Don't Ignore Inflation Ignorance:

On the Relevance of Money Illusion for Economic Modeling

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Abstract: Behavioral research on money illusion shows that investors tend to ignore inflation and focus on the nominal returns of their investment opportunities. Yet, economic modeling mostly disregards these findings and follows the standard paradigm in which investors base their decisions on real returns only. A possible reason for the disregard is that the degree of money illusion has not yet been quantified in a way that allows a well-founded discussion of the relevance for modeling. We conduct a rigorous investment experiment to close this gap. We find a substantial degree of money illusion in participant behavior and show that extending a standard model by a money illusion component can be vital to capture the observed behavior adequately. Our findings have far-reaching implications and call for a more prominent role of money illusion in economic modeling.

Keywords: Money illusion, financial decision-making, asset allocation.

JEL classifications: C91, D11, D14, D91.

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Abstract: Behavioral research on money illusion shows that investors tend to ignore inflation and focus on the nominal returns of their investment opportunities. Yet, economic modeling mostly disregards these findings and follows the standard paradigm in which investors base their decisions on real returns only. A possible reason for the disregard is that the degree of money illusion has not yet been quantified in a way that allows a well-founded discussion of the relevance for modeling. We conduct a rigorous investment experiment to close this gap. We find a substantial degree of money illusion in participant behavior and show that extending a standard model by a money illusion component can be vital to capture the observed behavior adequately. Our findings have far-reaching implications and call for a more prominent role of money illusion in economic modeling.

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1. Introduction

Real-world investors tend to ignore inflation and focus on the salient nominal returns of their investment opportunities (e.g., Shafir et al., 1997). Surprisingly, economic modeling mostly disregards this money illusion. A possible reason for the disregard is that the degree of money illusion has not yet been quantified in a way that makes the bias accessible to modeling. We conduct an innovative and fully incentivized investment experiment to close this gap. The experimental approach allows systematic variation in inflation rates, which enables us to extract the degree of money illusion from participant behavior and assess its relevance for modeling.

The experimental task is framed as a simple two-period consumption-investment problem: Participants are incentivized to maximize their intertemporal consumption opportunities by splitting their endowment between immediate consumption and an investment into a risky asset, which allows consumption at a later point of experimental time. Lower purchasing power at this later point of experimental time is captured by a lower conversion rate of nominal investment payoffs into consumption opportunities. To keep the experiment simple and our formal model tractable, we do not enforce consumption smoothing in the incentive structure. That is, there is no additional gain from targeting similar consumption levels at both points of experimental time: If the risky asset looks very attractive (unattractive), it is sensible to invest a very large (small) part of the endowment, possibly all or nothing. This allows a different perspective on the decision situation. It can be captured by a buy-and-hold asset allocation model: Investors maximize their terminal consumption opportunities by splitting their endowment between a risk-free asset with zero real return (corresponding to “immediate consumption”) and a risky asset whose return is exposed to inflation.[1] Assuming constant relative risk aversion (CRRA) preferences, the model has a closed-form solution. If there is no inflation, the only parameter that determines the share invested into the risky asset is the investor's relative risk aversion. In presence of inflation, money illusion becomes relevant: Illuded investors perceive the return of the risky asset to be larger than it "really" is, so that the share invested into the risky asset increases with the degree of money illusion.

For a profound analysis of money illusion, we implement two treatments. In our nominal treatment, we provide participants with an annual inflation rate to convert the displayed nominal long-term return of the risky asset into real terms. Albeit accounting for inflation is challenging under this information set, it mimics what real-world investors mostly face: Projected returns of long-term investments are usually presented in nominal terms and inflation information is mostly annualized. However, it can be argued that the data from the nominal treatment overstates the true degree of money illusion, because real-world investors exert more effort in capturing the long-term effects of inflation than our participants do (e.g., due to higher stakes). To address this argument, our hybrid treatment provides participants with the opportunity to switch without cost or effort between the display of the nominal and real long-term return of the risky asset. This eliminates the component of money illusion owed to lacking diligence and all remaining money illusion should reflect the mere preference to focus on nominal return information.

We start our analysis in the nominal treatment. In decision rounds where there is no inflation, our model (without money illusion component) fits the data very well and yields a plausible relative risk aversion estimate. Once inflation is present in the experimental environment, the same model loses all explanatory power and yields a highly implausible relative risk aversion estimate.

[1] The discrepancy between framing and modeling does not compromise our results: We use the consumption-investment framing in the experiment because it is better accessible to participants, while we use the asset allocation model in the analyses because it reflects the given experimental incentive structure.

Extending our model by a money illusion component turns out to be vital: The extended model fits the data very well again and yields a plausible relative risk aversion estimate. Most importantly, we measure a substantial degree of money illusion: Participants do not account for about 63% of the effects of inflation when judging the return of the risky asset. Lacking diligence is not the key driver of this result, as can be learned from the hybrid treatment: Even though participants inspect the risky asset's real return extensively, they base their decision mainly on its nominal return and do not account for about 52% of the effects of inflation. The availability of the alluring nominal return information seems to induce participants to neglect the provided real return information and thus inflation.

To keep the experimental design simple, we only consider scenarios with deterministic inflation rates initially. However, uncertainty about inflation is a real-world feature that might affect the degree of money illusion, for instance by inducing investors to think more carefully about the effects. When we introduce inflation risk to the experimental environment, we find that participants in both treatments overweight the high inflation rates, which increases their inflation expectations and mitigates their money illusion. However, the effect is small and money illusion remains high (47% in the nominal treatment, 35% in the hybrid treatment). Thus, adding a further layer of complexity to the model to capture inflation risk misperceptions seems much less important than including a general money illusion component.

Our study complements the discussion about the relevance of money illusion in several important aspects. Empirical studies on money illusion generally face a joint hypothesis problem (Fama, 1991), and their evidence for the relevance of money illusion therefore remains inconclusive. For instance, some studies find support in stock market data for the Modigliani and Cohn (1979) hypothesis: Investors seem to discount real company cash flows with nominal interest rates, which drives equity undervaluation in times of high inflation (e.g., Campbell and Vuolteenaho, 2004; Cohen et al., 2005; Acker and Duck, 2013a/b). Yet, it is impossible to distinguish whether this pattern truly reflects money illusion, or an inappropriate pricing model, or both. Our experimental approach mitigates this issue: We evaluate the appropriateness of our model when inflation is zero and money illusion therefore irrelevant, before we introduce inflation to the experimental environment and assess the relevance of money illusion. Thus, our findings provide compelling evidence that money illusion matters and that it is not an artefact of bad model choice.

Existing experimental studies on money illusion do not bear such problems either. In contrast to our study, however, they do not allow a well-founded discussion about the relevance of money illusion. For instance, several studies find that money illusion causes inertia in experimental asset markets to adjust to the new equilibrium after a nominal shock (see e.g., Fehr and Tyran, 2001/2007/2014; Bakshi, 2009; Noussair et al., 2012).[2] However, as they do not quantify money illusion in a way that is accessible to modeling, their findings do not allow predictions about real-world consequences and the relevance of money illusion remains vague.[3] Applying our money illusion estimate to the models of Basak and Yan (2010) or Miao and Xie (2013) predicts substantial reductions in economic growth and welfare. This shows that money illusion can have far-reaching consequences and resolves the vagueness about its economic relevance.

