

Investment Behaviors Under Epistemic versus Aleatory Uncertainty

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### Abstract

In nine studies, we find that investors intuitively distinguish two independent dimensions of uncertainty: *epistemic uncertainty* that they attribute to missing knowledge, skill, or information, versus *aleatory uncertainty* that they attribute to chance or stochastic processes. Investors who view stock market uncertainty as higher in epistemicness (knowability) are more sensitive to their available information when choosing whether or not to invest, and are more likely to reduce uncertainty by seeking guidance from experts. In contrast, investors who view stock market uncertainty as higher in aleatoriness (randomness) are more sensitive to their risk preference when choosing whether or not to invest, and are more likely to reduce uncertainty through diversification. We show, further, that investors' attributions of uncertainty can be perturbed by the format in which historical information is presented: charts displaying *absolute* stock prices from one quarter to the next promote perceptions of epistemicness and greater willingness to pay for financial advice, whereas charts displaying the *change* in stock price from one quarter to the next promote perceptions of aleatoriness and a greater tendency to diversify.

*Keywords:* Uncertainty, Epistemic, Aleatory, Investing, Financial Decision Making

## Investment Behaviors Under Epistemic versus Aleatory Uncertainty

Among the most important financial decisions we make are how to invest our savings, and different people approach investment decisions in dramatically different ways. Whereas some investors carefully select individual assets such as stocks based on research and financial advice, others diversify among larger bundles of assets, for instance by purchasing mutual funds. These stylized tendencies map onto two principle market segments: as of the end of 2017, about 45% of U.S. equity assets were held in passive funds and the remainder in either active funds or individual stocks (Bloomberg, 2018). Predicting when consumers will pursue these different styles of investing, and understanding why they do so, presents both a theoretical challenge for behavioral scientists and a practical concern for marketing professionals in the financial services sector.

In this paper we argue that distinct investment strategies are driven by investors' beliefs concerning the fundamental nature of market uncertainty. To illustrate, consider two investors, Warren and Burt. Warren views investment as primarily a game of skill: with the right information and investment strategy, one can identify winning and losing assets in advance and outperform the market. As a result, Warren spends considerable time and money researching individual assets and consulting experts. In contrast, Burt views investment as primarily a game of chance: because price movements of assets are inherently stochastic, nobody can reliably pick winners and losers in advance. Thus, Burt focuses his efforts on maintaining a diversified portfolio of assets that reflect his appetite for risk.

We propose that Warren's and Burt's mental models reflect an intuitive distinction that investors make about the nature of stock market uncertainty. Market uncertainty can be viewed as *epistemic* in nature, arising from deficiencies in one's knowledge, information, or skills in

assessing an event that is, in principle, knowable in advance. In contrast, market uncertainty can be viewed as *aleatory* in nature, arising from processes that are treated, for all intents and purposes, as random or stochastic. Simple examples of pure epistemic uncertainty include whether or not one has correctly answered a trivia question or a math problem, while examples of pure aleatory uncertainty include whether or not one has correctly predicted the outcome of a coin flip or the spin of a roulette wheel.

While the ontological distinction between epistemic and aleatory uncertainty has historical roots in the foundations of modern probability theory (Hacking 1975), the psychological distinction between these dimensions has only recently been investigated empirically (e.g., Fox, Goedde-Menke and Tannenbaum, 2019; Fox, Tannenbaum, Ülkümen, Walters and Erner, 2019; Tannenbaum, Fox, and Ülkümen 2017; Ülkümen, Fox, and Malle 2016). This research has found that perceptions of epistemic and aleatory uncertainty affect how people communicate their beliefs, judge probabilities, and make decisions. People tend to communicate degrees of epistemic uncertainty using expressions such as “I’m 90% sure” or “I’m fairly confident” whereas they tend to communicate degrees of aleatory uncertainty using expressions such as “I think there’s a 90% chance” or “I’d say there’s a high likelihood” (Ülkümen, Fox, and Malle 2016). Holding evidence strength constant, forecasters tend to make more extreme probability judgments the more they perceive relevant uncertainty to be epistemic in nature, and tend to make more regressive judgments the more they perceive uncertainty to be aleatory in nature (Tannenbaum, Fox, and Ülkümen 2016). To the extent that uncertainty is seen as more epistemic (i.e., knowable), forecasters receive more credit for correct predictions and blame for incorrect predictions; to the extent that uncertainty is seen as more aleatory (i.e., random), they are seen as lucky or unlucky (Fox, Tannenbaum, Ülkümen, Walters and Erner, 2019). The present article extends this stream of work to the important domain of investment

decisions, using both lab and field data, and using both correlational and experimental approaches.

We pause to emphasize two unique features of the present framework that distinguish it from previous treatments of variants of uncertainty (most notably, Kahneman and Tversky 1982; for references to additional accounts see Fox and Ülkümen, 2011). First, we treat epistemic and aleatory as independent dimensions of subjective uncertainty. Thus, one investor may see stock movements as *both* more knowable *and* more random than another, just as one investor may exhibit both more information seeking and more diversification than another. Second, we distinguish the perceived *nature* of uncertainty (epistemic or aleatory) from the perceived *level* of uncertainty. Individuals can perceive high or low levels of uncertainty, regardless of whether they view that uncertainty as epistemic or aleatory in nature. For instance, two people may see future stock movement as entirely knowable in principle (i.e., epistemic in nature) but differ in how much confidence they have in their predictions (i.e., vary in their level of epistemic uncertainty). Likewise, two people may both see future stock movement as entirely stochastic (i.e., aleatory in nature) but differ in their assessment of the entropy of the probability distribution over possible outcomes (i.e., vary in their judgments of the level of aleatory uncertainty).<sup>1</sup>

To keep the distinction between nature and level of uncertainty clear, we refer to the perceived *nature* of market uncertainty as *epistemicness* and *aleatoriness*. We measure these two dimensions using an instrument developed elsewhere, the Epistemic-Aleatory Rating Scale (EARS; Fox et al., 2019) and in some studies we also manipulate perceived nature of uncertainty. Our central thesis is that when investors perceive greater epistemicness they are more sensitive to the *level* of epistemic uncertainty (i.e., how much relevant knowledge, skill, or information they think they have at their disposal) and that when investors perceive greater

aleatoriness they are more sensitive to the *level* of aleatory uncertainty (i.e., assessed volatility of a particular investment or entropy in the assessed probability distribution over outcomes).

In the context of financial investing, people are generally understood to attempt to maximize expected returns while minimizing variability in possible returns (e.g., Markowitz 1952). We propose that viewing the stock market as entailing epistemic versus aleatory uncertainty leads to distinct investment strategies. Because epistemic uncertainty is attributed to missing knowledge, information, or skill, we expect investors who view the market as more epistemic in nature will also be more sensitive to the relevant information they have available when making investment decisions. Thus, we expect that these investors will attempt to reduce uncertainty by seeking information or consulting experts, will express a greater willingness to pay for financial advice (especially to the extent they feel relatively ignorant concerning relevant investments), and will make investment decisions that are more responsive to financial advice. In contrast, because aleatory uncertainty is attributed to stochastic and inherently unpredictable processes, we expect investors who view the market as more aleatory in nature will attempt to reduce uncertainty by engaging in general risk management strategies such as asset diversification<sup>2</sup> (especially to the extent that they are risk-averse). Furthermore, because aleatory uncertainty is attributed to random behavior, we expect investors who view the market as more aleatory in nature to make investment decisions that more closely accord with their general attitudes towards risk (e.g., choices involving chance gambles).

While most prior research on equity trading and portfolio choice has treated uncertainty as a single dimension (e.g., Bender, Osler, and Simon 2013; Capon, Fitzsimons, and Prince 1996; Cohn et al. 1975; French and Poterba 1991; Goetzmann and Kumar 2008; Gruber 1996; Kramer 2012), the economics literature has long acknowledged the relevance of second-order uncertainty to decision making. Keynes (1921) argued that decision makers ought to prefer to bet

on probabilities that are supported by a larger weight of evidence, and Knight (1921) proposed that entrepreneurs are compensated for exposing themselves to unmeasurable risk or *uncertainty* (i.e., unknown probability distributions over outcomes) as opposed to measurable *risk* (i.e., known probability distributions over outcomes). More recently this has given rise to a robust literature on ambiguity aversion (Ellsberg, 1961; for reviews see Camerer and Weber, 1992; Etner, Jeleva and Tallon, 2012). While economic theories typically model ambiguity using second-order probability distributions, multiple priors, or multi-stage lotteries, psychologists have provided empirical evidence that ambiguity aversion reflects reluctance to act in situations where the decision maker feels relatively ignorant, unskilled, or uninformed (Heath and Tversky, 1991; Fox and Tversky, 1995; Fox and Weber, 2002). Thus, in our framework, the distinction between risk and ambiguity might be construed as a distinction between purely aleatory uncertainty and uncertainty that is at least partly epistemic in nature (Fox and Ülkümen, 2011), and ambiguity aversion can be interpreted as reluctance to bet in situations where one experiences higher levels of epistemic uncertainty (Fox, Goedde-Menke and Tannenbaum, 2019).

Ambiguity has been incorporated into financial models of asset pricing and portfolio choice in an attempt to interpret various empirical phenomena such as the home bias and equity premium puzzle (for a review see Guidolin and Rinaldi, 2013). Supporting this approach, a recent empirical study found that participants in the American Life Panel who exhibited greater ambiguity aversion in an Ellsberg-like setup involving balls and urns were also less likely to have invested in the stock market, had less money invested in stocks, less money invested in foreign stocks, and more money invested in stock of the company for which they worked (Dimmock, Kouwenberg, Mitchell and Peijnenburg, 2016).

In this paper we depart from this prior literature on ambiguity and investing in three important respects. First, we are not interested in the relationship between *levels* of ambiguity/ignorance (epistemic uncertainty) or volatility/risk (aleatory uncertainty) and investment behavior, but rather the relationship between perceived *nature* of uncertainty and sensitivity to these dimension (e.g., the relationship between perceived epistemicness or aleatoriness and the desire to reduce ignorance or riskiness, respectively). Second, we do not treat epistemicness and aleatoriness as objective features of investments but rather as *subjective appraisals* of market uncertainty that may vary between individuals or even within-individuals as a function of how market data are framed. Third, unlike prior empirical work that is purely correlational we *experimentally manipulate* the extent to which the nature of market uncertainty is seen as epistemic versus aleatory, and examine the extent to which ratings of these dimensions, in turn, predict distinct investment strategies.

A visual depiction of our main hypotheses is presented in Figure 1. The top panel (Figure 1a) displays our predictions concerning uncertainty management strategies. First, we expect perceptions of epistemic uncertainty to be associated with an increased tendency to seek expert advice (Path A), whereas we do not predict perceptions of aleatory uncertainty to be related to advice seeking. Second, we expect perceptions of aleatory uncertainty to be associated with an increasing tendency toward asset diversification (Path B), whereas we do not predict perceptions of epistemic uncertainty to be related to diversification.<sup>3</sup>

The bottom panel (Figure 1b) presents our predictions concerning willingness to invest in a particular asset. First, we expect that greater perceived epistemicness (i.e., an increased tendency to view stock investment as a puzzle to be solved) will amplify the impact of expert advice on willingness to invest (Path C). To the extent that investors see uncertainty as epistemic in nature, they should be especially likely to go long on investments where the stock is



forecasted to increase in value and go short on investments where the stock is forecasted to decrease in value. Meanwhile, we expect no such interaction between perceptions of aleatory uncertainty and expert advice on willingness to invest. Second, we expect that greater perceived aleatoriness (i.e., an increased tendency to view stock investments as chance gambles) will amplify the impact of an investor's risk preference on their willingness to invest (Path D). To the extent that investors see uncertainty as aleatory in nature, they should be more likely to choose investments in accordance with their own preferences concerning chance events. Meanwhile, we expect no such interaction between perceptions of epistemic uncertainty and risk preferences on willingness to invest.<sup>4</sup> Note that the solid lines in Figure 1 refer to predicted relationships among variables whereas corresponding dotted lines refer to cases where we are generally agnostic concerning these relationships (i.e., we pre-registered no specific prediction). However, we test the relative strength of epistemic and aleatory paths in our studies and find that the solid lines are almost always relatively stronger than the dotted lines at a statistically significant level.

