Experiments on Electronic Double Auctions and Abnormal Trades

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Abstract: The flash crash experienced by U.S. markets in May 2010 provided stark evidence that a large trade can have a powerful influence. We explore the impact of an unusual trade on behavior in experimental bubbles markets. We chose the experimental design proposed by Smith, Suchanek, and Williams (1988) because replication shows it produces markets prone to mispricing. After several rounds of trading, our markets receive a large quantity order at an extreme price. In a standard double auction bubble market, pricing is unaffected by an abnormal order. However, with increased uncertainty about the underlying economic value of the asset, over-pricing weakens upon arrival of a negative price shock.

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I. Introduction

Well-functioning financial markets are crucial to investors and policymakers who strive to generate wealth and promote economic growth. To their dismay, asset markets can be very volatile and sometimes appear to move without regard for economic fundamentals. To add to concerns about the functioning of markets, price swings in recent decades have been quite dramatic.[1] In this decade, the Chinese stock market is certainly a prominent example. According to former Morgan Stanley Asia Chairman Stephen Roach, the Chinese market rose in an "enormous speculative frenzy" and now "the bubble is bursting" (Belvedere 2015).

The appropriate policy action in a frothy market is unclear and recent advances in technology further blur vision. Of particular concern is the advent of high-frequency, computer-based trading (HFT).[2] Offers to trade that are implemented algorithmically can be problematic if they are triggered by previous transactions that are not information based. We have seen that trader errors and computer glitches can lead to chaos, and leave many questioning the operational efficiency of markets and the role of HFT. This paper examines the impact of an aberrant order on the functioning of a market using an experimental method.

One extreme order can have a large impact on a market. For example, on September 17, 2012 several U.S. oil stocks experienced price swings likely due to a "fat-finger" order or data entry error (Jarzemsky 2012). In another newsworthy case, a large Chinese broker experienced a systems glitch that is blamed for a sudden 6% increase in the Shanghai Composite Index (Yan 2013). Of course the U.S. market disruption on May 6, 2010, the "flash crash," is etched in the memory of most market participants. Markets and regulators were in disbelief as they watched a sudden drop in stock prices and subsequent recovery all within a short 20-minute time period

(Report of the Staffs of the CFTC and SEC 2010). Recently much of the blame for the flash crash has been placed on a high frequency trader based in the United Kingdom. This trader has been charged with manipulating a market that was vulnerable due to a large trade previously initiated by an investor in the United States (Popper and Anderson 2015).

As market disruptions observed around the world have taught us, a large trade can have powerful, even if short-lived, influence in a market. In this article we explore the impact of an unusual order on behavior in an experimental bubbles market. After several rounds of trading in our markets the experimenter enters a large quantity order at an extreme price, i.e., a price quite distant from the underlying fundamental value. We then observe how the market responds to the aberrant order. While practitioners and policymakers are concerned about trader and computer errors, little systematic evidence has been presented on this issue. We use the experimental method, which allows control over the asset's fundamental value, the timing and size of the unusual order, and other aspects of the environment so that we can focus on the impact of an aberrant order on market outcomes.

We intentionally adopt the experimental design first proposed by Smith, Suchanek, and Williams (1988) because replication shows it produces markets prone to mispricing. In their design an asset with finite life is traded and all participants know the dividend-generating process. With this knowledge, fundamental value is easily computed as the expected dividend per period times the number of remaining trading periods. The evidence on behavior in bubbles markets is voluminous and Palan (2013) provides a recent review and synthesis. There is compelling evidence of mispricing in this market structure as researchers have replicated mispricing in a large variety of treatment conditions (e.g., King, Smith, Williams, and van Boening 1993; Ackert, Charupat, Church, Deaves 2006; Haruvy and Noussair 2006). Some have devoted attention to discovering why bubbles are generated in this particular design (e.g., Ackert, Charupat, Deaves, and Kluger 2009; Kirchler, Huber, and Stöckl 2012) or how they can be dissipated (e.g., Porter and Smith 1995; Lei, Noussair, and Plott 2001). In contrast, our goal is to provide insight into the impact of an aberrant order in a market prone to mispricing, an investigation that has not been previously conducted.

A great deal of research has examined the reaction of experimental markets to both quantitative (e.g., Coller 1996) and qualitative (e.g., Corgnet, Kujal, and Porter 2010) information. In some cases the reliability of the public information release is uncertain (e.g., Ackert, Church, and Gillette 2004), and in others the public release is actually uninformative (e.g., Stoian 2014). Unlike this previous research in which participants knew they would receive a message during the trading session, in our markets traders are given no reason to expect the unusual order that arrives at the market. As in naturally-occurring markets, when a curious offer to trade is placed, market participants do not know if the order reflects information or is in error. We examine how an unexpected and uninformative event, such as a fat-finger trade, impacts subsequent pricing in a market known to be prone to mispricing.

In addition to a baseline treatment (treatment 1) in which no aberrant order arrives at the market, we conduct treatments in which a large order arrives at an unusually high or low price after several periods of trading (treatments 2 and 3). As we report subsequently, a large order at an extreme price (high or low) has no discernable impact on observed mispricing.

To further investigate the impact of an unusual order, we conduct two additional treatments in which we increase the uncertainty of the dividend payments. Prior research by Hussam, Porter, and Smith (2008) indicates that price bubbles dissipate with experience but *only under stable conditions*.[3] In a second baseline (treatment 4), traders face additional uncertainty regarding dividend payments. Given the importance of a stable environment to efficient pricing as shown by Hussam, Porter, and Smith (2008), we include a treatment in which traders face additional uncertainty regarding the level of dividend payoffs when a large order arrives at an unusually low price (treatment 5). The more uncertain environment allows us to investigate whether behavior is affected by the mere *possibility* of a shift in the environment. In this extension of the previous treatments, the abnormal order could be indicative of a dividend regime change. We find that a large order at a low offering price reduces mispricing in a less stable market environment.

The remainder of this paper is organized as follows. Section 2 describes the experimental procedures and design. Section 3 reports the results. Section 4 contains a discussion of the results and concluding remarks.

2. Experimental Design

The asset market experiments were conducted at Tsinghua University in Bejing, China. Twenty-seven market sessions were conducted (in addition to one pre-test).[4] The experimental design, summarized in Panel A of Table 1, includes a baseline treatment (No Shock), markets with positive and negative shocks (Positive and Negative Shock), markets with fundamental value uncertainty and no shock (FV Uncertainty No Shock), and markets with fundamental value uncertainty and a negative shock (FV Uncertainty Negative Shock).

Ten traders participated in each session. The 270 participants were university students and all were inexperienced in that none had participated in an earlier session. Traders earned from 40.28¥ to 260.45¥ for participating, with an average (median) payout of 155.03¥ (154.40¥). Converted to U.S. dollars at contemporaneous exchange rates, traders earned from $6.49 to

$41.83 for participating, with an average (median) payout of $25.03 ($24.88). This level of compensation is quite motivating for students who earn approximately 6.20¥ per hour working as student assistants at the university. The sessions generally required 1½ hours to complete.