Our study proceeds as follows: Section 2 discusses the virtues of an experimental approach for our research question and presents the experimental design. Section 3 derives an asset allocation

[2] Note that the conception of money illusion in these studies is different from the one in our study: Price shocks deteriorate nominal values immediately and saliently, and money illusion is reflected in the inertia of market prices to adjust to the new equilibrium. In our study, inflation deteriorates nominal values slowly and latently over time, and money illusion is reflected in the individual's deficiency to anticipate these not yet materialized effects.

[3] Some survey-based studies quantify the degree of money illusion (e.g., Shafir et al. 1997; Weber et al. 2009), but the ordinal nature of their measures does not allow model-based predictions about real-world consequences either.

model under money illusion. Section 4 estimates the model parameters and assesses the relevance of money illusion for modeling. Section 5 summarizes the findings and discusses implications.

2. Experimental Design

2.1 ON THE VIRTUES OF AN EXPERIMENTAL APPROACH TO EXPLORE MONEY ILLUSION

Empirical studies on money illusion generally face a joint hypotheses problem (Fama, 1991): Evidence for money illusion can reflect money illusion, a bad model choice, or both. To mitigate this issue, the appropriateness of the model should be verified when inflation is zero before the model is used to assess the relevance of money illusion in times of positive inflation. While collecting the necessary data is difficult (if not impossible) in the real world, it is straightforward in an experiment where inflation rates can be induced exogenously and varied systematically.

Similarly, it is difficult to sort out competing explanations when using real-world data, because many factors change simultaneously with the inflation rate (interest rates, macroeconomic uncertainty, etc.). To ensure that evidence for money illusion is not a spurious result, adequate proxies for all these factors need to be identified. Our experimental approach circumvents this difficult task as it provides full control over all factors that should affect the decision.

For a proper assessment of money illusion, there should be a strong link between inflation and the dependent variable. Such links are rare in the real world. For instance, higher inflation should generally increase the propensity to buy durable goods (e.g., Bachmann et al., 2015), but the link may be impaired if there is uncertainty about technological developments. Our experimental approach allows modeling an unambiguous link between inflation and optimal behavior.

Lacking data on individual inflation expectations often prevents an assessment of money illusion on the individual level. Realized inflation rates (Boes et al., 2007) or professional forecasts (Schmeling and Schrimpf, 2011) may not be good substitutes, because individual inflation expectations are prone to judgment biases (Malmendier and Nagel, 2016), are affected by the survey wording (Armantier et al., 2013), may reflect macroeconomic uncertainty (Brandt and Wang, 2003), and are generally inaccurate (Ranyard et al., 2008). Our experimental approach provides full control over individual inflation expectations and thus circumvents such data issues.

2.2 DECISION SITUATION

Our experiment is based on the design proposed by Cordes and Langer (2017). The main task is framed as a simple two-period consumption-investment problem: Participants split their endowment of 10,000 monetary units (MU) between immediate consumption and an investment into a risky asset, allowing consumption at a much later point of experimental time. Consumption opportunities are measured in consumption units (CU). To mimic the long-term effects of inflation in our short-term experiment, the conversion rate between the investment's nominal payoffs (in MU) and consumption opportunities (in CU) decreases over experimental time.

As we are primarily interested in assessing the economic relevance of money illusion, we try to avoid confounding effects and keep the experimental design simple. For instance, our incentive structure does not enforce consumption smoothing: Remuneration is based on total consumption opportunities, and there is no additional gain from targeting similar consumption levels at both points of experimental time. If the risky asset looks very attractive (unattractive), it is sensible to invest a very high (low) part of the endowment, possibly all or nothing. This allows a different perspective on the decision situation, which we will follow for the remainder of this study: The decision situation can formally be captured by a buy-and-hold asset allocation model, where investors maximize their terminal consumption opportunities by splitting their endowment between a risk-free asset and a risky asset. The risk-free asset always yields a real return of zero (corresponding to "immediate consumption"-option in the experimental framing), whereas the risky asset's return is exposed to inflation (corresponding to the "investment"-option in the experimental framing). It is important to note that the discrepancy between experimental framing and formal modeling does not compromise our results: We use the consumption-investment framing in the experiment, because it is better accessible to participants. Yet, we use an asset allocation model in our analyses, because it properly reflects the experimental incentive structure.

2.3 INCENTIVIZATION

Participants receive a real-world payment of 0.001€ per consumption unit (CU) they can afford. The risk-free asset always yields a zero real return, that is, each MU invested provides 1 CU with certainty. The risky asset's return is exposed to inflation (i): Each MU the risky asset pays at the end of the investment horizon (T) only provides consumption opportunities of $(1+i)^{-T}$ CU.

An example may help to clarify the incentive structure: Consider a participant who invests 3,000 MU into the risk-free asset and 7,000 MU into the risky asset. The 3,000 MU invested into the risk-free asset provide 3,000 CU consumption opportunities with certainty. The return of the risky asset is unknown ex ante; assume it pays 9,000 MU at the end of a T = 10 year investment horizon. For i = 2% inflation, the purchasing power of 1 MU is $1.02^{-10} \approx 0.82$ CU then, and consumption opportunities provided by the risky asset's payoff are 9,000 MU · 0.82 CU/MU = 7,380 CU. In this case, the participant receives a real-world payment of (3,000 CU + 7,380CU) · 0.001€/CU = 10.38€. For i = 4% inflation, the purchasing power of 1 MU is only $1.04^{-10} \approx 0.68$ CU in T = 10, and the risky asset's payoff only provides 9,000 MU · 0.68 CU/MU = 6,120 CU. In this case, the participant only receives a real-world payment of (3,000 CU + 6,120 CU) · 0.001€/CU = 9.12€. Illuded participants do not sufficiently account for losses in purchasing power and perceive the return of the risky asset to be larger than it "really" is, so that the share invested into the risky asset should increase with the degree of money illusion.

2.4 PRESENTATION FORMAT AND INTERFACE

We use a 10-state chart to visualize the consequences of a decision, because this has been found to be a particularly intuitive visualization of a payoff distribution (Vrecko et al., 2009; Vrecko and Langer, 2013). In this approach, 10 discrete states represent the 10 possible portfolio payoffs (see Figure 1). All states are realized with the same probability (10% each) to minimize probability misperceptions and payoffs are ordered by size to facilitate the comprehension of the distribution. To visualize the distinction between nominal and real values, payoffs are separated into the risk-free asset's payoff (in CU; dark-blue bars to the left) and the risky asset's payoff (in MU; light-blue bars to the right). In the presented example, 3,000 MU are invested into the risk-free asset, providing 3,000 CU in each state. The remaining 7,000 MU are invested into the risky asset, providing payoffs between 5,010 MU and 19,105 MU.

[Place Figure 1 about here.]

