Market Reactions to Stock Splits: Experimental Evidence

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Abstract

We report on an experiment studying market reactions to stock splits and reverse splits. In the first environment, two assets have increasing fundamental values, and one asset is subject to a 2-for-1 share split while the other is not. In the second environment, the fundamental values of both assets are decreasing, and one asset is subject to a 1-for-2 reverse split while the other is not. We find that share prices do not fully adjust to changes in fundamental values per share following both types of splits and we relate this phenomenon to difficulties that traders have with proportional thinking.

Keywords: Stock splits, behavioral finance, proportional thinking, cognitive reflection, experimental finance.

JEL codes: C92, G10, G40, G41

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1 Introduction

Recent stock splits of two leading companies, Apple and Tesla, have renewed an ongoing debate on the impact of stock splits on the subsequent prices of the split stock. A stock split, unlike the issuance of new shares or a buyback of existing shares, does not dilute existing ownership claims. Therefore, absent any changes to a firm's profit-making potential (i.e., its fundamental value), stock splits should *not* affect the issuing firm's market capitalization. Since there are costs to implementing a stock split and no change in the firm's market capitalization, if capital markets are efficient, then we should not observe stock splits. Nevertheless, stock splits occur rather frequently and produce at least a temporary effect on a firm's market capitalization by driving the post-split share price of the company's stock higher or lower, depending on the nature of the split. Fama et al. (1969) were the first to report evidence of abnormal returns one to three years following the announced split of a company's stock with subsequent studies confirming positive abnormal returns for splits and the opposite, negative abnormal returns for reverse splits. See, for example, Grinblatt et al. (1984), Lamoureux and Poon (1987), Ikenberry and Ramnath (2002), and Titman et al. (2016).

In this paper, we study the market's reaction to stock splits and reverse splits in a novel market experiment that is based on the Smith et al. (1988) environment (hereafter SSW), which has been widely used in the experimental asset pricing literature. Our aim in conducting this experiment is to complement findings from the large empirical literature in finance on stock splits, while providing new insights as to the cause of the market's asymmetric reactions to stock splits and reverse splits. In our experiment, we consider environments where market participants can trade two types of assets with positively correlated returns. In our stock split treatment (SS), both assets' fundamental values follow a known upward trend. The rationale for this design is that stocks subject to splits are usually rising in value over time. At some time t that is unknown to market participants, one of the two assets —the one with the higher fundamental value— is subject to a 2 for 1 stock split, while the other asset continues to follow its original fundamental trend to provide a counterfactual scenario. This novel experimental design allows us to understand the effects of a stock split by comparing the deviation of asset prices relative to their fundamental values, both pre- and post-split for both the split and the non-split asset. We also consider a reverse split treatment (RS) where the two assets follow a known, downward fundamental trend, and where the asset with the lower fundamental value is subject, at some unknown date t, to a 1 for 2 reverse split. We use a downward trend for the fundamental value of the two assets in the RS treatment because a reverse stock split generally occurs only when the prices of a stock are falling. In fact, some exchanges have a minimum list price requirement which has triggered reverse splits in an effort to raise the price of a stock above the minimum requirement.

The experiment we present focuses solely on the reaction of market participants to the split (or to the reverse split) announcement in terms of the pricing, volatility of prices, and the volume of trades. One possible explanation for why stock splits occur focuses on an optimal price range of a stock, which balances the competing needs of investors of different means (Copeland, 1979). If the stock price departs from the optimal price range, a split (or a reverse split) can push it back within the optimal range. A second explanation explores signaling. For example, recent splits by Apple and Tesla may signal to investors that the firm expects profits to grow, leading to greater demand for the stock and triggering speculative, short-term oriented, trading behavior.[1] A third explanation relates to liquidity: shares which trade at lower prices are more liquid (Muscarella and Vetsuypens, 1996). In this paper, we set aside the question of *why* firms choose to split or reverse split their stock shares. Understanding *how* the market reacts to stock splits or reverse splits may be critically important for understanding why firms engage in splits or reverse splits in the first place, as it may be that market reactions to stock splits are the reason that firms engage in stock splits.

One possible mechanism that may contribute to short-term abnormal returns is difficulty in assessing market information *proportionally*. For example, Shue and Townsend (2021) find that low-priced shares have a higher volatility compared with high-priced shares following stock split events after carefully controlling for firm size.[2] Their results suggest that converted shares may react differently to market and corporate news. In our experiment, the news of a split converts both the liquidation value and the stream of cash flows for each share. Thus, subjects have to *proportionally* adjust both variables in order to determine the adjusted fundamental value of the converted asset. A failure to employ such *proportional thinking* can result in asset mispricing.[3] Non-proportional

[1] Indeed, Warren Buffet has stated that the reason he has never split class A shares of Berkshire Hathaway (currently trading in excess of USD $250,000 per share) is because, “I don't want anybody buying Berkshire thinking that they can make a lot of money fast.” (WSJ Aug 14, 2014). Cui et al. (2021) explore a signaling explanation in the Chinese stock market, and find evidence of greater optimism following stock splits, and improved future performance.

[2] Higher volatility following a stock split is also found in the options data (Gharghori et al., 2017).

[3] Our goal in this paper is *not* to test the specific model of Shue and Townsend (2021), which studies the market response to common shocks across similar firms that differ in the number of shares. Instead,

thinking has also been studied in an *individual-choice* experiment. Svedsäter et al. (2007) asked subjects individually whether they would be more willing to buy/sell a stock following a stock split or a reverse split and report that individuals were more willing to buy/sell lower priced stocks following a split than they were to buy/sell higher priced stocks following a reverse split, but trading was preferred in both cases even though nothing fundamentally had changed about the stock values. Our paper complements the field work of Shue and Townsend (2021) and the individual choice experiment of Svedsäter et al. (2007) by studying stock splits in a controlled laboratory *market experiment*. While some individual subjects might fail to engage in proportional thinking, one might conjecture that market interactions would eliminate or greatly reduce such suboptimal behavior. Alternatively, as in the work of Shue and Townsend (2021), the non-proportional thinking of some traders might not wash out in the market's reactions to stock splits. With the aim of increasing our understanding of the role played by non-proportional thinking, we further analyze how measures of our traders' abilities to reflect and think proportionally impact their bids and asks. Specifically, we use our subjects' performance on cognitive reflection test (CRT) questions (see, e.g., Frederick, 2005) as a proxy for their ability to reflect about the change brought about by a stock split as well as to make proportional adjustments.

The laboratory is an ideal setting for an event study examining market reactions to stock splits because we can control the information flows available to traders when making trades, as well as the true fundamental values of the assets being traded, which enables us to precisely measure the extent of any mispricing. We can also abstract from other confounding factors, such as macro shocks, that may be present in financial markets and coincide with a split announcement to cloud the market's reaction to a stock split. In addition, the laboratory allows us to study counterfactual scenarios and thus isolate variables which affect market behavior. In our environment, the counterfactual is the presence of another asset following the same trend path for fundamentals as the split asset, but which is not subject to a split (or reverse split). Finally, the laboratory also enables us to evaluate *individual characteristics*, such as cognitive ability, and their impact on market outcomes.

Our experimental results show abnormal positive returns in the short-run in the SS treatment, where the short-run is defined as the four periods immediately following the split announcement at the end of period five (out of 15). This as an under-reaction

we suggest that non-proportional thinking may also apply to split/reverse split events where the value of the shares must adjust proportionally following a share conversion.

by the market to the change in the fundamental value (FV) per share — that is, the adjustment is not proportional to the actual change. By contrast, the other asset in the market, which is not subject to a split, serves as a counterfactual and remains fairly priced relative to its fundamental value. We find that a subject's cognitive ability (CRT score) can help explain this market behavior. Subjects who score higher on the CRT submit orders closer to the FV of the assets.

In the *RS* treatment, we find that the reverse split asset is undervalued in the short-run relative to the asset that does not split. Thus, similar to the *SS* treatment, we find that the market under-reacts in the short-term following the announcement of a reverse split by not fully adjusting the price relative to the change in the FV per share. In later periods, when the difference between the FV of two assets shrinks, and the cash to asset ratio increases, both assets are overpriced relative to fundamentals. Such asset price bubbles are commonly observed in SSW environments when the FV of the assets, as in our *RS* treatment, are downward sloping (for recent experiments, see Kocher et al., 2019 and Weitzel et al., 2020). Overall, we find that subjects with higher CRT scores submit buy and sell orders that are closer to the FV of the asset.

Stock splits, which are a common occurrence in financial markets,[4] are often associated with abnormal returns. As noted earlier, Fama et al. (1969) were the first to the find evidence of abnormal returns in the periods following a stock split. More recently, Desai and Jain (1997) report that for stock splits, the buy and hold average for 1 and 3 year abnormal returns are 7.05% and 11.87%, respectively. For reverse splits, the 1 and 3 year abnormal returns are -10.76% and -33.90%, respectively. For an overview of the empirical literature on stock splits, we refer the reader to Easley et al. (2001) and He and Wang (2012).