## **Study Overview**

We test our conceptual framework across nine studies. In Study 1 we examine actual investment decisions using a panel of retail investors and find that those who view stock market uncertainty as higher in epistemicness are more likely to rely on financial advice, whereas those who view stock market uncertainty as higher in aleatoriness are more likely to engage in diversification (i.e., Paths A and B in Figure 1). In Studies 2, 3, and 4 we directly manipulate perceptions of epistemicness and aleatoriness by altering the presentation of historical stock information. In Study 2, we find that when investors view past stock movement in a frame that highlights absolute price trends they are willing to pay more for an analyst's advice, due to greater perceived epistemicness (and as expected we find no such reliable mediation by perceived aleatoriness) (Figure 1, Path A). In contrast, in Study 3 we find that when investors

view historical stock information in a frame that highlights changes in price, participants are more likely to diversify, due to greater perceived aleatoriness (and as expected we find no such reliable mediation by epistemicness) (Figure 1, Path B). In Study 4 we find that when past stock information is presented in an absolute price frame, investors have a greater tendency to follow the advice of a stock analyst due to increased perceptions of epistemicness (Figure 1, Path C); however, in a relative price frame, investors' decisions accord more closely with their independently measured risk preferences due to increased perceptions of aleatoriness (Figure 1, Path D). In Study 5 we show that ratings of aleatoriness moderate the association between risk preferences and investment decisions (Figure 1, Path D), and in Study 6 we show that ratings of epistemicness moderate the impact of an expert's forecast of stock movement on investors' willingness to invest (Figure 1, Path C).

### **Study 1: Uncertainty Management Among Investors**

In our first study we explore the association between the perceived nature of stock market uncertainty and uncertainty management strategies. We recruited a sample of retail investors who reported their actual investment behavior as well as their perceptions of the nature of stock market uncertainty. We predicted that investors who view the stock market as entailing greater epistemicness (but not necessarily aleatoriness) would be more likely to seek financial advice, while investors who view the stock market as entailing greater aleatoriness (but not necessarily epistemicness) would be more likely to take advantage of risk management strategies such as diversification. Thus, Study 1 represents a correlational approach to examining paths A and B in Figure 1.

### **Method**

We recruited participants from a Qualtrics panel to complete a survey in exchange for \$10. The Qualtrics panel was comprised of over 525,000 respondents ranging in age from 18 to

50 with a broad range of professional experience. Before completing the questionnaire, participants were screened for adequate financial experience.

**Criteria for eligibility.** To be eligible for the study, participants were required to own at least \$1,000 in stock market investments, be between the ages of 18 and 65, report making their own investment decisions, and rate their knowledge of the stock market as a three or higher on a five-point scale. To be included in the study we also required participants to correctly answer three simple financial literacy screening questions. A complete list of these questions, along with materials for all other studies in this paper, can be found in the Web Appendix. Of the 7,191 individuals who responded to the initial screening questions, 354 passed the screening. The average age was 35 years (range: 19–50 years), with the median respondent reporting their total investment assets (excluding home and pension equity) between \$50,000 and \$100,000 and investments in the stock market between \$5,000 and \$20,000.

**EARS rating.** Participants first evaluated stock market uncertainty using a 6-item version of the Epistemic-Aleatory Rating Scale (EARS; see Tannenbaum et al. 2017 for scale validation details). Participants rated the uncertainty associated with the “approximate return of an individual stock over 1 year” across six statements that measure perceptions of epistemicness (e.g., “... is something that becomes more predictable with additional knowledge or skills”) and aleatoriness (e.g., “... is something that has an element of randomness”). They rated each statement on a 7-point scale (1 = *not at all*, 7 = *very much*), and we randomized the order of the six statements for each participant. We computed ratings of epistemicness and aleatoriness by averaging the three items for each subscale (Cronbach’s  $\alpha$  was 0.81 for the epistemicness subscale, and 0.73 for the aleatoriness subscale). These two subscales were positively correlated ( $r = .44$ ). This positive correlation is notable as it contradicts the notion that investors who see market outcomes as more knowable necessarily see them as less random. We provide the

complete EARS instrument in the Web Appendix, where we also report factor analytic results for every study.

**Financial advisor.** Participants next reported whether they currently did or did not employ a financial advisor (0 = *no*, 1 = *yes*).

**Diversification.** Participants reported the number of distinct stocks they currently held. We operationalized stock diversification as the absolute number of distinct stocks held, with a greater number of stocks representing a less concentrated (i.e., in general, more diversified) stock portfolio. We winsorized the data at a maximum of 100 stocks (meaning that values of more than 100 stocks were transformed to 100 stocks). Of our 354 respondents, 5 reported holding more than 100 distinct stocks.<sup>5</sup>

**Risk perception.** As a control variable, we measured the perceived *level* of risk (as opposed to *nature* of the associated uncertainty that we measured with the EARS) using three risk perception items from the financial decision subscale of the Domain-Specific Risk Taking Scale (DOSPERT; Weber, Blais, and Betz 2002). Participants rated the amount of risk involved in various financial decisions (e.g., “Investing 10% of your annual income in a moderate growth mutual fund”) on 7-point scales (1 = *not at all risky*, 7 = *extremely risky*). We found that these three items displayed poor internal consistency (Cronbach’s  $\alpha = .44$ ), so for all regression analyses below we entered each item separately rather than combining them into a single index. Our results do not meaningfully differ when using a combined index for the three items.

**Other measures.** Participants also reported the percentage of their assets (from 0-100%) they invest in each of the following categories: individual stocks; stock mutual funds; stock index funds; individual bonds; bond mutual funds; bond index funds; individual commodities; commodities mutual funds; commodities index funds; individual real estate; real estate mutual funds; real estate index funds; home; pension; annuities; cash; and other. Participants provided

responses in open text boxes that were required to total to 100%. Participants also reported the total value of their investments in one of seven ranges (1 = \$0 to \$1,000, 2 = \$1,000 to \$50,000, 3 = \$50,000 to \$100,000, 4 = \$100,000 to \$250,000, 5 = \$250,000 to \$500,000, 6 = \$500,000 to \$1,000,000, and 7 = \$1,000,000 or more), the total value of other assets in the same seven ranges, the frequency with which they made changes to their investments (1 = *more than every day*, 7 = *fewer than one change every 12 months*), and the average period of time that they held stocks and mutual funds (1 = *several hours*, 6 = *many years*). If a participant did have a financial advisor, they then reported in an open text box the fee they paid to the financial advisor as a percentage of assets under management. While not part of our main analysis, we report an exploratory analysis of the relationship between EARS ratings and trading frequency, as well as the relationship between EARS ratings and fees paid to financial advisors in the Web Appendix.

At the end of the study, participants completed a 3-item financial literacy test (Lusardi, Mitchell, and Curto 2010). Participants also provided basic demographic information.

## **Results and Discussion**

Table 1 displays our main results. We first considered the prediction that attributions of greater epistemicness would be positively associated with reliance on expert advice. We tested this prediction by conducting a logistic regression on whether or not the respondent paid a financial advisor (0 = *no*, 1 = *yes*), with ratings of epistemicness and aleatoriness as our predictor variables. Epistemicness ratings were reliably and positively associated with paying for financial advice (confirming our prediction), whereas aleatoriness ratings were not significantly associated with paying for financial advice (Table 1, Column 1). This pattern holds when including additional controls of perceptions of riskiness of the market, the investor's total investment asset value, other asset value, number of stocks in which the respondent had invested, and financial literacy (Table 1, Column 2).

We next examined diversification. We predicted that greater perceived aleatoriness would be associated with less concentrated stock portfolios (i.e., greater diversification). To test this prediction we conducted an OLS regression with the number of stocks owned as our dependent variable. We found that aleatoriness ratings were significantly and positively associated with the total number of stocks held (Table 1, Column 3), confirming our prediction; meanwhile, epistemicness ratings were not reliably associated with the total number of stocks held. We also observe this pattern when including our additional controls (Table 1, Column 4).

Of note, we pre-registered no specific prediction about the relationships shown in Figure 1 as dotted lines, though generally, we expected weaker relationships than the solid lines. To examine this further, we conducted a test of the relative size of the regression coefficient for epistemicness and aleatoriness for each regression in Study 1. As expected, rated epistemicness was a stronger predictor than rated aleatoriness of whether an investor paid for financial advice (without controls:  $Z = 1.92, p = .054$ ; with controls,  $Z = 1.85, p = .065$ ). Conversely, rated aleatoriness was a stronger predictor than rated epistemicness of diversification (without controls:  $t(351) = 1.73, p = .085$ ; with controls:  $t(343) = 2.06, p = .040$ ).

The results of Study 1 suggest that individual differences in perceptions of epistemicness and aleatoriness in stock market uncertainty are associated with distinct strategies for reducing uncertainty. As predicted, investors who viewed stock market uncertainty as relatively epistemic in nature were more likely to pay for financial advice. Meanwhile, investors who perceived stock market uncertainty as relatively aleatory in nature held less concentrated stock portfolios. These findings are consistent with our predictions that investors tend to mitigate epistemicness by acquiring relevant information and tend to mitigate aleatoriness through diversification. We next turn to experimental tests of these hypotheses.

### **Study 2A: Managing Epistemic Uncertainty By Seeking Expert Advice**

The results of Study 1 are correlational and as such only provide suggestive evidence that perceptions of epistemicness and aleatoriness influence investment behavior. In the studies that follow, we manipulate perceptions of epistemicness and aleatoriness by presenting participants with financial information in one of two distinct (but informationally equivalent) ways.

Investors frequently consult data on past performance of the investments they are considering. Two alternative forms in which they receive these data are absolute price format, where asset prices are plotted in a time series, and relative price format, where changes in asset prices from one period to the next (i.e., returns) are plotted. In particular, one naturalistic setting in which this distinction between absolute and relative price formats is relevant is stock analysts' reports of their past performance. As illustrated in Figure 2, analysts' past performance can be depicted by displaying predicted prices alongside realized prices (i.e., an absolute price chart), or by displaying the predicted and actual changes in an asset from period to period (i.e., a relative price chart).

We conjectured that charts that highlight overall trends in an asset's value may augment impressions of its inherent knowability (i.e., epistemicness), whereas charts that highlight changes in an asset's value from period to period may augment impressions of its fundamentally stochastic nature (i.e., aleatoriness). Our rationale is follows.

Two features of absolute price charts may highlight the knowability of future stock prices. First, to the extent that overall trends exists in a given asset's history, absolute price charts make such trends more salient than relative price charts. Thus, by making past trends more easily discernible, absolute price charts may give the impression that future stock prices are more fundamentally knowable. Second, unlike relative price charts, absolute price charts also bake-in knowledge about past prices. In particular, when performance is presented alongside an analyst's forecasts, the analyst knew the previous period's price when making a forecast concerning the

next period's price. Thus, even when an analyst's forecasted changes in absolute prices are uncorrelated with subsequent realized price changes, the auto-correlation between forecasted and realized absolute prices can often appear extremely high (as illustrated in Figure 2), conveying the illusion that market prices are more knowable than they truly are.

In contrast, relative price charts present price changes from one period to the next, which makes short-term fluctuations in prices and variability in the direction of those changes more salient compared to absolute price charts. By making these variations more salient and expunging visual cues concerning overall trends, relative price charts give the impression of greater randomness in stock prices, compared to absolute price charts—whether forecasts are included or not.

In Studies 2-4 we attempt to manipulate perceptions of epistemicness and aleatoriness in stock market uncertainty by presenting historic return information in absolute versus relative formats.<sup>6</sup> For Studies 2 and 4, in which we focus on the impact of heightened epistemicness on investment behaviors, we also include analysts' forecasts; we reasoned that the market would appear more inherently predictable (epistemic) if the starting point of both forecasts and outcomes travel together as they do in the absolute but not relative format. For Study 3, in which we focus only on the impact of heightened aleatoriness on investment behaviors, there is no reason to include an analyst's forecast as predictability is irrelevant; instead we draw participants' attention only to the apparent randomness by highlighting variability more in the relative return format compared to the absolute return format.