To translate the displayed MU-payoffs of the risky asset into consumption opportunities (CU), the annual inflation rate and the investment horizon are clearly communicated: A pop-up window states the parameters at the beginning of each round and they are displayed on screen while participants make their decisions. We do not communicate the risky asset's expected return and standard deviation explicitly. Such numbers do not add relevant information beyond what is displayed in the 10-state chart, and we were concerned that they compromise the intuitive judgment through the promotion rule-based behavior (e.g., a focus on expected returns).

The portfolio weights can be changed with a slider below the 10-state chart. To avoid anchoring issues, participants decide on the initial weights at the beginning of each round by clicking on any position on the slider; afterwards the initial payoff distribution appears on screen. To allow for a quick evaluation of outcomes, the bars update automatically and in real-time to all changes.

2.5 TREATMENTS

In the nominal treatment, participants view the risky asset's nominal payoffs (in MU). To allow a judgment of the corresponding consumption opportunities (in CU), the investment horizon and the annual inflation rate are explicitly communicated. This information condition serves as our starting point for assessing the relevance of money illusion, because it comes closest to a real-world investment scenario: Projected payoffs of long-term investments are usually presented in nominal terms, and investors have to collect and integrate information on inflation (which is mostly annualized) to judge the real wealth consequences.

It can be argued that real-world investors exert more effort to capture the effects of inflation than our participants do, because stakes are typically higher in the real world than in our experiment.

Further, real-world investors may use computational assistance (like a calculator) to counteract arithmetic problems in capturing the effects of inflation. For instance, the exponential growth bias shows that people tend to underestimate the long-term effects of inflation when judging it from an annual inflation rate (e.g., Keren, 1983; Jones, 1984; Kemp, 1984; Stango and Zinman, 2009). Thus, the data from the nominal treatment may overstate the true degree of money illusion.

We address this concern with our second treatment, the hybrid treatment: Participants view the risky asset's nominal payoffs at the beginning of each round (we call this the nominal view), but they can subsequently switch to the display of the arising consumption opportunities (real view). Switching to the real view eliminates the component of money illusion that is owed to lacking diligence or arithmetic problems, and the remaining money illusion should reflect the preference to focus on alluring (but irrelevant) nominal returns. Participants can switch back and forth between the two views by clicking a button below the 10-state chart. A nice side effect of this design choice is that switching behavior directly proxies the interest in real return information.

2.6 PARAMETERIZATION

All participants complete 36 different decision rounds. The investment horizon is T = 10 years of experimental time in all rounds. To disentangle the risk preferences and money illusion, the risky asset's nominal return and the inflation rate vary systematically (see Table I). In Type 1 rounds, inflation is zero and money illusion is thus irrelevant. Decisions in these rounds allow assessing the appropriateness of our model and the participants' risk preferences. In Type 2 rounds, inflation is positive and money illusion may bias behavior. By controlling for the risk preferences estimated from Type 1 rounds, decisions in these rounds allow assessing the degree of money illusion. In Type 3 rounds, the inflation rate can take two possible values, both realized with 50% probability and independently of the risky asset's return. By controlling for the risk preferences estimated from Type 1 rounds and the degree of money illusion estimated from Type 2 rounds, asset allocations in these rounds allow assessing inflation risk misperceptions.

[Place Table I about here.]

The continuous return distribution of the risky asset is transformed into the 10 discrete states based on a solid theoretical foundation. Let $\ln x \sim \mathcal{N}(\mu_r, \sigma_r)$ denote the return realization of the risky asset. The 10 discrete state returns are given by the conditional expectations:

$$x_j = \begin{cases} \frac{1}{0.1} \int_{-\infty}^{q_j} x f(x) dx & if \quad j = 1 \\ \frac{1}{0.1} \int_{q_{j-1}}^{q_j} x f(x) dx & if \quad j = 2, \dots, 9 \\ \frac{1}{0.1} \int_{q_{j-1}}^{\infty} x f(x) dx & if \quad j = 10\,, \end{cases} \qquad (1)$$

where $f(x)$ denotes the probability density function of the return distribution and q_j are the deciles of the distribution:

$$q_j = F^{-1}\left(\frac{j}{10}\right) \quad if \quad j = 1, \dots, 9\,. \qquad (2)$$

2.7 PROCEDURES

The experiment was conducted under controlled conditions in the computer labs of a German university. The experiment was fully computer-based, except for a short introduction that was handed out and read aloud prior to the start of the experiment (Appendix A). Pen and paper were provided for notes and calculations; cellphones, pocket calculators, and all other personal items were prohibited. We recruited 96 participants from an undergraduate finance class (participation was voluntary) and randomly assigned them to our two treatments. Table II shows the sample characteristics. As differences between treatments are insignificant, we conclude that our randomization was effective and that our treatments form comparable samples.

[Place Table II about here.]

Figure 2 depicts the course of the experiment. Tutorial A explains the decision situation, the incentive structure, and the interface. We carefully check for comprehension: Participants can only continue if they answer 10 check-up questions correctly. In case of incorrect answers, the experimenter is notified on her screen and assists if necessary. Tutorial A concludes with a non-incentivized practice phase, where participants can familiarize themselves with the software until they feel comfortable using it.

[Place Figure 2 about here.]

Investment Task A consists of 21 decision rounds; 9 of Type 1 (no inflation) and 12 of Type 2 (positive inflation). The ordering is randomized and different for each participant. Rounds are independent from each other (i.e., decisions do not affect the endowment in subsequent rounds). Participants receive feedback on investment outcomes only after the experiment, because immediate feedback could affect subsequent risk-taking (e.g., Malmendier and Nagel, 2011).

Tutorial B explains inflation risk to participants. In the hybrid treatment, it further shows how to switch between the nominal view, the real view under the low inflation rate, and the real view under the high inflation rate by clicking on separate buttons.

Investment Task B consists of 15 decision rounds of Type 3 (inflation risk). Their ordering is again randomized and different for each participant, rounds are independent from each other, and participants do not learn about outcomes until after the experiment.

The experiment concludes with a questionnaire on demographics, attitudes, and preferences.

After the experiment, each participant is paid according to one of the 36 rounds. The round is selected randomly and for each participant individually by the computer. In case a Type 3 round is selected (inflation risk), the computer further determines randomly whether the high or the low inflation rate is applied. To increase trust into the payment scheme, participants draw a numbered ping-pong ball out of an urn with 10 balls afterwards. The number on the ball represents the state in the 10-state chart that is realized and rewarded with real money. The average remuneration was 11.40€ ($13.68) per participant and the average completion time was 63 minutes.

3. A Model of Asset Allocation under Money Illusion

The investor has access to two assets, a risk-free asset and a risky asset. The risk-free asset earns a real risk-free rate r_f. The log return $\ln R$ of the risky asset is given in nominal terms, with expectation μ_r and volatility σ_r.

The investor maximizes the expected utility from terminal consumption. He is endowed with some initial wealth W_0. In line with the experimental setup, we assume that he follows a buy-and-hold strategy with a portfolio weight of the risky asset equal to π. His (real) terminal wealth and thus his (real) consumption C_T at time T is:

$$C_T = W_0 \left[(1-\pi) e^{r_f T} + \pi \frac{S_T}{S_0} \right], \tag{3}$$

where S denotes the real price of the risky asset and T the investment horizon.

