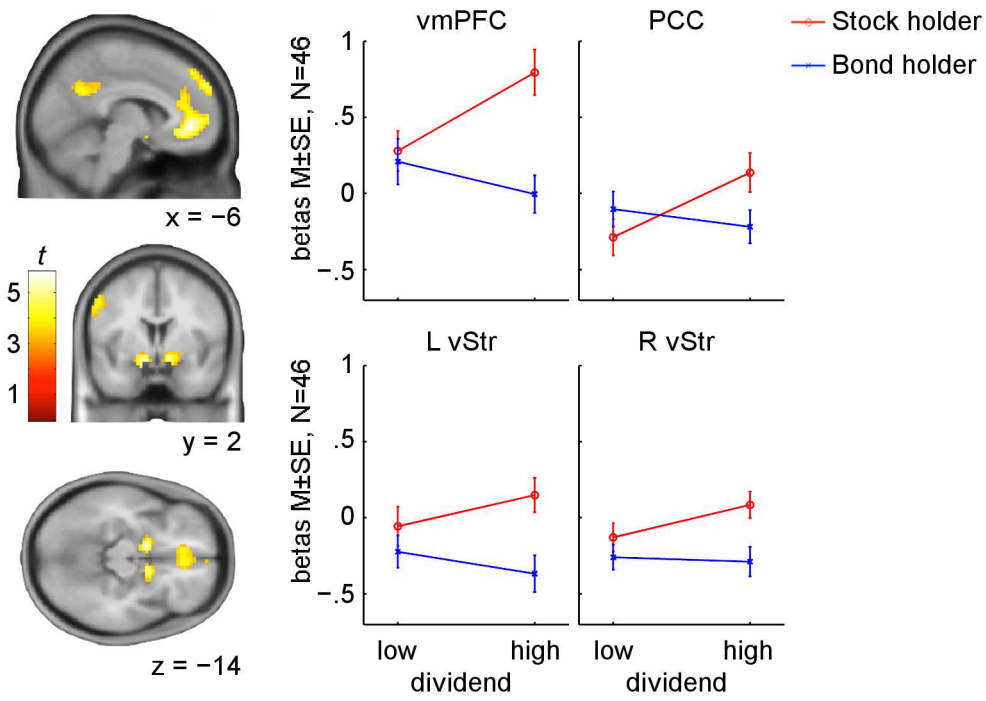


Figure 3: Stock ownership effect on the neural encoding of new stock information. Activity in the vmPFC/ACC, the bilateral vStr and the PCC is greater for high stock dividends when subjects hold the stock vs. when they hold the bond. The figures on the left show statistical parametric maps of the two-by-two ANOVA displayed at $p < 0.001$, uncorrected, projected on a template brain in MNI space, and color coded for the t-values as indicated by the color bar on the left. The graphs on the right show the mean (M) and standard error (SE) of the beta estimates for prior investments and high and low stock dividends separately, in the indicated anatomically defined regions of interest.(vmPFC=ventromedial prefrontal cortex; ACC=anterior cingulate cortex; PCC=posterior cingulate cortex; vStr=ventral striatum.)

Table 1: Experimental design. Subjects made 96 decisions to invest in one of two securities: a stock with risky payoffs coming from one of two distributions, one better than the other, and a bond with a known payoff. After each choice subjects provided an estimate of the probability that the stock was paying from the better distribution. Subjects were paid based on their investment payoffs and the accuracy of the probability estimates provided. The 96 trials are split into 16 blocks of 6 trials each: for these six trials, the learning problem is the same. That is, the computer either pays dividends from the good stock distribution in each of these six trials, or it pays from the bad distribution in each of the six trials. The good distribution is that where the high dividend occurs with 70% probability in each trial, while the low dividend occurs with 30% probability. The bad distribution is that where these probabilities are reversed: the high dividend occurs with 30% probability, and the low dividend occurs with 70% probability in each trial. At the beginning of each learning block, the computer randomly selects (with 50%-50% probabilities) whether the dividend distribution to be used in the following six trials will be the good or the bad one. See Figure 1 for examples of trials.

