Review of Finance Advance Access published August 13, 2015

Review of Finance, 2015, 1–21
doi: 10.1093/rof/rfv036

An Experimental Examination of Portfolio Choice*

Lucy F. Ackert[1], Bryan K. Church[2], and Li Qi[3]

[1]Kennesaw State University, [2]Scheller College of Business, Georgia Tech, and [3]Agnes Scott College

Abstract

Investors do not hold optimal portfolios. We use an experimental method to isolate factors that compel individuals to hold optimal portfolios. Our design includes two risky assets with perfectly negatively correlated payoffs so that all risk can be eliminated. We find that participants' holdings approach optimal portfolios only under very specific conditions: the variance cost of holding an imbalanced portfolio is substantial and feedback on period-by-period outcomes is suppressed (eliminating the impact of cognitive biases resulting from misperceptions of randomness).

JEL classification: C92, G15

1. Introduction

This article reports the results of four experiments designed to examine individuals' portfolio choices. Extant evidence offers little support for portfolio choice theory. Individuals do not hold portfolios of assets that are optimal, either *ex ante* or *ex post*. Research findings in experimental asset markets often document allocational inefficiencies (see Camerer and Weigelt, 1991; Copeland and Friedman, 1991; Ackert and Church, 1998; Kluger and Wyatt, 2004; Ackert, Mazzotta, and Qi, 2011). Empirical studies of individual portolio choices in naturally occuring environments also find that people do not form optimal portfolios in that they fail to adequately diversify (see Blume and Friend, 1975; Kelly, 1995; Benartzi and Thaler, 2001; Calvet, Campbell, and Sodini, 2007; Goetzmann and Kumar, 2008).

* Financial support of Agnes Scott College, the Coles College of Business, and the Federal Reserve Bank of Atlanta is gratefully acknowledged. The authors thank Sean Cuevo, Lori Shefchik, and Yujia Wang for research assistance, Kevin Ackaramongkolrotn and Todd Swarthout for technical assistance, and Burton Hollifield (the editor), an anonymous referee, Brian Kluger, Jim Steely, Adam Vitalis, and workshop participants at the University of Arkansas at Little Rock, University of South Carolina, and Wilfrid Laurier University for helpful comments. The authors also thank Jim Cox and the EXperimental Economics CENter (EXCEN) at the Andrew Young School of Policy Studies at Georgia State University for use of their experimental laboratory.

Our goal is to isolate factors that compel individuals to hold optimal portfolios. A better understanding of such factors is crucial for the appropriate development of theory and policy, particularly as self-directing retirement savings becomes more common practice. Using a very simple design with two risky assets, we examine participants' portfolio choices across a series of experiments. The two risky assets have payoffs that are perfectly negatively correlated so that participants can eliminate all risk. Following Rietz (2003), participants in our experiments can buy or sell each asset at a fixed price, set equal to the asset's expected payoff, and they do not incur transactions costs or holding costs when rebalancing their portfolios. Unlike Bossaerts, Frydman, and Ledyard (2014), who examine information revelation and pricing with perfectly negatively correlated assets, our experiment examines individual decision making. While our design certainly excludes many factors that shape portfolio decisions, its simplicity offers significant benefits. Our goal is to focus on the allocation decision, and our experimental setup allows insight into the conditions under which people hold optimal portfolios.[1] The design allows participants to costlessly diversify away risk, absent asset pricing considerations. An important feature is that the expected payoff is always the same regardless of whether an individual holds an optimal portfolio. However, the variance cost of failing to diversify is manipulated across experiments. This design choice allows us to investigate participants' sensitivity to increasing risk through the variance channel.

We vary the environment across four experiments to isolate conditions that nudge participants toward holding an optimal portfolio. In our Experiment 1, participants are endowed with cash and shares of two risky assets. They make portfolio choices by deciding on their holdings of each asset. The risky assets pay state-dependent liquidating dividends, and participants repeat the task over a series of 10 independent periods. State realizations are announced at the end of each period, and participants are paid based on their earnings over all 10 periods. Experiment 1 provides a baseline to gauge participants' portfolio choices.

In Experiment 2, we keep the same setup as Experiment 1, but increase the spread in possible dividends. While the mean return does not change, the variability in the expected payoff for an imbalanced portfolio doubles as compared to the baseline experiment. Experiment 2 allows us to investigate how the cost of an imbalance affects participants' portfolio choices.

In Experiment 3, we change the method used to compensate participants and pay them based on holdings in one randonly drawn period (multiplied by 10) rather than accumulated over 10 periods. Cox, Sadiraj, and Schmidt (2015) provide evidence that the method of payment in experimental studies (e.g., one period versus accumulated over multiple periods) affects participants' revealed preferences. In our setting, by restricting payment to one period, we increase the variance cost substantially, without changing the expected payoff. Specifically, the variance cost increases tenfold as compared to experiment two and twenty-fold as compared to experiment one.

Lastly, in Experiment 4, we suppress the announcement of state realizations at the end of each period, but do not change the variance cost due to an imbalance (i.e., the variance cost is the same as in Experiment 3). We restrict feedback so that participants do not try to outguess random draws (e.g., to impose order on randomness), which might underlie a failure to adequately diversify. Prior research suggests that individuals have a poor

1 See Bloomfield and Anderson (2010) on the usefulness of experiments in finance.

understanding of randomness, which can lead to cognitive biases (see Lopes and Oden, 1987; Ayton and Fischer, 2004). In our first three experiments, participants may use past state realizations to guess future realizations, even though the states are determined randomly each period. By restricting feedback on prior realizations, we eliminate the possibility that cognitive biases, due to misperception of randomness, lead to under-diversification.

We also probe potential explanations as to why participants might fail to hold an optimal portfolio in our experimental setting. In our experiments, we elicit measures of participants' overconfidence and risk tolerance. Archival findings suggest that overconfidence affects individuals' trading activity (see Barber and Odean, 2001), which can lead to under-diversification (see Goetzmann and Kumar, 2008). Odean (1999) asserts that a failure to adequately diversify arises because overconfident individuals hold unrealistic beliefs about specific stocks. Others suggest that risk preferences are linked to individuals' willingness and ability to diversify. Early work suggests that risk aversion is positively associated with the level of diversification (see Blume and Friend, 1975; Morin and Suarez, 1983).

Our findings indicate that participants fail to adequately diversify in our basic experimental setting, even when the variance cost doubles. Participants hold imbalanced portfolios, which unnecessarily exposes them to risk. When the variance cost increases substantially, asset imbalances decrease markedly (Experiment 3). In the design we alter the method used to compensate participants, paying them based on one randomly selected period, which pushes participants toward holding balanced portfolios. In addition, under this condition, participants' propensity to hold an imbalanced portfolio is positively associated with their tolerance for risk. Finally, when we suppress participants' knowledge of state realizations, coupled with paying them based on one randomly selected period (substantially increasing the variance cost), asset imbalances are reduced even further: the majority of participants have an average asset imbalance of one share or less (Experiment 4). Further, the association between participants' holdings and their risk tolerance all but disappears. Our findings provide direct evidence that the variance cost of holding an imbalanced portfolio coupled with cognitive biases have a pronounced impact on participants' portfolio choices.

The remainder of the article is organized as follows. Section 2 provides a general framework for our experimental investigation. Section 3 describes the design and results of the first experiment. Sections 4, 5, and 6 present the background, design, and results for Experiments2, 3, and 4, respectively. Section 7 reports the results of additional analyses across our four experiments, with the aim being to hone in on conditions that lead participants to hold balanced portfolios. Section 8 concludes the article.