We furthermore assume that the investor has CRRA preferences with a relative risk aversion of $\gamma \neq 1$. His optimization problem is thus:

$$\max_\pi E \left[\frac{C_T^{1-\gamma}}{1-\gamma} \right]. \tag{4}$$

The asset allocation problem can only be solved numerically.[4] For moderate parameters, however, the optimal solution for the buy-and-hold strategy is close to the optimal solution in case of continuous rebalancing (Rogers, 2001). For zero inflation, the optimal weight of the risky asset in the latter case is:

$$\pi^c = \frac{\mu_r - r_f}{\gamma \sigma_r^2}. \tag{5}$$

In our setup, the investor has to account for inflation. In general, the log inflation rate $\ln i$ is stochastic with expectation μ_i and volatility σ_i. We assume zero correlation between the nominal return of the risky asset and inflation. The real return of the risky asset is thus:

$$\ln R - i \qquad \text{with} \tag{6}$$

$$E[\ln R - i] = \mu_r - \mu_i \qquad \text{and} \qquad \sigma^2[\ln R - i] = \sigma_r^2 + \sigma_i^2 . \tag{7 and 8}$$

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[4] The first-order condition for π is $E\left[\left((1-\pi)e^{r_f T} + \pi \frac{S_T}{S_0}\right)^{-\gamma} \left(\frac{S_T}{S_0} - e^{r_f T}\right)\right] = 0$.

If the investor is subject to money illusion, he does not (fully) account for inflation when judging the risky asset's real return, given the nominal return and the inflation rate. Instead of $\ln R - i$, he relies on $\ln R - (1-\theta)i$, where θ captures the degree of money illusion. For θ = 0, there is no money illusion (the investor correctly uses the risky asset's real return), while θ = 1 corresponds to full money illusion (the investor wrongly uses the risky asset's nominal return).

The portfolio weight with continuous rebalancing in the presence of money illusion becomes:

$$\pi^c = \frac{\mu_r - (1-\theta)\mu_i - r_f}{\gamma[\sigma_r^2 + (1-\theta)^2\sigma_i^2]}. \tag{9}$$

Besides suffering from money illusion, the investor may also misperceive the risk of future inflation. We model inflation risk in the most simple way and assume that inflation can just take on two values, i_{hi} and i_{lo} (where $i_{hi} > i_{lo}$) with equal probability. Misperception of inflation risk is captured by the parameter e_w. Instead of 0.5, the investor assigns a probability of 0.5 + e_w to the high inflation state and a probability of 0.5 – e_w to the low inflation state. With this misperception, it holds that:

$$\hat{\mu}_i = (0.5 + e_w)i_{hi} + (0.5 - e_w)i_{lo} = \mu_i + e_w(i_{hi} - i_{lo}) \tag{10}$$

$$\hat{\sigma}_i^2 = (0.5 + e_w)(0.5 - e_w)(i_{hi} - i_{lo})^2 = \sigma_i^2 - e_w^2(i_{hi} - i_{lo})^2 \tag{11}$$

and the portfolio weight finally becomes:

$$\pi^c = \frac{\mu_r - (1-\theta)[\mu_i + e_w(i_{hi} - i_{lo})] - r_f}{\gamma[\sigma_r^2 + (1-\theta)^2(\sigma_i^2 - e_w^2(i_{hi} - i_{lo})^2)]}. \tag{12}$$

4. Results

We use non-linear least squares regressions to estimate Equation (12) from the observed portfolio weights of the risky asset (π). Estimated parameters are the relative risk aversion (γ) and, if applicable, the degree of money illusion (θ) and the parameter for capturing inflation risk misperceptions (e_w). The risky asset's nominal return (μ_r, σ_r) and the inflation rate (i or i_{hi}, i_{lo}) are determined by the decision round; the risk-free asset's real return is r_f = 0 throughout.

4.1 MONEY ILLUSION UNDER A STANDARD INFORMATION SET

We start our analyses in the nominal treatment. In Type 1 rounds, inflation is zero and money illusion is irrelevant. Therefore, we only estimate the relative risk aversion parameter (γ) and fix the other parameters of Equation (12) to zero. Panel A of Table III shows that the model yields high explanatory power ($\bar{R}^2$ = 0.5705) and a plausible relative risk aversion estimate (γ = 8.4800) with low estimation uncertainty (SE = 0.3094). Albeit the relative risk aversion estimate is in the high range of estimates provided by previous research, it seems plausible considering that the short sale constraint restricted higher risk taking in the experiment (π = 1 in 23.70% of decisions, while π = 0 in only 10.73% of decisions).[5] We conclude that our model captures investment behavior accurately when there is no inflation and do not test different specifications.

[Place Table III about here.]

We now study how investment behavior changes once inflation is present in the experimental environment (Type 2 rounds). To illustrate the consequences of disregarding money illusion, we

[5] See Charness et al. (2013) for an overview of experimental studies using multiple price list methods to estimate the relative risk aversion. Szpiro (1986, p. 157) gives an overview of empirical estimates of the relative risk aversion.

keep the money illusion parameter fixed to zero at first. Panel B of Table III shows that the model has no explanatory power ($\bar{R}^2$ = -0.0212) and yields an implausible relative risk aversion estimate (γ = 672.5585) with high estimation uncertainty (SE = 1,601.2759).[6] Thus, the model without money illusion component does not capture behavior adequately when money illusion is relevant.

To provide support for the conjecture that the modeling of money illusion will solve the problem, we now estimate both a relative risk aversion parameter and a non-zero money illusion parameter from the same data. Panel C of Table III shows that the explanatory power increases substantially ($\bar{R}^2$ = 0.5022) and that the relative risk aversion estimate takes a plausible value again (γ = 9.1308, SE = 0.4422). The fact that the relative risk aversion estimate is statistically indistinguishable from the benchmark (Panel A vs. C: Δ_γ = 0.6508, p = 0.2594)[7] indicates that the presence of inflation does not affect the intrinsic risk attitude, but rather the perception of the risky asset's return. In line with this argument, we measure a substantial degree of money illusion: Participants account for only 1 – θ = 37.18% of the effects of inflation when judging the attractiveness of the risky asset (θ = 0.6282, SE = 0.0205).[8]

Estimating the same model on the participant level yields additional insights: First, the mean individual money illusion estimate is $\bar{\theta}$ = 0.6583 (median: 0.6452), illustrating that the aggregate estimate (θ = 0.6282) is robust towards an alternative estimation methodology. Second, even though there is individual heterogeneity in money illusion, individual θ-estimates are distributed symmetrically around the mean (see Appendix B). Therefore, the high level of the aggregate estimate is not driven by a small fraction of participants. In fact, the lowest individual money

[6] Setting the starting value of γ to the benchmark (8.4800) yields identical estimates, indicating that Panel B is not a local optimum. Fixing γ to the benchmark does not enhance the explanatory power notably either ($\bar{R}^2$ = 0.0298).