Each market session consisted of 12 three-minute periods, organized as a computerized double auction market using the *Z-tree* (Zurich Toolbox for Readymade Economic Experiments) software (Fischbacher 2007).[5] With *Z-tree* traders can transact in real time over a number of market periods. Participants can post bids and asks and also act as price-takers. Multiple-unit transactions were permitted. Traders were not permitted to short sell or borrow additional capital.

On arrival traders received a set of instructions and were given 20 minutes to read through them.[6] Thereafter one of the experimenters did an extensive recap while addressing all procedural and technical questions. Participants were endowed with shares of a stock as well as the experimental currency, referred to as "francs." In the first three treatments the stock paid a dividend of 0 or 10 francs at the end of each period. The dividend payouts were equally likely, randomly determined, and cross-sectionally and intertemporally independent. Following Smith, Suchanek, and Williams (1988), the asset traded in our markets had a known dividend generating process and finite lifespan. After the final dividends were paid at the end of period 12, shares ceased to exist and had zero value. Thus, fundamental value (FV) was readily computed using backward induction as the expected dividend (5 francs) times the number of remaining periods. With 12 periods, the stock had an initial fundamental value of 12 x 5 = 60 francs. As summarized in Panel A of Table 1, each market included two trader types with different endowments of shares and cash. Though endowments varied, in the first three treatments all traders had a total expected portfolio value of 4,600 francs.

The experimental environment in the first three treatments was held constant across all 12 trading periods. However, at the beginning of period 6 a positive or negative shock occurred in treatments 2 and 3. In the Positive Shock treatment an order was placed to buy 100 shares at a price of 70 francs per share, whereas the Negative Shock treatment received an order to sell 100 shares at 17 francs. The fundamental value in period 6 was 30 francs so the high (low) order is 133% above (43% below) underlying economic value. Also note that the extreme order for 100 shares is significant in size as it represents 25% of the shares outstanding before the order is transacted. In designing the experimental parameters, we wanted price shocks that would be extreme and looked to the price experience reported in the existing literature, as well as our baseline treatment, for guidance. We chose these order price shocks because they were likely to lie far from trading prices in period 6, regardless of whether a bubble had generated or not.

All traders could see the large, extreme order on the trading screen but in no case did an order reveal a trader number. While the extreme order was placed by the experimenter, participants would have no reason to expect that the order was not entered by another trader. Participants received no instruction regarding the extreme order and no participant asked for additional information regarding the order or who placed it. Of course, they could not immediately discern whether the order was (or was not) information based. Each market received a single price shock and all aspects of the market setting were unchanged. Because the order was made exogenously, the cash-to-asset ratio in the market changed after the order is filled. With a large order to buy (sell) the units of the asset in the market falls (rises) and the cash increases (decreases).[7] An order placed by the experimenter is transacted against the opposite side of the order book, and any remainder is entered into the book as an outstanding offer to trade. All orders were fully filled in each market.

We included two additional treatments to investigate whether behavior changes in a more uncertain environment. In the FV Uncertainty treatments, traders faced additional uncertainty regarding dividend payoffs. Hussam, Porter, and Smith (2008) report on the importance of a stable environment to efficient pricing. With a potential shift to a less favorable environment, the impact of an aberrant order may be heightened. In the last eight markets there was a 2% probability that the observed state would be "bad." If the "bad" state was drawn, the equally likely dividends were 0 and 5 francs with an expected payout per period of 2.5 francs. All subsequent periods were "bad" if the "bad" state was drawn. The fundamental value each period was now *conditional on prior state draws* with expected payouts reported in Panel B of Table 1. The table reports the fundamental value per period with and without a bad draw in the previous period. In the FV Uncertainty treatment, participants learn about the observed state of the world (normal or bad) at the end of each period, as they also learn the result of the dividend draw. They are instructed that all draws, whether for the dividend or the state of the world, are made within the computer.[8] Though endowments varied across the two trader types, all traders had a total expected portfolio value of 4,382.33 francs in the final treatments. As in the Negative Shock Treatment, a negative price shock was received in period 6 of treatment 5 when an order to sell 100 shares at 17 francs was placed.

At the conclusion of each session, the final cash balance was (privately) displayed on a trader's computer screen. The experimental currency was converted to Yuan using a conversion rate of 0.025, so that 1,000 francs was equal to ¥25.00. Participants completed a post-experiment questionnaire that elicited subject attributes including sex, educational background, economic status, and reactions to the experiment. Each participant was called forward (privately) to check and receive cash earnings before filling out a receipt and leaving the room.

3. Market Behavior

In this section, we begin with descriptive data to assess price behavior in the experimental markets, followed by formal statistical tests.

Observed Price Paths

Figure 1 shows the mean price deviation from fundamental value per period for the three initial treatments and Figure 2 shows the deviation for the two treatments with FV uncertainty.[9] Consistent with earlier research, prices in the first three treatments reflect the typical bubble pattern. Early in trading, prices begin below fundamental value but quickly bubble up with valuations well above fundamentals. In the baseline No Shock treatment, prices remain well above fundamental value even as the market comes to a close and the asset is worthless. In the Positive and Negative Shock treatments, the markets crash to fundamentals as trading winds down.[10] For the Positive and Negative Shock treatments, average pricing as reflected in Figure 1 suggests the expected upward and downward impact for the large, unusual order in period 6. In every market, the unusual order is fully absorbed, so not surprisingly trading volume in period 6 is significantly higher than in other periods ($p < 0.01$). The average number of trades per period across periods 1-5 and 7-12 is 68, whereas the average is 171 in period 6.

Figure 2 illustrates the mean price deviation from fundamental value per period for the two treatments with FV uncertainty. In the FV Uncertainty No Shock treatment prices bubble above fundamentals fairly quickly and crash as the end of trading approaches. As in the other treatments, the observed price path shown in Figure 2 for the FV Uncertainty Negative Shock treatment begins with a typical pattern. While price appears to begin to bubble above fundamental value in the first half of trading, after the negative shock the average price across sessions rapidly falls below the underlying value, returning to fundamental value in the final trading period. The price pattern in the latter half of the trading session reflects a negative price bubble, as mispricing, but opposite in direction, continues to be observed. Haruvy and Noussair (2006) report negative price bubbles in their examination of constraints on short selling. They argue that the market's institutional features impact pricing. Greater ability to short sell increases the supply of the asset and reduces cash in the market. Recall that in the FV Uncertainty Negative Shock treatment, the cash-to-asset ratio is lower than the baseline because of the negative price shock. Consistent with Haruvy and Noussair, asset prices are lower in this case. Note that the fundamental value does not shift in the FV Uncertainty treatments based on state realizations. The Bad state was not observed in our experiment.