The experimental market study that is perhaps most closely related to this one is by Haruvy et al. (2014), who evaluate the effects of repurchase and share issues on asset prices in a market with a single asset that has a downward sloping fundamental value. In their environment, there is no change to the per-share fundamental value of the asset as in our split experiment; rather they focus on repurchase and issue of existing or new shares (by the experimenter, acting as the firm). They find that prices deviate significantly from the fundamental value when shares are repurchased. It should be noted that their implementation of a share issue or repurchase is different from a share split, as the latter changes the fundamental value per share. Furthermore, our split

[4]Between 2014 and 2019, there were about 140 such events in the USA (CSRP) and 500 in Australia (Morningstar).

environment assumes an upward trending fundamental value. Penalver et al. (2020) also provide experimental evidence on the repurchase of bonds via quantitative easing (QE) and find that QE raises bond prices. The effect of cognitive skills, which in our case serve as a proxy for the ability to engage in proportional thinking, is consistent with previous evidence that higher CRT scores are positively correlated with performance in laboratory (Corgnet et al., 2018) and individual portfolio choice experiments (Magnani et al., 2021). In field data, Grinblatt et al. (2011) find that higher-IQ investors achieve higher Sharpe ratios. Overall, the individual characteristics that we are able to observe in the laboratory help us to understand some of the behavior documented in the data.[5]

2 The environment

We extend the original SSW design where market participants trade a single asset having an uncertain dividend process to a setting where agents can trade two such assets. In the stock split treatment, SS, the two assets are indexed by $j \in S, B$ where asset S (the split stock) undergoes a change to its liquidation value and its dividend process due to stock split while the other asset B (the baseline stock) does not. In the SS environment, both assets follow an upward trending fundamental value (FV) process, where the asset with the higher fundamental value, S, splits at time $\tau = t^*$.[6] In environment RS, the two assets $j = \{\tilde{S}, \tilde{B}\}$ follow a downward trending FV process, where the asset having the lower fundamental value, $\tilde{S}$, undergoes a reverse split at $\tau = t^*$, while the other (baseline) asset, $\tilde{B}$, does not.[7] Note that both assets in each environment have perfectly positively correlated holding costs (or dividends) when the FV is upward (downward) trending. As noted earlier, this design feature enables a comparison of trends in the prices of the two assets, both pre- and post-split.

In each period, the costs (or dividends) per share d_j are either low or high with equal probability, $d_j = \{d_L, d_H\}$. These costs/dividends accrue to a separate account

[5] Ungeheuer and Weber (2020) also study in an experiment, and using field data, how the perception of dependence between stock returns affects investment decisions and stock prices.

[6] The second asset, which is used as a control, has a different FV to differentiate between the two assets. This can be interpreted as two firms with identical fundamental values, but different capital structures, i.e., the firm with the lower equity value has a higher debt burden. Charness and Neugebauer (2019) find that both firms, under different capital structures, are priced fairly when (as assumed in our experiment) dividends are perfectly positive correlated.

[7] In an SSW environment, if subjects are risk neutral, then given the same endowment, there should be no trade at all or trade will occur only at the fundamental price. However, past studies have shown significant trading in SSW environments.

for each subject that is *not* available for trading purposes so as to not alter the liquidity of the market over time. At the end of the terminal period, each share of asset j yields a liquidation payoff of TV_j which is paid to the participant in addition to the accrued balance of costs/dividends in the separate account, which may be positive or negative. In the SS treatment assets are subject to per period *holding costs*, which, together with large, positive termination values TV_j for the two assets works to implement an increasing FV for each asset. In the RS treatment (as in SSW) assets are subject to per period dividend payments, which together with small, but positive termination values for the two assets works to implement a decreasing FV as detailed below.

The number of shares, n, of each asset is such that $n_{(S,\tilde{S})} = n_{(B,\tilde{B})}$ prior to the split, and changes to $\phi \times n_{(S,\tilde{S})}$ after the split, where in a 2 for 1 split $\phi = 2$ and in a 1 for 2 reverse split $\phi = 1/2$. Prior to the start of period t^* (and not before) an announcement of the impending split (in SS) or reverse split (in RS) is sent to all market participants. Following the announcement, the adjusted liquidation value is TV_j/ϕ per share, and the dividend or holding cost per share is converted to d_j/ϕ. If a participant holds an odd number of shares and there is a reverse split, then the odd unit is paid out at the last available market price in cash which can be used to trade.[8] In the actual experiment, we work with the labels A and B for the two types of assets in a given market, where A is the split stock and B is the baseline (not-split stock). In the experimental instructions, we mention that a share conversion might occur and, if so, then it would be announced just prior to the period in which the conversion will take place.

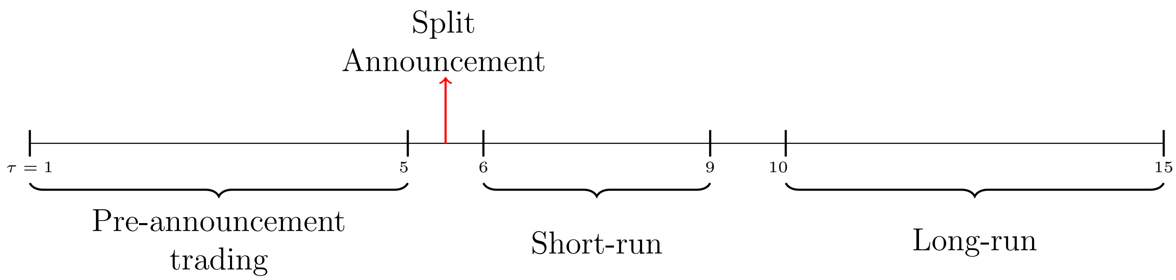


Figure 1: Market timeline in SS and RS environments

[8]Cash payment for fractional shares is commonly used, e.g. see https://www.investor.gov/introduction-investing/investing-basics/glossary/reverse-stock-splits.

2.1 Stock split

In treatment SS, the FV of an asset, assuming no discounting, is equal to the expected holding cost over the remaining life of the asset in periods $T-\tau+1$, plus the termination value, TV, such that

$$FV_{j,\tau} = \sum_{\tau=t}^{T} E[d_{j,\tau}] + TV_j. \tag{1}$$

In our environment $T = 15$, $t^* = 6$, $d_j = [-12, 0]$, $TV_S = 270$, and $TV_B = 210$. Figure 1 shows the timing of the stock split or reverse split announcement following the end of trading in period $t = 5$, and prior to the beginning of trade in $t = 6$. In our subsequent analysis, we concentrate on three trading intervals: (i) pre-announcement, where $\tau \leq 5$, (ii) short-run, immediately following the split where $6 \leq \tau \leq 9$, and (iii) long-run, where $\tau \geq 10$. The FV of each asset can be written as

$$\begin{aligned} FV_{S,\tau} &:= \begin{cases} 270 - 6 \times (T - \tau + 1) & \text{for } \tau \leq 5 \\ 135 - 3 \times (T - \tau + 1) & \text{for } 5 < \tau \leq 15 \end{cases} \\ FV_{B,\tau} &:= 210 - 6 \times (T - \tau + 1). \end{aligned} \tag{2}$$

We further assume that $n_S = n_B = 2$ at the start of the market for each trader. Participants can only sell assets that are currently in their portfolio —that is, short-selling is not allowed– and there is no borrowing. They can only utilize their cash holdings in order to trade. Table 1 summarizes the endowment per capita, and the parameters for both treatments.

2.2 Reverse split

In treatment RS, the FV of an asset, assuming no discounting, is also equal to the expected dividends over the remaining life of the asset in periods $T - \tau + 1$, plus TV (as in equation 2) such that

$$\begin{aligned} FV_{\tilde{S},\tau} &:= \begin{cases} 40 + 6 \times (T - \tau + 1) & \text{for } \tau \leq 5 \\ 80 + 12 \times (T - \tau + 1) & \text{for } 5 < \tau \leq 15 \end{cases} \\ FV_{\tilde{B},\tau} &:= 80 + 6 \times (T - \tau + 1). \end{aligned} \tag{3}$$

In the RS environment we specify the parameters as follows: $T = 15$, $t^* = 6$, $d_j =$

Table 1: Endowment bundles per capita and market parameters

	Split (SS)	Reverse split (RS)
Endowment per capita		
Cash	600	600
Number of converted shares	2	2
Number of baseline shares	2	2
Parameters		
Trading Periods	15	15
Dividends (holding cost) per share	{-12,0}	{0,12}
Liquidation value of converted share	135	80
Liquidation value of baseline share	210	80
Cash-Asset ratio (in terms of initial FV)	1	1

$[0, 12]$, $TV_{\tilde{S}} = 40$, and $TV_{\tilde{B}} = 80$. As in the SS environment, in the RS environment we set $n_{\tilde{S}} = n_{\tilde{B}} = 2$ at the start of the market and there is no short-selling, nor borrowing; participants can only utilize their current asset position and cash holdings to make trades. Table 1 summarizes the endowment per capita and the market parameters for both treatments.

