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Heads we both win, tails only you lose: the effect of limited liability on risk-taking in financial decision making *

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Abstract

One of the reasons for the recent crisis is that financial institutions took "too much risk" (Brunnermeier, 2009; Taylor et al., 2010). Why were these institutions taking so much risk is an open question. A recent strand in the literature points towards the "cognitive dissonance" of investors who, because of the limited liability of their investments, had a distorted view of riskiness (e.g., Barberis (2013); Bénabou (2015)). In a series of laboratory experiments we show how limited liability does not affect the beliefs of investors, but does increase their willing exposure to risk. This results points to a simple explanation for the over-investment of banks and hedge-funds: When incentives are not aligned, investors take advantage of the moral hazard opportunities.

Keywords Moral Hazard · Cognitive Dissonance · Behavioral Finance

JEL Classification C91 · D84 · G11 · G41

1 Introduction

Excessive risk-taking increases the vulnerability of financial markets (Edwards and Mishkin, 1995; Goodhart et al., 2006), an example being the recent financial crisis in which financial

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institutions took "too much risk" (Brunnermeier, 2009; Taylor et al., 2010). A common explanation for this excessive risk-taking is the limited liability of financial institutions (Acharya et al., 2010), as investors try to exploit the moral hazard situation this creates (Jensen and Meckling, 1976; Gropp et al., 2013). However, a recent trend in the literature suggests that limited liability might work through a different channel where investors systematically underestimate the risk of their investments due to "cognitive dissonance"[1] (Barberis, 2013; Bénabou, 2015). The argument in this case is that, in a situation of moral hazard, investors might inadvertently bias downwards the risk perception of their investments in order to justify to themselves any excessive risk-taking.[2]

In this paper, we test whether this hypothesis is true in the lab by comparing the risk assessment that experimental subjects make under full and under limited liability. In control rounds, subjects evaluate different assets and then decide how much of their endowment to invest with full liability. In treatment rounds, subjects are divided into bankers and clients. Bankers assess the riskiness of the different assets and decide how much of the clients' endowment to invest. If the investment results in gains, then the profits are split between banker and client. If, instead, there are losses, then the client absorbs all of them.

Such a treatment allows us to isolate any change in beliefs that might come from the introduction of limited liability in an otherwise identical setup. Our results are clear: subjects hold identical risk perceptions under full and limited liability, but significantly increase the level of risk that they are willing to take when liability is limited. The experiment shows the absence of "cognitive dissonance" among investors and, thus, calls for a critical scrutiny of the presence and impact of cognitive dissonance, as well as other similar biases like wishful thinking or overprecision in financial markets.

This paper is part of a recent trend in behavioral finance experiments which aims to understand how investors form beliefs and make decisions in financial markets (Nosić

[1]Cognitive dissonance is the psychological discomfort that arises when one cannot rationalize two conflicting views or actions (e.g., smoking while knowing that it is unhealthy). A common way to deal with this tension is to modify the beliefs one holds on the matter (Festinger, 1962). Studies on this phenomenon are numerous and range from workers adjusting their beliefs on the riskiness of their job (Akerlof and Dickens, 1982) to smokers believing that smoking is not that harmful (McMaster and Lee, 1991), or investors staying in low performance funds due to their overly optimistic perceptions of past fund performance Goetzmann and Peles (1997).

[2]This phenomena holds a strong resemblance to what Bénabou et al. (2018) call "absolving narratives." We believe that the "unconscious" downward bias of risk perception we study is the fundamental building block around which "absolving narratives" are constructed.

and Weber, 2010; Bosch-Rosa et al., 2018; Weber et al., forthcoming). More precisely, we are part of the literature that investigates cognitive biases in financial environments. Some previous work in this area that is close to our research are Chang et al. (2016) or Mayraz (2017). While the first investigates the effects of delegation on the disposition effect, the second studies the effects of "wishful thinking" on investors. Our contribution is to analyze whether limited liability affects the beliefs of investors, and consequently their actions. This is relevant as A) it contributes to the growing literature on "motivated beliefs" (Bénabou and Tirole, 2011, 2016; Bénabou, 2015; Gino et al., 2016) by shedding light on the effects that incentives have on the beliefs and actions of investors in a principal-agent setting, B) it clarifies the channels through which limited liability induces excessive risk-taking by financial investors, and C) it adds to the discussion around risk-taking on behalf of others, where results are mixed.[3]

2 Experimental Design

The core of our experiment is divided into two blocks of three rounds. In each round we present subjects with a graph showing the daily prices of a stock from the DAX30[4] for eleven consecutive years (see Figure 4 in Appendix A for the six graphs presented). Subjects know that the data comes from the DAX30, but are not told the exact years of the data nor the name of the company. Additionally, they are told that all time-series have been shifted such that the price at the beginning of the 12th year is always € 100. Additionally, they know that they will not get any feedback until the end of the experiment, and that the specific instructions for each block will be read immediately before it starts.

In each round, after seeing an animation representing the evolution of prices for the anonymous stock, subjects are presented with the Assessment Screen (see left panel of Figure 1). In this screen they are asked to assess the probability that the price of the stock will be below € 100 by the beginning of the 14th year (i.e., the likelihood of a loss),

[3]While, for instance, Chakravarty et al. (2011) and Agranov et al. (2014) provide evidence for higher risk-taking on behalf of others, Eriksen and Kvaløy (2010) and Pahlke et al. (2012) find the opposite. Our results provide support to the first group.