All orders placed by the experimenter (i.e., the price shock) are fully absorbed by the market during period 6 without exception.[11] Overall, the figures are suggestive of differences in behavior across FV Uncertainty treatments. The first three treatments reveal a fairly typical mispricing pattern. The extreme order appears to have a fleeting effect on market participants in the Positive and Negative Shock treatments. In contrast, the price shock in the FV Uncertainty Negative Shock treatment appears to impact trader behavior, moving price below fundamental value. In the next section we formally test for differences across treatments.

Descriptive Statistics

Table 2 reports summary statistics on the deviations in price from fundamental value. The empirical measures assume risk neutrality and are designed to gauge the bubble in asset price (if one is observed). A large number of bubble measures have been reported in experimental studies which complicates the comparison of findings (Palan 2009; Stöckl, Huber, and Kirchler 2010). We chose six bubble measures to summarize the experience in our markets. Table 2 reports the average value of each measure across sessions in each treatment.[12]

The first three measures are commonly reported in experimental bubbles studies.[13] First we compute the average number of periods for which the mean price is greater than the fundamental value. Second, we report positive duration which is computed as the average number of consecutive periods with price increases relative to fundamental value when the increase produces a price that exceeds fundamental value. The third bubbles measure is the peak deviation, a measure of the magnitude of the bubble using the normalized peak deviation in price from fundamental value (maximum observed (P_t - FV_t)/FV_t).

Table 2 reports two additional bubbles measures following Stöckl, Huber, and Kirchler (2010). Stöckl, Huber, and Kirchler argue that these measures are superior to many used in prior studies because they promote comparability and satisfy desirable criteria, such as being independent of the number of trading periods. The fourth bubble measure we report is the relative absolute deviation (RAD) which measures the absolute level of mispricing and is calculated as

$$RAD = \frac{1}{N}\sum_{t=1}^{N}\left|\overline{P}_t - FV_t\right| / \left|\overline{FV}\right| \tag{1}$$

where t is the trading period, N is the total number of periods, $\overline{P}_t$ is the period mean trading price, and $\overline{FV}$ is the mean underlying risk-neutral fundamental value across periods. RAD is easily interpreted. For example, when RAD = 0.20 the average mean price per period is 20 percent from the average fundamental value (above or below). The next bubble measure we report is the relative deviation (RD) which measures overvaluation and is computed as

$$RD = \frac{1}{N}\sum_{t=1}^{N}\left(\overline{P}_t - FV_t\right)/\left|\overline{FV}\right|. \tag{2}$$

Unlike RAD, RD is calculated based on signed average price deviations from fundamental value. The asset is overvalued when RD is positive, whereas negative RD indicates undervaluation.

The sixth and final bubbles measure is Overpriced Transactions or the percentage of transactions that exceed the maximum possible payout (Palan 2009). While trades at such extreme prices may be evidence of irrationality, it is also possible that participants are speculating that another will pay an even higher price.

The results are presented in Table 2 with Panel A reporting on periods before the shock and Panel B after. In the five periods prior to the shock, outcomes in the treatments appear to be somewhat similar, as would be expected. Recall that the first three treatments are actually identical prior to the shock. In the FV Uncertainty treatments additional uncertainty regarding the fundamental value exists, but as Panel B of Table 1 indicates the fundamental values are quite close. In fact, no “bad” draws are actually observed at any time in these markets. The summary statistics are consistent with the development of mispricing in the bubbles markets, as frequently reported by others. It is typical that bubbles generate slowly at the beginning of a market, as traders become accustomed to the environment, particularly if they are risk averse. Though periods with prices exceeding FV and positive duration provide some evidence of bubbles, generally the summary statistics do not provide strong evidence of large price deviations. Across the treatments RAD varies from 13% to 17% suggesting some mispricing. However, RD actually indicates pricing very close to fundamentals and there are very few Overpriced Transactions. Thus, overall, the summary statistics for the first five periods of trading are not striking.

The picture changes in later trading periods with most bubbles measures indicating mispricing in the first three treatments. For example, in the No Shock treatment, on average, 4.83

of 7 trading periods have prices exceeding FV, there are 4.83 periods with consecutive price increases, and the price deviation above fundamental value is over three times the level of the FV. RAD indicates that the price is 67% from FV with sizable overpricing (RD = 58%). In this treatment, we observe much extreme mispricing with 12% of the transactions at prices higher than the maximum possible dividend payout.

Interestingly, as we move across columns from treatment 1 to 5, we observe, in general, a decline in the size of the observed bubbles. In the FV Uncertainty Negative Shock treatment the summary statistics show less evidence of bubbles and, in fact, RD indicates negative mispricing. Most bubbles measures take their lowest value in the fifth treatment. For example, in the later periods the percentage of extremely irrational trades is zero in the last treatment.

Comparisons across Treatments

To provide insight into the significance of differences in the bubble measures across treatments we use simple t-tests. Table 3 reports comparisons of the average value of each bubble measure reported in Table 2 across treatment pairs. The No Shock treatment serves as the baseline for the Positive and Negative Shock treatments, whereas the FV Uncertainty No Shock treatment serves as the baseline for the FV Uncertainty Negative Shock treatment.

First, in Panel A the table reports the results of two-sided tests of the null hypothesis of no treatment effect for periods before the shock. For each paired comparison, the table reports the difference in mean values across the two treatments and p-values below in parentheses, where p-values are from a test of the null hypothesis of no difference in mean (two-sided). Recall that sessions in treatments 1-3 are identical in the first 5 periods of trading, as are sessions in treatments 4-5. Not surprisingly, with only one exception, the pairwise tests fail to indicate a significant difference in a bubble measure across treatments.[14]

Panel B of Table 3 reports tests for trading periods 6-12, after the shock. As in Panel A, p-values are for two-sided tests of the null hypothesis of no difference in mean. A treatment effect is not supported by the data for the positive or negative price shocks. With only one exception, the data fails to reject the null hypothesis that the aberrant order has no effect of pricing in the Positive Shock and Negative Shock treatments for all comparisons.

Unlike other treatments, casual consideration of Figure 2 suggested that the negative price shock had an impact in the case of FV Uncertainty. Formal tests reported in the last column of Table 3, Panel B, indicate that two of six bubbles measures are significantly smaller and suggest less over-pricing in comparison to the baseline treatment. Despite the limited number of sessions for treatments 4 and 5, the results provide some support for the view that a negative price shock in an unstable market environment can lead to mispricing *below* fundamental values.

4. Discussion and Concluding Remarks

This paper reports the results of experimental asset markets in which market participants trade a finitely-lived asset with public knowledge of the fundamental generating process. In the base treatment we observe the often-reported bubble pattern. In some treatments, a price shock hits the market after several periods of trading. The shock takes the form of a large order at an extreme (high or low) price. In the standard double auction bubble market, pricing is unaffected by abnormal orders. However, with increased uncertainty about fundamental valuations, over-pricing weakens upon arrival of a negative price shock.