2. Framework

In the traditional mean variance framework, investors are risk averse and maximize the expected utility of wealth. An investor's utility in the model is a function of state-dependent wealth and can be expressed as

$$U(w) = E(w) - b \cdot \mathrm{var}(w) \tag{1}$$

where w denotes wealth, $E(\cdot)$ is the expectation across states of the world, $\mathrm{var}(\cdot)$ is the variance, and b reflects the investor's risk attitude. As Bossaerts, Plott, and Zame (2007) argue, the pricing predictions of models of this type are sometimes confirmed by empirical studies, but the portfolio choice predictions receive very little support. Investors should hold the market portfolio of risky assets with those who are more risk averse holding a greater percentage of the risk-free asset.

Portfolio separation is a cornerstone of modern finance. In a world with a risk-free asset, all investors should hold the same portfolio of risky assets. Optimal diversification is determined by comparing the cost and benefit of rebalancing. If the benefit, in terms of risk reduction, exceeds the cost of adding an asset to the portfolio, the asset is added. Modern finance provides direction to investors on how to form optimal portfolios. Nobel Prize winner Harry Markowitz gave advice that seems very simple: “Don’t put all your eggs in one basket.” While Markowitz’s (1952) idea may seem very simple, it provides the basis for portfolio theory. The risk of a portfolio depends critically on the correlation among the assets. As long as the securities are not perfectly positively correlated, benefits from diversification occur. Because our assets are perfectly negatively correlated, risk can easily be eliminated by holding the assets in equal proportion.

Our experimental environment is very simple and allows clear predictions, regardless of the degree of participants’ risk aversion (see also Kroll, Levy, and Rapoport, 1988). Participants are endowed with cash and shares of a risky asset and, then, given the opportunity to rebalance their portfolio. Our design includes two risky assets (stocks A and B), which have payoffs that are perfectly negatively correlated.[2] An optimal portfolio can be formed by holding stocks A and B in equal numbers. We fix the transaction prices of stocks A and B, as our focus is on portfolio choices (asset allocation decisions), absent pricing consideration. For each stock, the transaction price is set at its expected payoff. Rietz (2003) points out that, in this environment, relative and absolute market prices are independent of the level of risk aversion. There is no aggregate risk and, in turn, no aggregate risk premium. Further, as noted earlier, we permit costless portfolio rebalancing. Therefore, participants are free to form their desired portfolios, such that participants’ choices are not constrained by factors often present in naturally occurring environments. For example, Bossaerts and Plott (2002) argue that a small number of traders in a market can make it difficult to identify trading partners with whom to transact. Because participants trade with the experimenter in our setting, market thinness cannot explain a failure to balance asset holdings.

The basic structure of our four experiments is summarized in Table I. Experiment 1is our baseline, which allows us to determine whether participants are inclined to hold a balanced portfolio in our setting. Recall that risk-averse participants should hold a balanced portfolio because they cannot increase expected earnings with a portfolio imbalance. In each subsequent experiment, we introduce a design change that is intended to move participants toward holding a balanced portfolio. Across experiments, expected earnings are constant regardless of whether participants hold balanced or unbalanced portfolios. However, the variability in potential payoffs increases markedly from Experiment 1 to 2, and 2 to 3. As the simple trade-off reflected in Equation (1) suggests, participants will be more strongly compelled to hold balanced portfolios as the variance cost increases.

2 As noted previously, we chose this simple design to focus on the allocation decision. Previous research indicates that individuals have great difficulty understanding asset correlation (see Hedesström, Svedsäter, and Gärling, 2006; Eyster and Weizäcker, 2010), so we chose the simplest possible correlation structure.

Table I. Summary of experiments

We conduct four experiments in which participants transact with the experimenter at a fixed price. Participants are endowed at the beginning of each of 10 periods with cash and 10 shares of stock A or 10 shares of stock B. They can buy or sell shares at the expected value of the period-end liquidating dividend (150 francs). Across the four experiments, we manipulate: (i) the range of the liquidating dividend; (ii) whether participants' earnings accumulate over all periods or are determined based on one randomly chosen period, which impacts the variance cost of participants' payoffs; and (iii) whether state realizations are announced at period end. Each design change, going from Experiment 1 to Experiment 4, is intended to move participants toward holding a balanced portfolio. In each experiment, we elicit measures of participants' overconfidence and risk tolerance. For overconfidence, we use a measure following Biais et al. (2005). For risk tolerance, we use a measure following Gneezy and Potters (1997).

Experiment	Number of Participants	Liquidating dividend range	Method of payment	Variance cost of payoffs	Announce state realizations	Elicit overconfidence and risk tolerance
1	36	300	All 10 periods	Baseline	Yes	Yes
2	48	600	All 10 periods	Doubled	Yes	Yes
3	33	600	One period	twentyfold	Yes	Yes
4	49	600	One period	twentyfold	No	Yes

In Experiment 2, we increase the variability of state-dependent liquidating dividends, which enables us to assess the effect of an increase in variability on participants' holdings (Table I). In Experiment 3, we change the method used to compensate participants, paying them based on one randomly chosen period (multiplied by 10) rather than on earnings accumulated over a series of periods. The change magnifies the importance of treating each period independently (i.e., each period has the same chance of being chosen as the payment period) and further increases the variability in possible payoffs (tenfold as compared to experiment two and twentyfold as compared to experiment one), potentially altering participants' choices (see Cox, Sadiraj, and Schmidt, 2015). In Experiment 4, we keep the same variance cost and do not announce state realizations at period end, which eliminates the potential effects of cognitive biases resulting from the misperception of randomness on participants' portfolio choices.

We also investigate whether participants' portfolio choices are affected by their level of confidence. Goetzmann and Kumar (2008) report that overconfident investors are less likely to diversify their portfolios than others. Bailey, Kumar, and Ng (2011) find that overconfident investors choose high-expense, high-load, and high-turnover funds, which produce inferior returns. The authors surmise that such investors are poorly diversified and exposed to large amounts of market risk. Other research suggests that overconfidence leads to poor trading outcomes (see Biais *et al.*, 2005). Barber and Odean (2001) analyze individuals' accounts at a discount brokerage house and suggest that overconfidence (proxied by gender) leads to churning and poor returns. The presumption is that men are more prone to overconfidence than women (see Lundeberg, Fox, and Punccohar, 1994) and, as such, overestimate the expected gains from trading activity. Following Biais *et al.* (2005), we use a confidence interval task to identify the extent to which individuals are miscalibrated and, thus, overconfident (see Russo and Schoemaker, 1992; Klayman *et al.*, 1999). We also use a straightforward risk measure, similar to that of Gneezy and Potters (1997), to examine whether participants' portfolio choices are affected by their risk tolerance.[3]

The details of the first experiment are presented in the next section, including participants, procedures, and results. In the following sections, we provide background, describe the participants and procedures, and present the results for Experiments 2, 3, and 4, respectively.

3. Experiment 1

3.1 Overview and Participants

Experiment 1 was conducted at two state universities in the same metropolitan area. The experiment included three sessions with 12 participants per session, for a total of 36 participants. Participants were university students across a variety of majors. Students earned from \$21.00 to \$77.75 for approximately two hours of time, with an average payout of \$52.22.