[4]Germany's prime blue chip stock market index.

and to guess the price of the stock at that point. Once this is done they move to the Investment Screen.

In the Investment Screen (see right panel of Figure 1) subjects are endowed with € 10 and asked to invest as much as they want of this endowment into the stock they just assessed.[5] The return (Π_i) to the investment (I_i) of subject i will be the difference between the price at the beginning of the 12th year (€ 100) and the price at the beginning of the 14th year ($price_{t=14}$). Any amount that the subject does not invest in the stock is assumed to go into a risk-free asset with no returns. This leaves the payoff for the investment phase as:

$$\Pi_i = I_i * \frac{price_{t=14}}{100} + €10 - I_i. \tag{1}$$

After making their investment decisions subjects immediately move to the next round where they are presented with a new Assessment Screen containing a different graph to asses. This process is repeated three times, after which the instructions for the second block of three rounds are read aloud. In each session one of the blocks is a Control block and the other is a Treatment Block. Sessions 1 to 4 start with the Control block while sessions 5 and 6 start with the Treatment block.

The difference between the Treatment and Control blocks is that before the start of Treatment blocks half of our subjects are assigned the role of "Bankers" while the other half are "Clients." Subjects are aware of their specific type before the the block starts, and they know they will keep the type for the whole block. The structure and tasks in Treatment blocks are identical to those of Control, except for the investment part. In this part, Bankers will be making investment decisions (I_i^B) not over their endowment, but over the endowment of clients (j). So while both get € 10 in each round, Bankers are assumed to invest their whole endowment in the risk-free asset, while deciding how much to invest of client j's endowment. If the investment is profitable (i.e., $price_{t=14} \geq 100$), then the Banker and Client split the gains. On the other hand, if the investment turns out sour (i.e., $price_{t=14} < 100$), then the Client absorbs the whole loss.[6] Therefore, the payoff for Banker i in Treatment rounds is:

[5] Notice that subjects are endowed for each stock with € 10. So the investment decisions are always independent.

[6] We acknowledge that incurring in losses might have a reputational cost for bankers. Yet, for the sake of simplicity, and to make moral hazard most salient, we decided that bankers incur a zero cost in case of a failed investment.

$$\Pi_i^B = \begin{cases} \left(I_i^B * \frac{price_{t=14}}{100} - I_i^B \right) * 0.5 + €10, & \text{if } p_{t=14} \geq 100 \\ €10, & \text{if } p_{t=14} < 100 \end{cases} \tag{2}$$

Analogously, the payoffs for Client j, who is paired with Banker i, are:

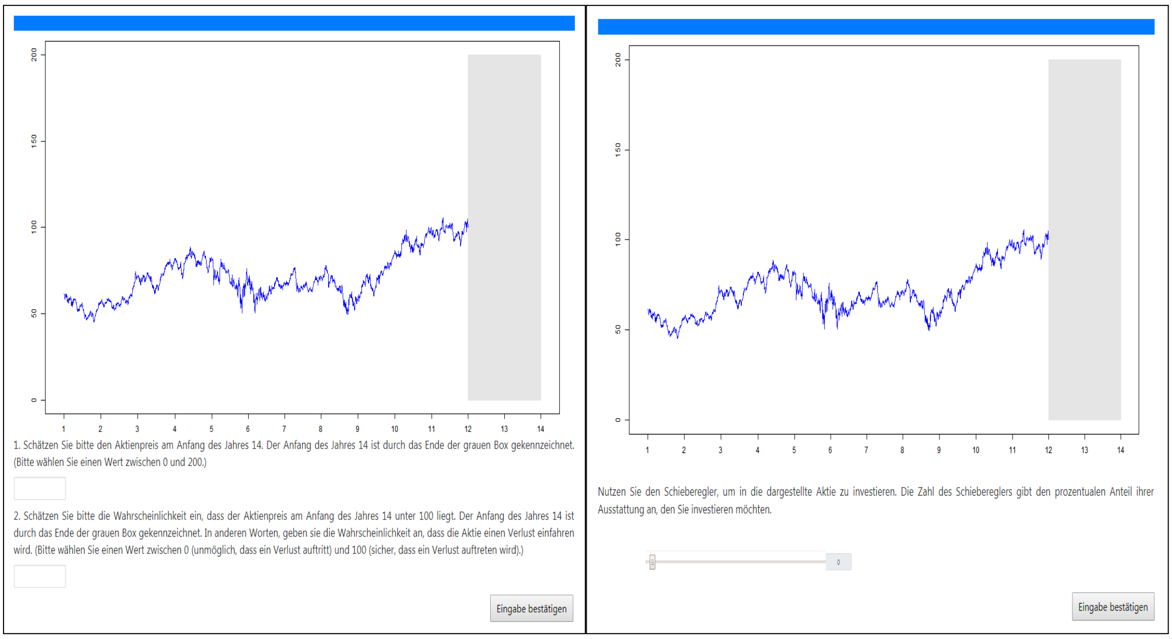
$$\Pi_j^i = \begin{cases} \left(I_i^B * \frac{price_{t=14}}{100} - I_i^B \right) * 0.5 + €10, & \text{if } p_{t=14} \geq 100 \\ I_i^B * \frac{price_{t=14}}{100} + €10 - I_i^B, & \text{if } p_{t=14} < 100 \end{cases} \tag{3}$$

The payoff structure and investment opportunities in our experiment seem well suited to study the effects of cognitive dissonance in financial markets. To see this, consider the example used by Barberis (2013) of traders on the mortgage desk of banks: because subprime products were usually complex, there was scope for traders to manipulate their beliefs (as a self-justification for excessive risk-taking), as it would be hard to argue against any assessment they had made.[7] Similarly, the ambiguity of the products offered to Bankers in our experiment lends itself particularly well to belief manipulation, allowing us to study the effects of limited liability on the risk assessment of Bankers.