In fast-paced markets, the potential for human error is nearly impossible to rule out. Price limits on individual stocks have recently been implemented in the United States to prevent trades at extreme prices that may be due to trader error.[15] Our results indicate that double auction markets are likely to be unaffected by aberrant orders except in a specific situation: a negative price shock with elevated uncertainty. Two aspects are vital. First, the direction of the shock decreases the cash-to-asset ratio. Others have shown that prices move below fundamental valuations in such conditions (Haruvy and Noussair 2006). Second, there is the potential of less favorable market conditions. Empirical evidence suggests that the stability of the environment is a key element of the bubble experience and our results suggest that the possibility of a negative shift might keep traders on edge, ready to react when a signal arrives at the market. Future research to disentangle these aspects is encouraged.

This paper is an initial exploration of how a market will react when an unusual order is placed and much more work is needed to add clarity. We specifically chose a market known to exhibit mispricing and future research into the impact of an unusual order in other market structures could provide interesting insight. While researchers have examined the impact of short selling and buying on margin in experimental bubbles markets (King, Smith, Williams, and van Boening 1993; Ackert, Charupat, Church, Deaves 2006), other institutional features and market structures deserve additional attention.

FIGURE 1. Time Series of Price Deviations from Fundamental Values for Initial Treatments

FIGURE 2. Time Series of Price Deviations from Fundamental Values for Treatments with Fundamental Value Uncertainty

FIGURE 1.

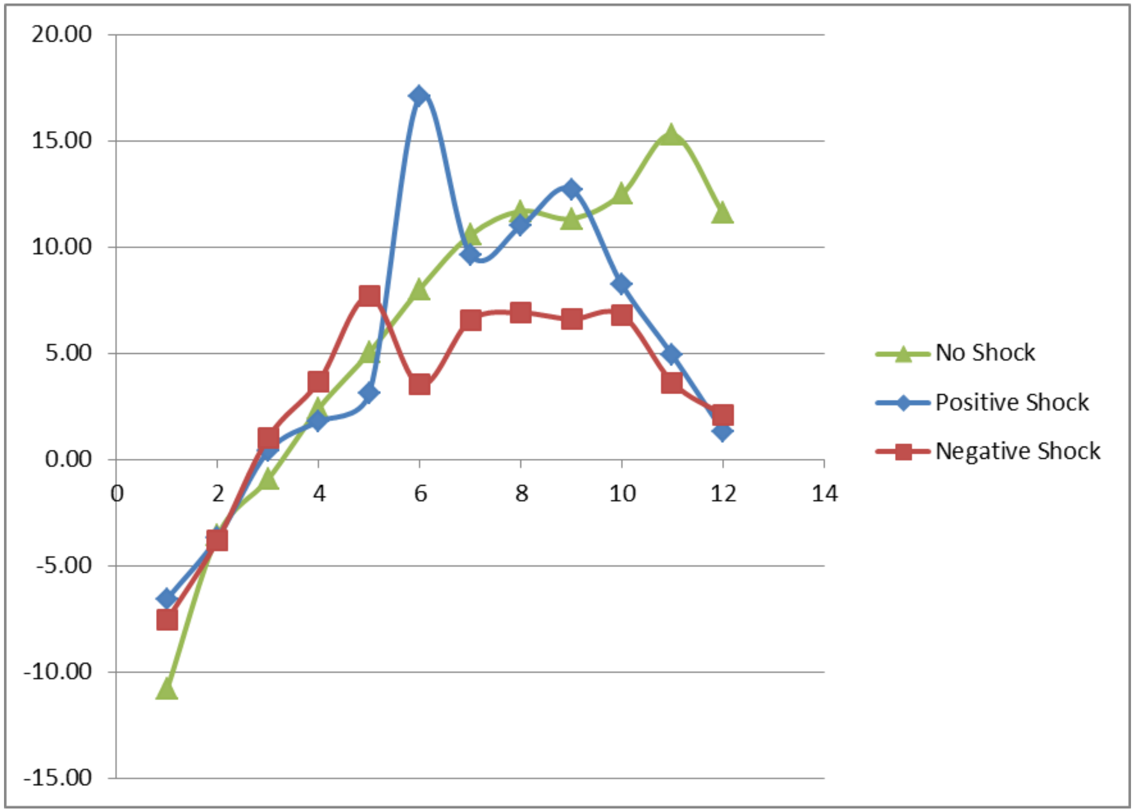
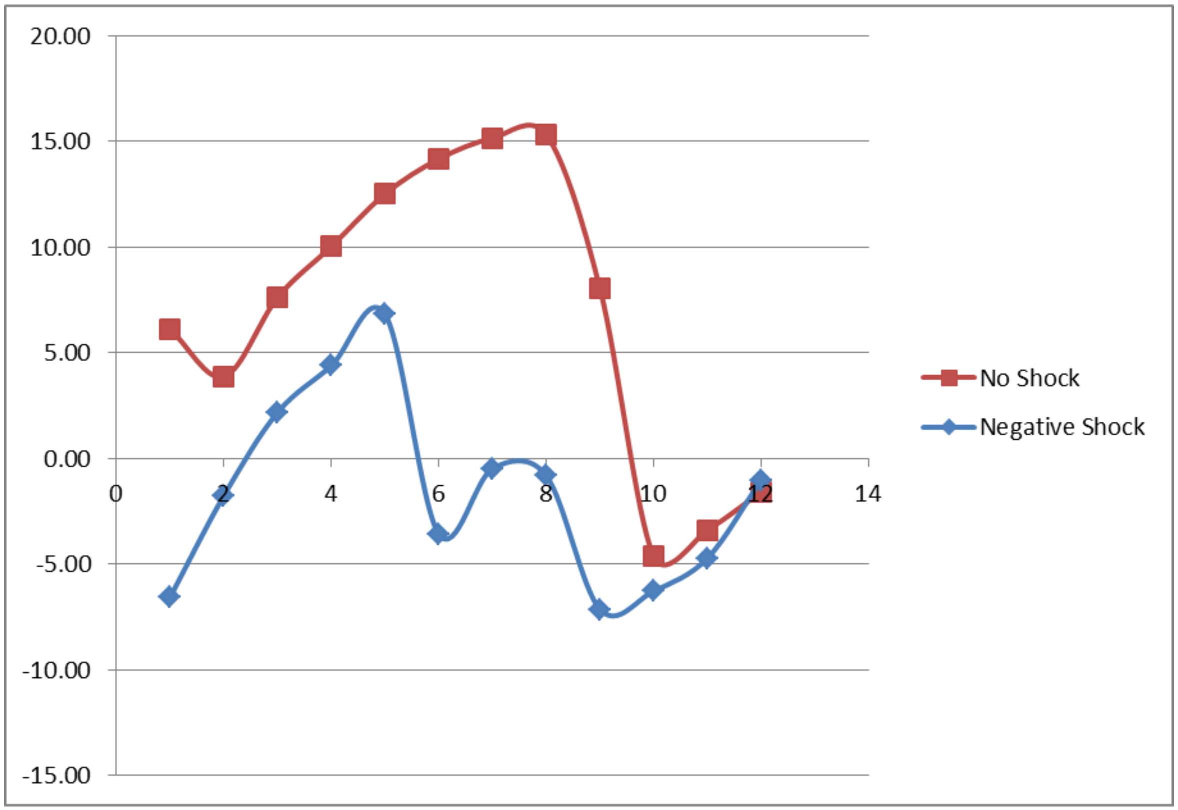

20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
0
2
4
6
8
10
12
14
No Shock
Positive Shock
Negative Shock

FIGURE 2.