Condition		Stock Payoffs	Bond Payoff	Number of blocks	Trials per block
Gain	Low variance	+ €10 or + €2	+ €6	4	6
Gain	High variance	+ €12 or + €0	+ €6	4	6
Loss	Low variance	– €10 or – €2	– €6	4	6
Loss	High variance	– €12 or – €0	– €6	4	6

Table 2: The degree to which participants make errors in assessing the stock when confronted with dividend information that contradicts their prior choice is predicted by the engagement of the vmPFC and the left ventral striatum during the presentation of that information (no other regions have significant effects, results omitted here for brevity). The data included in this analysis refers to instances when participants chose the bond at the beginning of a trial, and then observed that the stock paid a high dividend that trial. The three regression specifications in the table indicate that higher activation in the vmPFC, left ventral striatum, and their first principal component, all measured at the time of the dividend presentation in the trial, leads to a smaller probability estimation error at the end of the trial. The dependent variable, $Probability\ Estimation\ Error_{it}$, is defined as the absolute value of the difference between the estimate provided by subject i in trial t regarding the probability that the stock is paying dividends from the good distribution, and the objective Bayesian value of that probability. Standard errors are robust to heteroskedasticity and are clustered at the subject level. The regressions in the three specifications in the table include fixed-effects for each subject, as well as for each level of objective probability, and controls for the experimental condition faced by participant i in trial t (i.e., gain vs. loss, low vs. high variance conditions). t-statistics are reported in parentheses. * and ** denote statistical significance at $p < 0.1$ and $p < 0.05$, respectively.

Dependent variable	$Probability\ Estimation\ Error_{it}$		
$vmPFC_{it}$ at dividend presentation	–1.03		
	(–1.96)*		
$vSTR_{it}$ at dividend presentation		–1.28	
		(–1.97)*	
1^{st} principal component of			–0.84
$vmPFC_{it}$ and $vSTR_{it}$ at dividend presentation			(–2.39)**
Condition Fixed Effects	Yes	Yes	Yes
Objective Probability Fixed Effects	Yes	Yes	Yes
Subject Fixed Effects	Yes	Yes	Yes
R^2	0.38	0.38	0.38
Observations	1014	1014	1014

SUPPLEMENTARY MATERIALS

Methods

Subjects. A total of 54 healthy male subjects participated in the experiment. Participants were screened for general MRI-specific criteria, for absence of any neurologic and cardiovascular diseases and psychiatric disorders, for employment status and for smoking status (six smokers remained in the sample who smoked M 8.1 $\pm$ SD 4.6 cigarettes per day). Four subjects were excluded due to clinical exclusion criteria, two subjects were excluded because they failed to follow task instructions, and two subjects were excluded due to excessive head movements during the fMRI scan. The remaining 46 subjects (all male, age M 40.08 $\pm$ SD 6.53, range 29-49 years) were included in the analysis. All subjects gave informed written consent. The study was approved by the ethics committee of the University of Bonn.

The experiment lasted approximately 2 hours. Subjects received 25 Euros at the outset, as well as the payoff accumulated during the financial learning task. If the final payoff was less than 20 Euro per hour, the difference was compensated for. On average, participants' compensation for this study was 41.4 Euro.

fMRI session and financial decision making task To measure the BOLD signal during learning we used a task that requires subjects to update their beliefs about a stock's dividend distribution on a trial-by-trial basis in order to make optimal choices (cp. Kuhnen, forthcoming). Instructions for the task were presented to the subjects as a standardized slide presentation at a desktop computer. The subjects then proceeded with a training session for the task. The design and timing of the training session were identical to the task used during scanning, but the training was shortened to one gain and one loss block (order randomized across subjects). Next, the subject was placed in the MR scanner and accustomed with the choice button device (four buttons, one for each thumb and index finger). The subject viewed the experimental screen over video goggles that were adjusted to the subject's sight (subjects with an ametropia of more

than $\pm$ 5 dpt were excluded).

The task timing is described in Figure 1. In each of 96 trials, the subject chose between a stock and a bond. After each choice the subject learned – irrespective of his investment choice – how much the stock paid off in the current trial. For each block of six trials, the computer randomly assigned whether the stock was good or bad. From the instructions and the training the subject knew that if the stock was good, it would pay the higher outcome with a probability of 70% and the lower outcome with 30%. If the stock was bad it would pay the higher outcome with a probability of 30% and the lower outcome with 70%. Based on the number t of high stock outcomes out of the n outcomes seen so far in the current learning block, an objective Bayesian probability the stock is good can be calculated at the end of each trial (see Table S1). In the first trial of each block, the stock could be either good or bad with the same probability (50%). With every high (low) stock outcome, it is more (less) likely that the stock is good. After the stock payoff was shown in each trial, the subject was asked to estimate the objective Bayesian probability that the stock is good. Estimations within 5% of the correct answer were treated as correct and were incentivized with 0.10 Euro that were added to the final payoff. The last screen of each trial showed the subjects updated balance.

As prior work suggests that financial learning is different in the gain and the loss domains (Kuhnen, forthcoming), we implemented two context conditions. In the gain context, the outcomes of stock and bond were positive, in the loss context the outcomes were negative. A text cue at the beginning of each block indicated the context that applied to the upcoming six trials (see Figure 1). Moreover, we implemented two variance levels: For each block, the stock dividend distribution could have high variance (0 vs 12 Euro, or 12 vs 0 Euro) or low variance (2 vs 10 Euro, or 2 vs 10 Euro). The stock dividend distribution remained the same throughout the block. The bond always paid the initial expected outcome of the stock, i.e. 6 Euro in the gain context and 6 Euro in the loss context. The sequence of conditions (gain & high variance,

gain & low variance, loss & high variance, loss & low variance) was pseudorandomized so that every subject played each condition four times (see Table 1).