3.2 Procedures

At the beginning of each session participants receive a set of instructions (available from the authors upon request), which an experimenter reads aloud. The experimenter then addresses any procedural or technical questions. Though the data of primary interest consist of participants' asset allocation choices, we first administer two questionnaires. To provide a measure of overconfidence, participants complete a 10-question survey in which they indicate upper and lower values resulting in 90% confidence intervals. The survey questions follow closely those used by Biais *et al.* (2005), with minor adjustments. As an example, we ask participants to provide upper and lower values for the deepest known point in the oceans (in feet), where the correct answer is 36,070 feet. Participants are miscalibrated if the correct values lie outside of their upper and lower bounds, and miscalibration is symptomatic of overconfidence (see Biais *et al.*, 2005; Deaves, Luders, and Luo, 2009). Accordingly, the number of confidence intervals that do not contain the correct answer provides a measure of participants' overconfidence. To encourage participants to respond diligently and conscientiously, we pay them \$2 for completing the questionnaire.

The second questionnaire elicits individual risk tolerance in a financial domain. Participants make a single choice regarding the investment of cash. Each is given an endowment of \$10 and asked to choose how much to invest in a risky asset that has a 50% chance of success (see also Gneezy and Potters, 1997). A randomly chosen participant tosses a coin at the end of the session to determine the success of the investment. If the coin toss is heads, the investment is successful and the amount invested increases in value by 2.5 (or 250%). If the coin toss is tails, the investment is unsuccessful and participants lose the amount invested in the risky asset. Participants who invest more in the risky asset are presumed to have a greater tolerance for risk.

Next, we turn to the portfolio choice task. This task is administered in a computerized environment using *Z*-tree (Zurich Toolbox for Readymade Economic Experiments) software (see Fischbacher, 2007). For record-keeping purposes, we require participants to

3 We elicit a risk measure, rather than using gender as a proxy for risk tolerance. Men have a greater appetite for risk and are more prone to overconfidence as compared to women. Therefore, gender does not allow us to disentangle the two potential explanations for under-diversifying.

summarize their trading activity and earnings, at period end, on a hard copy record sheet—even though the computer tracks these data. We do so to draw participants' attention to their portfolio positions and resultant earnings on a period-by-period basis.

All transactions are in francs (the experimental currency), which are converted into dollars at a pre-specified rate. Each session includes two practice periods followed by 10, two-minute periods that count.[4] Each period, participants can trade shares of stocks A and B with the experimenter at a fixed price of 150 francs.

At the beginning of each period, participants are endowed with shares of A and B as well as cash to finance the purchase of shares. Initial endowments are as follows. All participants are endowed with 1,000 francs and 10 shares of stock. One half of the participants are endowed with 10 shares of stock A and 0 shares of stock B, and the other half are endowed with 0 shares of stock A and 10 shares of stock B. We endow participants with unbalanced portfolios because we want to determine whether they take actions to diversify their portfolios.

Participants can buy or sell as many shares of stock as they wish with certain restrictions. The maximum number of shares of either A or B that can be purchased is 60 shares.[5] Participants cannot short sell, but they are permitted to borrow from the experimenter with the stipulation that any francs borrowed have to be repaid at the end of the period, such that borrowings are interest free (see also Kroll, Levy, and Rapoport, 1988). If a participant has insufficient funds to repay borrowings at period end, the participant is bankrupt and exits the portfolio choice task.

Each stock has a single-period life. At the end of a period, each stock pays a randomly determined dividend based on one of two state realizations (I or II). In state I, stock A pays a dividend of 0 and stock B pays 300 francs. In state II, the dividends are reversed: stock A pays a dividend of 300 and stock B pays 0. Participants are reminded that the expected payoff for the two stocks is identical at 150 francs per period. At period end, the state realization is publicly announced. A summary screen reports the dividends earned for the period as well as cumulative earnings in dollars. The next period then begins. Each participant is endowed with the same cash/shares per period, and the experimental procedures are identical across each of the 10 periods.

At the end of the experiment, the final cash balance is displayed on each participant's computer screen. Participants are asked to complete a post-experiment questionnaire that includes demographic questions as well as reactions to the experiment. They receive additional compensation of $2 for completing the questionnaire in an effort to elicit conscientious responses. Finally, participants are paid privately in cash and dismissed.

3.3 Results

If participants hold diversified portfolios, they will hold equal numbers of stocks A and B. For each participant, we determine the absolute imbalance per period, defined as |#Stock A − #Stock B|, and then compute the average imbalance across the 10 periods. Two participants go bankrupt, as they are unable to repay borrowings at period end. For these two participants, we compute the average imbalance over the periods completed.

4 The two-minute time limit appeared reasonable as all participants submitted a decision within the allotted time.

5 The limit on purchases was added to the design after a participant in a pre-test bought a large number of shares in one stock, and we realized that a series of lucky dividend draws, though unlikely, could bankrupt the experimenters' research budget.

Table II. Summary statistics on holdings imbalance: Experiment 1

Experiment 1 provides a baseline for comparison. The table reports asset imbalances in participants' final stock positions. For participants who complete all 10 periods, the average absolute imbalance is computed as |#Stock A − #Stock B| per period averaged across the 10 periods. Two participants went bankrupt, at which point they exited the portfolio choice task. For them, the average absolute imbalance is computed as |#Stock A − #Stock B| per period averaged across the periods completed. The table provides information on the number of participants in each average imbalance interval for periods 1–10, 1–5, and 6–10, as well as the mean and median across participants. The table also provides information on the average asset holdings at period end. For periods 1–10 and 1–5, $n = 36$. For periods 6–10, $n = 35$ because one participant went bankrupt before period 6.

	Periods 1–10	Periods 1–5	Periods 6–10
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert = 0$	1	3	1
$0 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 1$	1	1	2
$1 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 2$	4	4	3
$2 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 3$	2	6	1
$3 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 4$	5	2	3
$4 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 5$	1	1	2
$5 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 10$	15	16	16
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert > 10$	7	3	7
Mean imbalance	7.99	7.35	7.01
Median imbalance	6.55	6.40	6.40
#Assets held at period end	21.41	20.09	21.08

Table II reports asset imbalances in final stock positions, including the number of participants in each imbalance interval for periods 1–10, 1–5, and 6–10. We find that many participants, on average, hold imbalanced portfolios. The mean (median) imbalance over all periods is 7.99 (6.55) shares, with the average imbalance being comparable over periods 1–5 and 6–10.[6] Ackert, Mazzotta, and Qi (2011) also report that, in their markets, traders fail to eliminate risk. We conduct binomial tests to assess the null hypothesis that the proportion of participants who balance their portfolios is 50% or more (i.e., the majority of participants), with balancing conservatively defined as an average imbalance of three shares or less.[7] We reject the null hypothesis ($p < 0.001$, one-tailed) over periods 1–10 and 6–10: most participants hold an imbalanced portfolio. Eyster and Weizäcker (2010) report evidence suggesting that their experimental participants provide insufficient attention to correlation among assets and tend to invest equally in available assets. In our experiment, equal holding across the two assets would be an optimal strategy, yet we find that the majority fails to balance.

Next, we investigate whether participants' final holdings are associated with their overconfidence and/or risk tolerance. We look at participants' responses to the two questionnaires administered before the portfolio choice task. Based on responses to the first questionnaire, participants can be characterized in general as overconfident: their elicited

6 On average, participants hold 21.41 shares at period end (more than double their initial endowment of shares), indicating that participants do not hesitate to rebalance their portfolios. Indeed, we find that portfolio rebalancing occurs 95% of the time (i.e., looking at all participants across all periods).