2.3 Market format

We employ a call market institution to clear the market for each asset. The call market institution was chosen due to the complexity of a market where agents can trade in two asset markets at the same time. The call market has the advantage of producing a single, uniform market price for each asset traded in period, τ, which can enable greater clarity of the differences in asset prices across markets. Subjects can trade in both call markets simultaneously, with one market assigned to each asset. In each period τ, market participants are allowed to submit one buy order and/or one sell order in each of the two asset markets. They can also choose not to participate in one or both markets. A complete buy order specifies a single bid price and the number of units desired at that price. Similarly, a complete sell order includes a single ask price and the number of units for sale at that price. Our computer program checks that each individual's posted bid and ask orders are feasible given that trader's current endowment of assets and cash; if not, then the trader must change to feasible positions. After all bids and asks are submitted, the computer program sorts the submitted bids in a descending order and the submitted asks in an ascending order, to derive the demand and supply schedules for each asset. The intersection of demand and supply (if it exists) results in a single, uniform market price for each asset market (and in the case of a price range, we use the midpoint price). All buyers whose bids are greater than or equal to the market price can buy the number of units of the asset they specified at the market price, while all sellers whose asks are less than or equal to the market price can sell the number of units they had specified at the market price. A rationing rule is applied when there are more bids or asks made at the market clearing price.[9]

2.4 Asset market measures

We follow the tradition in experimental asset market literature and study the behavior of prices relative to their fundamental values by first computing the relative deviation (RD) of the price of each asset j, p_j, with respect to its FV. In Table 2 we provide the formula employed to calculate this RD, as well as a number of other relevant measures. RD is computed as the average dispersion per period. In field data, such a measure cannot be easily computed since the FV is not observable. As noted in the discussion of the timeline (Figure 1, we classify the 15 periods per call market into pre-announcement, short-term, and long-term periods, inspired by the approach used in the field. Since our environment consists of two assets, we also incorporate the relative price deviation with respect to relative FVs ($\text{RD}_{j/-j}$), following the approach of Duffy et al. (2021).

We complement the study of market price dispersion by also measuring the spread, relative spread, and trading volume of each asset. The spread is computed as the average difference between bids and asks, per period, in absolute value terms to avoid negative values. We also evaluate the relative spread of asset j, which divides the spread measure by the price of asset j, observed in period τ, $p_{j,\tau}$, to account for the change in the FV per share in one of the assets. Finally, we study the volume of trade for each asset j as the average market quantity transacted per period. Following the announcement of a share conversion, we adjust the market quantity by $\phi \in (1/2, 2)$ so that market units are comparable in the periods before and after the announcement of the stock (reverse) split.

[9]Specifically, on the long side of the market, some traders are randomly chosen to have their bid/ask orders implemented while the rest are precluded from trading.

Table 2: Market Measures

Measure	Formula
RD: relative deviation of asset j • Measures the difference between price p and fundamental value FV.	$\frac{1}{T}\sum_{\tau=1}^{T} p_{j,\tau}/FV_{j,\tau} - 1$
$\text{RD}_{j/-j}$: RD of relative prices • Extends the measure of RD to two assets (Duffy et al., 2021).	$\frac{1}{T}\sum_{\tau=1}^{T} \frac{p_{j,\tau}/p_{-j,\tau}}{FV_{j,\tau}/FV_{-j,\tau}} - 1$
Spread (of asset j) • $\overline{\text{Asks}_{j,\tau}}$ ($\overline{\text{Bids}_{j,\tau}}$) is the average of asks (bids) at time τ.	$\frac{1}{T}\sum_{\tau=1}^{T} \lvert\overline{\text{Asks}_{j,\tau}} - \overline{\text{Bids}_{j,\tau}}\rvert$
Relative Spread (of asset j) • Divides the spread by the price of asset j at each τ.	$\frac{1}{T}\sum_{\tau=1}^{T} \lvert\overline{\text{Asks}_{j,\tau}} - \overline{\text{Bids}_{j,\tau}}\rvert/p_{j,\tau}$
Volume: average volume of trade for asset j • $q_{j,\tau}$ is the market quantity. • $q_{j,\tau}$ is divided by $\phi \in (1/2, 2)$	$\frac{1}{T}\sum_{\tau=1}^{T} q_{j,\tau}/\phi$

2.5 Hypotheses

While abnormal returns following share conversions have been well-documented in the empirical literature, we structure our hypotheses first based on the assumption of perfect rationality, and then explain possible deviations from the first two predictions on the basis of difficulties that traders may have with proportional thinking.

Hypothesis 1: *Asset prices of split and non-split assets follow the respective FV in both treatments.*

Under the assumption of perfect rationality, traders should react to the (reverse) stock split by adjusting their bids and asks so that they are proportional to the change in the FV per share.

Hypothesis 2: *Volume of trade pre- and post-split is the same across both treatments.*

If traders are rational, then the volume of trade, or the average market quantity transacted each period, should not change following a stock (reverse) split, given that the volume is adjusted for the new number of shares in the market. We adjust for the increase (decrease) in the number of shares in the case of a (reverse) split in order to make the volume of trade comparable across the two assets in the market. To account for the effect of a share conversion, we calculate the volume of trade as $\frac{1}{T}\sum_{\tau=1}^{T} q_{j,\tau}/\phi$, where $\phi = 2$ for the *SS* treatment and $\phi = 1/2$ for *RS* treatment.

Hypothesis 3: *Lower CRT scores are associated with further departures from the FV.*

Using field data, Shue and Townsend (2021) provide evidence that the market might not react to events proportionally. In our case, proportional thinking is required to find the new FV per share following the split or the reverse split announcement. We use the response to one of the three CRT questions (discussed below in section 3) to proxy for subjects' ability to think proportionally. We conjecture that subjects who fail to answer this question correctly, or more generally, subjects with lower scores on the entire set of CRT questions, are more likely to have difficulty tracking changes in the FV.

3 Laboratory procedures

The experiment was conducted online using the oTree software (Chen et al., 2016). Subjects were undergraduate students recruited from Monash University (Australia), who had no prior experience with our experimental asset markets. Subjects were assigned to participate in just one of the two treatments: $\{SS, RS\}$.[10] At the start of each session, subjects were asked to read some written instructions. Copies of these instructions are provided in the online appendix. After reading the instructions, subjects were asked to complete a comprehension quiz to check their understanding of the instructions. After completing the quiz, subjects received feedback, and the experimenter (one of the authors) answered any remaining questions privately via a chat room in Zoom. Subjects then participated in two, 15 period markets. Following completion of the second market, subjects were asked to answer three cognitive reflection test (CRT) questions taken from Toplak et al. (2014), which are similar and positively correlated with the original CRT questions of Frederick (2005) but less well-known.[11] As in the original CRT questions, these new CRT questions have an automatic, intu-

[10] The between-subjects design that we employ is common in asset market experiments where much time is devoted to instructing subjects on the trading rules, thereby making multiple treatments interventions costly.

[11] We also elicited subjects' risk preferences using the bomb risk elicitation task of Crosetto and Filippin (2013).

itive or unconscious "system 1" answer that is *wrong* and a more reflective"system 2" answer requiring deeper reasoning that is correct, as outlined in Kahneman (2011). The precise questions, along with the correct (reflective) and incorrect (intuitive) answers (which were *not* given to subjects) are:

1. Jerry received both the 13th highest and the 13th lowest mark in the class. How many students are in the class? [Correct Answer: 25, Intuitive Wrong Answer: 26]

2. Simon decided to invest $8,000 in the stock market one day early in 2008. Six months after he invested, on July 17, the stocks he had purchased were down 50%. Fortunately for Simon, from July 17 to October 17, the stocks he had purchased went up 75%. At this point, Simon has: (i) broken even in the stock market, (ii) is ahead of where he began, or (iii) has lost money. [Correct Answer: iii) Lost Money. Intuitive Wrong Answer: (ii)]

3. If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together? [Correct Answer: 4 days. Intuitive Wrong Answer: 9 days.]

We will focus on Question 3 in particular (which Shane Frederick himself offered to Toplak et al. (2014)), as it provides a measure of the individuals' ability to both reflect and (more specifically) engage in proportional thinking.

Each session consisted of two identical 15 period markets.[12] In each period, each subject had the option to input into boxes buy and/or sell orders, subject to the constraints that buy orders did not exceed cash endowments and sell orders were for assets currently in possession (i.e., no borrowing or short selling was allowed). Once a subject decided on their order, they had to confirm the order by clicking on the button labeled *Next*. Figure 2 presents the user-interface, where the first (third) columns allowed subjects to enter per unit bids (asks) for assets A and B, and the second (fourth) columns allowed subjects to specify the number of units to buy (sell) of each asset at his/her bid (ask) prices. Subjects who did not want to buy and/or sell assets were instructed to enter zeros in the relevant boxes. While we displayed a timer

[12]The repetition of an asset market more than once is common in the experimental asset pricing literature, as experienced subjects are often less prone to mispricing than inexperienced subjects. Indeed, in the analysis that follows we will mainly focus on outcomes in the second repetition of the asset market.

counting down 180 seconds, there was no binding time constraint; market prices were not determined until all participants had completed and confirmed their orders.

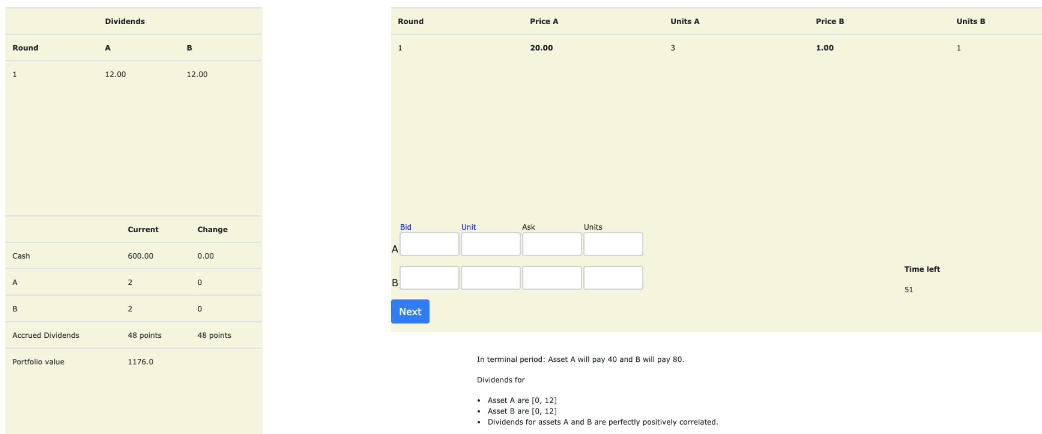


Figure 2: User interface for the RS treatment.