In Study 2A we focus on the relationship between perceptions of epistemicness and willingness to pay for financial advice. We predicted that participants will pay more for an analyst's advice concerning a new stock when prior predictions of trending stocks were presented in absolute terms rather than relative terms. Importantly, we also predicted that this



effect would be statistically mediated by perceived epistemicness (but not necessarily aleatoriness) of stock forecasting accuracy. This latter prediction derives from our conceptual model in which epistemicness (but not aleatoriness) promotes motivation to seek financial advice. We preregistered our hypotheses, experimental design, and analysis plan at <http://aspredicted.org/blind.php?x=km4uy5>.

## Method

We recruited 201 participants (61% male, mean age = 36 years, range: 18–84 years) from an online labor market<sup>7</sup> (Prolific Academic) to participate in a brief study for £0.60 each. We told participants that they would read stock recommendations from two professional stock analysts, Richard and Phillip, and would be asked to make stock investment decisions. Participants were also informed that they would learn stock prices from real companies whose identities had been concealed (labeled Stock A or Stock D). We avoided using real stock names so that there would not be variation in behaviors due to differences in stock familiarity (Song and Schwarz 2008) or company level understanding (Long, Fernbach, and De Langhe 2018). In order to promote relatively constant risk perceptions, we told participants that each stock carried a similar level of risk.

We next asked participants to evaluate recommendations from the two stock analysts, and displayed a historical chart of each analyst's performance in one of two formats, generated from the same data: Approximately half of participants first saw forecasts and outcomes presented in terms of absolute prices (*absolute price chart*) followed by (the same) forecasts and outcomes presented in terms of proportional changes in the stock price relative to the previous period (*relative price chart*), while the remaining participants viewed the two graphs in the opposite order (we observed no significant order effects so we combined order conditions in all analyses

reported below). Thus, all participants viewed the same prediction and performance data twice, presented in two different formats, in randomized order.<sup>8</sup>

In both charts data points represent quarterly intervals from 2000 to 2017. We told participants that each analyst made forecasts “exactly three months in advance” and “has the best track record of any analyst at predicting Company [A/D].” Furthermore, we scaled the absolute and relative price charts so that the visual magnitude (i.e., vertical length) of analyst errors was equivalent across presentation formats.

Following the presentation of each stock chart, all participants completed two question blocks in an order that we randomized for each participant. One block measured participants’ perceptions of the nature of uncertainty concerning the “task of forecasting the price of Stock [A/D] over three months” using the 6-item EARS. The other block measured participants’ willingness to pay (WTP) to receive a forecast from the analyst concerning two new stocks:

Now, imagine you have \$1,000 that you must invest in one of two other stocks, Stock [B/E] or Stock [C/F] (the real names of these stocks have also been hidden). [Richard/Phillip], the expert stock analyst, can forecast the price of Stock [B/E] and Stock [C/F] to the same degree of accuracy as Stock [A/D], as shown above. Please indicate if you would be willing to pay the amounts below to see [Richard’s/Phillip’s] forecast for these stocks if you were making this investment in real life.

Participants next indicated whether or not they would be willing to pay for Richard’s or Phillip’s forecast from a price list of 16 choices that ranged from “\$0.01” to “\$1,000 or more” in approximately logarithmic increments. For each of the 16 prices, they indicated whether they would or would not be willing to pay that amount. We coded WTP as the largest value that participants indicated that they would be willing to pay, \$0 if they were not willing to pay any amount, and \$1,000 if they were willing to pay \$1,000 or more. For the analysis involving WTP we omitted data from 22% of trials in which a participant’s responses violated dominance (as specified in our preregistration document).

Finally, participants completed a comprehension check and answered some basic demographic questions. For the comprehension check, participants were shown the same charts they had viewed earlier, and for each chart were asked whether points on the chart represented: (a) the stock price or (b) the percentage change in the stock price. Participants were also asked when the stock analyst had made each forecast, with response options being: (a) three months in advance or (b) all of the forecasts were made before 2000.

## **Results and Discussion**

Because our study uses a repeated-measures design, we calculated all test statistics and *p*-values using robust standard errors clustered by participants.

**Comprehension check.** A large majority of participants appear to have properly understood the task materials. After viewing the absolute price chart, 84% of participants correctly responded that each point represents a stock price, and when viewing the relative price chart, 81% of participants correctly responded that each point represented a percentage change. Furthermore, 85% of the participants correctly responded that forecasts were made three months in advance in the relative price chart, and 85% correctly responded in the absolute price chart. We retain all 201 participants in the analysis reported below because this is what we specified in our preregistration analysis plan; this said, restricting the analysis to participants who correctly answered all comprehension check questions ( $n = 126$ ) does not change the direction or statistical significance of our findings.

**Manipulation check.** Recall that we predicted that participants would view stock market uncertainty as higher in epistemicness in the absolute price condition and as higher in aleatoriness in the relative price condition. Indeed, these predictions were confirmed: participants rated stock market uncertainty as higher in epistemicness when outcomes were presented as absolute prices ( $M = 5.12$ ,  $SD = 1.05$ ) versus relative prices ( $M = 4.66$ ,  $SD = 1.24$ ),  $t(200) = 5.34$ ,

$p < .001$ ,  $d = 0.40$ , and participants rated stock market uncertainty as higher in aleatoriness when outcomes were presented as relative prices ( $M = 4.98$ ,  $SD = 1.14$ ) versus absolute prices ( $M = 4.49$ ,  $SD = 1.32$ ),  $t(200) = 5.62$ ,  $p < .001$ ,  $d = 0.40$ .

**Willingness to pay.** Also as predicted, participants expressed greater willingness to pay for stock advice when outcomes were presented as absolute prices ( $M = \$158.91$ ,  $SD = \$266.00$ ) than when outcomes were presented as relative prices ( $M = \$86.56$ ,  $SD = \$181.74$ ),  $t(162) = 3.90$ ,  $p < .001$ ,  $d = 0.32$ . Because we measured WTP using a roughly logarithmic scale we also conducted two additional (preregistered) robustness checks by transforming the data. First, we log-transformed WTP and again found that participants expressed greater willingness to pay for advice when the analyst's performance was presented in absolute rather than relative prices,  $t(162) = 4.69$ ,  $p < .001$ . We also performed an inverse hyperbolic sine transformation of WTP, and again found a similar pattern,  $t(162) = 5.47$ ,  $p < .001$ .

**Mediation analysis.** We next examined whether the higher WTP for financial advice in the relative price condition compared to the absolute price condition could be statistically explained by the different effects each chart format had on perceptions of epistemicness and aleatoriness. We tested this using a structural equation model with WTP as the dependent variable, condition (0 = *relative price chart*, 1 = *absolute price chart*) as the independent variable, and ratings of epistemicness and aleatoriness as separate mediator variables. We calculated indirect pathways for epistemicness and aleatoriness using bootstrapped standard errors (10,000 resamples). When using raw WTP, we found a statistically reliable indirect effect through ratings of epistemicness (as predicted),  $b = 42.18$ , bias-corrected 95% CI = [22.78, 66.88],  $p < .001$ , and a marginally significant effect in the opposite direction (that we did not predict) through ratings of aleatoriness,  $b = -14.42$ , bias-corrected 95% CI = [-35.57, -1.06],  $p = .086$ . When using the log and inverse hyperbolic sine transformations of WTP, we again found a

statistically reliable indirect effect through perceptions of epistemicness  $b_{log} = 0.39$ , bias-corrected 95% CI = [0.18, 0.66],  $p = .001$ ;  $b_{ihs} = 0.37$ , bias-corrected 95% CI = [0.22, 0.58],  $p < .001$ . However, this time we found no such indirect effects through perceptions of aleatoriness,  $b_{log} = 0.01$ , bias-corrected 95% CI = [-0.13, 0.18],  $p = .897$ ;  $b_{ihs} = -.02$ , bias-corrected 95% CI = [-0.14, 0.09],  $p = .689$ . Thus, Study 2A confirmed our major prediction that participants would be willing to pay more for financial advice when a stock chart was presented in a format that conveyed perceptions of greater epistemicness (Path A in Figure 1).

We note that Study 2A employed a within-participant design: we presented the same forecasted and realized price information to participants in two different formats, less than 5 minutes apart. Remarkably, participants were willing to pay twice as much for the same financial advice when past performance was presented in absolute terms compared to relative terms.

### **Study 2B: Between-participant Replication of Study 2A**

The results of Study 2A conformed well to our preregistered predictions. However, one concern that could arise is that beliefs about a particular analyst's level of skill might have driven willingness to pay for that analyst's financial advice, rather than beliefs about general epistemicness of the stock market. After all, presentation of prices in an absolute format likely convey the impression of not only greater advance knowability but also greater forecaster accuracy than presentation of prices in a relative format. While the finding of mediation by epistemicness (but not aleatoriness) supports the conclusion that perceived nature of uncertainty drives differences in willingness-to-pay, we wished to replicate this result using a modified experimental design that casts further doubt on the skill-based account.

In Study 2B we tested the robustness of our results by modifying the design of Study 2A in two critical respects. First, we asked participants to report their willingness to pay for stock advice from a *different* analyst to the one they had viewed in the price chart. If increased

willingness-to-pay for financial advice following presentation of absolute compared to relative stock charts is merely driven by the enhanced perception of analyst skill, then we should be less likely to observe a treatment effect when asking participants to price financial advice from an *unrelated analyst*. Second, Study 2B uses a between-participant design to establish greater external validity—we suspect that outside the laboratory people typically evaluate either absolute or relative stock price information, but not both in the same setting. We preregistered our hypotheses, experimental design, and analysis plan at <http://aspredicted.org/blind.php?x=bx7xf7>.

## Method

We recruited 395 participants (50% male, mean age = 32 years, range: 18–74 years) from Prolific Academic to complete a survey in exchange for £0.30. Instructions and stimulus materials were identical to those in Study 2A, except for two differences. First, we randomly assigned participants to view predicted and realized stock movement using only a relative price chart (relative price condition,  $n = 197$ ) or only an absolute price chart (absolute price condition,  $n = 198$ ). Second, we asked participants to imagine that they were considering investing \$1,000 in either the stock shown in the chart (labeled Stock A) or a different stock (labeled Stock B). We then asked participants to indicate, using the same measure from Study 2A, how much they were willing pay to see forecasts for both Stock A and Stock B made by a *second* analyst, rather than the same analyst shown in the chart. Participants also rated the “task of forecasting the price of Stock A over three months” using the 6-item EARS.

## Results and Discussion

**Manipulation check.** As predicted, participants rated the stock as entailing greater epistemicness when outcomes were presented as absolute prices ( $M = 4.93$ ,  $SD = 0.92$ ) than when presented as relative prices ( $M = 4.16$ ,  $SD = 1.07$ ),  $t(393) = 7.68$ ,  $p < .001$ ,  $d = 0.77$ .

Participants also rated the stock as entailing greater aleatoriness when outcomes were presented

as relative prices ( $M = 4.73$ ,  $SD = 0.96$ ) than when presented as absolute prices ( $M = 4.16$ ,  $SD = 1.05$ ),  $t(393) = 5.64$ ,  $p < .001$ ,  $d = 0.57$ .

**Willingness to pay.** We first examined raw (i.e., untransformed) willingness to pay and found that the difference between the two conditions was not statistically significant,  $t(391) = 0.58$ ,  $p = .538$ . This may have occurred because WTP was highly skewed, ( $p < .001$ , Shapiro-Wilk test). To address this, we log-transformed the raw WTP data as specified in our preregistration plan. As predicted, participants expressed greater  $WTP_{log}$  for stock advice when outcomes were presented as absolute prices ( $M = 3.44$ ,  $SD = 1.88$ ) than when presented as relative price changes ( $M = 2.95$ ,  $SD = 2.32$ ),  $t(391) = 2.30$ ,  $p = .022$ ,  $d = 0.23$ . We also performed an inverse hyperbolic sine transformation of raw WTP and again found a reliable difference between conditions,  $t(391) = 2.54$ ,  $p = .011$ .