2.1 Details on payoffs

In total, across both blocks, we elicit six times the probability that the stock will suffer a loss, the expected price, and the investment decision for each subject. To incentivize the choices in the Assesment Screen we used the binarized scoring rule (Hossain and Okui, 2013), an incentive compatible scoring rule robust to any risk preferences subjects might have. Additionally, to avoid any hedging, subjects were paid for only one of their six choices for the loss assessments, price predictions, and investment (be it in the Control or Treatment block). The payoff relevant decisions were randomly and independently

[7]To be precise, Barberis (2013) writes "How can we use cognitive dissonance to formalize the story I told above? If a trader on the mortgage desk of a bank begins to sense that the holdings of subprime securities he is building up may pose serious risks to his institution and to the broader financial system, this will threaten his positive self-image [...] To remove the dissonance, he could resign his position – but that would be financially costly. Instead, he manipulates his beliefs, telling himself that his business model is not that risky. For example, he might stop himself from inspecting the quality of the subprime loans he is working with too closely, lest he stumble on some disturbing information. [...] It is worth noting that, for at least two reasons, subprime securitization may have lent itself particularly well to belief manipulation. The first reason is that subprime-linked products were often complex. Given their intricacies, it would have taken considerable effort to disprove the claim that they were relatively safe. This may have made it easier for people to delude themselves about their risks."



(a) First Screen (b) Second Screen

Figure 1: Screen for the belief elicitation phase. Subjects are asked for the probability that the price of this stock will be below 100 at the beginning of the fourteenth year, and for an exact estimate of this price. Notice that the graph presented in this screen is one of the randomly generated graphs used during practice rounds. For more details on practice rounds see the instructions in Appendix D.

chosen by the computer, so a subject might get paid for her price prediction in round three, her investment in round four, and the accuracy of the assessed loss likelihood in round six. This payoff structure makes the moral hazard effect even more salient since the (unique) payoff for the investment decision was equally likely to come from the Control or Treatment block.

2.2 Personality Traits

Finally, subjects take part in a third block in which we elicit their personality traits. This block includes tests for risk, ambiguity, and loss aversion through a modification of the multiple price lists used in Rubin et al. (2017). Additionally, to measure their cognitive ability, subjects answer the CRT (Frederick, 2005), CRT2 (Thomson and Oppenheimer, 2016) and eCRT (Toplak et al., 2014) questions. Subjects also answer the short version of the Big Five personality traits suggested by Rammstedt and John (2007), as well as the three questions on financial literacy that we borrow from Lusardi and Mitchell (2011). At the end of the block they are asked to state their gender, field of study, and age.

3 Results

A total of 130 subjects were recruited through ORSEE (Greiner, 2004). All sessions lasted two hours and were run at the Experimental Economics Laboratory of the Technische Universität Berlin. Subjects made on average 23.04€, and the experiment was programmed and conducted using O-Tree (Chen et al., 2016).

We ran three types of sessions: Type 1 sessions ran first the Control Block presenting subjects with graphs 1-3 and then the Treatment Block using graphs 4-6. Type 2 sessions started with the Treatment block using graphs 4-6 and followed by the Control Block using graphs 1-3. This allows us to control for the ordering effects of each block. Type 3 sessions, on the other hand, have the same ordering as Type 1 sessions (Control then Treatment), but with inverted graph order, so in Control subjects are presented with graphs 4-6 and in Treatment graphs 1-3.

Table 1 presents the median value across all subjects for the expected probability of a loss (ProbLoss), the expected price (PriceExp), and the share of the endowment invested in the stock (Investment). The table is divided by types of session (rows) and graph (columns). Note that across all three session types Control always has twice as many observations as Treatment does. This is because we use only the data of Bankers in Treatment blocks (65 observations) while for Control blocks we use the data of all participants (130 observations).

It is clear from Table 1 that beliefs and investment decisions differ substantially across graphs. These difference are (in most cases) statistically significant (see Table 3 in Appendix B for pairwise comparisons), and go in the direction one would expect from looking at the graphs.[8] Additionally, there is a clear correlation between the expected price and the probability of losses, the more likely a loss is, the lower the expected price. These two results lead us to believe that our graphical interface is understood by our subjects, and that their beliefs respond to the graphs we present them.

The second thing to notice from Table 1 it that there seem to be no ordering effects, as the differences in beliefs and investment between Type 1 sessions and Type 2 sessions appear to be negligible. We confirm this by using pairwise Wilcoxon rank-sum tests to

[8] For example, Graph 1, with a clear upward trend, is approximately half as likely to have losses than Graph 2, which has a less clear upward trend.