Notes: The top right panel of the screen shows the market clearing prices and volume of trade in the two assets while the top left panel displays the dividends earned per share of each asset in each period (in this example, both assets earned a dividend of \$12). The bottom left panel shows the individual's asset holdings and cash, and the bottom right panel displays the white input boxes where subjects enter buy/sell orders. The dividends accrued (in this example $48 = 12 \times 2 + 12 \times 2$) are put into a separate account, which is not available for trading. The column change refers to the recent flows of variables. Portfolio values use cash and the terminal value per asset plus the sum of expected dividends for the future periods ($1176 = 600 + 2 \times [40 + 6 \times 14 + 80 + 6 \times 14]$).

Each period, subjects were provided with information on the market history (upper right panel) for all previous periods of play. Any holding costs in treatment SS or dividends in treatment RS that subjects accrued over the course of the market were put into a separate account that was paid out or deducted from their earnings at the end of the session. The dividends (holding costs) were displayed to subjects if and only if the subject held the relevant asset. Current asset and cash holdings were also provided, as well as the change in agents' holdings of the two assets relative to the previous period, which appeared as a positive (negative) value for assets bought (sold), and a negative (positive) value for the cash paid (received). We also provided information on the (present) value of the portfolio, which includes cash holdings and the value of the risky assets, computed as the terminal value plus the sum of the expected dividends (or holding costs) per asset for the future periods. Subject endowments of cash and assets for all sessions are presented in Table 1, including the parameters of the market experiment.

Table 3: Overview of experimental sessions

Treatment	Sessions	Participants	Payoff (AUD, without show-up fee)
split (SS)	7	85	24.64
reverse (RS)	7	94	24.21
Total	14	179	24.41

Note: Each session consisted of 10-14 participants. All sessions were conducted online using the subject pool at Monash University. The participants also received a $ 5 AUD as show-up fee.

In total, we conducted 14 online sessions with seven sessions for each of our two treatments (SS and RS) and between 10 and 14 subjects per session. We present an overview of all sessions from our experiment in Table 3. Subjects were undergraduate students studying various programs at Monash University and no subject had any prior experience with our study.

All subjects participated in two, 15-period markets. At the end of the experiment, one of the two markets was randomly selected and subjects' total point earnings from the selected market were converted into AUD dollars at the known exchange rate of $1.25 per 100 points. Subjects' market earnings were equal to the sum of their dividends (holding costs) over all 15 rounds from assets held plus the remaining cash balance and the value of the asset position at the end of the 15th round. On average, each session lasted about one hour and 45 minutes, and the average earnings were $24.78. In addition to these market earnings, subjects also received a show-up fee of $5.

4 Results

4.1 Stock split

We begin our discussion of results with Figure 3 which shows the average prices of assets S and B over the course of 15 periods, in the second market.[13] We classify the periods of trading into three time intervals: (i) pre-announcement, which corresponds to periods $\tau \in [1, 5]$, (ii) the short-run, which are the four periods following the announcement $\tau \in [6, 9]$, and (iii) the long-run, which are the last six periods of trading, $\tau \in [10, 15]$.

[13] In appendix A, we provide complete graphs for all market sessions. In the first market, subjects generally learn how to use the platform and they also learn about the FV process for each asset. It is common to focus on the second market after subjects gain trading experience.

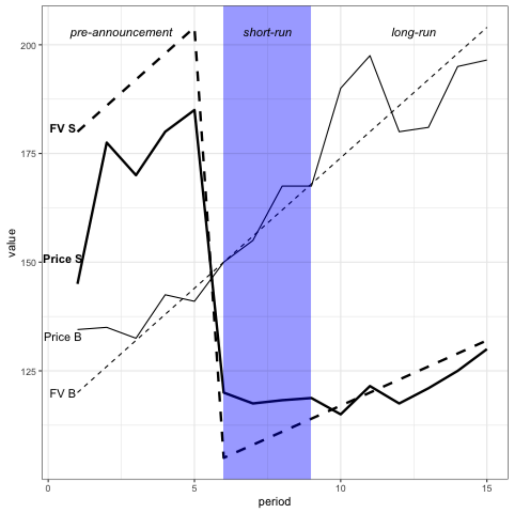


Figure 3: Prices per period in the *SS* treatment.

Note: The average price is computed using data from the second market across the 7 sessions. The FV process follows equation (2) for the converted share S and the benchmark share B. The split is announced following the end of trading in period 5. The short-run, periods 6-9, are shaded.

In the periods during the pre-announcement stage, we observe that the price of shares of asset B, with the lower fundamental value, closely follow that fundamental value (FV B). By contrast, shares of the higher fundamental value asset A are significantly undervalued, trading at a discount relative the FV. This behavior is commonly observed in single asset markets with upward sloping FVs. The share conversion decreases the FV of asset S in the short-run. In period 6, following the announcement, asset S appears to be immediately overvalued while asset B continues to be priced closely to its FV. In the long-run, both shares S and B converge to their respective FVs, though there is some dispersion at the beginning of the long-run phase for asset B. The reversal of asset mispricing to eventually approach the FV is commonly observed in asset market experiments, especially toward the end of asset lifetimes.

Next, we present the summary of measures first introduced in Table 2, and then formally test the impact of share conversion on prices, bid-ask spreads and the volume of trade. Overall, asset B shows a very small deviation with respect to its FV, as measured by RD, in all three stages according to Table 4. The RD for asset S suggests a difference in behavior across the three stages. In the periods leading up to the announcement, the asset S is undervalued by about 14 percent, then overvalued by about 13 percent immediately following the announcement of a split, and then approaches its FV in the long-run. The RD of relative prices, $RD_{B/S}$ which looks at the relative pricing of both assets with respect to their FVs, confirms that both assets approach the FV in the long-run. In the pre-announcement periods, this measure shows a nearly 30 percent deviation suggesting that asset B in initially overpriced relative to asset S, and in the short-run it suggests that B is undervalued by ten percent. In the long-run, the mispricing of both assets decreases as this measure approaches zero.

Table 4: Summary of results for split (SS) treatment

	pre-announcement $1 \leq \tau \leq 5$		short-run $6 \leq \tau \leq 9$		long-run $10 \leq \tau \leq 15$	
	S	B	S	B	S	B
RD	-0.14	0.06	0.13	0.02	-0.04	-0.07
$\text{RD}_{B/S}$	–	0.28	–	-0.10	–	0.05
Spread	90.15	84.09	62.86	96.85	52.25	91.95
Relative spread	0.53	0.58	0.51	0.57	0.46	0.50
Volume	2.17	2.11	1.30× 2	1.64	1.02× 2	1.14

Note: S is the converted share, and B is the benchmark share. All variables of study are defined in Table 2. In our statistical analysis, volume is divided by 2 in the short-run and long-run periods in order to have a fair comparison with respect to B.

The third, "Spread" measure in Table 4, presents the results for the absolute spread between the average ask and bid. We see that the spread for asset S decreases over time, which is consistent with convergence to FVs. The next measure, Relative Spread, considers Spread taking into account the price of the asset. Once the asset price is considered, there is no difference in the spreads of the two assets. Finally, we look at the volume of trade which is measured by the number of transactions in the market. According to Table 4, the adjusted volume of trade decreases over time from about two units per trader, to about one.

Result 1: *Asset S is overpriced in the short-run of the SS treatment.*

In support of Result 1 Table 5 reports on a regression analysis of data from the SS treatment in which we study the impact of stock splits on: (1) mispricing, (2) relative mispricing, (3) the bid-ask spread, (4) relative spread and (5) the volume of trade. The independent variables include SR, which is a dummy variable equal to 1 for the immediate post-split period where $\tau \in [6, 10]$, LR which is a dummy variable for period $\tau \in [11, 15]$, S which takes the value of one for asset S, and zero otherwise, and finally two interaction variables. The constant across all specifications shows the relationship between the aforementioned measures and asset B in the pre-announcement period.

In specification (1) we find that asset S is underpriced in the pre-announcement

Table 5: Market measures in stock split (SS) treatment (OLS regression)

	(1) rd	(2) rd B/S	(3) spread	(4) relative spread	(5) volume
constant	0.060	0.249***	84.09***	0.570***	2.114***
	(0.0448)	(0.0641)	(10.91)	(0.0745)	(0.344)
SR	-0.037	-0.333***	12.76	0.042	-0.471*
	(0.0642)	(0.0698)	(8.155)	(0.0766)	(0.283)
LR	-0.101	-0.217***	7.446	-0.100**	-0.971***
	(0.0713)	(0.0204)	(5.829)	(0.0464)	(0.203)
S	-0.192***	—	6.063	-0.058	0.057
	(0.0439)		(6.194)	(0.0451)	(0.208)
$S \times SR$	0.280***	—	-40.050***	-0.048	-0.396
	(0.0501)		(13.28)	(0.0895)	(0.258)
$S \times LR$	0.195***	—	-45.380***	0.043	-0.176
	(0.0352)		(8.903)	(0.0464)	(0.200)
N	174	150	208	174	210
R^2	0.258	0.330	0.107	0.023	0.131

Notes: S is the converted asset, and B is the benchmark asset (captured by the constant). All dependent variables are defined in Table 2. In our statistical analysis, volume is divided by 2 in the short-run (SR, periods 6-9) and long-run (LR, 9-15) periods to have a fair comparison with respect to B. Standard errors are clustered at the session level and computed via bootstrapping. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

stage, and overpriced by 0.09 in the short-run, or $0.280 - 0.192$, which is different than zero (p-value of 0.001 using a Wald test). In the long-run, we fail to reject that the relative deviation is different from zero, using the sum of the coefficients on S and $S \times LR$ (p-value of 0.549). For the baseline asset B, which does not undergo conversion, we fail to reject that the relative deviation of prices with respect to the fundamental value is zero for all time periods. The overpricing of asset S in the short-run is confirmed by specification (2), which studies the RD of relative prices, and shows that the sum of coefficients is $-0.084 = 0.249 - 0.333$ (p-value < 0.001). This suggests that the relative price of B/S is lower than its relative fundamental.