20.00
15.00
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5.00
0.00
-5.00
-10.00
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2
4
6
8
10
12
14
No Shock
Negative Shock

Table 1. Experimental Set Up

Panel A: Experimental Design

Treatment		Number of Sessions	Trader Type	Endowments		Shock	FV Uncertainty
				Shares	Cash		
1	No Shock	6	X	60	1,000	No	No
			Y	20	3,400		
2	Positive Shock	7	X	60	1,000	Positive	No
			Y	20	3,400		
3	Negative Shock	6	X	60	1,000	Negative	No
			Y	20	3,400		
4	FV Uncertainty No Shock	2	X	60	1,000	No	Yes
			Y	20	3,255		
5	FV Uncertainty Negative Shock	6	X	60	1,000	Negative	Yes
			Y	20	3,255		

Panel B: Fundamental Values

Periods Remaining	Treatments 1, 2, and 3	Treatments 4 and 5 No "bad" draws	Treatments 4 and 5 "Bad" draw in previous period
12	60	56.3722	56.3722
11	55	51.4222	27.5
10	50	46.5212	25
9	45	41.66822	22.5
8	40	36.8623	20
7	35	32.1025	17.5
6	30	27.38789	15
5	25	22.71758	12.5
4	20	18.09067	10
3	15	13.5063	7.5
2	10	8.9636	5
1	5	4.4618	2.5

The asset has an equal probability of paying 0 and 10 francs in each of 12 periods in the first three treatments. In treatments 4 and 5 with additional FV Uncertainty, the payouts of 0 and 10 francs are also equally likely in the "Normal State." However, there is a 2% chance that the state is "Bad," in which case the dividends are 0 and 5 francs with equal probability. If the "Bad" state is drawn, it is observed for all remaining periods.

Table 2. Summary Statistics

Panel A: Before the Shock (Periods 1-5)

	Treatment				
	No FV Uncertainty			FV Uncertainty	
	No Shock	Positive Shock	Negative Shock	No Shock	Negative Shock
Periods when mean $P_t > FV_t$	2.99	3.29	2.83	4.50	2.67
Positive Duration	2.00	3.29	2.83	3.50	2.67
Peak Deviation	0.14	0.11	0.19	0.46	0.20
Relative Absolute Deviation	0.14	0.17	0.13	0.15	0.16
Relative Deviation	-0.043	-0.02	0.002	0.12	-0.05
Overpriced Transactions	0	0	0	0.002	0

Panel B: After the Shock (Periods 6-12)

	Treatment				
	No FV Uncertainty			FV Uncertainty	
	No Shock	Positive Shock	Negative Shock	No Shock	Negative Shock
Periods when mean $P_t > FV_t$	4.83	4.00	3.30	2.50	1.17
Positive Duration	4.83	3.71	3.33	2.50	1.67
Peak Deviation	3.02	1.41	0.86	0.72	0.37
Relative Absolute Deviation	0.67	0.64	0.37	0.53	0.38
Relative Deviation	0.58	0.52	0.19	0.24	-0.28
Overpriced Transactions	0.12	0.05	0.02	0.06	0.00

The table reports the average value of each measure across sessions in the five treatments. First the table reports the average number of periods for which the mean price (P_t) is greater than the fundamental value (FV_t). Positive duration is the average number of consecutive periods with price increases relative to fundamental value when the increase produces a price that exceeds fundamental value. Peak deviation is a measure of the magnitude of the bubble using the normalized peak deviation in price from fundamental value (maximum observed $(P_t - FV_t)/FV_t$). The relative absolute deviation (RAD) measures mispricing and is calculated using equation (1). The relative deviation (RD) measures overvaluation and is computed using equation (2). Overpriced Transactions indicates the percentage of transactions that exceed the maximum possible payout.

Table 3. Tests

Panel A: Before the Shock (Periods 1-5)

	Pairwise t-tests			
	Positive Shock	Negative Shock	FV Uncertainty No Shock	FV Uncertainty Negative Shock
Periods when Mean $P_t > FV_t$	1.29 (0.25)	0.83 (0.48)	2.50 (0.20)	-1.83 (0.26)
Positive Duration	1.29 (0.25)	0.83 (0.48)	1.50 (0.42)	-0.83 (0.60)
Peak Deviation	-0.02 (0.89)	0.05 (0.62)	0.33 (0.11)	-0.26 (0.15)
Relative Absolute Deviation	0.03 (0.76)	-0.01 (0.72)	0.01 (0.88)	0.02 (0.72)
Relative Deviation	0.01 (0.96)	0.03 (0.71)	0.15 (0.25)	-0.17 (0.25)
Overpriced Transactions	NA	NA	0.002* (0.08)	NA

Panel B: After the Shock (Periods 6-12)

	Pairwise t-tests			
	Positive Shock	Negative Shock	FV Uncertainty No Shock	FV Uncertainty Negative Shock
Periods when mean $P_t > FV_t$	-0.83 (0.54)	-1.50 (0.32)	-2.30 (0.30)	-1.30 (0.19)
Positive Duration	-0.12 (0.41)	-1.50 (0.32)	-2.30 (0.30)	-1.30 (0.19)
Peak Deviation	-1.61 (0.27)	-2.16 (0.18)	-2.31 (0.41)	-0.35 (0.59)
Relative Absolute Deviation	-0.03 (0.92)	-0.29 (0.27)	-0.14 (0.76)	-0.15 (0.50)
Relative Deviation	-0.05 (0.88)	-0.39 (0.24)	-0.33 (0.53)	-0.52** (0.05)
Overpriced Transactions	-0.07 (0.22)	-0.10 (0.10)*	-0.06 (0.56)	-0.06* (0.08)

The table compares the average value of each bubble measure reported in Table 2 across treatment pairs with the No Shock treatment serving as the baseline for the Positive Shock, Negative Shock, and FV Uncertainty No Shock. The baseline for the FV Uncertainty with Negative Shock is the FV Uncertainty No Shock treatment. Panel A includes periods before the shock and Panel B those after a shock. For each paired comparison, the table reports the difference in mean values across the two treatments and p-values below in parentheses. In Panels A and B, p-values are from a test of the null hypothesis of no difference in mean (two-sided).