[7] Throughout this study, p-values refer to the results of two-sided t-tests. Standard errors are adjusted for clustering on the participant level if applicable.

[8] The joint estimation of relative risk aversion (γ) and money illusion (θ) does not overstrain our data: Fixing γ to the benchmark (8.4800) and only estimating θ provides very similar results (θ = 0.6065, SE = 0.0216; $\bar{R}^2$ = 0.5006).

illusion estimate is θ = 0.3524, showing that not a single participant revealed unbiased behavior. Third, the correlation between individual money illusion estimates and the number of errors in the check-up questions of the tutorials is low and statistically insignificant, suggesting that misconceptions of the experimental task do not drive our results (ρ = 0.0933, p = 0.5284).

Taken together, we find that accounting for money illusion can be vital to ensure that the model captures investment behavior adequately. Our previously well-suited model (without money illusion component) loses all its explanatory power and provides a highly implausible relative risk aversion estimate once inflation is present in the experimental environment (Panel A vs. B of Table III). Extending our model by a money illusion component increases its explanatory power again and provides a plausible relative risk aversion estimate (Panel C). Most importantly, we measure a high degree of money illusion: Participants do not account for about 63% of the effects of inflation when judging the return of the risky asset.

4.2 DOES HIGHER DILIGENCE ELIMINATE MONEY ILLUSION?

We now turn to the hybrid treatment, where participants can conveniently switch between the display of the risky asset's nominal and real return. This eliminates the component of money illusion that is owed to lacking diligence or arithmetic problems and all remaining money illusion can be attributed to the mere preference to focus on the alluring nominal returns.

Our analysis follows the same structure as in the previous section. First, we use Type 1 rounds (no inflation) to estimate the relative risk aversion. Panel A of Table IV shows the results: As in the nominal treatment, the model has high explanatory power ($\bar{R}^2$ = 0.5933) and provides a plausible relative risk aversion estimate (γ = 8.0086) with low estimation uncertainty (SE =

0.2058). We conclude that our model captures investment behavior adequately in the hybrid treatment, too, when inflation is zero and money illusion therefore irrelevant.[9]

[Place Table IV about here.]

Supporting the presumption that the provision of real return information reduces the cognitive costs to account for inflation, participants make extensive use of the real view in Type 2 rounds: Upon starting each round in the nominal view, they subsequently spend on average 44.02% of the total decision time in the real view inspecting the risky asset's real return (median: 51.51%). Surprisingly, money illusion seems to prevail: Panel B of Table IV shows that the model without money illusion component has no explanatory power ($\bar{R}^2$ = 0.0008) and provides an implausible relative risk aversion estimate (γ = 49.6171) with high estimation uncertainty (SE = 9.7912).[10]

To verify this notion, Panel C of Table IV estimates both the relative risk aversion and the money illusion parameter from the same data: The extended model yields high explanatory power ($\bar{R}^2$ = 0.4433) and a plausible relative risk aversion estimate again (γ = 8.9584, SE = 0.3669). Most importantly, money illusion remains on a substantial level (θ = 0.5219, SE = 0.0214).[11]

Estimating money illusion on the participant level provides additional insights again: First, the mean individual money illusion estimate is $\bar{\theta}$ = 0.5240 (median: 0.4478), showing that the aggregate estimate (θ = 0.5219) is robust towards an alternative estimation methodology. Second, albeit the distribution of estimates is slightly right-skewed (see Appendix B), the high level of aggregate money illusion is not driven by a small fraction of participants. Third, the correlation between individual money illusion estimates and the number of errors in the check-up questions

[9] The fact that relative risk aversion estimates do not differ between the nominal and hybrid treatment confirms that the treatments form comparable samples and ensures trust into our estimations (Δ_γ = -0.4714, p = 0.2049).

[10] Setting the starting value of γ to the benchmark (8.0086) yields identical estimates, indicating that Panel B does not describe a local optimum. Fixing γ to the benchmark enhances the $\bar{R}^2$ to 0.1401, but it remains notably impaired.

[11] The result is not compromised by the joint estimation of γ and θ: Fixing γ to the benchmark (8.0086) and only estimating the degree money illusion yields a similar result (θ = 0.5008, SE = 0.0193; $\bar{R}^2$ = 0.4386).

is low and insignificant, illustrating that misconceptions of the experimental task do not drive our results (ρ = 0.2060, p = 0.1600). Last, individual money illusion estimates are negatively correlated to the average relative time spent in the real view: The longer participants inspect the risky asset's real return, the lower their money illusion (ρ = -0.4367, p < 0.0001). This is in line with our behavioral arguments and confirms our interpretation of the money illusion coefficient.

Taken together, lacking diligence or arithmetic problems are not the drivers of the documented money illusion: The convenient display of the risky asset's real return reduces money illusion only marginally compared to the nominal treatment (Δ_θ = -0.1063, p = 0.0003). The mere availability of the alluring (but irrelevant) nominal return information induces participants to ignore the provided real return information and thus inflation. This strongly supports our proposition that money illusion should obtain a more prominent role in economic modeling.

4.3 MONEY ILLUSION UNDER INFLATION RISK

We now assess the degree of money illusion when inflation is risky (Type 3 rounds). On the one hand, the higher information content may induce participants to think more carefully about the consequences of inflation and reduce their money illusion. On the other hand, the "vagueness" about the consequences of inflation may induce participants to care even less about it.

We start our analysis in the nominal treatment. For convenience, Panel C of Table V restates the relative risk aversion and money illusion estimates from rounds with deterministic inflation rates (see Table III). Panel D of Table V estimates the same parameters when inflation risk is present in the experimental environment (but misperceptions are not yet modeled). The explanatory power remains high ($\bar{R}^2$ = 0.4723) and the relative risk aversion estimate seems plausible (γ =

7.7655, SE = 0.4219). Interestingly, albeit the degree of money illusion is substantial (θ = 0.4691, SE = 0.0223), it is notably lower than the benchmark value (Panel C vs. D: Δ_θ = -0.1591, p < 0.0001).

[Place Table V about here.]

To understand this reduction better, we next account for misperceptions of inflation risk in the model (Panel E of Table V). The explanatory power ($\bar{R}^2$ = 0.4751) and the relative risk aversion estimate (γ = 7.6183, SE = 0.4124) are virtually unaffected by the extension. However, we find that participants overweight the high inflation rate (e_w = 0.1153, SE = 0.0244), which increases their expectations about inflation and puts less pressure on the money illusion parameter (θ = 0.5342, SE = 0.0237): About half of the reduction that was initially attributed to the introduction of inflation risk (Panel C vs. D: Δ_θ = -0.1591, p < 0.0001) can now be attributed to the overweighting of the high inflation rate (Panel D vs. E: Δ_θ = -0.0651, p = 0.0456). Reconciling the remaining reduction (Panel C vs. E: Δ_θ = -0.0940, p = 0.0036) is beyond the scope of our data; the notion that inflation risk induces participants to think more carefully about the possible consequences of inflation for their financial wellbeing seems plausible though.