Result 2: *The volume of trade and relative spreads are not affected by stock splits in the SS treatment.*

According to Table 5 the relative spread, and volume of trade do not vary in the short-run relative to the pre-announcement periods. In the long-run, we find that both the relative spread and the volume of trade decrease over time. The spread of asset B is consistent throughout all periods, and the spread of asset S decreases in the short and long-run, which is consistent with share conversion.

4.2 Reverse stock split

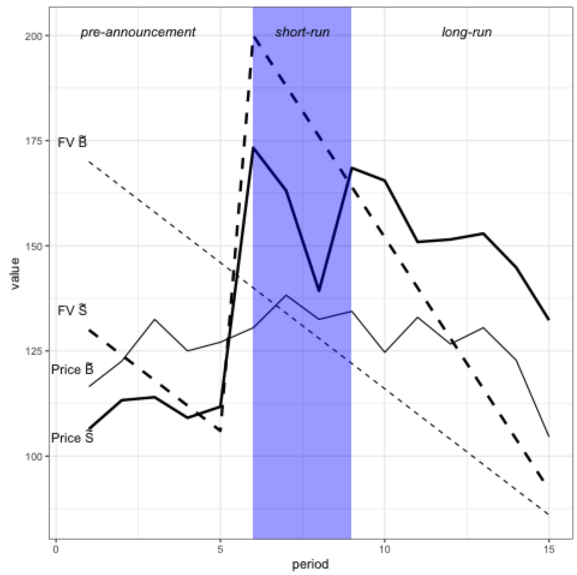


Figure 4: Price per period in the RS treatment

Note: The average price is computed using data for the second market across 7 sessions. The FV process follows equation (3) for the converted share $\tilde{S}$ and the benchmark share $\tilde{B}$. The reverse split is announced at the end of trading following period 5. The short-run periods, 6-9, are shaded.

We next consider the reverse stock, RS treatment. To provide an overview of the effects of a reverse split, we begin our discussion with Figure 4, which presents the average prices per period over the 15 periods of the second market for the seven sessions of the RS treatment.[14]

Consistent with the initial price dynamics observed in the SS treatment, the asset with the higher FV, $\tilde{B}$, is underpriced. In the short-run, following the reverse split (periods 6-9 inclusive), we observe that $\tilde{B}$ is roughly fairly price while $\tilde{S}$ is underpriced.

Similar to the summary of results presented for the SS treatment, Table 6 presents the various asset market measures for the RS treatment. The RD measure suggests that in the pre-announcement period, the asset with the lower FV, (asset $\tilde{S}$), is fairly

[14] In Appendix B, we provide complete graphs of prices for all market sessions of the RS treatment.

priced (-0.05), while the asset with the higher FV (asset $\tilde{B}$) is underpriced (-0.19). In the short-run period following the reverse split, $\tilde{B}$ is now fairly priced (0.02), while the reverse split asset is underpriced (-0.14). Bubbles appear in the long-run (0.25 and 0.22 for $\tilde{S}$ and $\tilde{B}$, respectively). The RD of relative prices shows that while $\tilde{B}$ is underpriced relative to $\tilde{S}$ in the pre-announcement periods, it becomes overpriced in the immediate short-run period following the reverse split. In the long-run, we observe that the relative price dispersion decreases significantly.

Table 6: Summary of results for reverse split treatment

	pre-announcement $1 \leq \tau \leq 5$		short-run $6 \leq \tau \leq 9$		long-run $10 \leq \tau \leq 15$	
	$\tilde{S}$	$\tilde{B}$	$\tilde{S}$	$\tilde{B}$	$\tilde{S}$	$\tilde{B}$
RD	-0.05	-0.19	-0.14	0.02	0.25	0.22
$\text{RD}_{\tilde{B}/\tilde{S}}$	–	-0.13	–	0.23	–	0.02
Spread	49.86	73.91	94.39	46.70	74.83	59.38
Relative spread	0.41	0.54	0.62	0.33	0.43	0.44
Volume	2.43	2.29	2.14÷2	2.11	2.28÷2	1.64

Note: $\tilde{S}$ is the converted asset, and $\tilde{B}$ is the benchmark asset. All variables are defined in Table 2. In the short-run and long-run periods, volume is multiplied by 2 for the converted share $\tilde{S}$ for a fair comparison with respect to $\tilde{B}$.

The next measure presents the results for the absolute spread between the average ask and bid. The spread for asset $\tilde{B}$ decreases in the short-run relative to the pre-announcement period (from 73.91 to 46.70), and increases in the long-run (59.38). The relative spread for $\tilde{B}$, which is adjusted for asset price, shows a similar pattern compared to the spread, decreasing in the short-run (from 0.54 to 0.33) and increasing in the long run (0.43). For asset $\tilde{S}$, we observe an increase in the spread in the short-run from 49.86 to 94.39, which is consistent with share conversion, followed by a decrease in the long-run (0.43).

The volume of transactions appears to be similar across both assets. In the pre-announcement period, it is 2.29 for $\tilde{B}$ and 2.43 for $\tilde{S}$, and in the short-run and long-run, it is appropriate to multiply by two the number of shares transacted to account for conversion (in this case, reduction of shares in the market). Once adjusted for conversion, the average quantity of units transacted is 2.14 for $\tilde{S}$ and 2.11 for $\tilde{B}$. In the long run, the volume is 2.28 for $\tilde{S}$ and 1.64 for $\tilde{B}$.

Result 3: *In the RS treatment, assets $\tilde{S}$ is underpriced in the short run, and fairly priced in the long-run, relative to $\tilde{B}$.*

Table 7: Market measures in the reverse split (RS) treatment (OLS regression)

	(1) rd	(2) rd $\tilde{B}/\tilde{S}$	(3) spread	(4) relative spread	(5) volume
constant	-0.208***	-0.122**	73.91***	0.496***	2.286***
	(0.0326)	(0.0489)	(17.68)	(0.114)	(0.296)
SR	0.230***	0.364***	-27.21**	-0.178*	-0.179
	(0.0478)	(0.110)	(13.70)	(0.0925)	(0.242)
LR	0.449***	0.142***	-14.53	-0.0735	-0.643**
	(0.0588)	(0.0497)	(16.86)	(0.112)	(0.290)
$\tilde{S}$	0.146***	—	-25.35*	-0.0894	0.143
	(0.0480)		(13.32)	(0.0881)	(0.211)
$\tilde{S} \times SR$	-0.286**	—	70.22***	0.386***	-0.107
	(0.114)		(17.77)	(0.0905)	(0.458)
$\tilde{S} \times LR$	-0.128***	—	40.08***	0.113*	0.500
	(0.0411)		(10.30)	(0.0640)	(0.530)
N	164	134	198	164	210
R^2	0.541	0.398	0.087	0.059	0.024

Note: $\tilde{S}$ is the converted asset, and $\tilde{B}$ is the benchmark share, captured by the constant. All dependent variables are defined in Table 2. In our statistical analysis, volume is multiplied by 2 in the short-run (SR, periods 6-9) and long-run (LR, 9-15) periods in order to have a fair comparison with respect to B. Standard errors are clustered at the session level and computed via bootstrapping. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

We formally test the impact of a reverse split on relative deviation (RD) in the first specification of Table 7, which like Table 5 uses OLS regressions to understand various asset market measures. In the first specification regarding RD, we observe that in the pre-announcement period, the asset with the higher FV, $\tilde{B}$, is undervalued while the asset with a lower FV, $\tilde{S}$, is fairly priced given that we cannot reject that the constant estimate plus the value of the coefficient on $\tilde{S}$ is equal to zero (p-value of 0.26 using a Wald test). In the short-run period, following the reverse split, we fail to reject that asset $\tilde{B}$ is fairly priced in a test of whether the sum of coefficients $0.230 - 0.208$ is different than zero (p-value of 0.66). For asset $\tilde{S}$, there is weak evidence that asset $\tilde{S}$ is under-priced in the short-run by about 0.12, the sum of the four coefficients $0.230 + 0.146 - 0.286 - 0.208$, since we can reject the null that this sum is equal to zero (p-value of 0.06). In the long-run, we find that asset $\tilde{B}$ is over-priced by $0.366 = 0.449 - 0.208$ (p-value < 0.001) as is asset $\tilde{S}$, by $0.26 = 0.449 + 0.146 - 0.128 - 0.208$ (p-value < 0.001).