**Mediation analysis.** We next examined whether the marginal increase in WTP for financial advice in the absolute price condition compared to the relative price condition was statistically explained by differences in perceived nature of uncertainty across conditions. We conducted mediation tests using the same procedure as in Study 2A. When using the raw measure of WTP, we found a statistically reliable indirect effect through ratings of epistemicness (as predicted),  $b = 9.15$ , bias-corrected 95% CI = [2.92, 18.29],  $p = .017$ , and no reliable indirect effect through ratings of aleatoriness,  $b = 3.06$ , bias-corrected 95% CI = [-1.37, 8.74],  $p = .229$ . When using the log transformation of WTP, we found a statistically reliable indirect effect through ratings of epistemicness,  $b_{log} = 0.36$ , bias-corrected 95% CI = [0.17, 0.61],  $p = .001$ , and a marginally significant effect through ratings of aleatoriness,  $b_{log} = 0.12$ , bias-corrected 95% CI = [0.00, 0.28],  $p = .091$ . When using the inverse hyperbolic sine transformation of WTP, we found a statistically reliable indirect effect through ratings of epistemicness,  $b_{ihs} = 0.26$ , bias-

corrected 95% CI = [0.14, 0.42],  $p < .001$  and no reliable indirect effect through ratings of aleatoriness,  $b_{ihs} = 0.07$ , bias-corrected 95% CI = [-0.01, 0.18],  $p = .124$ .

In sum, confirming our predictions, participants in Studies 2A and 2B were willing to pay more for financial advice when a stock chart was presented in an absolute price format as opposed to a relative price format. This effect was mediated by the perception of greater epistemicness (Path A in Figure 1). In contrast, perceptions of aleatoriness did not consistently mediate willingness to pay for financial advice.

### **Study 3: Managing Aleatory Uncertainty through Diversification**

Studies 2A and 2B provide evidence that heightened perceptions of epistemicness lead to increased willingness to pay for financial advice (Path A, Figure 1). We next turn to the prediction that heightened perceptions of aleatoriness lead to greater diversification (Path B, Figure 1). Study 3 also employed an incentive-compatible design. We preregistered our hypotheses, experimental design, and analysis plan at <http://aspredicted.org/blind.php?x=qp23kj>.

#### **Method**

We recruited 269 participants (62% male, mean age = 34 years, range: 18–77 years) from Prolific Academic to complete a short survey in exchange for £0.30 plus the possibility of receiving additional bonus money. Participants were randomly assigned to evaluate four stocks displayed in either a relative price chart (designed to promote impressions of aleatoriness,  $n = 134$ ) or an absolute price chart (designed to promote impressions of epistemicness,  $n = 135$ ). The charts depicted the actual prices of Apple, Home Depot, Walmart, and Netflix over the previous five years, but the stock names were replaced with the generic labels Stock A, B, C, and D (see Figure 3). Unlike Studies 2A and 2B, participants in Study 3 viewed stock charts with only the realized prices and without forecasts, as our primary goal was to manipulate impressions of aleatoriness and so expert predictions were not relevant for this study.<sup>9</sup>



After presenting participants with a stock chart in either absolute or relative price format, we asked them to allocate \$100 however they saw fit across the four stocks, which would be invested over the ensuing six months. We told participants that one randomly-selected respondent would receive the realized value of their investment portfolio at the end of six months. On a separate page, participants also rated the “task of forecasting the prices of the four stocks listed above six months in the future” using the 6-item EARS.

## Results and Discussion

**Manipulation check.** As predicted, participants rated the task as higher in aleatoriness when outcomes were presented as relative prices ( $M = 5.10$ ,  $SD = 1.21$ ) than as absolute prices ( $M = 4.59$ ,  $SD = 1.37$ ),  $t(267) = 3.26$ ,  $p = .001$ ,  $d = 0.40$ . We made no such prediction concerning epistemicness ratings, and indeed perceptions of epistemicness did not reliably differ when outcomes were presented as relative prices ( $M = 4.30$ ,  $SD = 1.17$ ) compared to absolute prices ( $M = 4.31$ ,  $SD = 1.14$ ),  $t(267) = 0.12$ ,  $p = .901$ ,  $d = 0.02$ .

**Diversification.** We measured diversification as the variance in proportion invested across all four stocks (i.e., average squared deviation from 25%), with smaller numbers reflecting greater diversification and larger numbers reflecting greater concentration. As predicted, participants’ allocations were more diversified when outcomes were presented as relative prices ( $M = 456.50$ ,  $SD = 579.01$ ) than when outcomes were presented as absolute prices ( $M = 769.36$ ,  $SD = 631.56$ ),  $t(267) = 4.23$ ,  $p < .001$ ,  $d = 0.52$ .

**Mediation analysis.** To test whether the marginal increase in diversification in the relative price condition compared to the absolute price condition could be statistically explained by increased perceptions of aleatoriness in the relative price condition, we conducted mediation tests using the same procedure as in Study 2. As predicted, we found a reliable indirect effect through perceptions of aleatoriness,  $b = 73.15$ , bias-corrected 95% CI = [27.44, 139.48],  $p =$

.011. Meanwhile, also consistent with the present account, we found no reliable indirect effect through perceptions of epistemicness,  $b = -0.77$ , bias-corrected 95% CI =  $[-21.01, 12.24]$ ,  $p = .920$ .

The results of Study 3 suggest that presenting past stock price information in terms of relative rather than absolute prices can elevate perceptions of aleatoriness and promote greater portfolio diversification (Path B in Figure 1).

#### **Study 4: Influencing Willingness to Invest**

Studies 1–3 focused on the relationship between investors' perceptions of the nature of stock market uncertainty and the strategies they use to manage uncertainty in their investments. Our results so far suggest that perceptions of epistemicness increase advice-seeking (Figure 1, Path A), whereas perceptions of aleatoriness increase portfolio diversification behavior (Figure 1, Path B). We next turn to the relationship between investors' perceptions of the nature of stock market uncertainty and their willingness to invest. In particular, we test two predictions: (i) perceptions of epistemicness will amplify the influence of expert advice on willingness to invest (Figure 1, Path C), and (ii) perceptions of aleatoriness will amplify the influence of risk preferences on willingness to invest (Figure 1, Path D). To test these two predictions together, we asked participants whether they preferred to bet that a stock would go up, based in part on advice from a professional analyst, or whether they preferred to receive a smaller, certain amount. In Study 4, participants viewed the same analyst performance charts as in Study 2 and were also provided an investment recommendation by the analyst.

We predicted two independent effects: (i) that greater perceived epistemicness imparted by the absolute price format should prompt investors to put greater weight on the analyst's recommendation, leading to a greater willingness to invest in the recommended stock, and (ii) greater perceived aleatoriness imparted by the relative price format should prompt investors to

put greater weight on their own risk attitudes. Since most people are risk averse, this should lead to less willingness to invest in the stock.

We preregistered our hypotheses, experimental design, and analysis plan at <http://aspredicted.org/blind.php?x=g3s2q9>.

## Method

We recruited 794 participants (30% male, mean age = 38 years, range: 18–73 years) from Prolific Academic to participate in a short study for £1.00 each. Approximately half of participants first saw an analyst's forecasts and outcomes presented in terms of absolute prices (*absolute price chart*) followed by (the same) forecasts and outcomes presented in terms of proportional changes in the stock price relative to the previous period (*relative price chart*), while the remaining participants viewed the two charts in the opposite order, as in Study 2A (we observed no significant order effects so we combined order conditions in all analyses reported below). After viewing the analyst's performance for a single stock (in either an absolute or relative price chart), participants learned that the analyst made predictions for two new stocks. The analyst predicted that one stock would go up and the other would go down, and participants then chose between receiving: (a) \$150 if the stock favored by the analyst would have a higher 3-month return than the stock disfavored by the analyst, or (b) \$50 for sure. Thus, all participants viewed the same prediction and performance data twice, presented in two different formats and responded to two different hypothetical investment prospects, in randomized order.

Participants also rated the “task of forecasting the price of Stock [A/D] over three months” using the 6-item EARS.

At the end of the study we measured each participant's general risk preference by asking them to complete a short task adapted from Barsky et al. (1997), in which they accepted or rejected two chance gambles. Participants were told: “Below you will find a choice between a

sure gain and a 50/50 coin flip prospect. Please indicate if you prefer the sure gain or the coin flip prospect in the following scenario.” In the first round participants chose between “Gain \$50 for sure” or “If the coin turns up heads you gain \$150, if the coin turns up tails, you gain \$0.” If a participant selected the risky option in the first round, then he or she was presented in the second round with a choice between \$50 for sure and a 50/50 coin flip for \$100. If a participant instead selected the safer option in the first round, then he or she was presented in the second round with a choice between \$50 for sure and a 50/50 coin flip for \$200. This two-step titration procedure categorizes participants into one of four levels of risk preference, ranging from those who always chose the certain \$50 prospect (1 = *strongly risk averse*) to those who always chose the risky prospect (4 = *risk seeking*). Following this risk preference task, participants characterized their investment expertise on a 5-point scale (1 = *low*, 5 = *high*) and provided demographic information.

## Results and Discussion

Because our study used a repeated-measures design, we calculated all test statistics and  $p$ -values using robust standard errors clustered by participants.

**Manipulation check.** As predicted, participants rated the stock as higher in epistemicness when outcomes were presented as absolute prices ( $M = 4.83$ ,  $SD = 1.09$ ) than as relative prices ( $M = 4.16$ ,  $SD = 1.14$ ),  $t(793) = 15.68$ ,  $p < .001$ ,  $d = 0.60$ . Participants also rated the stock as higher in aleatoriness when outcomes were presented as relative prices ( $M = 4.96$ ,  $SD = 1.05$ ) than as absolute prices ( $M = 4.41$ ,  $SD = 1.17$ ),  $t(793) = 14.50$ ,  $p < .001$ ,  $d = 0.50$ .

**Willingness to invest.** Consistent with our prediction that epistemicness would amplify the influence of advice on investment decisions, participants were more likely to accept the recommended investment prospect in the absolute price chart condition (54% accepting prospect) compared to relative price chart condition (42% accepting prospect),  $Z = 5.81$ ,  $p <$

.001. This result is also consistent with our prediction that aleatoriness would amplify risk aversion since participants were more likely to reject the risky investment prospect in the relative compared to absolute price condition.

**Mediation analysis.** We note that Study 4 pits positive financial advice (which should increase willingness to invest among investors who see the advice as bullish to the extent that stock return uncertainty is viewed as epistemic in nature) against risk preferences (which should generally decrease willingness to invest among mostly risk averse investors to the extent that stock return uncertainty is viewed as aleatory in nature). This setup therefore lends itself to a parallel mediation analysis in which the impact of the presentation format (absolute versus relative prices) on willingness to invest is *simultaneously* mediated by perceived epistemicness (which enhances willingness to invest in the absolute price chart condition) and perceived aleatoriness (which diminishes willingness to invest in the relative chart condition). In other words, this mediation analysis is designed to demonstrate that the main effect of our manipulation is driven by shifts in the perceived nature of uncertainty.

This analysis further can implicitly test the amplification hypotheses of Figure 1b, paths C and D. Because financial advice is always positive and most participants are risk averse, the observation that greater perceived epistemicness increases willingness to invest and greater perceived aleatoriness decreases willingness to invest is consistent with the hypothesized interactions between these variables.

A visual representation of this mediation analysis is displayed in Figure 4. We used a logistic regression model with willingness to invest as the dependent variable (0 = *chose certain prospect*, 1 = *chose risky prospect*), condition as the independent variable (0 = *relative price chart*, 1 = *absolute price chart*), and ratings of epistemicness and aleatoriness as separate mediator variables. For the mediation model, we conducted 10,000 resamples, clustered standard

errors by participants, and adjusted the test procedure to account for binary choice data (Karlson, Holm, and Breen 2012). Confirming our prediction, we found a statistically reliable indirect effect through both ratings of epistemicness,  $b = 0.15$ , bias-corrected 95% CI = [0.09, 0.23],  $p < .001$ , and ratings of aleatoriness,  $b = 0.06$ , bias-corrected 95% CI = [0.00, 0.12],  $p = .050$ .

**Risk preferences and aleatoriness.** Our results suggest that greater perceived aleatoriness is associated with an increased avoidance of betting on a future stock movement. Our interpretation of this result assumes that most participants are risk averse. Indeed, we found that 78% of our sample exhibited risk aversion in choices among chance gambles in the Barsky et al. (1997) task. Because we measured these individual differences in risk preferences, we can further investigate more directly whether investment decisions are more sensitive to general risk preferences when the investment is viewed as more aleatory in nature (i.e., path D in Figure 1b). To do so we conducted a logistic regression with investment decision as the dependent variable (0 = *chose certain prospect*, 1 = *chose risky prospect*). Our predictor variables included ratings of aleatoriness, epistemicness, risk preference, as well as interaction terms between risk preference and each type of subjective uncertainty.