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

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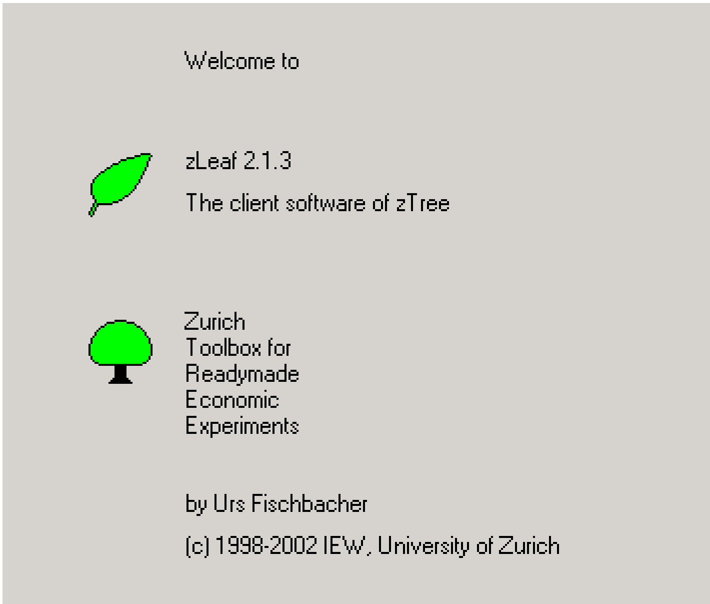
APPENDIX 1
EXPERIMENTAL INSTRUCTIONS

The computerized double asset markets were conducted using Z-tree, though participants were given the following written instructions. Instructions for the first three treatments are identical and follow. Instructions for the FV Uncertainty treatment are similar and differ only in terms of the description of the possible states and resulting dividend payouts. Changes to the instructions for the FV Uncertainty treatments (4 and 5) are noted in ***{bold italics and within brackets}*** *below.*

We are about to begin an asset market experiment in which you can purchase and sell shares of stock. The experiment is conducted in a computerized electronic market. We will describe to you how this experiment works and your interface with it. Based on your decisions you will be able to generate profits. These profits will be paid to you in cash at the conclusion of the experimental session today.

Please raise your hand and let the experimenter know if you don't see the following screen on your computer:



Please follow along as the experimenter reads these instructions aloud. Feel free to ask questions at any time. We will practice trading on the computer before the actual markets begin.

General Instructions

This experiment is concerned with the economics of market decision-making. You are going to participate in a market in which you will buy and sell shares of a stock in a sequence of 12 periods, with each period lasting 3 minutes. Based on your trading decisions, you will be able to generate profits. You can keep track of your position on the record sheets that are in front of you. **Your profits will be paid to you in cash at the conclusion of the experiment today.**

General Trading Instructions

Each period you will trade shares of a stock. All ten participants in this room today will participate in the same market for this stock. At the beginning of the first period, every trader will be provided with an endowment of the trading currency, francs, and shares of stock. Half of the traders in this room will receive an endowment of 1,000 francs and 60 shares of stock and the other half will receive an endowment of 3,400 francs and 20 shares of stock. Your endowment will be shown on your trading screen before trading commences.

When trading begins in each period, you can sell part or all of your holdings of the stock. Alternatively, you can use your cash endowment to purchase more shares. You may also decide not to trade and hold on to the shares that you have at the start of the period. Sales of your share holdings increase your cash balance by the amount of the sale price. Similarly, purchases reduce your cash balance by the amount of the purchase price.

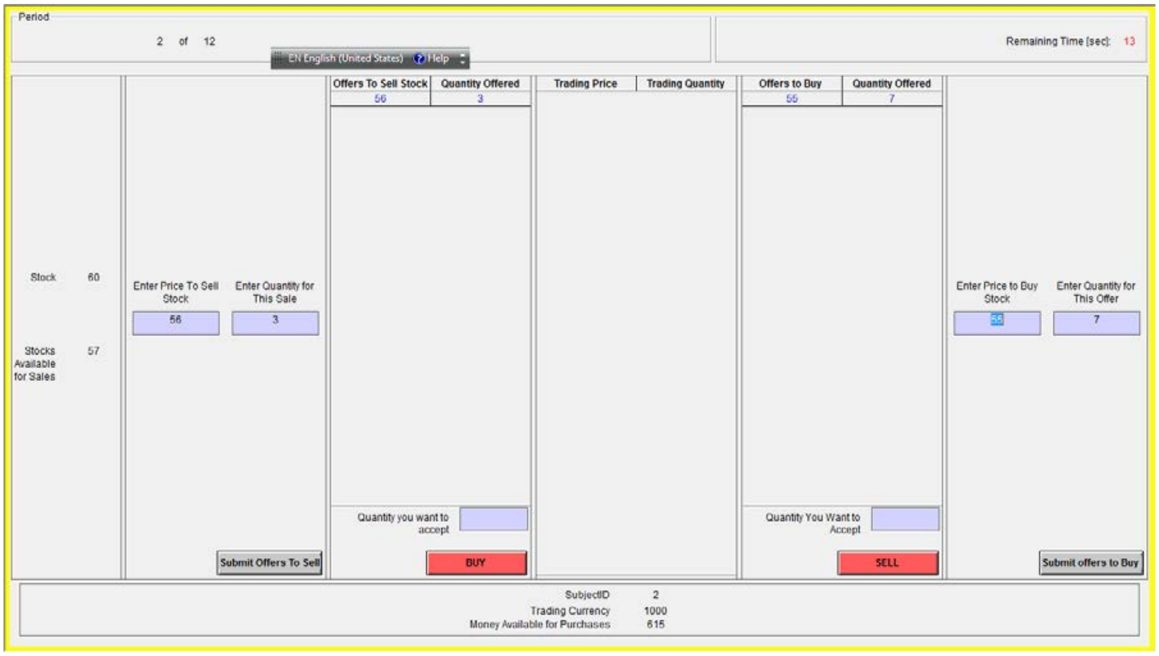
The trading system will automatically update your cash balance and share holdings to reflect your purchases and/or sales of shares. Your cash and shares of the stock at the end of a period carry over to the next trading period.

Shares of stock earn dividends at the end of each trading period, as will be described shortly. At the end of the 12 trading periods, the stock will cease to exist and will be worthless at that time.

Trading Screen

The left upper corner of the screen shows you the current trading period and the total number of trading periods in the session today. The right upper corner shows the remaining *seconds* of the *current* trading period. In today's experiment, each trading period is 3 minutes and the session includes a sequence of 12 periods.

The screen displays the cash you hold at the beginning of the period on the left hand side. The rest of the screen is divided into two boxes for offers to sell and offers to buy.



On the trading screen above you see the number of shares you hold. The above window indicates that you have 60 shares of the stock. You submit offers to sell in the column to the right and next to it is the column of existing offers submitted to the market to sell. The middle column indicates the trading prices for the stock. The next column on the right shows existing offers submitted to the market to buy. You submit offers to buy in last column on the very right of the screen.