Table VI verifies that higher diligence does not alter the previous findings: Participants in the hybrid treatment overweight the high inflation rate as well (e_w = 0.0499, SE = 0.0194).[12] This mitigates their money illusion (Panel C vs. E: Δ_θ = -0.1296, p = 0.0001), but it does not eradicate the bias altogether (θ = 0.3923, SE = 0.0240).

[Place Table VI about here.]

[12] The view choice behavior supports this result: Participants spend on average much more time in the real view with the high inflation rate than in the real view with the low inflation rate (35.41% vs. 15.72% of the total decision time).

In sum, we find that the introduction of inflation risk reduces the degree of money illusion, but that it remains on an economically relevant level. About half of the reduction can be attributed to the participants' focus on the worst case (i.e., the high inflation rate), which increases their inflation expectations and mitigates their money illusion. Given that the effect is weak, we conclude that adding a further layer of complexity to the model to capture these misperceptions is much less important than including a general money illusion component in the first place.

5. Conclusion

Projected investment outcomes are usually represented in nominal terms. Therefore, investors might be tempted to judge investment opportunities by their nominal returns and ignore the effects of inflation. Existing behavioral research provides support for this money illusion (e.g., Shafir et al., 1997; Weber et al., 2009). Yet, economic modeling mostly disregards these findings and sticks to the standard paradigm in which investors judge investment opportunities only by their real returns. A plausible explanation for the disregard is that the relevance of money illusion for economic modeling has not yet been studied in a compelling manner. We conduct an innovative and fully incentivized investment experiment to close this gap.

We find that modeling money illusion can be crucial to capture investment behavior adequately: A formerly well-suited asset allocation model (without money illusion component) loses all its explanatory power and provides highly implausible parameter estimates once participants are required to adjust the presented nominal returns for inflation. Extending our model by a money illusion component turns out to be vital. The extended model explains the data very well again, provides plausible parameter estimates, and, most importantly, documents a substantial degree of money illusion; participants ignore up to 63% of the effects of inflation when judging the "real" attractiveness of their investment opportunities. The high degree of money illusion is not an expression of lacking diligence: Even the explicit display of real returns next to the standard nominal information reduces the degree of money illusion only marginally.

Our findings not only illustrate the importance of accounting for money illusion in modeling, but also indicate that money illusion can have far-reaching economic consequences: Basak and Yan (2010) and Miao and Xie (2013) study the impact of money illusion on economic growth from a theoretical perspective. Applying our money illusion estimates to their settings predicts a significant impact on market outcomes, in this case reductions in growth and welfare. The importance of this insight derives from the fact that the answer to many economic questions depends on whether money illusion affects market outcomes. For example, money illusion may explain the non-neutrality of money, that is, the central banks' ability to affect production and consumption through the stimulation of inflation rates (e.g., Sun, 1992; Brandt and Wang, 2003; Eraker et al., 2016). Money illusion may also explain market inefficiencies, such as equity mispricings (Modigliani and Cohn, 1979; Campbell and Vuolteenaho, 2004; Cohen et al., 2005; Acker and Duck, 2013a/b) and price bubbles (Brunnermeier and Julliard, 2008). For financial institutions, money illusion may be important for the design of investment products, as their attractiveness should depend on whether investors care about nominal or real returns (Lachance and Mitchell, 2003; Cordes and Langer, 2017). Similarly, money illusion may be an important determinant of a company's wage agreements (Clark and Oswald, 1996) and defined contribution savings plans (Thaler and Benartzi, 2004), as their optimal design should depend on whether employees care about nominal or real income. Following this idea, money illusion could be key to understanding the relationships between income, inflation, and life satisfaction (Di Tella et al., 2001; Boes et al., 2007).

We believe that our experimental paradigm is useful for obtaining a deeper understanding of the role of money illusion in the above-mentioned questions, because it provides a high level of control over alternative explanations. However, there are limitations in the extent to which the results can be generalized, as the design of any experiment is subject to simplifications. For instance, we chose not to provide learning opportunities to our participants. Real-world investors, however, may experience the consequences of their money illusion, which could subsequently increase their propensity to account for inflation. Therefore, we acknowledge that the money illusion estimate provided in this study should be considered as a rough benchmark, and that it needs rigorous examination by future research. This could include the use of different contexts (e.g., multi-period consumption-investment experiments to study learning effects), different participant samples (e.g., elderly people to study the impact of longer inflation experiences), or different methods (e.g., field experiments to study external validity). Still, we believe that our study provides compelling evidence for the relevance of money illusion for economic modelling and therefore propose a reconsideration of the general disregard of money illusion.

Figures

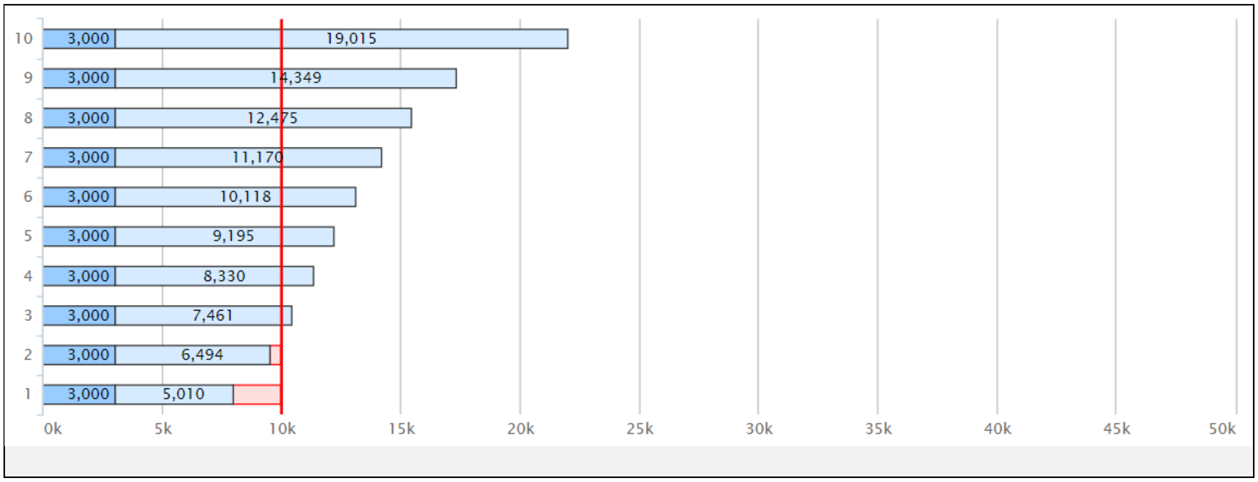


Figure 1: Screenshot of the 10-state chart.

Tutorial A (~15 minutes)
Instructions, comprehension filter, and practice phase.

Investment Task A (~20 minutes)
9 rounds with no inflation (Type 1), 12 rounds with deterministic inflation (Type 2).

Tutorial B (~5 minutes)
Explanation of inflation risk.

Investment Task B (~15 minutes)
15 rounds with stochastic inflation (Type 3).

Questionnaire (~10 minutes)
Demographics, preferences and attitudes, experiment feedback.