7 Looking at individual periods, we find that participants hold perfectly balanced portfolios (i.e., equal numbers of shares of stocks A and B) 19.9% of the time.

confidence intervals, on average, do not contain the correct answer 7.4 out of 10 times. We compare the average score of participants who hold a balanced portfolio (the average absolute imbalance is three or less) with the average score of those who hold an imbalanced portfolio. As shown in Panel A of Table III, overconfidence is higher, surprisingly, for participants holding a balanced portfolio, with the difference being significant at the 1% level using a parametric test and at the 10% level using a nonparametric test. We also compute the correlation between participants' average absolute imbalance and their overconfidence and find evidence of a marginally significant negative association (Pearson's $\rho = -0.33$, $p = 0.051$ and Spearman's $\rho = -0.32$, $p = 0.056$). Because the correlation is negative with higher overconfidence associated with lower imbalances, the findings are not consistent with overconfidence underlying a failure to adequately diversify.

Looking at risk tolerance, participants' responses indicate that they have a taste for risk, choosing to invest \$6.24 out of \$10.00 in the risky asset. We compare the average risk tolerance of participants who hold a balanced portfolio (the average absolute imbalance is three or less) with the average risk tolerance of those who hold an imbalanced portfolio. As shown in Panel A of Table III, risk tolerance is higher for those holding an imbalanced portfolio, with the difference being statistically significant at the 1% level using both parametric and nonparametric tests. We also compute the correlation between participants' average absolute imbalance and their risk tolerance and find evidence of a significant positive association (Pearson's $\rho = 0.52$, $p = 0.001$ and Spearman's $\rho = 0.46$, $p = 0.004$). The findings are consistent with the conjecture that risk taking is linked to participants' failure to hold a diversified portfolio.

Overall, the results indicate that participants typically under-diversify in our experimental setting. Defining a balanced portfolio conservatively as an average imbalance of three shares or less, we find that only 8 of 36 participants (22%) are adequately diversified. Further inspection of the data indicates that across periods 1–10, 1–5, and 6–10 the majority of participants hold a portfolio that has an average imbalance in excess of five shares (Table II)! As to why participants hold imbalanced portfolios, we find some evidence that risk tolerance plays a role. Participants who hold imbalanced portfolios have a greater taste for risk than those who hold a balanced portfolio. We seek to isolate contextual conditions that compel participants to hold balanced portfolios. In the following sections, we design and conduct additional experiments with the aim being to identify such conditions.

4. Experiment 2

4.1 Background

In Experiment 2, we examine whether participants are more likely to balance their holdings of the two risky assets when payoff variability increases. In this experiment, the variance cost of an imbalanced portolio is twice that of Experiment 1. As before, participants can hedge against risk simply by holding stocks A and B in equal numbers. We examine whether doubling the variability of potential outcomes deters participants from holding suboptimal portfolios.[8] With the

8 In experiment two, when we increase the variability of state-dependent liquidating dividends, we also introduce the possibility of a negative payout. Evidence suggests that people place more weight on losses than on gains of equal size (see Tversky and Kahneman, 1985; Kahneman, Knetsch, and Thaler, 1991; Abdellaoui, Bleichrodt, and Paraschiv, 2007). Later, we report additional results that support the view that the variance cost, rather than loss aversion, drives participants' portfolio choices in our experimental setting.

Table III. Overconfidence, risk tolerance, and portfolio holdings

We classify participants as holding a balanced portfolio if the average absolute imbalance in final holdings across the 10 periods is three or less, otherwise imbalanced. Participants' overconfidence is increasing in the number of elicited confidence intervals (out of 10) that do not contain the correct answer. Participants' risk tolerance is increasing in the amount of money (out of $10) they are willing to invest in a risky asset. The cell entries include mean (standard deviation) scores based on participants' responses to the overconfidence and risk tolerance questionnaires. We conduct parametric *t*-tests and nonparametric Mann–Whitney tests to compare the individual characteristic scores of participants who, on average, hold balanced versus imbalanced portfolios. One, two, and three asterisks, *, **, and ***, indicate statistical significance at the 10, 5, and 1% levels, respectively, two-tailed tests.

Individual characteristic	Mean (Standard deviation)		*t*-statistic (*z*-statistic)
	Balanced	Imbalanced	
Panel A: Experiment 1			
Overconfidence	8.50	7.07	2.95***
	(0.76)	(2.14)	(−1.72)*
Risk tolerance	4.06	6.86	−3.14***
	(1.61)	(2.35)	(−2.65)***
Panel B: Experiment 2			
Overconfidence	6.83	7.39	−0.88
	(1.75)	(2.27)	(−0.98)
Risk tolerance	5.79	6.24	−0.52
	(2.91)	(2.48)	(−0.63)
Panel C: Experiment 3			
Overconfidence	7.28	7.67	−0.62
	(1.93)	(1.63)	(−0.53)
Risk tolerance	4.33	7.00	−3.32***
	(2.20)	(2.42)	(−2.96)***
Panel D: Experiment 4			
Overconfidence	6.34	6.91	−1.28
	(1.74)	(1.14)	(−0.89)
Risk tolerance	5.72	5.80	−0.07
	(2.92)	(3.60)	(−0.34)

increase in the variance cost, participants in Experiment 2 should be more likely to hold a balanced portfolio as compared to participants in Experiment 1.

4.2 Participants and Procedures

Experiment 2 included four sessions with 12 participants each for a total of 48. Participants were recruited from the same participant pool as Experiment 1, and none participated in the earlier experiment. Students earned from \$6.40 to \$90.80 for approximately two hours of time, with an average payout of \$37.16.

The experimental procedures are identical to those of Experiment 1, with one exception. We widen the distribution of the state-dependent liquidating dividends (Panels B and C of Table I). We hold constant the expected dividend of each stock per period, but increase the spread between the high (450) and low (−150) dividends, doubling the spread as compared to Experiment 1 and doubling the per unit variance cost of a unit of imbalance.[9]

4.3 Results

On average, participants hold 10.36 shares at period end. As before, we compute each participant's absolute imbalance per period and then determine the average imbalance across the 10 periods. As compared to Experiment 1, we observe a much higher rate of bankruptcy ($\chi^2 = 17.66$, $p < 0.001$). We find that 23 of 48 participants go bankrupt in Experiment 2: 14 experience bankruptcy in the first half of the experiment (periods 1–5) and nine in the second half (periods 6–10).[10] For these participants, we compute the average imbalance over the periods completed.

Table IV reports the asset imbalances in final positions for periods 1–10, 1–5, and 6–10. The mean (median) absolute imbalance over all periods is 6.01 (6.00) shares, with the average imbalance being comparable over periods 1–5 and periods 6–10. Once again, we conduct binomial tests to assess the null hypothesis that the proportion of participants who balance their portfolio is 50% or more, with balancing conservatively defined as an average imbalance of three shares or less. We reject the null hypothesis over periods 1–10, 1–5, and 6–10 ($p < 0.07$, one-tailed): the majority of participants hold an imbalanced portfolio. As might be expected, participants who go bankrupt are more likely to hold an imbalanced portfolio (i.e., an average absolute imbalance in excess of three shares) than participants who remain solvent ($\chi^2 = 14.72$, $p < 0.001$). Indeed, in our experiment, the only way for participants to go bankrupt is if they have a large imbalance in their portfolio.