MRI data acquisition. All MRI sessions were run on a Siemens Trio 3.0 T scanner with a standard eight-channel head coil. Scan sessions started off with a localizer scan followed by a structural scan that included T1-weighted images (TR, 1570 ms; TE, 3.42 ms; flip angle, 15; 1 mm slices). While subjects played the financial learning task, T2*-weighted echoplanar images (EPIs) were collected (TR, 2500 ms; TE, 30 ms; flip angle, 90; 37 3 mm slices in ascending order; field of view, 192 mm; voxel size, 3 x 3 x 3.3 mm; approx. 840 volumes). The task was implemented in Presentation (Neurobehavioral Systems; www.neurobs.com).

Behavioral analysis. Behavioral data were logged by the Presentation software during scanning and analyzed in STATA. Table S2 shows the result of a within-subject estimation of the effect of the stock vs. bond choice, as well as of the effect of observing a high vs. a low dividend, on the probability estimates produced by participants in each trial.

fMRI data preprocessing Preprocessing of the functional images was implemented in the MATLAB (MathWorks) based software Statistical Parametric Mapping 8 (SPM8, version r5236; www.fil.ion.ucl.ac.uk/spm). It included realignment, normalization on MNI standard (Evans et al., 1993; www.bic.mni.mcgill.ca) using SPM8's optimized segmentation of the T1 image and the mean realigned EPI into gray and white matter, cerebrospinal fluid, bone matter, soft tissue and air tissue classifications and the application of these deformations on the remaining EPI images, as well as spatial smoothing with an 8 mm full width half maximum Gauss kernel.

Whole-brain fMRI analysis The statistical fMRI analysis was also implemented in SPM8 (version r5236). For the first-level analysis we used a general linear model (GLM) which was estimated with SPM8's canonical hemodynamic response function and included a high-pass filter of 128 Hz as well as correction for autocorrelations. SPM8's internal masking threshold

for the estimation of beta parameters was set to 0.4. The first goal of the fMRI analysis was to identify brain regions that are sensitive to prior investment choices during the processing of new stock information. For this we computed a GLM that included the following events for every trial of the financial decision making task: onset of the choice screen, onset of the stock outcome presentation, onset of the estimation screen, and onset of the accumulated payoff presentation. Each event was modeled by four onset regressors as stick functions. The onset of the choice screen was modeled by regressors for the four conditions: 1. gain & low variance, 2. gain & high variance, 3. loss & low variance, 4. loss & high variance. The onset of the stock outcome presentation was modeled by indicator variables for the subject's prior investment choice and the presented stock outcome, creating four onset regressors: 1. stock choice & high dividend, 2. bond choice & high dividend, 3. stock choice & low dividend, 4. bond choice & low dividend. Because we were primarily interested in the effect of prior investment decisions on the BOLD signal when new stock information was presented, these four onset regressors were defined as regressors of interest. To ensure that the BOLD signal was not simply driven by changes in the objective Bayesian probability that the stock is good we added this variable as a parametric modulator of the regressors of interest. The onsets of the estimation screen and the accumulated payoff presentation were modeled by the same indicator variables, but without parametric modulations. Together with six motion parameters, they were added to the GLM as nuisance regressors. For each subject, we computed contrast images for the four regressors of interest and tested them in a two-by-two ANOVA at the group level with a within-subject factor for prior investment (stock and bond) and a within-subject factor for stock outcome (high and low dividend). The ANOVA was designed as a full factorial model with dependent measurements. We tested the positive interaction of the two factors and applied whole-brain correction for multiple comparisons based on familywise error (FWE) control. We report results that survive a FWE-corrected threshold of $p < 0.05$ at the peak or cluster level in Table S3. We expected

activation in brain areas associated with outcome and reward encoding, such as the vmPFC, the ventral striatum, and the PCC (e.g. Bartra, 2013). To illustrate the results we extracted the mean beta parameters for each subject and each regressor of interest from anatomically defined ROI masks for the vmPFC, the bilateral striatum, and the PCC derived from the Automated Anatomical Labeling (AAL) atlas (Maldjian et al., 2003; Tzourio-Mazoyer et al., 2002) using the MarsBaR toolbox (Brett et al., 2002). . We then plotted the mean and standard error of the beta parameters across all subjects against the four regressors of interest in Figure 3.

fMRI time course analysis The second goal of the fMRI analysis was to investigate the effect of prior investments on the processing of new stock information on a trial-by-trial basis.