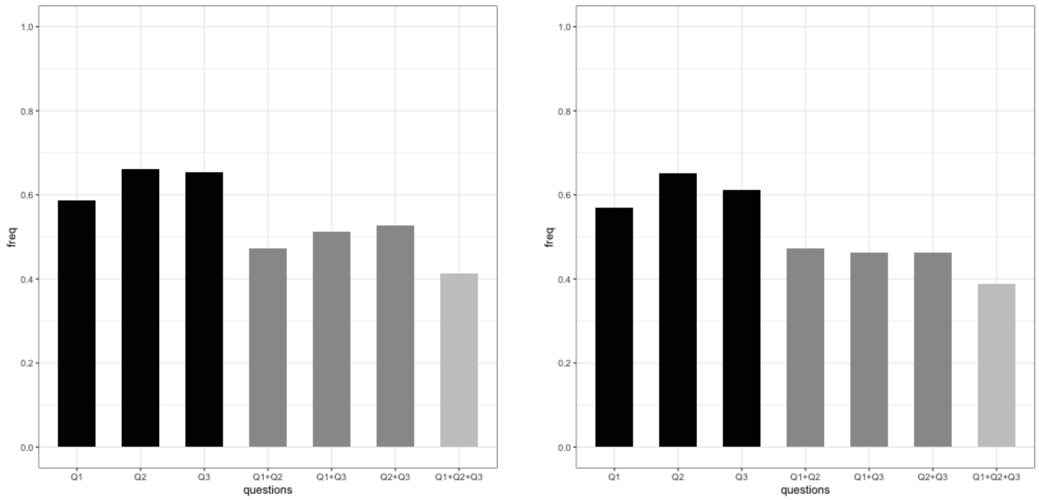
In terms of the RD of relative prices, we observe that asset $\tilde{B}$ is undervalued with respect to $\tilde{S}$ (-0.122, p-value < 0.05) in the pre-announcement period and overvalued in the short-run by 0.24 (p-value < 0.01). Thus, the measure of relative price dispersion provides clear evidence that the reverse split asset is underpriced relative to the benchmark asset. In the long-run, we find that asset $\tilde{B}$ is fairly priced relative to $\tilde{S}$ (p-value of 0.47).

Result 4: *In the RS treatment, the volume of trade does not change in the short-run, and decreases for all assets in the long-run. The relative spread for asset $\tilde{S}$ is higher in the short-run compared with asset $\tilde{B}$.*

In the pre-announcement period we observe that an average of 2.28 units are transacted per period. In the long run, the number of units transacted for both assets decreases by 0.643 (p-value < 0.05) according to specification (5) in Table 7. Furthermore, we find that the relative spread for asset $\tilde{S}$ increases by 0.386 (p-value < 0.001) in the short-run according to specification (4) in Table 7. For $\tilde{B}$, we find evidence that the relative spread decreases in the short run by 0.178 (p-value < 0.10). In the long-run, we do not find evidence of a significant change in the relative spread (at the five percent significance level) for either asset.

5 Cognitive ability and non-proportional thinking

In addition to participating in an asset market, subjects in both treatments answered three CRT questions taken from Toplak et al. (2014) as discussed earlier. Figure 5 presents the frequency of correct responses for both treatments, *RS* and *SS*, and as well as a breakdown of which of the three questions were answered correctly. We look at the following categories: (i) the frequency of correct responses to individual questions, shaded in back, (ii) the frequency of correct responses to two of the three questions, shaded in dark grey, and (iii) the frequency of correct responses to all three CRT questions, shaded in light grey. The results suggest that the distribution of questions answered correctly is the same across both treatments. The percentage of correct responses is about 60 percent for each question, and 40 percent of subjects answered all three questions correctly. On average, subjects answered about two of the three questions correctly.



(a) SS treatment   **(b)** RS treatment

Figure 5: Frequency of correct responses per question (percentage)

In order to better understand the under-reaction of asset prices in the SS and RS treatments to stock (reverse) split announcements, we use regression analysis to study the relationship between a subject's cognitive ability (CRT performance) and the deviations of their bids and asks with respect to fundamental values. These results are presented in Table 8 for the SS treatment, and Table 9 for the RS treatment.

We report on OLS regressions with standard errors clustered at the session level, where the dependent variable is the absolute value of the difference between the bid and the FV for asset S in specification (1), and the ask and the FV for asset S in specification (2), and present the results in Table 8. Specifications (3) and (4) employ the same approach for asset B. For independent variables we used the period dummies, SR (to capture the short-run periods 6-9) and LR (to capture the long run periods 10-15), and each subject's CRT score for question 3 (correct=1, incorrect=0). We isolate question 3 because as noted earlier it not only requires reflection, but also specifically requires proportional thinking, which is the ability that we are trying to estimate in our analysis. We also present a similar regression analysis table, but where we use the overall score (out of 3) on all CRT questions in Appendix C, which supports the results discussed here. The interaction terms, $SR \times CRT$, and $LR \times CRT$, estimate how a correct answer to question 3 affects the dependent variable in the short and in the long-run, respectively.

The constant in all specifications can be interpreted as the difference between the

Table 8: *SS*: Bids and asks relative to the FV (OLS regression)

	(1) |Bid S - FV S|	(2) |Ask S - FV S|	(3) |Bid B - FV B|	(4) |Ask B - FV B|
constant	101.7***	66.13***	61.50***	51.66***
	(3.457)	(8.186)	(3.744)	(5.922)
SR	-35.61***	-15.61*	2.944	8.874**
	(4.656)	(8.316)	(2.916)	(4.092)
LR	-49.23***	-20.12***	25.44***	19.39***
	(3.724)	(4.320)	(6.875)	(7.005)
CRT	-43.52***	-6.708	-23.67***	-1.774
	(7.805)	(11.23)	(6.461)	(8.046)
$SR \times CRT$	8.134*	5.318	-1.093	-16.17***
	(4.818)	(10.54)	(3.246)	(2.975)
$LR \times CRT$	21.76***	-12.54***	-10.77*	-34.98***
	(4.877)	(4.063)	(6.154)	(7.150)
N	1929	2034	1971	1638
R^2	0.181	0.0508	0.0936	0.0441

Note: S is the split asset, and B is the benchmark asset. FV is the fundamental value per share at time τ. The CRT score uses question 3: "If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together?" SR includes periods 6-9 and LR includes periods 10-15. Standard errors are clustered at the session level and computed via bootstrapping. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

bid and the FV, or the difference between the ask and the FV, in the pre-announcement period for subjects who *do not* answer the CRT question correctly. We find that across all specifications, these deviations from the FV, from both the buyer and seller perspectives, are highly significant. In the pre-announcement period, subjects who answer the CRT question correctly, submit bids that are significantly closer to the FV. For example, in specification (1) for asset S in Table 8 the coefficient on the CRT dummy variable is negative, which means that those who answered the CRT question correctly bid closer to the FV by about 43.5 points.

In the short-run, the deviation of bids from the FV decreases for those who answer the CRT question incorrectly (by 35.61). However, subjects who answer the CRT question correctly submit orders that are even closer to FV since the sum of the coefficients for $SR \times CRT$ and CRT is negative and significantly different from zero (p-value$<$ .001 using a Wald test). In the long-run, the bids of subjects with low CRT scores are closer to the FV, though their deviations are still greater than for subjects with high CRT scores (the sum of coefficients for $LR \times CRT$ and CRT is negative and statistically

Table 9: *RS*: Bids and asks relative to the FV (OLS regression)

	(1) $\lvert$Bid $\tilde{S}$ - FV $\tilde{S}\rvert$	(2) $\lvert$Ask $\tilde{S}$ - FV $\tilde{S}\rvert$	(3) $\lvert$Bid $\tilde{B}$ - FV $\tilde{B}\rvert$	(4) $\lvert$Ask $\tilde{B}$ - FV $\tilde{B}\rvert$
constant	57.59***	63.12***	80.25***	83.69***
	(7.323)	(7.575)	(10.59)	(7.686)
SR	41.84***	62.74***	-23.08***	-20.93***
	(5.820)	(15.17)	(6.876)	(5.245)
LR	5.002*	26.24***	-21.84***	-22.50***
	(2.955)	(5.856)	(7.863)	(6.980)
CRT	-19.38**	-25.31*	-26.02**	-24.77
	(7.771)	(15.03)	(10.75)	(18.84)
$SR \times CRT$	-11.39*	-14.27	-2.441	10.95
	(6.269)	(11.52)	(6.982)	(9.785)
$LR \times CRT$	-6.423	6.956	-5.354	25.07*
	(6.448)	(13.19)	(8.649)	(12.99)
N	814	508	763	647
R^2	0.170	0.0753	0.186	0.0116

Note: $\tilde{S}$ is the split asset, and $\tilde{B}$ is the benchmark asset. FV is the fundamental value per share at time τ. The CRT score uses question 3: "If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together?". SR includes periods 6-9 and LR includes periods 10-15. Standard errors are clustered at the session level and computed via bootstrapping. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

different than zero, p-value< .001 using a Wald test). The deviation of asks relative to the FV for S is lower in the long-run for subjects with higher CRT scores. The bids and asks for B show a similar pattern — subjects who answer the CRT question correctly submit bids/asks that are closer to the FV than those who do not.

To analyze subject behavior in the RS treatment, we report on similar OLS regressions, where the dependent variable is the absolute value of the difference between the bid and the FV for asset $\tilde{S}$ in specification (1), and the ask and the FV for asset $\tilde{S}$ in specification (2). We perform a similar analysis for asset $\tilde{B}$ in specifications (3) and (4), and present all results in Table 9. The coefficient on the constant term, which is significant in all specifications, represents the difference between the bid and the FV, or the ask and the FV, in the pre-announcement period for subjects who answered the CRT question incorrectly. Just as in the SS treatment, we find that a higher CRT score is associated with more accurate bids relative to the FV. For the asks, we do not find a statistically significant effect of the CRT variable on our dependent variables at the 5 percent level.