	Control			Treatment		
	Graph 1	Graph 2	Graph 3	Graph 4	Graph 5	Graph 6
Session type 1:						
ProbLoss	30.0	60.0	47.5	45.0	40.0	35.0
PriceExp	120.0	90.0	102.5	110.0	117.0	120.0
Investment	40.0	12.5	22.5	90.0	100.0	100.0
Session type 2:						
ProbLoss	37.0	60.0	50.0	60.0	40.0	45.0
PriceExp	120.0	85.0	100.0	99.0	120.0	107.5
Investment	50.0	10.0	20.0	50.5	70.0	67.5
	Treatment			**Control**		
	Graph 1	Graph 2	Graph 3	Graph 4	Graph 5	Graph 6
Session type 3:						
ProbLoss	30.0	53.5	47.5	50.0	45.0	35.0
PriceExp	120.0	90.0	105.0	100.0	116.0	115.0
Investment	80.0	40.0	64.5	16.5	30.0	39.5
Wilcoxon rank-sum tests:						
	Graph 1	Graph 2	Graph 3	Graph 4	Graph 5	Graph 6
Prob Loss	0.727	0.374	0.371	0.669	0.304	0.335
Price Exp	0.417	0.786	0.797	0.420	0.762	0.316
Investment	0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 1: The upper part of the table shows the median values of loss probability, price expectation, and investment for each of the six graphs in each of the three session types. For Treatment cases only the data of Bankers is taken into consideration considered. The bottom part of the table shows the p-values resulting from Wilcoxon rank-sum tests comparing Treatment and Control decisions.

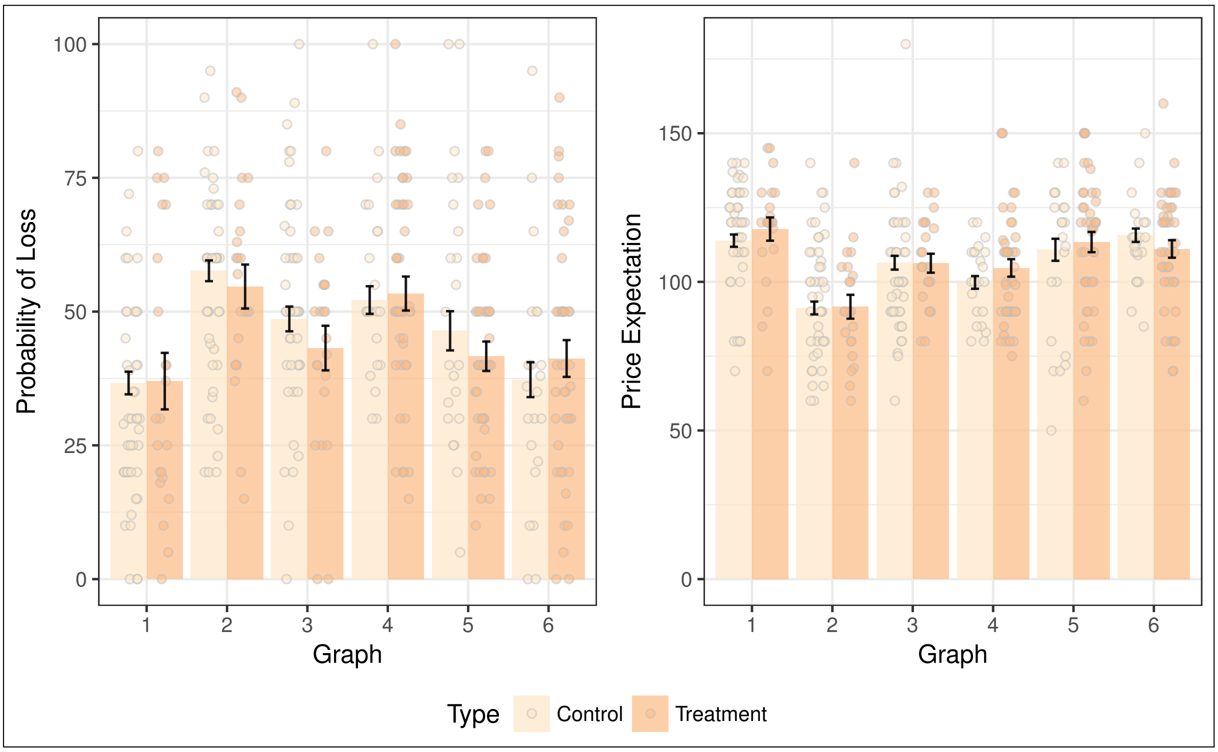


Figure 2: In the vertical axis we plot the subjects' stated loss probabilities (left panel) and price expectations (right panel). In the horizontal axis we separate by graph. The bars represent the average belief, the black error bar represents the standard error. Each dot is an individual belief. Light-shaded columns collect beliefs of all subjects in Control blocks, dark-shaded columns collect beliefs of Bankers only in Treatment blocks.

compare beliefs and investments for the same graph across session types (see Table 4 in Appendix B). Consequently, we pool the data for sessions Type 1 and 2 for the analysis.