Trading a Stock

To place an offer to sell stock, type the price and quantity (*in francs*) at which you want to sell in the boxes under the labels “Enter Price to Sell Stock” and “Enter Quantity for this Sale.” Click the button “Submit offer to Sell Stock” to send your offer. Your offer will be posted in the column of “Offers to Sell,” which is to the right of the column where you submitted your offer. Once you submit an offer either to buy or sell, *you are committed to that offer until someone accepts the offer, or if no one accepts your offer, until the end of the trading period*.

Follow the same steps to place an offer to buy stock. The column to submit offers to buy and the column showing the current submitted offers to buy are laid symmetrically to the right of the box for each stock. The offers are displayed in descending order using submitted prices. As with offers to sell, enter the quantity you want to buy and your offering price. Remember, prices are in francs, the trading currency.

Accepting an offer results in a trade. If you would like to accept any of the offers (either to buy or sell a share of the asset) submitted to the market, click on the offer you would like to accept, enter the number of units you would like to buy or sell, and click the “BUY” or “SELL” button.

Note that accepting an offer from the column of “Offers to Sell” means that you are buying that stock from the subject who submitted the offer, while accepting an offer from the column of “Offers to Buy” means that you are selling that stock to the subject who submitted the offer at the specified price. After the transaction, the corresponding shares of the stock you traded and the cash remaining will be updated. In addition, the trading price and units transacted will be posted in the middle column labeled “Trading Price.”

You can place offers to buy or sell for multiple shares and accept to buy or sell portions of posted offers. For example, if another trader submits an offer to buy 3 shares and you would like to sell only 1 share at the offered price, enter “1” in the quantity box (“Q you want to sell”) and then click “SELL.”

Because some trades may involve only a portion of an offer, the balance of the offer will remain open. For example, suppose a trader made on offer for 6 shares. If the offer is accepted for fewer than 6 shares, the balance of the offer will still appear in the column of existing offers. If four units were bought or sold in this transaction, an offer for the remaining two shares will appear. If the offer is accepted for all 6 shares, the original offer will be eliminated from the column of existing offers.

Please refer again to the trading screen on the previous page. Notice that this trader has 60 shares of stock. Because the trader has posted an offer to sell 3 units at a price of 56, the screen shows that the trader has 57 units left for sale. This means the trader has 57 shares on which new offers to sell can be posted. The trader can also sell up to 57 shares by accepting other traders’ offers to buy. Similarly, if the trader has posted offers to buy, additional offers are limited by the cash available.

Best offers

Note that the best offers to sell or buy the stock will appear in the final row of the "Offers to Sell" and "Offers to Buy" columns.

The trading screen above provides an example of how orders are cued by the computer. If you want to buy stock, the best offer will be the lowest purchase price. Notice that the computer automatically orders the incoming offers so that the best offer to sell is the last offer in the "Offers to Sell" column. Similarly, the computer orders the buy offers so that the highest offer to buy appears in the last row of the "Offers to Buy" column. If you want to sell stock, the highest price is most favorable to you so you will want to choose the offer appearing in the last row.

When you accept an offer to sell or buy, you must click on the offer you are accepting. It is important to remember that the offer appearing in the last row will be most favorable to you if you are buying (lowest price) or selling (highest price).

Make sure the quantity and price you type are correct before you hit the submit button.

Once an offer is accepted, a trade cannot be reversed.

Trading Restrictions

There are a few restrictions regarding submitting and accepting offers when trading. They are summarized as follows:

1. You are not allowed to trade with yourself, meaning that you cannot accept offers submitted by yourself.

2. No short-selling is allowed, which means that if you don't have a share of a stock, you can't send out an offer to sell that stock.

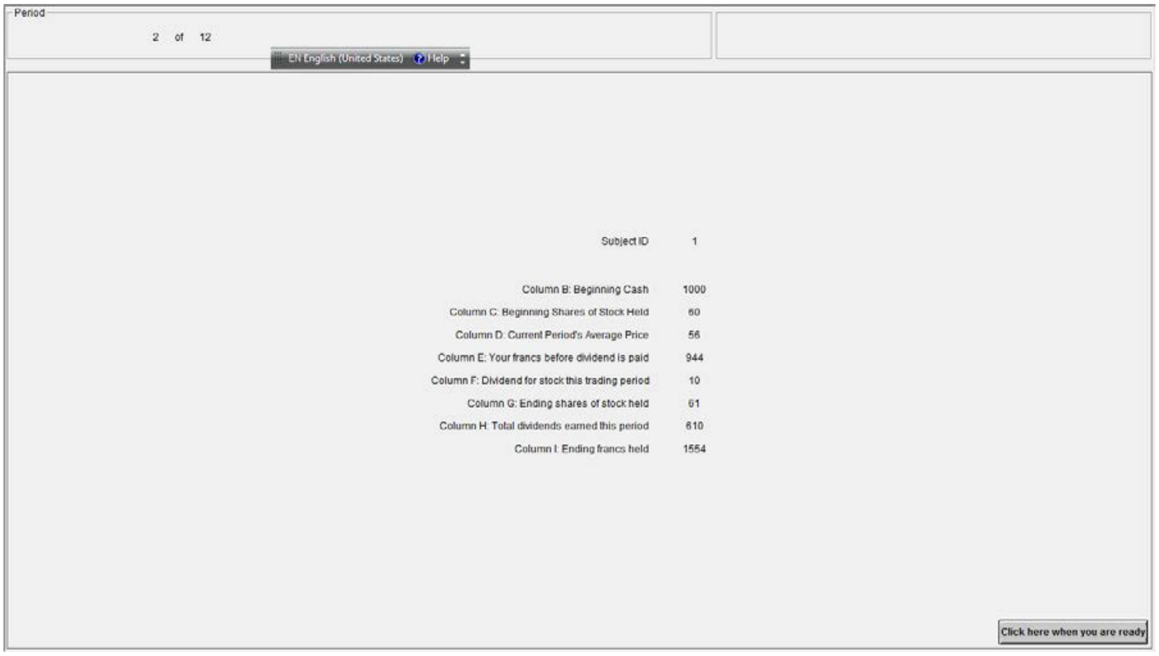
3. You are not permitted to place offers or accept the offers of others if you do not have enough shares to cover all the outstanding offers you have submitted. Suppose, for example, that you currently hold 7 shares. You have posted an offer to sell 4 of your shares and another trader then posts an offer to buy 6 shares. You cannot accept to sell 6 shares to this trader because you have 4 committed in an open offer to sell. You could, however, accept to sell the 3 shares you hold that are not already committed.

4. You can't place a buy order if you don't have enough money left in your account.

An error message will inform you of the situation in any of these cases.

Summary Screen

At the end of each trading period, a summary screen will pop up.



On this screen, you will see summary information for the trading period. The "Column" refers to the column on the Record Sheet. You will record trading information on the Record Sheet each period. The information included is:

A. The trading period (and your subject ID)
B. Beginning cash
C. Beginning shares of stock held
D. Current (and previous) period's average price
E. Your francs held before dividend is paid
F. Dividend paid on the stock this trading period
G. Ending shares of stock held
H. Total dividends you earned this period
I. Ending francs held

When you are finished, please click the "Please Wait" button to wait until other participants are ready to continue to the next trading period.