6 Conclusion

In this paper, we introduce a novel experiment to study the effect of stock splits and reverse splits on the immediate short-term pricing of assets subject to a split as well as assets that do not experience a split. In the *SS* treatment, where we study the effect of a 1 for 2 share split, we find that the split asset is overpriced relative to its fundamental value in the short-term, while the non-converted asset is fairly priced. In the long run, the price of the split asset reverts to its fundamental value. In the *RS* treatment, where we study the effect of a 2 for 1 *reverse* share split, we find that prices are below the fundamental value in the immediate short-term for the split asset and above the fundamental value for both assets in the long run, which is consistent with previous experiments in a SSW environment. Thus, we show that markets under react to (reverse) splits — that is, they do not make the full adjustment necessary to be consistent with the new fundamental value per share in either case. Further, across both treatments, we find no evidence of a change in trading volume following the split announcements.

The laboratory provides an ideal environment in which to study stock splits, allowing us to control for survival bias (Brown et al., 1995), and capture some of the anomalies observed in field data.[15] Our design further allows us to highlight the importance of individual behavior in explaining market phenomena (see also Daniel et al., 2020 and references therein) while controlling for the signaling effects of such events. We provide evidence of non-proportional thinking by studying the relationship between cognitive ability and the bids and asks of market participants. Our findings show that subjects with higher CRT scores submit orders closer to fundamental values as compared to subjects with lower CRT scores following a stock (reverse) split announcement.

In studying the market's reaction to stock splits in a laboratory experiment, we have tremendous internal validity (causal inference) but our findings might be viewed more skeptically on the external validity dimension in that our student subjects are not professional market traders. Further, there may be important elements of financial markets that we abstract away from in our experimental design. For instance, it may be that stock splits provide market signals attracting traders from the sidelines and/or

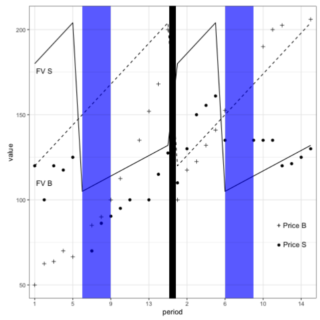
[15] Fink et al. (2020) also provide evidence of abnormal returns following earnings announcements.

speculators who would not otherwise be present and we do not allow for such changes in the number of traders in our market experiment.

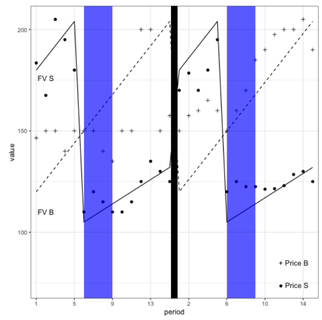
Nevertheless, we believe there are good reasons to think that our results are externally valid and that our non-proportional thinking rationale for market reactions to stock splits (or reverse splits) extends to the field as well. In particular, Weitzel et al. (2020) find that financial market professionals are also susceptible to asset market bubbles and crashes of the SSW variety and do not differ from student subjects in their performance on CRT tests questions of the same variety that we used in our experiment.[16] Bosch-Rosa et al. (2018) report that more cognitively sophisticated groups of subjects (based on measures such as CRT tests) are less likely to misprice SSW-type assets than are less cognitively sophisticated subjects. While our results are consistent with this literature studying the role of cognitive ability on trader performance, our finding that market reaction to *events* such as splits and reverse splits can also be explained by individual characteristics provides some greater context for the cognitive-biases explanation for financial market behavior. Finally, as noted earlier, Shue and Townsend (2021) report field evidence consistent with non-proportional thinking in their analysis of the asymmetric price volatility of low priced stocks in reaction to announced splits versus reverse splits. For all of these reasons, we think that our experimental findings are relevant to understanding the market's reactions to stock splits and reverse splits.

[16]More generally, Frechette (n.d.) surveys experimental studies comparing professionals versus students and finds, remarkably, that only in 1 study out of 13 under consideration is the behavior of professionals closer to the theoretical predictions than that of students.

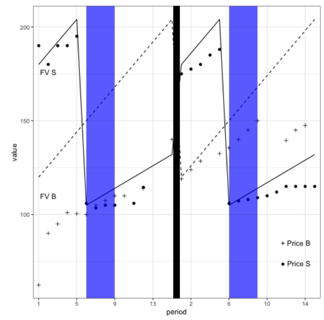
Appendix A: Price plots for the SS treatment



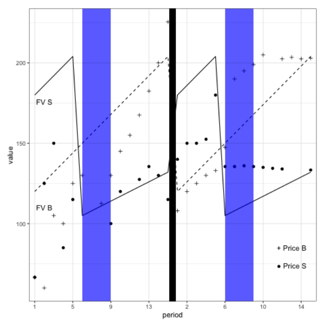
(a) Session 1



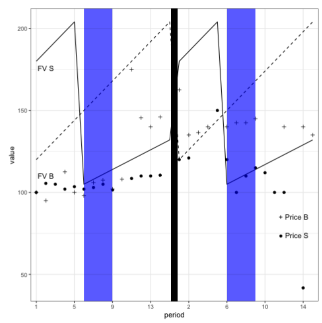
(b) Session 2



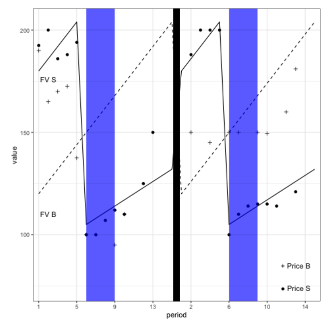
(c) Session 3



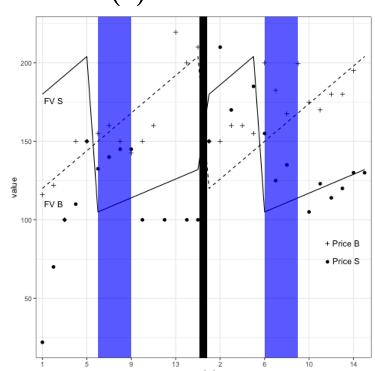
(d) Session 4



(e) Session 5



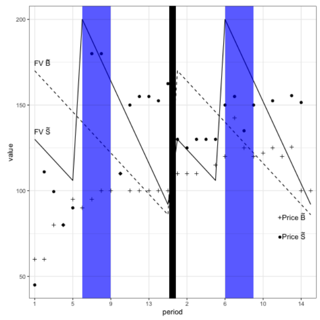
(f) Session 6



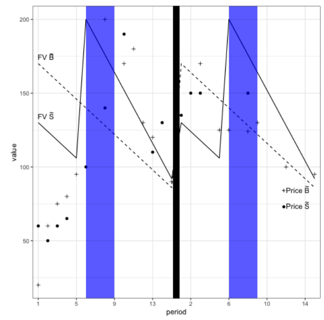
(g) Session 7

Figure 6: Asset prices and fundamental values per period (2 markets).

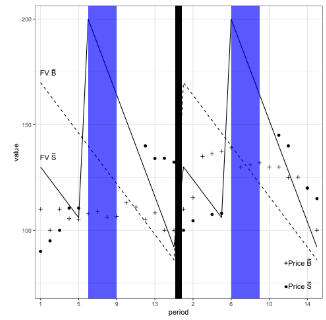
Appendix B: Price plots for the RS treatment



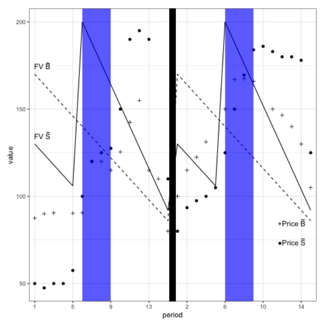
(a) Session 1



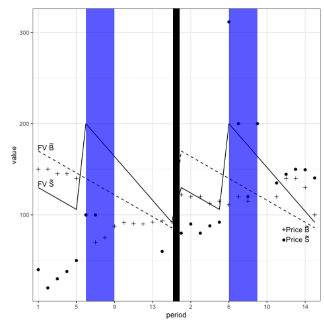
(b) Session 2



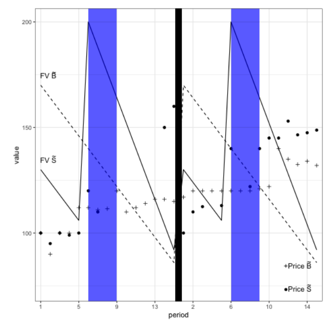
(c) Session 3



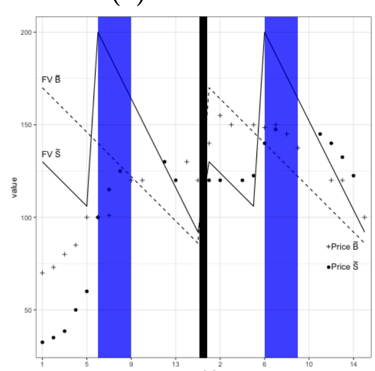
(d) Session 4



(e) Session 5



(f) Session 6



(g) Session 7

Figure 7: Asset prices and fundamental values per period (2 markets).