Contrary to our prediction, the interaction between aleatoriness and risk preference was not statistically significant ( $b = 0.001$ , 95% CI = [-0.09, 0.08],  $p = .975$ , though a post-hoc analysis that excludes participants with the lowest level of investment expertise reveals a marginally significant effect.<sup>10</sup> In Studies 5A–5C we will take a closer look at the relationship between aleatoriness and risk preference by simplifying our experimental design (i.e., to make it easier for less sophisticated participants to understand) and increasing statistical power.

In summary, Study 4 provides support for the notion that willingness to invest in a stock among risk averse investors who receive a bullish report is enhanced by perceptions of epistemicness and diminished by perceptions of aleatoriness. This also provides indirect

support for the amplification hypotheses depicted in Figure 1b, paths C and D. We next turn to more direct tests of these hypotheses.

### **Study 5: Aleatory Uncertainty Amplifies Sensitivity to Risk Preference**

In Studies 5A–5C we tested the prediction that perceptions of aleatoriness (but not necessarily perceptions of epistemicness) will amplify the impact of risk preferences on willingness to invest (Figure 1, Path D). To do this we collected three independent samples of participants. In all three studies, participants first made a prediction about movement of stocks or stock indices, and then we assessed their willingness to bet on their prediction by giving them a choice between receiving a larger amount of money if their prediction is correct versus a smaller certain amount of money. Importantly, we controlled for participants' perceived likelihood that their predictions were correct in order to rule this out as a potential confound. Study 5A involved movement of the S&P 500 index; Study 5B involved the movement of individual stocks; and Study 5C involved the movement of a single stock over different time horizons. Furthermore, Studies 5A and 5B employed incentive-compatible designs.

### **Method**

**Study 5A.** We recruited 564 participants<sup>11</sup> (44% male, mean age = 36 years, range: 18–85 years) from Amazon.com's Mechanical Turk labor market (MTurk) who were each paid \$0.40 for their participation. Participants first indicated the current value of their stock market investments in U.S. dollars and rated their investment knowledge on a 5-point scale (1 = *low*, 5 = *high*). Next, participants reported their risk preference using the same procedure as in Study 4.

We then asked participants to rate the uncertainty of “whether the S&P 500 will go up or down over the next six months” using the 6-item EARS. Participants then predicted whether the S&P 500 would increase or decrease over the next six months (0 = *S&P 500 decreases in value or remains the same*, 1 = *S&P 500 increases in value*). Next, participants chose between: (a)

receive \$90 if your prediction was correct and \$0 otherwise, or (b) receive \$30 for sure. We informed participants in advance that some respondents would be selected at random to have their choice honored for real money. As another control variable, participants assessed the likelihood that their prediction would be correct on a scale from 50–100%. Finally, participants provided basic demographic information and were debriefed.

**Study 5B.** We recruited 365 participants (58% male, mean age = 35 years, range: 18–70 years) from MTurk who were each paid \$0.50 for their participation, along with the potential to receive a bonus payment. Participants first indicated the current value of their stock market investments in dollars and rated their investment knowledge on a 5-point scale (1 = *low*, 5 = *high*), and then reported their risk preference using the same procedure as in Study 4.

Participants then evaluated the return of eight individual stocks relative to the S&P 500 over the subsequent week, in a randomized order: Amazon.com, Wal-Mart, Netflix, the Coca-Cola Company, Rowan Companies, Covidien, Vornado Realty Trust, and the Mosaic Company.<sup>12</sup> For each stock, participants first read a paragraph from Reuters providing general information about the company, such as its customers, suppliers, and products. Participants then rated the uncertainty of “the return of [stock] relative to the S&P 500 over the course of one week” using the 6-item EARS.

Next, participants predicted whether the return of that stock, including any dividends or buybacks, would be greater than the return of the S&P 500 over the following week (0 = *stock returns less than or the same as the S&P 500*, 1 = *stock returns more than the S&P 500*). We then asked participants to choose between: (a) receive \$90 if your prediction was correct and \$0 otherwise, or (b) receive \$30 for sure. We informed participants in advance that some respondents would be selected at random to have one of their choices honored for real money. As another control variable, participants assessed the likelihood that each prediction would be



correct, on a scale from 50–100%. After completing this task for all eight stocks, participants provided basic demographic information and were debriefed.

**Study 5C.** We recruited 404 participants (46% male, mean age = 33 years, range: 18–71 years) from MTurk who were each paid \$0.50 for their participation. Participants first indicated the current value of their stock market investments in dollars and rated their investment knowledge on a 5-point scale (1 = *low*, 5 = *high*). Next, participants reported their risk preference using the same procedure as in Study 4. As a second (control) measure of risk preference we asked participants if they preferred stocks with low, medium, or high volatility, based on a scale used by the investment advisory company Vanguard.

Participants then assessed the movement of Apple stock over six time periods: the next day of trading, the next week, the next month, the next year, the next 5 years, and the next 20 years. Approximately half of our participants encountered time periods in an ascending order and half encountered time periods in a descending order. We found no significant effects of order on any of our reported results, so we combined order conditions in all analyses that follow. For each time period, participants also rated the uncertainty concerning “the return of Apple stock relative to the S&P 500 over the next [time period]” on the 6-item EARS. Next, participants predicted whether Apple stock would exceed the return of the S&P 500 over that same time period (0 = *less than or equal to the S&P 500*, 1 = *more than the S&P 500*). As a control variable, we also measured participants’ confidence in this forecast on a 7-point scale (1 = *not at all confident*, 7 = *extremely confident*). Participants then chose between: (a) receive \$150 if your prediction is correct and \$0 otherwise, or (b) receive \$50 for sure. As a second control variable, participants assessed the likelihood that their prediction would be correct on a scale from 50–100%. Finally, at the end of the study, participants rated their knowledge of Apple stock on a 5-point scale (1 = *low*, 5 = *high*) and provided basic demographic information.

## Results and Discussion

We predicted that perceptions of aleatoriness would amplify the impact of risk preferences on willingness to invest. Because Studies 5B and 5C used a repeated-measures designs, for those two studies we calculated test statistics and  $p$ -values using robust standard errors clustered by participants.

For each study we conducted a logistic regression with investment decision as the dependent variable (0 = *chose sure amount*, 1 = *chose uncertain prospect*). For each model our predictor variables were ratings of aleatoriness, epistemicness, risk preference, as well as interaction terms between risk preference and each type of subjective uncertainty. Table 2 provides results for each study, both with and without additional controls. In all three studies we found, as predicted, a significant positive interaction between risk preference and aleatoriness: risk preferences were most predictive of investment decisions for participants who viewed the market higher in aleatoriness (see the shaded in row in Table 2). Figure 5 illustrates, for each study, the likelihood of accepting the risky investment prospect as a function of ratings of aleatoriness for the most extreme risk preference groups (strongly risk averse and risk seeking). For all three studies the Figure shows an association between risk preference and willingness to invest that is much stronger for higher levels of rated aleatoriness.<sup>13</sup> Also consistent with our framework, Table 2 indicates that for all three studies there was no significant interaction effect between risk preference and perceptions of epistemicness.

As previously noted, we pre-registered no specific prediction about the relative strength of the relationship between risk preference and aleatoriness compared to risk preferences and epistemicness, though generally, we expected weaker relationships with epistemicness. To examine this further, we tested whether the interaction between risk preference and aleatoriness on choice was larger than the interaction between risk preference and epistemicness in studies

5A-C. As expected, this was always the case. The aleatory x risk preference interaction was reliably larger than the epistemic x risk preference interaction in Study 5A (without controls:  $Z = 2.95$ ;  $p = .003$ ; with controls,  $Z = 2.52$ ,  $p = .012$ ), in Study 5B (without controls:  $Z = 1.95$ ;  $p = .051$ ; with controls,  $Z = 2.19$ ,  $p = .029$ ), and in Study 5C (without controls:  $Z = 3.20$ ;  $p = .001$ ; with controls,  $Z = 3.76$ ,  $p < .001$ ).

In summary, we find support for the prediction that the more people see uncertainty in investment outcomes as aleatory in nature, the more their investment decisions are sensitive to their own risk preference. In contrast, we find no evidence that the relationship between risk preference and investment decisions is moderated by perceptions of epistemicness.

### **Study 6: Epistemic Uncertainty Amplifies Sensitivity to Expert Advice**

In our final study we tested the prediction, using an incentive-compatible design, that participants who view stocks as higher in epistemic uncertainty will be more responsive to expert investment advice when deciding how to invest (Figure 1, Path C). We preregistered our hypotheses, experimental design, and analysis plan at <http://aspredicted.org/blind.php?x=gi82zm>.

### **Method**

We recruited 195 participants (67% male, mean age = 35 years, range: 18–70 years) from an online labor market (Prolific Academic) to participate in a brief study in exchange for £0.25 plus the potential to receive bonus money.

**Round 1: Baseline Investment.** We first asked participants to invest any amount from \$0 to \$100 in Apple stock over the following six months. We told participants that any uninvested amount would be held in cash, which would earn no return over this same period. We also told participants that one randomly-selected respondent would receive the realized value of their investment (i.e., the market value of stock and cash investments) at the end of six months.

**Round 2: After-Information Investment.** After completing Round 1 we presented participants with a real analyst research report predicting that the Apple stock price would increase in the coming months (see Web Appendix). We then asked participants to complete the same investment task as in Round 1 and we told participants that this second investment decision was the choice to be honored should they be selected as the “real money” participant. Afterwards, participants rated the uncertainty concerning “the stock price of Apple 6 months in the future” using the 6-item EARS. Finally, participants provided demographic information and were debriefed.

## Results and Discussion

We predicted that participants who view stock market uncertainty as more epistemic in nature will exhibit a greater increase in willingness to invest in Apple stock from Round 1 to Round 2 (consistent with the content of the research report). Because our study uses a repeated-measures design, we calculated all test statistics and  $p$ -values using robust standard errors clustered by participants.

**Investment decision.** We submitted the amount invested in Apple Stock (out of a possible \$100) to an OLS regression with dollars invested in Apple stock as the outcome variable. Our predictor variables included time period ( $0 = \text{round } 1$ ,  $1 = \text{round } 2$ ), epistemicness rating, aleatoriness rating, and interaction terms between time period and each dimension of subjective uncertainty. As predicted, we found a significant positive interaction between time period and rated epistemicness, where the increase in dollars allocated to Apple stock from round 1 to round 2 was greater for respondents higher in rated epistemicness,  $b = 6.29$ , 95% CI = [2.68, 9.90],  $p = .001$ . In contrast, the interaction between time period and ratings of aleatoriness were not significant,  $b = -0.21$ , 95% CI = [-3.09, 2.66],  $p = .884$ . We then tested whether the interaction between round and epistemicness on predicted stock investment choice was larger

than the interaction between round and aleatoriness. As expected, the epistemic x information interaction was reliably larger than the aleatory x information interaction,  $t(194) = 3.13, p = .002$ .

To determine at which level of epistemicness investment in Apple was significantly impacted by the analyst's report, we conducted a floodlight analysis. The Johnson Neyman point occurred at an epistemicness rating of 4.2, meaning that at and above this value of rated epistemicness, Apple stock investment significantly increased following the analyst's report; below this value there was no significant impact of the analyst's report. At one standard deviation above the mean of epistemicness rating, the predicted investment amount before the report was \$66 and after the report was \$78. In contrast, at one standard deviation below the mean epistemicness rating, the predicted investment amount before the report was \$62 and after the report was \$62 (for an associated plot, see Web Appendix).

The results of Study 6 thus support our prediction that stock advice has a greater influence on investors who view uncertainty in future stock price as more epistemic in nature (Path C, Figure 1). Meanwhile, we observe no similar effects for those who view the uncertainty in stock price as more aleatory in nature, consistent with our expectations.