Figure 2: Course of the experiment.

Tables

Table I: Parameter combinations.

Type 1 (no inflation)		Type 2 (deterministic inflation)		Type 3 (inflation risk)		
(μ_r, σ_r)	i	(μ_r, σ_r)	i	(μ_r, σ_r)	μ_i	(i_{lo}, i_{hi})
(2%, 4%)	0%	(2%, 4%)	1%	(2%, 4%)	1%	(0%, 2%)
(2.5%, 6%)	0%	(2%, 4%)	2%	(2%, 4%)	2%	(1%, 3%)
(3%, 8%)	0%	(2%, 4%)	3%	(2%, 4%)	2%	(0%, 4%)
(3.5%, 10%)	0%	(2%, 4%)	4%	(2%, 4%)	3%	(2%, 4%)
(4%, 12%)	0%	(4%, 12%)	1%	(2%, 4%)	3%	(0%, 6%)
(4.5%, 14%)	0%	(4%, 12%)	2%	(4%, 12%)	1%	(0%, 2%)
(5%, 16%)	0%	(4%, 12%)	3%	(4%, 12%)	2%	(1%, 3%)
(5.5%, 18%)	0%	(4%, 12%)	4%	(4%, 12%)	2%	(0%, 4%)
(6%, 20%)	0%	(6%, 20%)	1%	(4%, 12%)	3%	(2%, 4%)
		(6%, 20%)	2%	(4%, 12%)	3%	(0%, 6%)
		(6%, 20%)	3%	(6%, 20%)	1%	(0%, 2%)
		(6%, 20%)	4%	(6%, 20%)	2%	(1%, 3%)
				(6%, 20%)	2%	(0%, 4%)
				(6%, 20%)	3%	(2%, 4%)
				(6%, 20%)	3%	(0%, 6%)
Σ = 9 rounds		Σ = 12 rounds		Σ = 15 rounds		

All parameters are annualized. The risky asset's return is log normally distributed with expectation μ_r and volatility σ_r. i denotes the inflation rate. In case of inflation risk, μ_i denotes the expectation and (i_{lo}, i_{hi}) the realizations.

Table II: Sample characteristics.

	All	Treatment: Nominal	Treatment: Hybrid	p-value
Female [%]	48.96	45.83	52.08	0.545
Age [years]	21.76	21.67	21.85	0.644
Semesters of study	4.39	4.52	4.25	0.402
Business students [%]	78.13	79.17	77.08	0.808
International students [%]	12.50	10.42	14.58	0.542
HL risk aversion [1;10]	6.08	6.13	6.04	0.840
Self-stated risk aversion [1;7]	4.14	4.00	4.27	0.398
N	96	48	48	

Average demographics, by treatment. "HL" refers to the Holt and Laury (2002) risk aversion score. The p-values indicate statistical significance of the difference between treatments, based on two-sided t-tests.

Table III: CRRA and money illusion estimates in the nominal treatment.

Panel	Data	γ	θ	$\bar{R}^2$	AIC	BIC	N
A	Type 1	8.4800 ***	0	0.5705	696.5648	700.6332	432
		(0.3094)	(fixed)				
B	Type 2	672.5585	0	-0.0212	1,177.3509	1,181.7070	576
		(1,601.2759)	(fixed)				
C	Type 2	9.1308 ***	0.6282 ***	0.5022	765.5119	774.2241	576
		(0.4422)	(0.0205)				

Results from non-linear least squares regressions in the nominal treatment. γ denotes the CRRA parameter, θ the money illusion parameter, $\bar{R}^2$ the adjusted coefficient of determination, AIC the Akaike information criterion, BIC the Bayesian information criterion. Type 1 data comprises decision rounds with zero inflation (deterministic), Type 2 data comprises decision rounds with positive inflation (deterministic). Cluster-robust standard errors are provided in parentheses. ***, **, * indicate statistical significance on the 1%, 5%, 10% level.

Table IV: CRRA and money illusion estimates in the hybrid treatment.

Panel	Data	γ	θ	$\bar{R}^2$	AIC	BIC	N
A	Type 1	8.0086 ***	0	0.5933	706.1546	710.2231	432
		(0.2058)	(fixed)				
B	Type 2	49.6171 ***	0	0.0008	1,069.8666	1,074.2227	576
		(9.7912)	(fixed)				
C	Type 2	8.9584 ***	0.5219 ***	0.4433	735.0092	743.7215	576
		(0.3669)	(0.0214)				

Results from non-linear least squares regressions in the hybrid treatment. γ denotes the CRRA parameter, θ the money illusion parameter, $\bar{R}^2$ the adjusted coefficient of determination, AIC the Akaike information criterion, BIC the Bayesian information criterion. Type 1 data comprises decision rounds with zero inflation (deterministic), Type 2 data comprises decision rounds with positive inflation (deterministic). Cluster-robust standard errors are provided in parentheses. ***, **, * indicate statistical significance on the 1%, 5%, 10% level.

Table V: Perception of inflation risk in the nominal treatment.

Panel	Data	γ	θ	e_w	$\bar{R}^2$	AIC	BIC	N
C	Type 2	9.1308 ***	0.6282 ***	0	0.5022	765.5119	774.2241	576
		(0.4422)	(0.0205)	(fixed)				
D	Type 3	7.7655 ***	0.4691 ***	0	0.4723	942.9457	952.1042	720
		(0.4219)	(0.0223)	(fixed)				
E	Type 3	7.6183 ***	0.5342 ***	0.1153 ***	0.4751	941.2061	954.9439	720
		(0.4124)	(0.0237)	(0.0244)				

Results from non-linear least squares regressions in the nominal treatment. γ denotes the CRRA parameter, θ the money illusion parameter, e_w the inflation risk misperception parameter, $\bar{R}^2$ the adjusted coefficient of determination, AIC the Akaike information criterion, BIC the Bayesian information criterion. Type 2 data comprises decision rounds with positive inflation (deterministic), Type 3 data comprises decision rounds with positive expected inflation (stochastic). Cluster-robust standard errors are provided in parentheses. ***, **, * indicate statistical significance on the 1%, 5%, 10% level.

Table VI: Perception of inflation risk in the hybrid treatment.

Panel	Data	γ	θ	e_w	$\bar{R}^2$	AIC	BIC	N
C	Type 2	8.9584 ***	0.5219 ***	0	0.4433	735.0092	743.7215	576
		(0.3669)	(0.0214)	(fixed)				
D	Type 3	7.9025 ***	0.3549 ***	0	0.3878	894.1605	903.3190	720
		(0.4130)	(0.0184)	(fixed)				
E	Type 3	7.8083 ***	0.3923 ***	0.0499 **	0.3888	894.9244	908.6622	720
		(0.4090)	(0.0240)	(0.0194)				

Results from non-linear least squares regressions in the hybrid treatment. γ denotes the CRRA parameter, θ the money illusion parameter, e_w the inflation risk misperception parameter, $\bar{R}^2$ the adjusted coefficient of determination, AIC the Akaike information criterion, BIC the Bayesian information criterion. Type 2 data comprises decision rounds with positive inflation (deterministic), Type 3 data comprises decision rounds with positive expected inflation (stochastic). Cluster-robust standard errors are provided in parentheses. ***, **, * indicate statistical significance on the 1%, 5%, 10% level.