Appendix C: Additional regressions using all CRT questions

Table 10: Bids and asks relative to the FV (OLS regression)

	(1) |Bid S - FV S|	(2) |Ask S - FV S|	(3) |Bid B - FV B|	(4) |Ask B - FV B|
constant	101.7***	78.54***	63.54***	51.17***
	(3.401)	(8.631)	(2.986)	(4.667)
SR	-32.74***	-19.46*	1.904	4.093
	(4.750)	(9.939)	(4.600)	(6.831)
LR	-45.06***	-30.92***	25.89***	17.99**
	(3.606)	(9.751)	(9.022)	(8.443)
CRT	-14.90***	-8.480***	-9.143***	-0.388
	(2.143)	(2.968)	(2.044)	(1.876)
$SR \times CRT$	1.610	3.971	0.0813	-3.396
	(1.470)	(4.589)	(1.699)	(3.049)
$LR \times CRT$	5.579***	0.878	-3.905	-11.67***
	(1.780)	(4.021)	(2.952)	(2.900)
N	1929	2034	1971	1638
R^2	0.162	0.0603	0.0845	0.0285

Note: S is the split asset, and B is the benchmark asset. The CRT score uses all three questions. SR includes periods 6-9 and LR includes periods 10-15. Standard errors are clustered at the session level and computed via bootstrapping. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

Table 11: Bids and asks for *RS* treatment relative to the FV (OLS regression)

	(1) $\lvert$Bid $\tilde{S}$ - FV $\tilde{S}\rvert$	(2) $\lvert$Ask $\tilde{S}$ - FV $\tilde{S}\rvert$	(3) $\lvert$Bid $\tilde{B}$ - FV $\tilde{B}\rvert$	(4) $\lvert$Ask $\tilde{B}$ - FV $\tilde{B}\rvert$
constant	68.72***	79.23***	93.56***	103.1***
	(6.002)	(9.165)	(9.064)	(9.134)
SR	50.88***	82.61***	-28.53***	-17.68*
	(5.568)	(20.96)	(4.207)	(9.367)
LR	4.358	32.69**	-30.46***	-23.35**
	(4.043)	(13.21)	(4.083)	(9.204)
CRT	-12.60***	-17.49***	-15.59***	-19.67***
	(3.089)	(3.224)	(3.331)	(3.491)
$SR \times CRT$	-8.229***	-18.38***	1.466	2.152
	(1.918)	(6.845)	(1.918)	(5.942)
$LR \times CRT$	-1.841	-2.426	1.605	9.839**
	(2.641)	(5.518)	(2.109)	(4.399)
N	814	508	763	647
R^2	0.241	0.143	0.232	0.0421

Note: $\tilde{S}$ is the split asset, and $\tilde{B}$ is the benchmark asset. The CRT score uses all three questions. SR includes periods 6-9 and LR includes periods 10-15. $^{***}p \leq 0.01$, $^{**}p \leq 0.05$, $^{*}p \leq 0.1$

References

Bosch-Rosa, Ciril, Thomas Meissner, and Antoni Bosch-Domènech, "Cognitive bubbles," *Experimental Economics*, 2018, *21* (1), 132–153.

Brown, Stephen J, William N Goetzmann, and Stephen A Ross, "Survival," *The Journal of Finance*, 1995, *50* (3), 853–873.

Charness, Gary and Tibor Neugebauer, "A Test of the Modigliani-Miller Invariance Theorem and Arbitrage in Experimental Asset Markets," *The Journal of Finance*, 2019, *74* (1), 493–529.

Chen, Daniel L, Martin Schonger, and Chris Wickens, "oTree—An open-source platform for laboratory, online, and field experiments," *Journal of Behavioral and Experimental Finance*, 2016, *9*, 88–97.

Copeland, Thomas E, "Liquidity changes following stock splits," *The Journal of Finance*, 1979, *34* (1), 115–141.

Corgnet, Brice, Mark Desantis, and David Porter, "What makes a good trader? On the role of intuition and reflection on trader performance," *The Journal of Finance*, 2018, *73* (3), 1113–1137.

Crosetto, Paolo and Antonio Filippin, "The "bomb" risk elicitation task," *Journal of Risk and Uncertainty*, 2013, *47* (1), 31–65.

Cui, Chenyu, Frank Weikai Li, Jiaren Pang, and Deren Xie, "The market reaction to stock splits," *Available at SSRN: https://ssrn.com/abstract=3541201*, 2021.

Daniel, Kent, David Hirshleifer, and Lin Sun, "Short-and long-horizon behavioral factors," *The Review of Financial Studies*, 2020, *33* (4), 1673–1736.

Desai, Hemang and Prem C Jain, "Long-run common stock returns following stock splits and reverse splits," *the Journal of Business*, 1997, *70* (3), 409–433.

Duffy, John, Jean Paul Rabanal, and Olga Rud, "The impact of ETFs in secondary asset markets: Experimental evidence," *Journal of Economic Behavior & Organization*, 2021, *188*, 674–696.

Easley, David, Maureen O'hara, and Gideon Saar, "How stock splits affect trading: A microstructure approach," *Journal of Financial and Quantitative Analysis*, 2001, pp. 25–51.

Fama, Eugene F, Lawrence Fisher, Michael C Jensen, and Richard Roll, "The adjustment of stock prices to new information," *International economic review*, 1969, *10* (1), 1–21.

Fink, Josef, Stefan Palan, Erik Theissen et al., "Earnings Autocorrelation and the Post-Earnings-Announcement Drift–Experimental Evidence," *Karl-Franzens-Universität Graz, Sozial-und Wirtschaftswissenschaftliche Fakultät Working Paper Series*, 2020, *2020.*

Frechette, Guillaume, "Laboratory Experiments: Professionals versus Students," in Guillaume Frechette and Andrew Schotter, eds., *Handbook of Experimental Economic Methodology.*

Frederick, Shane, "Cognitive reflection and decision making," *Journal of Economic perspectives*, 2005, *19* (4), 25–42.

Gharghori, Philip, Edwin D Maberly, and Annette Nguyen, "Informed trading around stock split announcements: Evidence from the option market," *Journal of financial and quantitative analysis*, 2017, *52* (2), 705–735.

Grinblatt, Mark, Matti Keloharju, and Juhani Linnainmaa, "IQ and stock market participation," *The Journal of Finance*, 2011, *66* (6), 2121–2164.

Grinblatt, Mark S, Ronald W Masulis, and Sheridan Titman, "The valuation effects of stock splits and stock dividends," *Journal of financial economics*, 1984, *13* (4), 461–490.

Haruvy, Ernan, Charles N Noussair, and Owen Powell, "The impact of asset repurchases and issues in an experimental market," *Review of Finance*, 2014, *18* (2), 681–713.

He, Yan and Junbo Wang, "Stock split decisions: A synthesis of theory and evidence," *Journal of Applied Finance (Formerly Financial Practice and Education)*, 2012, *22* (2).

Ikenberry, David L and Sundaresh Ramnath, "Underreaction to self-selected news events: The case of stock splits," *The Review of Financial Studies*, 2002, *15* (2), 489–526.

Kahneman, Daniel, *Thinking, fast and slow*, Farrar, Straus and Giroux, 2011.

Kocher, Martin G, Konstantin E Lucks, and David Schindler, "Unleashing animal spirits: Self-control and overpricing in experimental asset markets," *The Review of Financial Studies*, 2019, *32* (6), 2149–2178.

Lamoureux, Christopher G and Percy Poon, "The market reaction to stock splits," *The journal of finance*, 1987, *42* (5), 1347–1370.

Magnani, Jacopo, Jean Paul Rabanal, Olga Rud, and Yabin Wang, "Efficiency of Dynamic Portfolio Choices: An Experiment," *The Review of Financial Studies*, 2021.

Muscarella, Chris J. and Michael R. Vetsuypens, "Stock splits: Signaling or liquidity? The case of ADR 'solo-splits'," *Journal of Financial Economics*, 1996, *42* (1), 3–26.

Penalver, Adrian, Nobuyuki Hanaki, Eizo Akiyama, Yukihiko Funaki, and Ryuichiro Ishikawa, "A quantitative easing experiment," *Journal of Economic Dynamics and Control*, 2020, *119*, 103978.

Shue, Kelly and Richard R Townsend, "Can the market multiply and divide? Non-proportional thinking in financial markets," *The Journal of Finance*, 2021.

Smith, Vernon L, Gerry L Suchanek, and Arlington W Williams, "Bubbles, crashes, and endogenous expectations in experimental spot asset markets," *Econometrica: Journal of the Econometric Society*, 1988, pp. 1119–1151.

Svedsäter, Henrik, Amelie Gamble, and Tommy Gärling, "Money illusion in intuitive financial judgments: Influences of nominal representation of share prices," *The Journal of Socio-Economics*, 2007, *36* (5), 698–712.

Titman, Sheridan, Chishen Wei, and Bin Zhao, "Corporate actions and the manipulation of retail investors in China," *Second Annual Volatility Institute at NYU Shanghai (VINS)*, 2016.

Toplak, Maggie E., Richard F. West, and Keith E. Stanovich, "Assessing miserly information processing: An expansion of the Cognitive Reflection Test," *Thinking & Reasoning*, 2014, *20* (2), 147–168.

Ungeheuer, Michael and Martin Weber, "The perception of dependence, investment decisions, and stock prices," *The Journal of Finance*, 2020.

Weitzel, Utz, Christoph Huber, Jürgen Huber, Michael Kirchler, Florian Lindner, and Julia Rose, "Bubbles and financial professionals," *The Review of Financial Studies*, 2020, *33* (6), 2659–2696.