### **General Discussion**

In this paper we first observe that investors differ in their perception of stock market uncertainty along two independent dimensions: the extent to which they see future movement of stocks and markets as inherently knowable or epistemic, and the extent to which they see future movement as inherently random or aleatory. Second, we provide evidence that these two dimensions of subjective uncertainty influence what actions people take to reduce uncertainty: investors who perceive uncertainty to be more epistemic in nature are more likely to seek information or expertise, whereas investors who perceive uncertainty as more aleatory in nature are more likely to diversify their assets. Third, we provide evidence that these two dimensions of

subjective uncertainty influence how people invest. Investors who perceive stock or market uncertainty to be more epistemic in nature are more responsive to expert advice, whereas investors who perceive stock or market uncertainty to be more aleatory in nature are more likely to act in accordance with their general attitudes towards risk as measured using chance gambles.

In Study 1 we examined real investment decisions and found that investors who perceive stock market uncertainty to be more epistemic in nature are more likely to seek financial advice, whereas investors who perceive stock market uncertainty to be more aleatory in nature have less concentrated stock portfolios. In Studies 2, 3, and 4 we manipulated perceptions of epistemicness and aleatoriness through graphical displays of an analyst's past performance. When stock prices and forecasts were presented in absolute prices rather than as relative prices (i.e., changes in price), participants viewed market uncertainty as more epistemic in nature. They were also willing to pay more money for stock advice (Figure 1, Path A) and were more responsive to expert advice in their investment decisions (Path C). When stock returns and forecasts were presented as relative prices rather than as absolute prices, participants viewed market uncertainty as more aleatory in nature. They were more likely to engage in diversification to manage risk (Path B), and made investment decisions that accorded more closely with their risk preferences concerning chance gambles (Path D). In Study 5 we found that perceived aleatoriness (but not epistemicness) amplifies the relationship between risk attitudes and investment decisions (Path D), and in Study 6 we found that perceived epistemicness (but not aleatoriness) amplifies the impact of expert stock advice on investment decisions (Path C).

We conducted our studies across a variety of investment contexts. The investment horizons in our studies ranged from 1 day to 20 years, and involved investments in the S&P500, a basket of stocks, single stocks from a variety of industries, and stock investments as an asset

class. We employed incentive-compatible designs in four studies, and one study measured real investment behaviors of a panel of retail investors.

Our studies also address how investors — at least those in our samples — view the nature of stock market uncertainty. Do investors tend to view the stock uncertainty as relatively high in both epistemicness and aleatoriness, relatively low in both, or as some combination of high and low? Figure 6 displays the joint distribution of epistemic and aleatory uncertainty ratings, as scatterplots, from all nine studies, including investors from a Qualtrics panel with at least \$1,000 in stock market investments and at least moderate self-rated knowledge of the stock market (Study 1), and novice participants from Prolific Academic (Studies 2A, 2B, 3, 4, and 6) and Amazon Mechanical Turk (Studies 5A-C). Ratings among our panel of investors in these studies reveal a great deal of heterogeneity on both dimensions, with many respondents seeing the market as relatively moderate to high in both epistemicness and aleatoriness, several respondents seeing uncertainty as high on one dimension and low on another, while very few participants viewed stock market uncertainty as relatively low in both. While the placement of ratings on a subjective (ordinal) scale should be interpreted with caution, the fact that few participants in our studies view the market as low in both epistemicness and aleatoriness might be taken as an indication that the EARS adequately characterizes at least part of the nature of uncertainty that participants see in the stock market. Moreover, the tendency for many respondents to view stock uncertainty as both knowable and random may help to explain why many investors both pay a significant amount for financial advice while also engaging in diversification.

### **Related Constructs**

Prior research has found that willingness to invest increases with subjective knowledge (Hadar, Sood, and Fox 2013), feelings of competence (Graham, Harvey, and Huang 2009), one's sense of understanding (Long, Fernbach and De Langhe 2018), and familiarity with an asset or

investment decision (Huberman 2001). We assert that these constructs are associated primarily with the *level* of epistemic uncertainty an investor perceives in these investments, rather than the perceived *nature* of uncertainty. According to the present framework the impact of subjective knowledge, competence, sense of understanding, and/or familiarity should be moderated by the extent to which relevant uncertainty is perceived to be epistemic in nature (for more on this topic see Fox, Goedde-Menke and Tannenbaum, 2019). Throughout the present studies we control for level of uncertainty, subjective knowledge of the stock market, and relevant demographic variables such as financial literacy and investment net worth. Likewise, we note again that some studies have documented an association between ambiguity attitudes (as measured in a decision theoretic manner) and investment behaviors including willingness to invest in stocks as well as a preference to invest in domestic stocks and one's company's stock (Dimmock, Kouwenberg, Mitchell and Piejnenburg, 2016). The present work departs from this work in that we examine the impact of perceived *nature* of uncertainty (rather than preferences to act under conditions of ambiguity) on sensitivity to one's level of knowledge when investing and on the value of information or expertise.<sup>14</sup>

Past research also finds that heightened risk perceptions are associated with a decreased willingness to invest in an asset (Weber, Blais, and Betz 2002). One difficulty with interpreting subjective measures of risk perception, however, is that they tend to conflate risk with related constructs (Fox, Erner, and Walters 2015). Notably, risk perception may be associated with both unfamiliarity (Long, Fernbach and De Langhe 2018) and high variance in outcomes (cf. Slovic 1987). In our framework perceived "risk" associated with unfamiliarity is epistemic in nature, whereas perceived "risk" associated with volatility is aleatory in nature. Thus, one contribution of this paper is to begin to tease apart epistemic and aleatory components of subjective "riskiness" and identify their independent consequences for investor behavior.



## **Managerial Implications**

Understanding individual differences in perceptions of epistemicness and aleatoriness may be important for segmenting investors and providing effective financial advice. For instance, Vanguard clients complete a financial survey that includes risk preferences, investment horizon, and subjective knowledge (see Web Appendix). Evaluation of uncertainty using an EARS-like measure could provide a fast assessment of diversification preferences, investment management style preferences (e.g., active selection of particular assets versus indexing and automatic rebalancing), and willingness to pay for financial advice. Our results demonstrate that perceptions of epistemicness and aleatoriness independently predict investment behaviors after controlling for risk preferences (including the Vanguard-specific measure), risk perceptions, investment horizon, subjective knowledge, financial literacy, and other demographic variables.

To the extent that our findings generalize to other settings, financial advisors and regulatory agencies should also be aware of how the communication of financial information may impact perceptions of epistemicness and willingness to pay for financial advice. In the present studies (Studies 2A, 2B, and 4 in particular), we found that individual investors were willing to pay roughly double the amount for advice when a stock analyst's past predictions were presented in absolute prices rather than as relative prices. In these studies, the actual financial forecasts were uncorrelated with stock movements, so investors should, in fact, not have paid anything for stock advice.

A recent audit by Walters et al. (in progress) suggests that the overwhelming majority of analyst reports — nearly 99% in their sample — presented past performance in absolute prices, rather than in terms of relative prices. This suggests that the way in which analyst performance is typically presented to consumers also likely inflates the degree to which consumers see such investment tasks as inherently knowable. We note that the two bodies governing analyst

disclosure in the United States — the Securities and Exchange Commission and the Financial Industry Regulatory Authority — do not require disclosure of past analyst performance and do not specify whether past performance, if disclosed, must be in terms of absolute or relative prices. Our research suggests that many equity research firms are (deliberately or accidentally) presenting this optional financial information in a way that artificially inflates perceptions of epistemicness and therefore the perceived value of that advice to consumers. A further discussion concerning potential regulation of how this information is presented may be in order.

### **Broader Implications**

While we have been agnostic in this article concerning the appropriateness of attributing stock market uncertainty to epistemic or aleatory factors, we surmise that most people perceive greater epistemicness in the stock market than is warranted. We note that this hypothesis accords with ample research demonstrating that people are biased to see patterns where none exist (e.g., Gilovich, Vallone, and Tversky 1985). We speculate that consumers may benefit from interventions that dampen perceived epistemicness of the market and amplify perceived aleatoriness. Past research suggests that paying a financial advisor is an investment strategy that generally incurs additional costs with no incremental returns (Bender, Osler, and Simon 2013; Sharpe 1991), while diversification is the cornerstone of modern portfolio theory (Markowitz 1952). In addition, the efficient-market hypothesis (Basu 1977; Malkiel and Fama 1970) holds that all publicly available information useful for predicting a future stock price has already been incorporated into the current stock price. Thus, based on modern finance theory, stock market uncertainty *ought to* be viewed as fairly low in epistemicness, with information-seeking strategies doing little to reduce such uncertainty.

Interestingly, investment professionals appear to have a different view of stock market uncertainty than investment amateurs. In a preliminary exploration of these differences we

measured perceptions of epistemicness and aleatoriness in Study 1 and compared these perceptions to those measured in a sample of 37 practicing financial advisors (recruited through an executive education program at UCLA). Naturally, inferences across different populations should be interpreted with caution. This said, we found that perceptions of aleatoriness did not reliably differ between financial advisors ( $M = 4.97$ ,  $SD = 1.36$ ) and non-professional investors ( $M = 5.32$ ,  $SD = 1.04$ ),  $t(39.32, \text{unequal variances assumed}) = 1.47$ ,  $p = .149$ ,  $d = 0.32$ . In contrast, despite having considerably less experience and less knowledge, non-professional investors perceived greater epistemicness in stock market uncertainty ( $M = 4.91$ ,  $SD = 1.32$ ) compared to professional financial advisors ( $M = 3.04$ ,  $SD = 1.29$ ),  $t(42.74) = 8.24$ ,  $p < .001$ ,  $d = 1.42$ .

Finally, we note the asymmetric consequences of overestimating epistemicness versus aleatoriness in an investment context. Overestimation of epistemicness may lead to poor investment decisions, such as overpaying experts for financial advice (Bender, Osler, and Simon 2013; Sharpe 1991), purchasing over-priced mutual funds (Chen, Jegadeesh, and Wermers 2000), the tendency to overinvest in the domestic stock market relative to foreign markets (French and Poterba, 1991), and overinvesting 401(k) savings in company stocks (Benartzi and Thaler 2001). Overestimation of epistemicness may also be quite costly over an investor's lifetime and help to explain why more than \$4 trillion was held in actively managed funds in 2018 (Bloomberg, 2018), even though investors tend to earn similar or better returns when investing in low fee index funds (Carhart 1997). In contrast, overestimating true aleatoriness is likely to lead to relatively desirable (or at least, benign) consequences, such as increased diversification and portfolios that accord more closely with risk preferences. Thus, it may be in many consumers' best interest to temper their impressions of stock market epistemicness, but not

aleatoriness. Further research is certainly needed to better understand the accuracy of investor perceptions of the nature of market uncertainty.

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## Footnotes

<sup>1</sup> In the organizational theory literature, Milliken (1987) distinguishes *state uncertainty*, which refers to uncertainty over the state of the external environment (e.g. the reaction of a competitor or the government's future actions toward one's industry), from *effect uncertainty*, which refers to a manager's inability to predict the impact of future states of the environment on the organization (e.g. the effect of a predicted demographic shift on company sales), and *response uncertainty*, which refers to lack of advanced knowledge concerning response alternatives and/or likely consequences of these choices. We note that all three of these forms of uncertainty may be epistemic and/or aleatory in nature. While it has been observed in this literature that volatility in the environment is not the same as unpredictability (e.g., Lawrence and Lorsch, 1973) and that perceived information adequacy can be distinguished from one's ability to predict an outcome and one's confidence on a prediction (e.g., Duncan, 1972), these authors do not distinguish inherent *randomness* from inherent *knowability* as two independent dimensions of state, effect, or response uncertainty.

<sup>2</sup> Note that in the present studies we do not measure diversification in its technical sense since our participants are non-professional investors. Instead, we use degree of portfolio concentration as our measure of diversification.

<sup>3</sup> We note that these predictions reflect two implicit assumptions: (1) most investors feel they are less knowledgeable than a professional financial advisor and therefore can benefit from professional financial advice, and (2) most investors are risk averse and therefore prefer to expose themselves to lower variance in the probability distribution over outcomes. A sample drawn from Studies 5A-C where we measured risk preference and subjective knowledge on a sample from Amazon Mechanical Turkers supports these assumptions: participants rated their knowledge of investments as relatively low on a 7-point scale ( $M = 3.17$ ,  $SD = 1.32$ ,  $N = 1,547$ ), and most participants were risk averse (82% risk averse,  $N = 1,538$ ).