3.1 The Effects of Limited Liability on Beliefs and Investment Behavior

The left (right) panel of Figure 2 presents the probabilities that subjects assign to a loss (expected price) for each of the six graphs presented to subjects. The light-shaded columns are the elicited beliefs of all subjects in Control, while the dark-shaded columns only include the beliefs of Bankers in Treatment. It is clear from the figure that limited liability seems to have no effect on the belief of subjects. This is confirmed through a series of Wilcoxon rank-sum tests comparing the beliefs of subjects between Treatment and Control (see results at the bottom part of Table 1). Because the informational content of null results is often unclear, in Appendix C we follow Buser et al. (2017) and study the impact of our observed results on the probability that the null is true. The outcome lends credibility to our results, as for different priors and alternative hypotheses, our observed

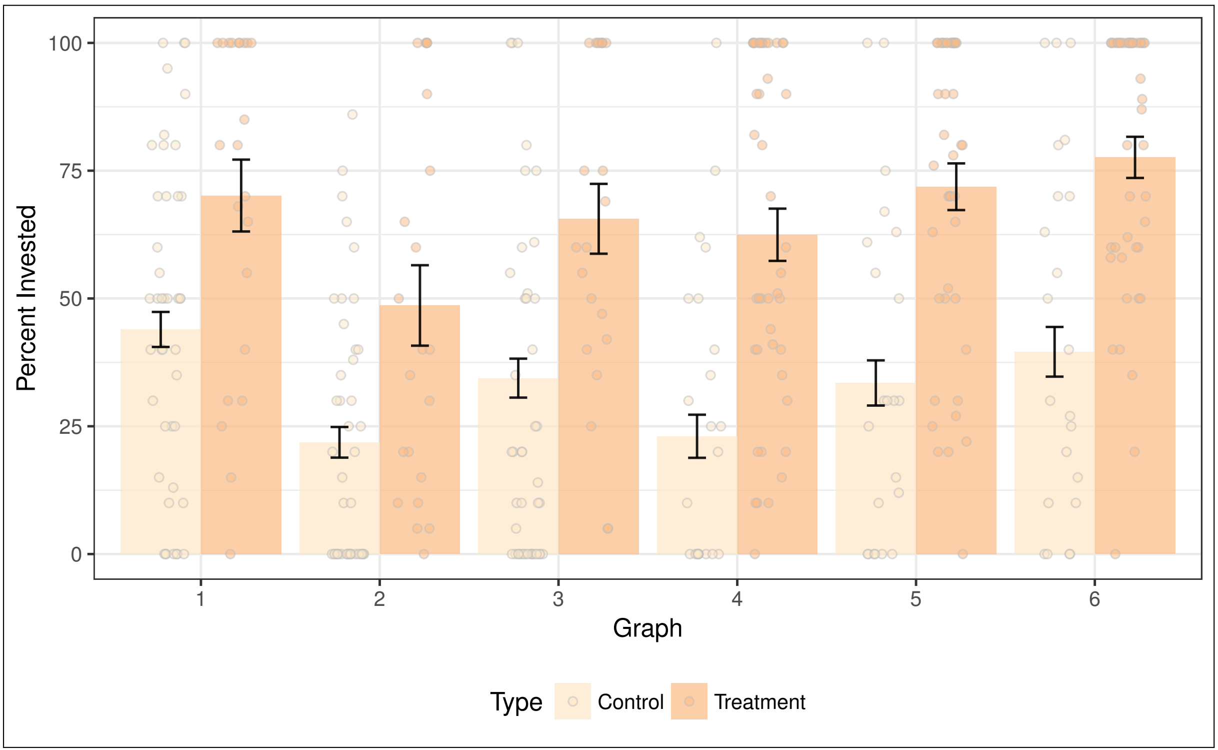


Figure 3: In the vertical axis we plot the percent of endowment invested. In the horizontal axis we separate by graph. The bars represent the average investment, the black error bar represents the standard error. Each dot is an individual investment decision. Light-shaded columns collect investments of all subjects in Control blocks, dark-shaded columns collect investments of Bankers only in Treatment blocks. The vertical black bars report the standard errors.

outcomes largely increase the probability that the null hypothesis is true, practically discarding any Type II errors. Therefore we state:

Result 1: Limited liability has no effect on the beliefs of subjects.

Analogous to the previous figure, Figure 3 presents the investment decisions of all subjects in Control (light-shaded bar) and Bankers in Treatment (dark-shaded bar) for each of the six graphs. It is clear that, in this case, limited liability has a strong effect: for the same graph, subjects in Treatment blocks invest substantially more than subjects in Control blocks. This is confirmed by a series of Wilcoxon rank-sum tests comparing the investment in Treatment and Control. The results can be found in the last row of Table 1. Therefore we state:

Result 2: Limited liability significantly increases the amount invested by subjects.

3.2 Regression Analysis

To quantify the effects of limited liability on beliefs and investment behavior, we run a series of linear models where the dependent variable is either (1) the probability that subjects assign to a loss, (2) the expected stock price, or (3) the investment share in the stock (see Table 2). Our main explanatory variable is "Treatment" which takes value unity if the observation is from a Banker in a Treatment round, or zero if it comes from a Control round. Additionally, we control for gender, graph, graph and treatment order, risk/ambiguity/loss aversion, cognitive ability, and various other personality traits, and cluster all standard errors at the subject level.

Columns [1] and [2] have as dependent variable the expected probability of a loss, and the expected price at $t = 14$ respectively. In both cases, while the treatment variable has the sign we would expect, it is never statistically significant. This result confirms what we observed using non-parametric tests in section 3.1: Limited liability has no effect on the subjects' stated beliefs.