Next, we examine the link between final holdings and our elicited measures of overconfidence and risk tolerance (Panel B of Table III). We find that neither measure differs significantly between participants who hold a balanced portfolio and those who hold an imbalanced portfolio ($p > 0.30$). Likewise, neither measure is significantly correlated with participants' average absolute imbalance ($p > 0.25$). By comparison, we find that risk tolerance is higher for participants who go bankrupt than for those who remain solvent ($t = -1.84$, $p = 0.072$ and $z = -2.08$, $p = 0.038$), which is not surprising.

9 The payoff to a one-unit imbalance in experiment one can be expressed as $10{*}300B$ where B is a Bernoulli random variable with variance of ¼. For experiment two, the imbalance payoff is $10{*}(600B - 150)$ per unit, which gives a standard deviation that is two times larger than that in experiment one. We thank an anonymous referee for suggesting this representation.

10 The high bankruptcy rate is likely driving the lower average earnings observed in experiment two.

Table IV. Summary statistics on holdings imbalance: Experiment 2

In Experiment 2, the distribution of the state-dependent liquidating dividends is larger. The table reports asset imbalances in participants' final stock positions. For participants who complete all 10 periods, the average absolute imbalance is computed as |#Stock A – #Stock B| per period averaged across the 10 periods. Twenty-three participants went bankrupt, at which point they exited the portfolio choice task. For them, the average absolute imbalance is computed as |#Stock A – #Stock B| per period averaged across the periods completed. The table provides information on the number of participants in each average imbalance interval for periods 1–10, 1–5, and 6–10, as well as the mean and median across participants. The table also provides information on the average asset holdings at period end. For periods 1–10 and 1–5, $n = 48$. For periods 6–10, $n = 34$ because 14 participants went bankrupt before period 6.

	Periods 1–10	Periods 1–5	Periods 6–10
$\|\#\text{Stock A} - \#\text{Stock B}\| = 0$	0	1	0
$0 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 1$	6	7	6
$1 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 2$	2	3	4
$2 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 3$	4	5	2
$3 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 4$	5	8	2
$4 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 5$	3	2	5
$5 < \|\#\text{Stock A} - \#\text{Stock B}\| \leq 10$	22	17	12
$\|\#\text{Stock A} - \#\text{Stock B}\| > 10$	6	5	3
Mean	6.01	5.70	5.52
Median	6.00	4.10	4.70
#Assets held at period end	10.36	11.31	10.68

All in all, the results of Experiment 2 are very similar to those of Experiment 1, except the rate of bankruptcy is markedly higher. A comparison of the proportion of participants holding a balanced portfolio over periods 1–10, 1–5, and 6–10 does not indicate any significant differences between the two experiments ($p > 0.15$). Hence, doubling the payoff variability has little impact on participants' propensities to hold a balanced portfolio. In Experiment 3, we probe whether a large increase in variability, implemented by changing the payment method, influences participants' final holdings.

5. Experiment 3

5.1 Background

In our first two experiments, participants' earnings in the portfolio choice task are accumulated over 10 periods. To examine the conditions under which participants hold balanced portfolios, we alter the payment method in the portfolio choice task. Instead of paying participants based on earnings accumulated over 10 periods, we pay them based on one randomly chosen period and multiply their earnings by 10. This change increases the variance of potential payoffs substantially. We keep the same state-dependent liquidating dividends as in Experiment 2, which results in a 10-touple increase in the standard deviation of payoffs as compared to Experiment 2 and a 20-touple increase as compared to Experiment 1. By increasing the variability we expect participants to be much less tolerant of imbalances and, as a consequence, to move toward holding a balanced portfolio.

5.2 Participants and Procedures

Experiment 3 included two sessions and 33 participants. Students were recruited from the same participant pool as Experiments 1 and 2 and none participated in an earlier experiment. Students earned from \$8 to \$101.40 for approximately 2 hours of time, with an average payout of \$51.16.

The experimental procedures are identical to those of Experiment 2, with the following exceptions. First, participants are paid based on their portfolio choices from one randomly selected period, rather than accumulated over all 10 periods. To make incentives comparable to our earlier experiments, participants' earnings are computed by multiplying the randomly chosen period's earnings by 10. Second, we do not permit borrowing because losses can occur if participants hold imbalanced portfolios and, more so, if they borrow heavily: that is, a loss in one randomly determined period multiplied by 10 can result in large negative earnings. However, participants do not face downside risk, as they do not have to cover their losses.[11] To alleviate this concern, we disallow borrowing. Third, the portfolio choice task is conducted using paper and pencil. Participants compute their earnings, and the experimenters (and assistants) check participants' record sheets at period end.[12] We note, however, that participants in our first two experiments summarized their trading activity and earnings per period using paper and pencil. As a consequence, participants' portfolio positions and resultant earnings should be salient on a period-by-period basis across all of our experiments.

5.3 Results

On average, participants hold 8.27 shares at period end. Table V reports asset imbalances in final stock positions for periods 1–10, 1–5, and 6–10. The mean (median) average absolute imbalance over all periods is 3.70 (2.50), noticeably lower than in Experiments 1 and 2. We also observe that a small number of participants choose only to hold cash in Experiment 3, selling all of their stock to the experimenter. Such behavior is equivalent to holding a balanced portfolio: in both cases, risk is eliminated and participants' returns are identical. We treat participants who do not hold any stock (i.e., zero shares of stock A and B) as having a balanced portfolio. Notwithstanding, inferences are unaffected if we exclude these participants from the data analyses.[13]

We conduct binomial tests to assess the null hypothesis that the proportion of participants who hold a balanced portfolio is 50% or more. Unlike Experiments 1 and 2, we are unable to reject the null hypothesis over periods 1–10, 1–5, and 6–10 ($p > 0.30$, one-tailed). An inspection of the data indicates that slightly more than half the participants hold a balanced portfolio (see Table V). Further analysis indicates that the proportion of participants who hold a balanced portfolio does not differ between the first and second halves of the experiment ($\chi^2 = 0.24$, $p = 0.621$).

Next, we examine the link between final holdings and our elicited measures of overconfidence and risk tolerance (Panel C of Table III). We find that participants holding a balanced portfolio have a lower risk tolerance than those holding an imbalanced portfolio, with the difference being statistically significant at the 1% level using both parametric and

11 The Institutional Review Boards at our universities do not allow us to force participants to cover losses.

12 Participants are permitted to use calculators in all sessions.

13 We do not observe any bankruptcies in experiment three.

Table V. Summary statistics on holdings imbalance: Experiment 3

In Experiment 3, participants' payment in the portfolio choice task is based on one randomly selected period. The table reports asset imbalances in participants' final stock positions. The average absolute imbalance is computed as |#Stock A – #Stock B| per period averaged across the 10 periods. The table provides information on the number of participants in each average imbalance interval for periods 1–10, 1–5, and 6–10, as well as the mean and median across participants. The table also provides information on the average asset holdings at period end.

	Periods 1–10	Periods 1–5	Periods 6–10
No shares held	5	6	5
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert = 0$	3	3	3
$0 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 1$	0	0	1
$1 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 2$	6	7	5
$2 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 3$	4	3	3
$3 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 4$	4	3	5
$4 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 5$	4	4	3
$5 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \leq 10$	3	4	4
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert > 10$	4	3	4
Mean	3.70	3.42	3.97
Median	2.50	2.20	2.80
#Assets held at period end	8.27	8.45	8.36

nonparametric tests. We also find that the correlation between participants' average absolute imbalance and their risk tolerance is positive and statistically significant (Pearson's $\rho = 0.49$, $p = 0.004$ and Spearman's $\rho = 0.57$, $p = 0.001$). Hence, participants' propensity to hold an imbalanced portfolio is associated with their appetite for risk. We note that overconfidence is not significantly correlated with participants' average absolute imbalance (Pearson's $\rho = -0.11$, $p = 0.532$ and Spearman's $\rho = -0.08$, $p = 0.647$).