<sup>4</sup> We also note a caveat: in some cases, epistemic uncertainty may be viewed as irreducible because an investor has no means to reduce uncertainty or doing so is too costly. In these cases, investors may treat irreducible epistemic uncertainty akin to aleatory uncertainty (i.e., manage such uncertainty with diversification and make investment choices that accord with their risk preferences). This may contribute to the phenomenon of naïve diversification (Benartzi and Thaler, 2001; Langer and Fox, 2005).

<sup>5</sup> We winsorized this measure of diversification because the distribution of stocks held by individuals was highly skewed ( $p < .001$ , Shapiro-Wilk test). We also re-ran our analysis taking the log of number of stocks and found a similar pattern of results. We also observed a reliable Spearman rank-ordered correlation between aleatory uncertainty and the raw number of stocks an individual holds, ( $r_s = .18$ ,  $p < .001$ ).

<sup>6</sup> In the Web Appendix we report three additional studies using alternative experimental manipulations of epistemicness and aleatoriness, and find results consistent with those reported here.

<sup>7</sup> All studies run on Prolific Academic recruited participants only from the United Kingdom and United States.

<sup>8</sup> We constructed the chart by simulating data on stock prices and forecasts in which the correlation between the predicted and realized changes was approximately 0 but the stock also trended upward or downward somewhat over the period displayed—as is common for real stocks and analyst predictions. In Study 2A the starting price was given in the absolute price graph, but not the relative price graph. In all subsequent studies the starting price was provided in both conditions in order to maintain full information equivalence.

<sup>9</sup> Omitting prediction information was also necessary to ensure clear presentation of information: because this study involved four stocks, using predicted and actual information results in eight lines in the same chart, making it hard for the subjects to comprehend all the information presented. We also suspected that omitting expert forecasts could moderated the impact of this manipulation on perceptions of epistemicness. Given this uncertainty we made no specific prediction about how perceptions of epistemicness would be impacted by this manipulation.

<sup>10</sup> When we exclude participants who expressed the lowest level of investment expertise (i.e., a rating of 1 on a 5-point scale; this represents 53% of our sample), the interaction between risk preference and perceived aleatoriness is

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marginally significant ( $b = 0.13$ , 95% CI =  $[-.01, 0.26]$ ,  $p = .064$ ). In contrast, we fail to find a reliable interaction between risk preference and perceived epistemicness in this sub-sample ( $b = 0.00$ , 95% CI =  $[-0.06, 0.20]$ ,  $p = .268$ ) or in the full sample ( $b = 0.01$ , 95% CI =  $[-0.07, 0.10]$ ,  $p = .766$ ).

<sup>11</sup> A number of participants ( $n = 78$ ) started but did not finish the survey and were excluded from analysis, as choice data was not recorded for these participants.

<sup>12</sup> We selected these companies because we found in a pretest that they encompassed a wide range on ratings of epistemic and aleatory uncertainty.

<sup>13</sup> As a robustness check we conducted these same regressions with added controls for the interaction of each of the controls and risk preference and find no changes in the results. This analysis is included in the Web Appendix.

<sup>14</sup> The theoretical model of Boyle, Garlappi, Uppal and Wang (2012), to which Dimmock et al. (2016) refer, predicts stock market participation and diversification are influenced by the perceived degree of ambiguity of the market and individual stocks, but again this model does not address the perceived nature of uncertainty.

Table 1: Study 1 regression estimates of investment uncertainty on investment behaviors

Dependent Variable	Have a Financial Advisor (1=yes, 0=no)		Diversification (number of stocks held)	
	(1)	(2)	(3)	(4)
Epistemicness	0.082*** (0.020)	0.067** (0.022)	0.877 (0.694)	0.911 (0.731)
Aleatoriness	0.003 (0.027)	0.000 (0.027)	2.801*** (0.834)	2.828** (0.871)
Risk Perceptions 1 (DOSPERT)		0.015 (0.012)		-0.131 (0.425)
Risk Perceptions 2 (DOSPERT)		-0.020 (0.013)		-0.605 (0.489)
Risk Perceptions 3 (DOSPERT)		0.008 (0.013)		0.800 (0.530)
Percentage of investment in individual stocks		-0.003*** (0.001)		0.141*** (0.041)
Net investment value		0.012 (0.022)		2.653** (0.826)
Other assets		-0.006 (0.023)		-0.948 (0.842)
Number of stocks held		-0.001 (0.001)		
Financial Literacy		-0.040 (0.028)		-0.025 (1.161)
Constant	0.494*** (0.026)	0.494*** (0.025)	-7.211 (4.963)	-17.484* (7.652)
Observations	354	352	354	352
R-squared			0.035	0.111

*Note:* Robust standard errors in parentheses. For the “financial advisor” column, estimates represent the average marginal effect from a logit model. For the “Diversification” columns, estimates represent OLS coefficients.

\* $p < 0.05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Table 2: Study 5 regression estimates of the interaction of aleatoriness and risk preference on investment decisions

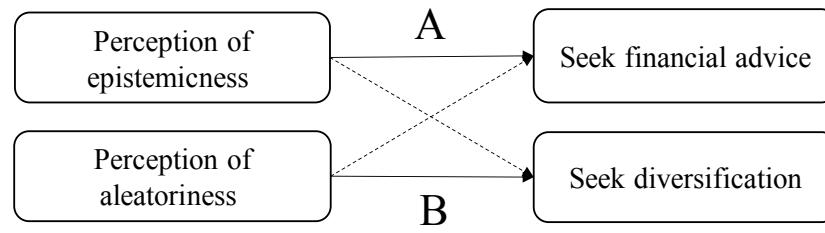
Investment Prospect (0 = reject, 1 = accept)	Study 5a		Study 5b		Study 5c	
	(1)	(2)	(3)	(4)	(5)	(6)
Risk Preference	0.109 (0.492)	−0.357 (0.523)	0.142 (0.283)	0.142 (0.304)	0.406 (0.390)	0.278 (0.466)
Aleatory Uncertainty	0.183 (0.159)	−0.019 (0.161)	0.352** (0.112)	0.229* (0.116)	0.393*** (0.107)	0.205 (0.116)
Epistemic Uncertainty	−0.463** (0.171)	−0.463** (0.177)	−0.345** (0.106)	−0.347** (0.119)	−0.200 (0.131)	−0.323 (0.165)
Epistemic*Risk Preference	−0.097 (0.070)	−0.025 (0.071)	−0.025 (0.045)	−0.029 (0.045)	−0.074 (0.048)	−0.068 (0.054)
Aleatory*Risk Preference	0.216** (0.080)	0.251** (0.086)	0.100* (0.043)	0.121* (0.050)	0.121* (0.058)	0.184** (0.067)
Prediction (0 = down, 1 = up)		0.236 (0.211)		0.773*** (0.130)		0.391* (0.169)
Probability		0.034*** (0.009)		0.026*** (0.004)		0.033*** (0.005)
Total Investment Assets		−0.003 (0.035)		0.039 (0.028)		0.044 (0.037)
Gender (0 = female, 1 = Male)		0.137 (0.213)		0.267 (0.168)		−0.011 (0.218)
Age		−0.001 (0.009)		0.016 (0.008)		0.021* (0.010)
General Knowledge		0.082 (0.079)		−0.083 (0.090)		−0.261 (0.154)
Specific Company Knowledge				0.025 (0.038)		−0.024 (0.074)
Volatility (Vanguard)						0.293 (0.167)
Confidence						0.168* (0.068)
Constant	−0.318 (1.034)	−2.201 (1.212)	−1.549* (0.695)	−3.859*** (0.874)	−2.057* (0.886)	−5.068*** (1.243)
Observations	564	549	2,920	2,873	1,834	1,738

Note: Robust standard errors in parentheses. Estimates represent log odds coefficients from a logistic regression. Company fixed effects are included in column 4 and time period fixed effects are included in column 6.

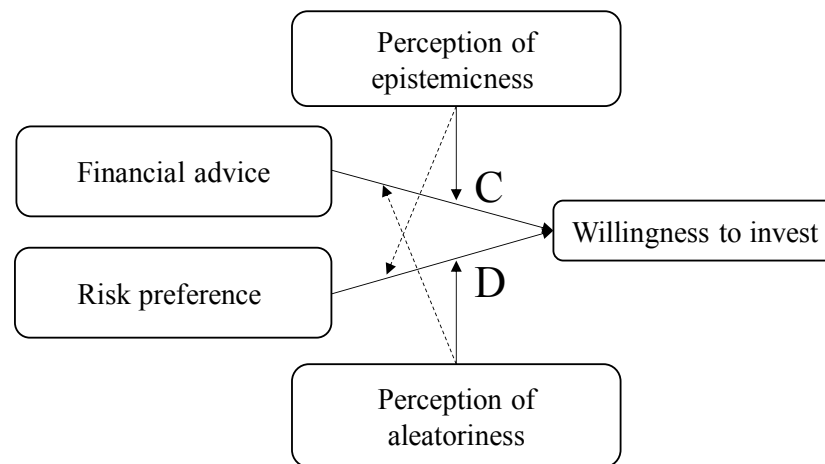
\* $p < 0.05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Figure 1: Conceptual framework linking perceptions of epistemicness and aleatoriness in the stock market to uncertainty management and willingness to invest.

### 1a: Uncertainty management



### 1b: Willingness to invest



*Note:* Solid lines indicate relationship between variables predicted to be relatively strong and reliable, dashed lines indicate relationships predicted to be relatively weak or unrelated.

Figure 2: Illustration of absolute and relative price charts used in Studies 2A, 2B, and 4. The absolute price chart shows the actual and forecasted price whereas the relative price chart shows the actual and forecasted return.

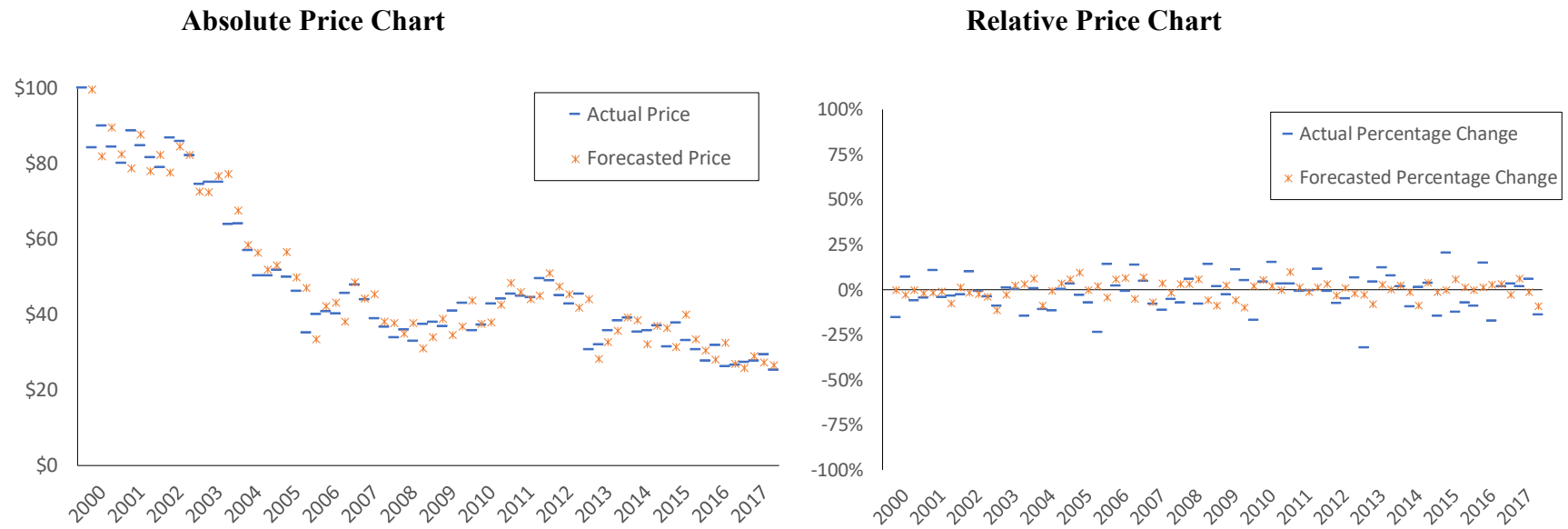


Figure 3: Illustration of absolute and relative price charts used in Study 3. The absolute price chart shows the actual price whereas the relative price chart shows the actual monthly return.