Appendix A: Introduction that was handed out prior to the start of the experiment.

Dear Participant,

Welcome to our experiment – your participation is greatly appreciated! Participants from previous studies told us that they have enjoyed taking part in economic experiments. We hope that you will share this feeling! Today's experiment is fully computer-based and consists of three parts:

Part 1:	Introduction and explanations
Part 2:	36 different investment rounds
Part 3:	Concluding questionnaire

Detailed explanations of the exact tasks and payment rules will be given in Part 1. It is strictly required that you carefully read and understand all instructions. Please raise your hand if you have any questions or if you encounter any problems – the experimenter will immediately come and help you.

In each of the 36 different investment rounds of Part 2, you have to decide how much experimental money you want to keep safe at hand and how much experimental money you want to invest into a risky long-term investment product. The investment product will yield one out of 10 possible returns. All 10 returns have the same probability of occurrence (that is, 10% each). Some of the 10 possible returns will be positive and some will be negative. You will be told about the possible returns of the following investment round at the beginning of each round.
Please note: Decisions that you have made in earlier rounds will not affect later rounds – in every round of Part 2, you will have the same amount of experimental money available.

The experiment concludes with a questionnaire (Part 3). Please take your time and answer all questions carefully and truthfully. You can trust us that your answers will be treated anonymously and that they will be used for research-purposes only. No third party will obtain access to your answers at any time whatsoever!

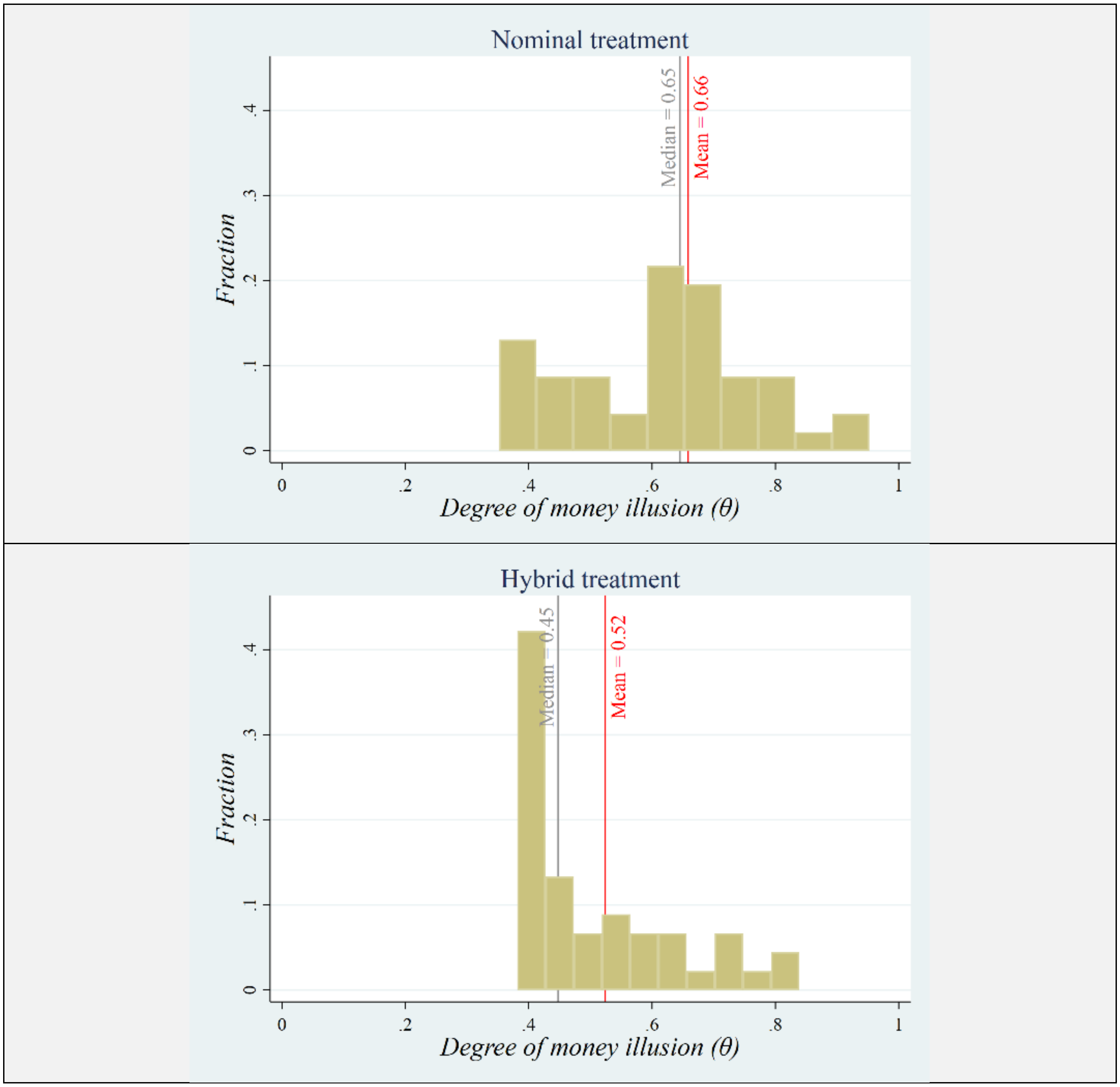
After the experiment, the computer will randomly select one of the 36 investment rounds from Part 2. Only your decision from this one round will be relevant for determining your payment. Then, you will draw a ball out of an urn with 10 numbered ping-pong balls. If you pick the number "1", your investment in the round that was selected by the computer yields the lowest possible return of that round. If you pick the number "10", your investment yields the highest possible return of that round. Taken together, your payment for participating in this experiment will be determined by your decision from the round that was selected by the computer, and from the ping-pong ball that you have drawn from the urn. Of course, you do not know in advance which round the computer will select and what ping-pong ball you will draw. So take your time and think about all 36 decisions carefully.

During the experiment, the use of the internet or personal devices (such as cellphones or pocket calculators) is not allowed. Please do not talk to your neighbors or look at other participants' screens. The other participants will perform different tasks than you, so do not let their actions influence your own decisions.

Do you have any questions at this time?

We will now distribute the login passwords. You can then start with the experiment.

Appendix B: Money illusion estimates on the participant level.



Distribution of money illusion estimates (θ) on the participant level in the nominal treatment (upper panel) and the hybrid treatment (lower panel), based on the model specifications of Panels C of Tables III and IV respectively. A money illusion parameter could not be estimated for 1 participant in the nominal treatment and 2 participants in the hybrid treatment due to non-variance of the portfolio weights in all Type 2 rounds. Further, one money illusion estimate in both the nominal and the hybrid treatment is outside the meaningful range $\theta \in [0, 1]$ and therefore not displayed in the above distributions (omitted estimates are $\theta = 2.4448$ and $\theta = 1.2906$, respectively).

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