To analyze the fMRI time courses, we first defined Volumes of Interest (VOIs) in the vmPFC and the bilateral ventral striatum based on a whole-brain meta-analysis of subjective value effects at the decision stage as reported by Bartra et al. 2013 (their figure 6A).

For each subject and each VOI, we extracted the first BOLD eigenvariate from the preprocessed image files. As part of the extraction each BOLD eigenvariate was whitened, high-pass filtered, and corrected for confounds like scanner drifts. From the BOLD eigenvariates we selected, trial by trial, the values that corresponded to the expected peak BOLD responses of the same four events as estimated in the GLM: onset of the choice screen, onset of the estimation screen, onset of the accumulated payoff presentation, and onset of the stock outcome presentation. We used the latter in the prediction analysis in Table 2.

Supplemental References

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Table S1. Objective Bayesian Posterior Beliefs The table provides all possible values for the objectively correct Bayesian posterior that the stock is paying from the good dividend distribution, starting with a 50%-50% prior, and after observing each possible dividend history path in a learning block. Every trial a new dividend (high or low) is revealed. There are six trials in each learning block. The objective Bayesian posterior that the stock is the good one, after observing t high outcomes in n trials so far is given by: $\frac{1}{1+\frac{1-p}{p}*(\frac{q}{1-q})^{n-2t}}$, where $p = 50\%$ is the prior that the stock is good (before any dividends are observed in that learning block) and $q = 70\%$ is the probability that a good stock pays the high (rather than the low) dividend in each trial.

n trials so far	t high outcomes so far	Probability$\{$stock is good $\mid$ t high outcomes in n trials$\}$
1	0	30.00%
1	1	70.00%
2	0	15.52%
2	1	50.00%
2	2	84.48%
3	0	7.30%
3	1	30.00%
3	2	70.00%
3	3	92.70%
4	0	3.26%
4	1	15.52%
4	2	50.00%
4	3	84.48%
4	4	96.74%
5	0	1.43%
5	1	7.30%
5	2	30.00%
5	3	70.00%
5	4	92.70%
5	5	98.57%
6	0	0.62%
6	1	3.26%
6	2	15.52%
6	3	50.00%
6	4	84.48%
6	5	96.74%
6	6	99.38%

Table S2. Stock holders react more strongly than bond holders to high dividends, and are more positive, when estimating the probability that the stock is paying dividends from the good distribution. The dependent variable in the linear regression in the table, $ProbabilityEstimate_{it}$, is the probability estimate produced by subject i in trial t. The independent variables of interest are $HighDividend_{it}$, which is equal to 1 if the stock paid a high dividend that trial and 0 otherwise, $StockHolder_{it}$, which is equal to 1 if the participant chose to hold the stock at the beginning of the trial and 0 otherwise, and their interaction ($HighDividend_{it}$ X $StockHolder_{it}$). The regression includes subjects-fixed effects and controls for the experimental condition faced by each participant i in each trial t (i.e., gain vs. loss, low vs. high variance conditions), as well as for the subject's probability estimate in the prior trial. t-statistics are reported in parentheses. *, ** and *** denote statistical significance at $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively.

Dependent variable	$ProbabilityEstimate_{it}$
$HighDividend_{it}$ X $StockHolder_{it}$	5.15
	(2.31)**
$HighDividend_{it}$	25.15
	(11.98)***
$StockHolder_{it}$	5.04
	(3.53)***
$ProbabilityEstimate_{it-1}$	0.52
	(7.39)***
$GainCondition_{it}$	1.74
	(1.92)*
$LowVarianceCondition_{it}$	0.11
	(0.21)
Subject Fixed Effects	Yes
R^2	0.687
Observations	3663

Table S3. Brain regions positively correlated with the interaction effect of prior investments (stock or bond) and stock dividend (high or low dividend) at the time of stock outcome presentation. Results from the two-by-two ANOVA are shown. Height threshold, $t > 3.14$; extent threshold, $kE > 10$. Asterisks denote activations that survive whole-brain correction for multiple comparisons at $p < 0.05$ based on FWE control at the peak level (*) or at the cluster level (**). ACC, anterior cingulate cortex; vmPFC, ventromedial prefrontal cortex; dlPFC, dorsolateral prefrontal cortex; PCC, posterior cingulate cortex; IPL, inferior parietal lobule.

		MNI coordinates			Cluster	Max
Region	Side	x	y	z	size k_E	stat t
ACC, vmPFC, dlPFC	L	-6	41	-4	1228	5.82*
ventral striatum	L	-12	2	-14	52	5.55*
ventral striatum	R	12	2	-14	49	4.80*
PCC	L	-9	-58	29	201	4.28**
IPL, postcentral gyrus	L	-54	-28	52	160	3.90**