On the other hand, when investment is the dependent variable (columns [3] and [4]), Treatment is positive and highly significant. Again, these results are in line with what we observed in section 3.1: When investors are not accountable for their losses they invest larger amounts than when they are fully responsible for their actions. All results are robust to the introduction of personality and individual trait controls, suggesting a strong effect of moral hazard on the decision-making of investors.

Finally, column [4] shows that a higher expected loss probability leads to a reduction in investment for any given stock. This result is robust to the inclusion of the Treatment variable, implying that, even under limited liability, subjects condition their investments on expected returns. This result is foreshadowed in Figures 2 and 3 where expected probability of a loss and invested money move in opposite directions for both Treatment and Control.

	[1] ProbLoss	[2] ExpPrice	[3] Investment	[4] Investment
Treatment	-1.099	1.173	33.20***	32.49***
	(1.750)	(1.474)	(4.045)	(4.113)
Gender	-0.344	0.976	-0.338	-0.558
	(2.620)	(2.277)	(4.423)	(4.251)
Order Graphs	-3.408	2.119	10.59*	8.412
	(2.609)	(2.166)	(5.548)	(5.325)
Order Treatment	2.462	-1.178	5.413	6.987
	(2.744)	(2.226)	(5.042)	(4.897)
Ambiguity Aversion	-0.676**	0.317	0.790	0.358
	(0.334)	(0.285)	(0.713)	(0.697)
Risk Aversion	0.182	0.115	0.915	1.031
	(0.382)	(0.365)	(0.988)	(0.933)
Loss Aversion	-0.0353	-0.251	1.710	1.688*
	(0.346)	(0.410)	(1.063)	(0.956)
Correct CRT	-1.110**	0.361	1.237	0.527
	(0.487)	(0.422)	(0.969)	(0.889)
Extraversion	-1.372*	0.208	0.0423	-0.835
	(0.701)	(0.568)	(1.367)	(1.322)
Agreeable	0.497	-0.722	1.230	1.548
	(0.583)	(0.728)	(1.438)	(1.338)
Conscientious	0.231	-0.308	-0.317	-0.169
	(0.536)	(0.604)	(1.079)	(1.015)
Neurotic	0.0646	0.226	0.159	0.200
	(0.507)	(0.583)	(1.349)	(1.242)
Open	0.972**	-0.609	-1.161	-0.539
	(0.413)	(0.460)	(1.026)	(0.966)
ProbLoss				-0.640***
				(0.0678)
Constant	43.96***	117.9***	-0.401	27.71
	(9.784)	(11.11)	(25.92)	(24.24)
N	585	585	585	585
Graph Joint Significance p-value	<0.01	<0.01	<0.01	<0.01
adj. R^2	0.142	0.147	0.289	0.414

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Three linear models and four specifications. The first two columns study the effect of limited liability on the probability of the stock having a loss, and expected prices respectively. The third and fourth columns study the effect of limited liability on investment decisions.

4 Conclusion

Cognitive dissonance is the psychological discomfort that arises when one cannot rationalize two conflicting views or actions. A common way to deal with this tension is by modifying the beliefs one holds on the matter (Festinger, 1962). A recent strand in the behavioral finance literature argues that this might be a new channel through which limited liability affects the behavior of financial investors. Because they need to justify to themselves their excessive risk-taking, financial investors might (inadvertently) bias downwards their risk perception (Barberis, 2013; Bénabou, 2015; Bénabou et al., 2018).

In this paper we test whether limited liability has such an effect by comparing the risk assessment of experimental subjects for different investment opportunities both under full and limited liability. The results are straightforward: our subjects hold the same risk perception under full and under limited liability, but are much more prone to invest in the risky assets when they do not respond for any potential losses. This result is robust to gender effects, various personality traits, and differences in cognitive ability. In addition, a post-study-probability analysis (in Appendix C) shows that our results are highly "informative," in the sense that they are unlikely due to an underpowered test and, thus, practically discarding the possibility of a Type II error.

The absence of cognitive dissonance among investors in our experiment, as well as the observation of a deliberate abuse of moral hazard calls for a more critical scrutiny of the presumed role and impact of cognitive dissonance and other similar psychological biases, like wishful thinking or overprecision, in financial markets.