In sum, the results Experiment 3 indicate that paying participants based on one randomly selected period, which substantially increases the variance cost of potential payoffs, pushes more of them to hold a balanced portfolio: just over one-half, on average, hold a balanced portfolio. The results are markedly different from those of Experiments 1 and 2, where most participants hold an imbalanced portfolio.

We recognize that loss aversion could play a role in nudging participants toward holding balanced portfolios because one of the state-dependent liquidating dividends is negative. Previous research indicates that people are loss averse and assign greater weight to losses than corresponding gains (see, e.g., Kahneman and Tversky, 1979; Tversky and Kahneman, 1991). Notwithstanding, our results are consistent with the view that it is the variance cost, rather than loss aversion, that leads to the observation of more optimal portfolios. Note that when we introduce the possibility of a loss, Experiment 1 versus Experiment 2, we observe little change in suboptimal behavior. However, when we significantly increase the variance cost, Experiment 2 versus Experiment 3, we see a signficant decrease in participants' imbalances.

To further investigate the importance of the variance effect, we collected additional data. We recruited 29 students from the same participant pool as our earlier experiments, and none participated in an earlier session. The experimental procedures are similar to those of Experiment 3, with two exceptions. First, participants are asked to make a single portfolio allocation choice. Second, the possible state-dependent dividends are 0 and 600 francs and the conversion rate to dollars is adjusted so that the range in possible payments and expected earnings are consistent with the parameters of Experiment 3. Thus, the dividend variability is identical to that of Experiment 3, but losses are not possible. We find that the absolute imbalance in the additional data is 2.73. By comparison, the absolute imbalance in Experiment 3 (looking at participants' allocation decisions in the first period) is 3.21. Parametric and nonparametric tests indicate that the difference is not significantly: $t=-0.38$, $p=0.704$ and $z=-0.93$, $p=0.351$, respectively.[14] Taken together, the results indicate that a large increase in the variance cost, rather than loss aversion, is the fundamental driving force behind the shift toward balanced holdings. In the next section, we delve further into whether the experimental setup can be altered to induce participants to diversify risk, thereby reducing the average imbalance in holdings.

6. Experiment 4

6.1 Background

One reason that some individuals do not hold a balanced portfolio is because they believe that they can predict (to some degree) market outcomes—that intuition yields insight into future outcomes. In Experiments 1, 2, and 3, participants observe state realizations at period end. Their portfolio choices may exhibit sequential dependencies: prior state realizations may provide a basis for them to forecast the next period's realization. Previous studies suggest that individuals search for and imagine patterns in outcomes that do not exist (see Yellott, 1969; Ayton and Fischer, 2004; Wolford *et al.*, 2004). Individuals tend to perceive sequential dependencies, including gambler's fallacy and trend chasing (also known as hot hand fallacy).[15] Accordingly, participants' failure to adequately diversify may be indicative of cognitive bias.

In Experiment 4, we suppress period-end state realizations. Participants do not receive any feedback on state outcomes until the portfolio choice task is completed. By suppressing state realizations, we eliminate the possibility that participants fall prey to cognitive biases (see also Barron and Leider, 2010), which may underlie some participants' choice to hold an imbalanced portfolio. We acknowledge that this design choice prevents experiential learning over the course of the experiment (i.e., it prevents participants from learning based on the outcomes of their portfoio choices over time), which potentially impacts period-end holdings. We choose to keep the same basic structure as our earlier experiments (except that state realizations are not revealed) to enhance comparabiltiy across experiments.

14 The average imbalance in experiment three is 3.70 units across all periods, whereas the average observed asset imbalance is 2.73 in the additional data. Parametric and nonparametric tests indicate that the difference is not statistically significant: $t=0.90$, $p=0.372$ and $z=-1.42$, $p=0.156$, respectively.

15 Gambler's fallacy is the belief that consecutive occurrences of a particular outcome will be balanced out by future occurrences of the opposite outcome. In other words, trends are expected to reverse. Trend chasing, however, is the belief that consecutive occurrences of a particular outcome will persist in the future, that the same outcome will recur. In this case, trends are expected to continue.

Table VI. Summary statistics on holdings imbalance: Experiment 4

In Experiment 4, participants are not shown period-by-period state realizations until the portfolio choice task is completed. The table reports asset imbalances in participants' final stock positions. The average absolute imbalance is computed as |#Stock A – #Stock B| per period averaged across the 10 periods. The table provides information on the number of participants in each average imbalance interval for periods 1–10, 1–5, and 6–10, as well as the mean and median across participants. The table also provides information on the average asset holdings at period end.

	Periods 1–10	Periods 1–5	Periods 6–10
No shares held	9	11	10
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert = 0$	5	8	6
$0 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 1$	12	8	8
$1 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 2$	5	8	7
$2 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 3$	7	4	5
$3 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 4$	5	5	5
$4 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 5$	2	1	4
$5 < \lvert\#\text{Stock A} - \#\text{Stock B}\rvert \le 10$	4	4	4
$\lvert\#\text{Stock A} - \#\text{Stock B}\rvert > 10$	0	0	0
Mean	1.84	1.62	2.05
Median	0.00	0.00	0.00
#Assets held at period end	6.70	7.25	6.98

6.2 Participants and Procedures

Experiment 4 included four sessions and 49 participants. Students were recruited from the same participant pool as for the other experiments, and none participated in an earlier session. Students earned from \$11.00 to \$120.20 for approximately 2 hours of time, with an average payout of \$52.11.

The experimental procedures are identical to those of Experiment 3, with one exception. Participants are not given feedback on state realizations until all 10 periods are completed: that is, after participants have made 10 asset allocation decisions.[16] As a consequence, participants who hold an imbalanced portfolio cannot determine their earnings for a particular period until the conclusion of the experiment.

6.3 Results

On average, participants hold 6.70 shares at period end. Table VI reports the asset imbalances for periods 1–10, 1–5, and 6–10, indicating a mean (median) imbalance of 1.84 (0.00) over all periods. As compared to Experiment 3, a few more participants choose to only hold cash at period end. Notwithstanding, inferences are similar if we exclude these participants from further analysis.

We conduct binomial tests to assess the null hypothesis that the proportion of participants who hold a balanced portfolio is 50% or more. As in Experiment 3, we are unable to reject the null hypothesis over periods 1–10, 1–5, and 6–10 ($p > 0.49$, one-tailed). The data indicate that the vast majority of participants hold a balanced portfolio (see Table VI).

16 We also elicit participants' risk tolerance using a second method, based on Holt and Laury (2002). The results are similar to those reported in the article and, thus, not discussed.

We also document that the proportion of participants who hold a balanced portfolio does not differ between the first and second halves of the experiment ($\chi^2 = 0.51$, $p = 0.475$).