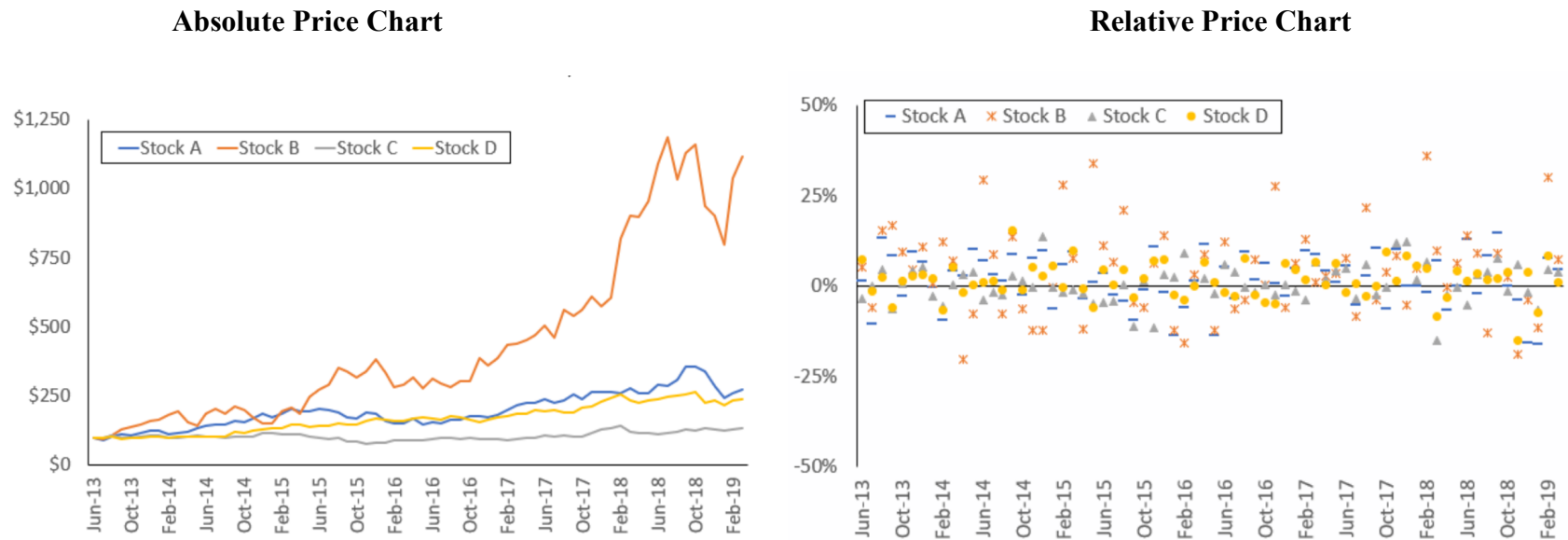
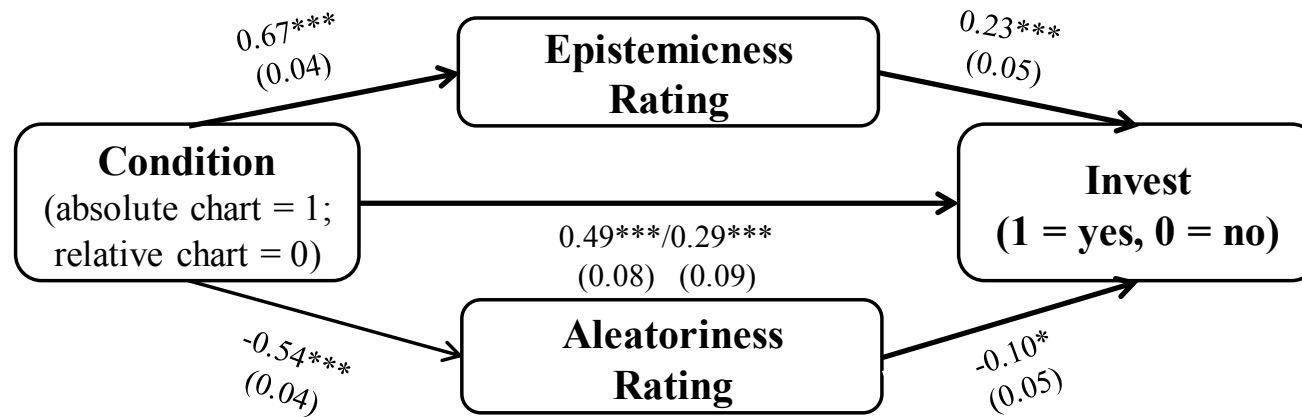


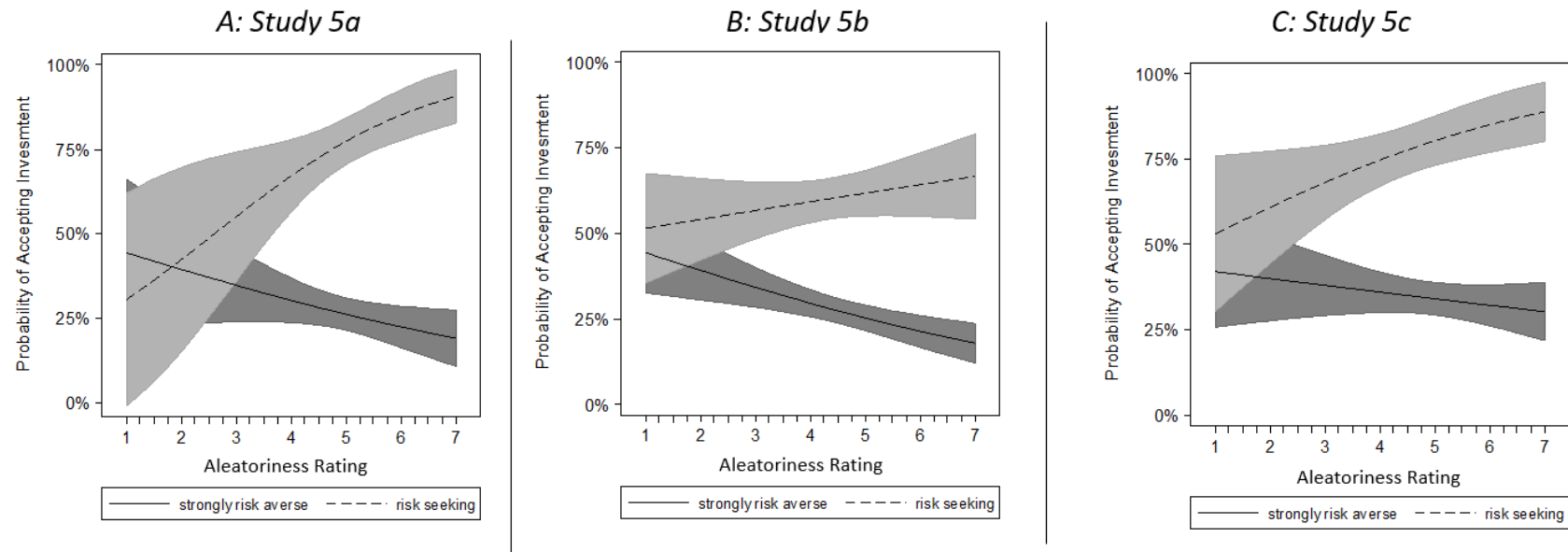
Figure 4: Study 4 Mediation Model



*Notes:* Indirect effect of Epistemic Rating  $b = 0.13$ ,  $p < .001$ , 10,000 bootstraps; Indirect effect of Aleatory Rating  $b = 0.06$ ,  $p = .050$ , 10,000 bootstraps. Path coefficients are unstandardized OLS and logistic regression coefficients, robust standard errors in parentheses. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$

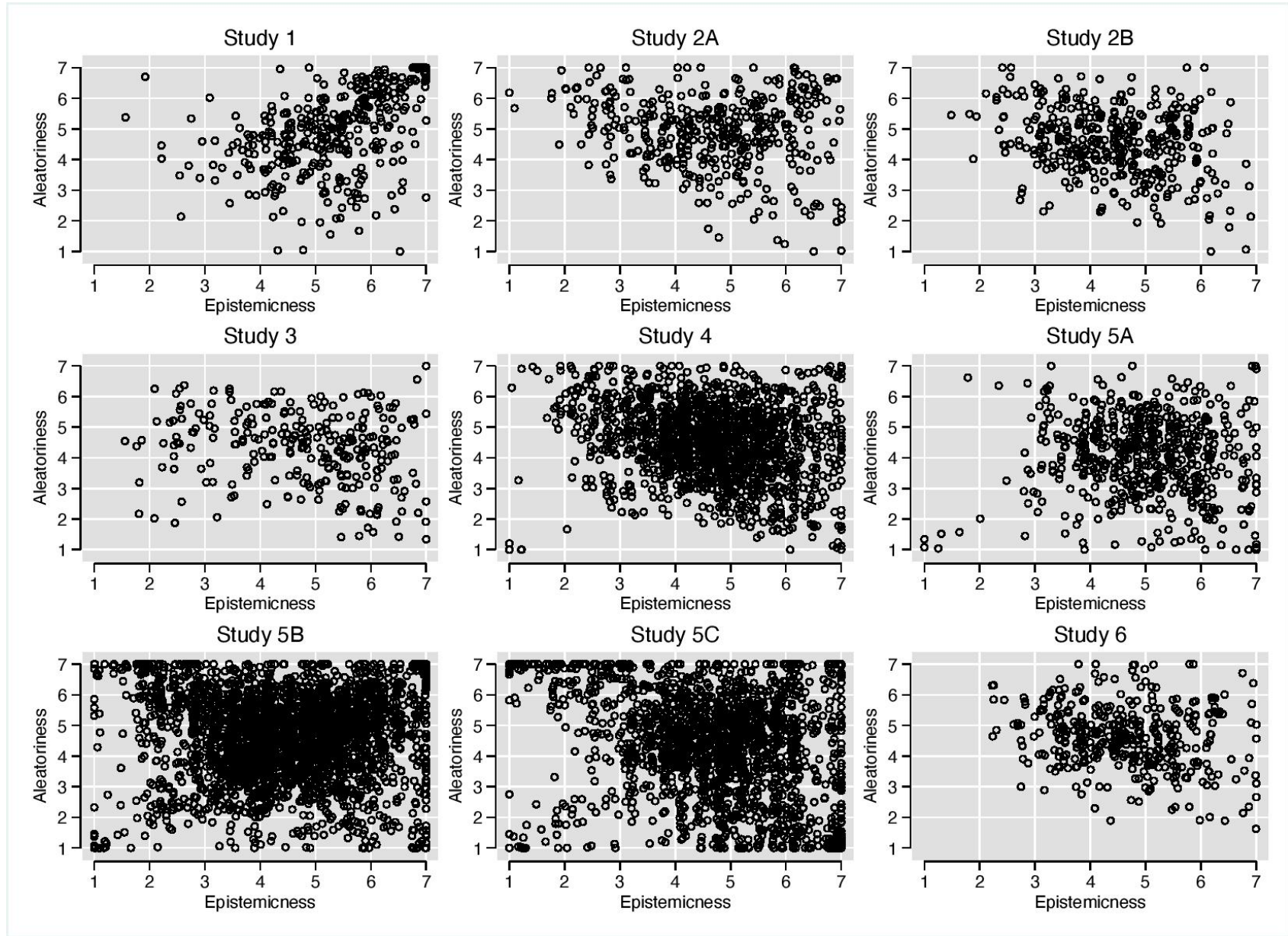


Figure 5: Results from Study 5



*Note:* Plots 5a–5c represent the interaction between aleatoriness and risk preferences in Studies 5A–5C on the probability of accepting an investment (versus taking a sure payment). Solid lines represent the predicted average marginal effect (based on the logistic regression model discussed in the results) for strongly risk averse participants (risk preference of 1 out of 4) and dotted lines represent the average marginal effect for risk seeking participants (risk preference of 4 out of 4). Error bands represent 95% confidence intervals.

Figure 6: Scatterplots in Studies 1 and 2A



*Note:* We added a small amount of jitter to the data points in order to indicate density. For studies with repeated measures, data points represent observations at the participant-trial level.