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A Additional Figures

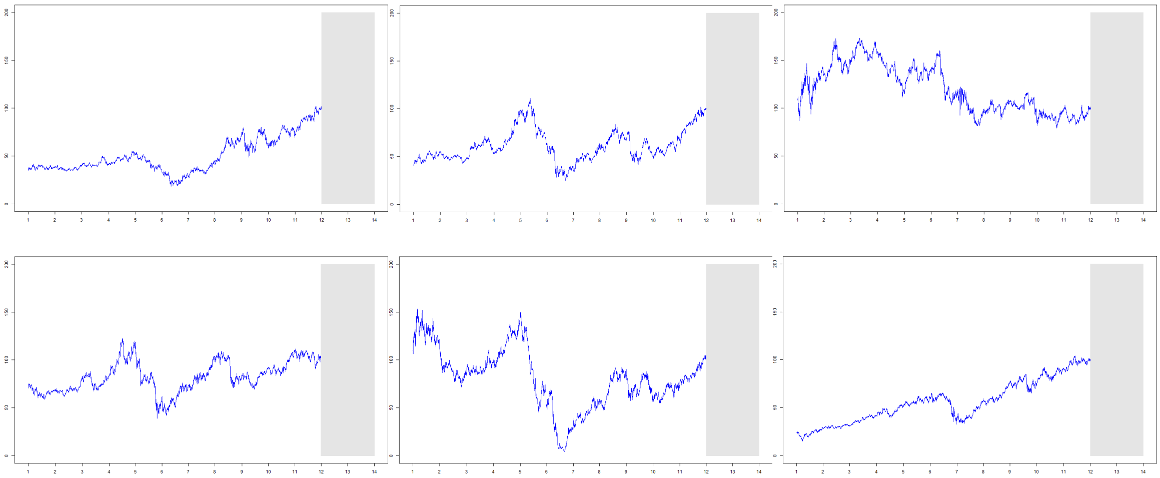

Figure 4: The six graphs presented to subjects (from left to right and from top to bottom): (1) Bayerische Motoren Werke AG, 27-Jun-03 – 27-Jun-16; (2) Daimler AG, 20-Jun-03 – 20-Jun-16; (3) Deutsche Telekom AG, 10-Sep-02 – 10-Sep-15; (4) Siemens AG, 05-Jan-04 – 05-Jan-17; (5) Infineon Technologies AG, 08-Jul-03 – 08-Jul-16; (6) Linde AG, 18-Dec-02 – 18-Dec-15. All data are downloaded from Google Finance

B Additional Tables

	1 v 2	1 vs 3	2 vs 3	4 vs 5	4 vs 6	5 vs 6
Session type 1:						
Prob Loss	0.0005	0.0442	0.0258	0.5410	0.0753	0.7223
Price Exp	0.0001	0.1791	0.0024	0.7320	0.4806	0.6666
Investment	0.0006	0.1272	0.0332	0.3074	0.0187	0.2848
Session type 2:						
Prob Loss	0.0000	0.0010	0.0242	0.0053	0.0522	0.8126
Price Exp	0.0000	0.0161	0.0018	0.0066	0.1503	0.4770
Investment	0.0000	0.0053	0.0049	0.0881	0.0176	0.2091
Session type 3:						
Prob Loss	0.0238	0.1725	0.0425	0.2472	0.0010	0.0748
Price Exp	0.0009	0.0383	0.0248	0.0223	0.0000	0.2501
Investment	0.0011	0.2657	0.0082	0.0298	0.0001	0.2200

Table 3: p-values of Wilcoxon signed-rank test for pairwise comparisons of session medians per graph (from Table 1).

	Graph 1	Graph 2	Graph 3	Graph 4	Graph 5	Graph 6
Prob Loss	0.5177	0.1058	0.1330	0.0547	0.5082	0.2169
Price Exp	0.7540	0.4070	0.4260	0.1512	0.5500	0.3349
Investment	0.4955	0.5751	0.6464	0.3422	0.1278	0.2000

Table 4: p-values of Wilcoxon rank sum tests for pairwise comparisons of session medians from session types 1 and 2 per graph (from Table 1).

C Post-Study-Probability

In this section we formally analyze how "informative" our null result is. In other words, if our null result comes from a high-powered test that correctly estimates a zero effect, or if it is the result of an underpowered test, and therefore a Type II error. To do so we follow Buser et al. (2017), who provide a variation of the Post-Study-Probability (henceforth: PSP) introduced in Maniadis et al. (2014).

The PSP is defined as the posterior probability that the null hypothesis (H_0) holds, given a prior probability that the null hypothesis is true ($\pi(H_0)$) and the p-value observed in our statistical tests (p^*). Formally:

$$P(H_0|p \geq p^*) = \frac{P(p \geq p^*|H_0)\pi(H_0)}{P(p \geq p^*|H_0)\pi(H_0) + P(p \geq p^*|H_1)(1 - \pi(H_0))}, \tag{4}$$

where $P(p \geq p^*|H_0)$ and $P(p \geq p^*|H_1)$ are the two mutually exclusive reasons we might observe a null result. That is, respectively, either the effect is truly null or we make a Type II error. An important advantage of the PSP over more traditional power analyses is that it not only uses information on the power of the tests, but also takes into account the observed p-values.[9] This allows us to compute by how much our observed p-value shifts the posterior probability that the null is true. To calculate the PSP we use the results of the Wilcoxon tests in Table 1. For the sake of completeness we present the PSP both for each individual graph and for the aggregate case in Tables 6 and 5, respectively.[10]

[9]Notice also that we look for a value above the observed p-value and not the 0.05 threshold, The idea is that for any given power, the higher the observed p-value, the less likely it is that we are observing a false negative.

[10]For the aggregate case we pool the p-values weighted by the number of observations each graph has. The result is marginally different from a non-weighted average which would result in a p-value of 0.50 instead of the 0.47 we use.

	Effect Size (H_1)		
	5pp	10pp	15pp
$P(p \geq p^* \mid H_0)$	0.767	0.767	0.767
$P(p \geq p^* \mid H_1)$	0.335	0.057	0.003
$PSP(\pi(H_0) = 0.9)$	0.954	0.992	0.999
$PSP(\pi(H_0) = 0.8)$	0.901	0.982	0.999
$PSP(\pi(H_0) = 0.5)$	0.696	0.931	0.996
$PSP(\pi(H_0) = 0.2)$	0.364	0.770	0.984
$PSP(\pi(H_0) = 0.1)$	0.203	0.598	0.964

Table 5: Post-Study-Probabilities for Aggregate Data

For $P(p \geq p^*|H_0)$, we are interested in the probability of observing a one-sided p-value above the one-sided p-value actually observed in the analysis (p^*), given H_0 is true. For the aggregate case, the observed p-value from a two-sided test is 0.47; therefore $p^* = 0.47/2 = 0.235$. Finally, because $P(p \geq p^*|H_0)$ is equal to one minus the one-sided p-value of interest (which is $p^* = 0.235$), it follows that $P(p \geq p^*|H_0) \approx 0.77$.