As before, we investigate the association between final holdings and participants' overconfidence and risk tolerance. Neither association is statistically significant (see Panel D of Table III). Notably, the correlation between participants' risk tolerance and their final holdings, which is positive and statistically significant in Experiment 3, all but disappears in Experiment 4 (Pearson's $\rho = -0.04$, $p = 0.782$ and Spearman's $\rho = -0.03$, $p = 0.823$). As the imbalance does not differ significantly from zero, it is not surprising that the correlation also does not differ significantly from zero. Overall, our findings indicate that suppressing participants' knowledge of state realizations, coupled with substantially increasing the variance cost (paying them based on one randomly selected period), moves most participants toward holding a balanced portfolio.

7. Additional Analyses

We estimate a regression, collapsing the data over our four experiments ($n = 166$), to provide additional insight into participants' portfolio allocation decisions. The regression analysis allows us to decipher differences in participants' portfolio choices across experiments, isolating factors that explain behavior. The dependent variable is computed as the absolute imbalance per period (summed over periods completed) divided by the periods completed. The independent variables include three dummy variables, which take a value of one (zero otherwise) as follows: participants are from Experiment 2 (variance cost is doubled as compared to the baseline case), participants are from Experiment 3 (variance cost is increased twentyfold as compared to the baseline case), and participants are from Experiment 4 (period-end state realizations are not revealed). We also include two independent variables, using our measures to elicit participants' overconfidence and risk tolerance.

The regression results are presented in Table VII. The results indicate that substantially increasing the variance cost of payoffs (Exp3) and suppressing state realizations (Exp4) reduces participants' portfolio imbalances, with the effects being statistically significant at $p < 0.005$. By comparison, simply doubling the variance cost of payoffs (Exp2) does not significantly impact participants' portfolio imbalances. Overconfidence also has an insignificant relationship with imbalances.[17] The regression results also indicate that participants who have a lower tolerance for risk hold portfolios with smaller imbalances. Overall, the regression results are consistent with the observed differences (between experiments) discussed throughout the article.[18]

17 Overconfidence and risk tolerance potentially are related. We examine this relationship and find that the correlation is positive, but only statistically significantly in experiment one. Specifically, in experiment one, the Pearson correlation is $\rho = 0.39$, $p = 0.018$ and the Spearman correlation is $\rho = 0.32$, $p = 0.059$. In the other three experiments, $p > 0.25$.

18 We repeat the regression model, adding a dummy variable for participants' gender. We did so because prior findings suggest that portfolio choices differ between males and females (see Frijns, Koellen, and Lehnert, 2008; Save-Soderbergh, 2012). We find that inferences are unaffected. We also perform additional analyses to investigate whether cognitive biases underlie participants' portfolio imbalances. We find that, in our first two experiments (when earnings are accumulated over ten periods), participants decrease their holdings of the stock that pays the higher liquidating dividend in period $t-1$ and increase their holdings of the other stock. Such behavior is consistent with gambler's fallacy.

Table VII. Regression of factors affecting participants' portfolio imbalances

The table reports the results of a regression in which the dependent variable is computed as the absolute imbalance per period summed over periods completed, divided by the periods completed. The data includes the portfolio choices of those who participated in Experiments 1 through 4 ($n = 166$). The independent variables include three dummy variables, which are coded as one (zero otherwise) as follows: participants are from Experiment 2 (Exp2), participants are from Experiment 3 (Exp3), participants are from Experiment 4 (Exp4). The dummy variables reflect fundamental changes in the experimental setup as compared to Experiment 1, our baseline case. In Experiment 2, the variance cost of payoffs is doubled; in Experiment 3, the variance cost of payoffs is 20-toupled; and in Experiment 4, period-end state realizations are not revealed. We also include two independent variables using elicited measures of participants' overconfidence (Overconfidence) and risk preference (Risk tolerance). Higher scores for each measure indicate greater overconfidence and a greater taste for risk, respectively. One, two, and three asterisks, *, **, and ***, indicate statistical significance at the 10, 5, and 1% levels, respectively, two-tailed tests. For the overall regression, $F = 8.76$, $p < 0.001$ and adjusted $R^2 = 0.19$.

Independent variable	Estimated coefficient (*t*-statistic)
Constant	6.83
	(2.27)***
Exp2 (variance cost doubled)	−1.82
	(1.20)
Exp3 (variance cost twentyfold)	−6.15
	(1.22)***
Exp4 (state realizations not revealed)	−3.93
	(1.32)***
Overconfidence	−0.27
	(0.23)
Risk tolerance	0.50
	(0.16)***

8. Concluding Remarks

We report the results of four experiments designed to investigate individuals' portfolio allocation decisions. We find that participants, in general, hold balanced portfolios only under very specific conditions: when their payout is contingent on a single period and knowledge of payouts is suppressed until the end of the experiment. Importantly, when participants are paid based on the outcome of a single period, the variance cost of an imbalance increases substantially. Furthermore, the lack of feedback on state realizations eliminates the possibility of cognitive biases resulting from misunderstanding of randomness.

The generalizability of our findings is subject to certain limitations. Our experimental setting is simple and stark, which abstracts away from naturally occurring settings. But a stark and simple setting allows us to isolate the effects of various contextual factors on participants' portfolio choices. Importantly, such a setting enables us to control for potential confounds and, at the same time, identify forces that underlie participants' behavior. We readily acknowledge that such simplicity may dampen the generalizability of our results to naturally occurring markets. Notwithstanding, our findings provide fodder for future theoretical work on individuals' portfolio allocation decisions. Though it is often assumed that individuals optimally diversify, our findings indicate that the cost of an imbalance must be sizable to push an individual toward the optimal portfolio. Furthermore, guarding against behavioral biases appears to be important.

As with any gauge of psychological factors, our measures of participants' overconfidence and risk tolerance are subject to error. The measures may not fully capture the constructs of interest, both of which are difficult to quantify. But the measures have been used elsewhere with success (see Gneezy and Potters, 1997; Gneezy *et al*., 2003; Biais *et al*., 2005). Thus, we have comfort in the construct validity of the overconfidence and risk tolerance measures.

Finally, our study does not consider alternatives to the traditional mean-variance framework, such as behavioral portfolio theory (see Shefrin and Statman, 2000; Statman, 2004). Under the alternative framework, investors do not evaluate portfolios as a package, but rather they layer investments as a pyramid. At the bottom are low-risk investments that provide downside protection. At the top are riskier ones that allow investors to strive for higher aspirations (e.g., a shot at the riches). Investors are willing to take greater risk with a portion of money if there is a chance, even if small one, of large winnings. We encourage future studies that examine the applicability of alternative frameworks to better understand investors' portfolio choices.

Despite the limitations detailed above, our findings provide important insight into investor decision making. The economic significance of our evidence is revealed by the continued public debate surrounding self-directed retirement funds. If individuals do not form optimal portfolios in our simple environment, can we expect them to in the ever more complicated real world? Perhaps they need a nudge to improve their decisions (Thaler and Sunstein, 2009). Research suggests that education can change behaviors associated with retirement planning (Thaler and Benartzi, 2004). We present evidence of factors that are linked to suboptimal portfolio allocations. Careful consideration of the investor's decision environment and behavioral inclinations is critical to further the development of theory and provide direction for policymakers.

References

Abdellaoui, M., Bleichrodt, H., and Paraschiv, C. (2007) Loss aversion under prospect theory: a parameter–free measurement, *Management Science* **53**, 1659–1674.

Ackert, L. F. and Church, B. K. (1998) Information dissemination and the distribution of wealth: evidence from experimental asset markets, *Journal of Economic Behavior and Organization* **37**, 357–371.

Ackert, L. F., Mazzotta, S., and Qi, L. (2011) An experimental investigation of asset pricing in segmented markets, *Southern Economic Journal* **77**, 585–598.

Ayton, P. and Fischer, I. (2004) The hot hand fallacy and the gambler's fallacy: two faces of subjective randomness, *Cognition and Memory* **32**, 1369–1378.

Bailey, W., Kumar, A., and Ng, D. (2011) Behavioral biases of mutual fund investors, *Journal of Financial Economics* **102**, 1–27.

Barber, B. M. and Odean, T. (2001) Boys will be boys: gender, overconfidence, and common stock investment, *Quarterly Journal of Economics* **116**, 261–292.

Barron, G. and Leider, S. (2010) The role of experience in the gambler's fallacy, *Journal of Behavioral Decision Making* **23**, 117–129.

Benartzi, S. and Thaler, R. H. (2001) Naïve diversification strategies in defined contribution saving plans, *American Economic Review* **91**, 79–98.

Biais, B., Hilton, D., Mazurier, K., and Pouget, S. (2005) Judgemental overconfidence, self–monitoring, and trading performance in an experimental financial market, *Review of Economic Studies* **72**, 287–312.

Bloomfield, R. and Anderson, A. (2010) Experimental finance, in: H. Kent Baker and J. R. Nofsinger (eds), *Behavioral Finance: Investors, Corporations, and Markets*, John Wiley & Sons, Hoboken, NJ, 113–129.

Blume, M. E. and Friend, I. (1975) The asset structure of individual portfolios and some implications for utility functions, *Journal of Finance* **30**, 585–603.

Bossaerts, P., Frydman, C., and Ledyard, J. (2014) The speed of information revelation and eventual price quality in markets with insiders: comparing two theories, *Review of Finance* **18**, 1–22.

Bossaerts, P. and Plott, C. (2002) The CAPM in thin experimental financial markets, *Journal of Economic Dynamics & Control* **26**, 1093–1112.

Bossaerts, P., Plott, C., and Zame, W. (2007) Prices and portfolio choices in financial markets: theory, econometrics, experiments, *Econometrica* **75**, 993–1038.

Calvet, L. E., Campbell, J. Y., and Sodini, P. (2007) Down or out: assessing the welfare costs of household investment mistakes, *Journal of Political Economy* **115**, 707–747.

Camerer, C. and Weigelt, K. (1991) Information mirages in experimental asset markets, *Journal of Business* **64**, 463–493.

Copeland, T. E. and Friedman, D. (1991) Partial revelation of information in experimental asset markets, *Journal of Finance* **46**, 265–295.

Cox, J. C., Sadiraj, V., and Schmidt, U. (2015) Paradoxes and mechanisms for choice under risk, *Experimental Economics* **18**, 215–250.

Deaves, R., Luders, E., and Luo, G. Y. (2009) An experimental test of the impact of overconfidence and gender on trading activity, *Review of Finance* **13**, 555–575.

Eyster, E. and Weizäcker, G. (2010) *Correlation neglect in financial decision–making*. Working paper, London School of Economics.

Fischbacher, U. (2007) z–tree: Zurich toolbox for ready–made experiments, *Experimental Economics* **10**, 171–178.

Frijns, B., Koellen, E., and Lehnert, T. (2008) On the determinants of portfolio choice, *Journal of Economic Behavior and Organization* **66**, 373–386.

Goetzmann, W. and Kumar, A. (2008) Equity portfolio diversification, *Review of Finance* **12**, 433–463.

Gneezy, U., Kapteyn, A., and Potters, J. (2003) Evaluation periods and asset prices in a market experiment, *Journal of Finance* **58**, 821–837.

Gneezy, U. and Potters, J. (1997) An experiment on risk taking and evaluation periods, *Quarterly Journal of Economics* **112**, 631–645.

Hedesström, T. M., Svedsäter, H., and Gärling, T. (2006) Covariation neglect among novice investors, *Journal of Experimental Psychology* **12**, 155–165.

Holt, C. A. and Laury, S. K. (2002) Risk aversion and incentive effects, *American Economic Review* **92**, 1644–1655.

Kahneman, D., Knetsch, J. L., and Thaler, R. H. (1991) The endowment effect, loss aversion, and status quo bias, *Journal of Economic Perspectives* **5**, 193–206.

Kahneman, D., and Tversky, A. (1979) Prospect theory: an analysis of decision under risk, *Econometrica* **47**, 263–291.

Kelly, M. (1995) All their eggs in one basket: portfolio diversification in U.S. households, *Journal of Economic Behavior and Organization* **27**, 87–96.

Klayman, J., Soll, J., Gonzalez–Vallejo, C., and Barlas, S. (1999) Overconfidence: it depends on what, how, and whom you ask, *Organizational Behavior and Human Decision Processes* **79**, 216–247.

Kluger, B. D. and Wyatt, S. B. (2004) Are judgment errors reflected in market prices and allocations? Experimental evidence based on the Monty Hall problem, *Journal of Finance* **59**, 969–997.

Kroll, Y., Levy, H., and Rapoport, A. (1988) Experimental tests of the mean–variance model for portfolio selection, *Organizational Behavior and Human Decision Processes* **42**, 388–410.

Lopes, L. L. and Oden, G. C. (1987) Distinguishing between random and nonrandom events, Journal of Experimental Psychology: Learning, Memory and Cognition **13**, 392–400.

Lundeberg, M. A., Fox, P. W., and Punccohar, J. (1994) Highly confident but wrong: gender differences and similarities in confidence judgments, *Journal of Educational Psychology* **86**, 114–121.

Markowitz, H. (1952) Portfolio selection, *Journal of Finance* **7**, 77–91.

Morin, R. A. and Suarez, A. F. (1983) Risk aversion revisited, *Journal of Finance* **38**, 1201–1216.

Odean, T. (1999) Do investors trade too much?, *American Economic Review* **89**, 1279–1298.

Rietz, T. A. (2003) *Trader behavior, arbitrage, and efficiency in experimental asset markets*. Working paper, University of Iowa.

Russo, J. and Schoemaker, P. J. H. (1992) Managing overconfidence, *Sloan Management Review* **33**, 7–17.

Save–Soderbergh, J. (2012) Self–directed pensions: gender, risk, and portfolio choices, *Scandinavian Journal of Economics* **114**, 705–728.

Shefrin, H. and Statman, M. (2000) Behavioral portfolio theory, *Journal of Financial and Quantitative Analysis* **35**, 127–151.

Statman, M. (2004) The diversification puzzle, *Financial Analysts Journal* **60**, 44–53.

Thaler, R. H. and Benartzi, S. (2004) Save more tomorrow: using behavioral economics to increase employee saving, *Journal of Political Economy* **112**, S164–S187.

Thaler, R. H. and Sunstein, C. R. (2009) *Nudge*, Penguin Books, New York, NY.

Tversky, A. and Kahneman, D. (1985) Rational choice and the framing of decisions, *Journal of Business* **59** (pt. 2) S251–S278.

Tversky, A. and Kahneman, D. (1991) Loss aversion in riskless choice: a reference–dependent model, *Quarterly Journal of Economics* **106**, 1039–1061.

Wolford, G., Newman, S. E., Miller, M. B., and Wig, G. S. (2004) Searching for patterns in random sequences. *Canadian Journal of Experimental Psychology* **58**, 221–228.

Yellott, J. I. (1969) Probability learning with noncontingent success, *Journal of Mathematical Psychology* **6**, 541–575.