For $P(p \geq p^*|H_1)$, on the other hand, we are interested in the probability of observing a one-sided p-value above the p-value of interest (0.235), for any given alternative hypothesis H_1. To compute this probability, note that $P(p < p^*|H_1)$ denotes the power of the test using an α of 0.235 instead of (the usual) 0.05. Therefore, $P(p \geq p^*|H_1)$ is simply equal to 1 minus the power of the test.[11] We calculate power for three alternative hypothesis, namely an effect size of 5, 10, and 15 percentage points.[12]

The results for the aggregate case are summarized in Table 5. The first two rows report the probability of observing a p-value greater than the one observed for the different alternative hypotheses. Take for example the case where the alternative hypothesis is a shift of 15 percentage points between treatment and control. The probability of observing a p-value larger (or equal) to the one we actually observed is very low (0.003). This means that Type II errors are extremely unlikely and therefore that any null results is most likely a true result for almost any chosen prior probability of H_0 (see column 3 of Table 5).

A very clear example of how informative results are is shown in the first column of

[11] We compute this power taking the average number of observations across graphs (65 for control and 32 for treatment).

[12] Note that Buser et al. (2017) pick a values ranging from 10pp to 30 pp. In our case we become more restrictive and analyze smaller differences between the null and alternative hypotheses.

Table 5. In this case we hypothesize that our treatment has an effect of only 5 percentage points, yet, even in the case in which we give H_0 a prior of 0.5 ($\pi(H_0) = 0.5$), our observed results shift the posterior that the null will hold by over 20 percentage points. This result is doubled to almost certainty if we keep the same prior but consider the effect size of our treatment to be of just 10 percentage points.

Table 5 shows that our results are robust; even if we expect small treatment effects and have strong confidence in the effects of the treatment (i.e., priors smaller than $\pi(H_0) = 0.5$) our observed p-values are highly informative. Because of these results, we feel comfortable when concluding that moral hazard, most likely, has no effect on the risk assessment of laboratory subjects. The results are qualitatively identical when we study each graph individually (see Table 6).

	Graph 1			Graph 2		
	5pp	10pp	15pp	5pp	10pp	15pp
$P\left(p \geq p^* \mid H_0\right)$	0.636	0.636	0.636	0.813	0.813	0.813
$P\left(p \geq p^* \mid H_1\right)$	0.237	0.037	0.002	0.393	0.076	0.005
$\pi\left(H_0\right) = 0.9$	0.960	0.994	0.999	0.949	0.990	0.999
$\pi\left(H_0\right) = 0.8$	0.915	0.986	0.999	0.892	0.977	0.999
$\pi\left(H_0\right) = 0.5$	0.729	0.945	0.996	0.674	0.914	0.994
$\pi\left(H_0\right) = 0.2$	0.402	0.810	0.986	0.341	0.727	0.977
$\pi\left(H_0\right) = 0.1$	0.230	0.655	0.970	0.187	0.542	0.950
	Graph 3			**Graph 4**		
	5pp	10pp	15pp	5pp	10pp	15pp
$P\left(p \geq p^* \mid H_0\right)$	0.815	0.815	0.815	0.666	0.666	0.666
$P\left(p \geq p^* \mid H_1\right)$	0.469	0.146	0.021	0.176	0.011	0.000
$\pi\left(H_0\right) = 0.9$	0.940	0.980	0.997	0.972	0.998	0.999
$\pi\left(H_0\right) = 0.8$	0.874	0.957	0.993	0.938	0.996	0.999
$\pi\left(H_0\right) = 0.5$	0.635	0.848	0.974	0.791	0.984	0.999
$\pi\left(H_0\right) = 0.2$	0.303	0.582	0.905	0.487	0.938	0.999
$\pi\left(H_0\right) = 0.1$	0.162	0.382	0.809	0.296	0.871	0.998
	Graph 5			**Graph 6**		
	5pp	10pp	15pp	5pp	10pp	15pp
$P\left(p \geq p^* \mid H_0\right)$	0.848	0.848	0.848	0.833	0.833	0.833
$P\left(p \geq p^* \mid H_1\right)$	0.528	0.188	0.033	0.456	0.118	0.012
$\pi\left(H_0\right) = 0.9$	0.935	0.976	0.996	0.943	0.985	0.998
$\pi\left(H_0\right) = 0.8$	0.865	0.947	0.990	0.880	0.966	0.997
$\pi\left(H_0\right) = 0.5$	0.616	0.819	0.963	0.646	0.876	0.986
$\pi\left(H_0\right) = 0.2$	0.286	0.530	0.866	0.314	0.639	0.946
$\pi\left(H_0\right) = 0.1$	0.151	0.334	0.742	0.169	0.440	0.887

Table 6: Post-Study-Probabilities for Graph 1 to 6