Dividends

At the end of each period, the actual dividend paid for each share of stock will be indicated on your summary screen. The dividend each period is randomly determined by the computer program and there are two equally likely dividend amounts. The dividend per share in each period is either 0 or 10 francs. A random number draw determines whether the dividend is 0 or 10.

{The two following paragraphs are inserted here in the FV Uncertainty treatment:

The dividend payments differ across two states of the world. The "Normal" state of the world occurs with probability 98% and the "Bad" state of the world with 2% probability. In the Normal state, the dividend per share is either 0 or 10 francs, with 0 and 10 being equally likely. In the Bad state of the world the dividend is 0 or 5 and the payouts of 0 and 5 are again equally likely. A random number draw determines whether the state is Normal or bad and whether the dividend is low or high.

Note that once a period is determined to be "Bad," all subsequent periods will be "Bad." For example, if the random number draw indicates that the first period is "Bad," then all 12 periods will be "Bad." Thus all dividend payments will be determined with a 50% chance of 5 francs per share and 50% chance of 0 francs per share. To further illustrate, if the "Bad" state is drawn in the 5th period, then periods 5 through 12 are "Bad."}

The total dividends you receive are computed by multiplying the dividend per share by the number of shares you hold at the end of the period. Suppose, for example, that you hold 10 shares of stock at the end of period 1. If the dividend per share for that period is 10 francs, then your total dividends for the stock in period 1 are (10 shares x 10 francs) = 100 francs. If, on the other hand, the dividend per share for that period is 0 francs, then your total dividends for the stock in period 1 are (10 shares x 0 francs) = 0 francs.

Notice that the expected payoff for a share of stock is 5 francs because half of the time you will earn 0 francs and the other half of the time you earn 10 francs. You can easily calculate that the expected value of dividends per period is 5 francs.

{The following paragraph replaces the preceding paragraph in the FV Uncertainty treatment.

Notice that in the Normal state of the world the expected payoff for a share of stock is 5 francs because half of the time you earn 0 francs and the other half of the time you earn 10 francs. You can easily calculate that the expected value of dividends per period is 5 francs. Similarly, in the Bad state of the world the expected payoff for a share of stock is 2.5 francs because half the time you earn 0 francs and the other half of the time you earn 5 francs.*}*

At the end of the experiment, we will convert your earnings into yuan. We will add the dividends you earn in the final trading period (period 12) to your francs before the dividend is paid. Then we take the ending francs held and multiply by 0.025. This is your compensation for participating today. Notice that 1,000 francs in total would be equal to ¥25.00.

In period 1, the expected value of a share of stock is 5 francs*12 periods = 60 francs. If you buy a share of stock in period 1 and hold it until the end of the experiment, you will earn the dividends paid over all 12 periods and the total expected value is 60 francs. Similarly, if you buy a share of stock in period 2 and hold it until the end of the experiment, you will earn the dividends paid over the 11 remaining periods and the total expected value is 55 francs

{The following paragraph replaces the preceding paragraph in the FV Uncertainty treatment.

In period 1, the expected value of a share of stock is 56 francs. If you buy a share of stock in period 1 and hold it until the end of the experiment, you will earn the dividends paid over all 12 periods and the total expected value is 56 francs. Similarly, if you buy a share of stock in period 2 and hold it until the end of the experiment, you will earn the dividends paid over the 11 remaining periods and the total expected value is 51 francs.}

Dividend Independence

The dividend paid each period is determined by the program independently of past payments and the two dividends (0 and 10) are equally likely.

Carry Forward

The cash balance and shares that you have at the end of one period will be carried forward to the next period. Notice that even if you do not trade, the shares you hold will earn the randomly determined dividend.

The expected value per period for the stock is 5 francs. Notice that the expected value the stock in any period is exactly 5 times the number of periods remaining. So, for example, in period 1, the expected value of the stock is 60 francs. In period 2, the expected value is 5*11 = 55 francs, and so forth.

Your Earnings

Your trading profit is each period comes from two sources. First, you earn dividends on shares held at the end of the period. Second, you can generate trading profits and losses when you purchase and sell shares of stock.

The Final Trading Period

At the end of the last period, the shares will pay a final dividend and cease to exist. Your trading screen will then display the final cash balance. You will be paid this amount in cash at the end of the session today. If your final profit is negative, you will be paid a small attendance fee.

Now let's practice trading!

At this time we will conduct two practice trading periods so that you can become familiar with the computer interface. The practice periods are 3 minutes, the same time as later periods, and we encourage you to take advantage of this practice by making and accepting offers.

Post-Experimental Questionnaire

This questionnaire is designed to collect general information. Such information may help us better understand differences found between participants in this experiment.

1. What year are you in university (e.g., 3rd, 4th)? __________

2. What is your sex? (check one) male _____ female _____

3. What is your age? _____ years

4. What is your primary means of financial support (check one)?
   _____ self supported
   _____ parent or relative
   _____ spouse or significant other
   _____ financial aid or other loans
   _____ scholarship

5. What is your major or concentration (e.g., finance, economics, etc.)? ____________

6. How many economics or finance courses have you successfully completed at the university level? _____ courses

7. How many economics or finance courses are you currently enrolled in? _____ courses

8. How interesting did you find this experiment? (circle the appropriate number)

Not very Interesting	Very Interesting

1--------2--------3--------4--------5--------6--------7--------8--------9-------10--------11

9. Have you ever participated in a market experiment where you actively trade with other participants and receive financial compensation? (check one) yes _____ no _____

10. Have you ever traded securities for yourself or others, or participated in the management of an investment portfolio? (check one) yes ____no____

11. For the time spent, how would you characterize the amount of money earned for participating in this experiment? (circle the appropriate number)

Nominal Amount — Considerable Amount

1--------2--------3--------4--------5--------6--------7--------8--------9-------10--------11

12. How would you characterize your financial expertise? (circle the appropriate number)

Very Little Knowledge — Very Knowledgeable

1--------2--------3--------4--------5--------6--------7--------8--------9-------10--------11

13. During the experiment, you had the opportunity to purchase shares of stock. Briefly explain how you decided to buy, sell, or hold.

14. What do you think about the behavior of other traders based on your observations today? Explain.

Endnotes

[1] The experience of the Standard and Poor's 500 Stock Index provides glaring evidence. In December 1999 the index level was 1,428.68, a peak at that time. The market fell 35% in the next few years, to a relative low of 935.96 in March 2003. As it recovered, the market peaked in 2007 with a gain of 65% from the previous low. The recent financial crisis left the index at 757.13 in March 2009, a loss of 51%. Since then, the index has risen a whopping 182%, reaching 2,134.72 in May 2015.

[2] Michael Lewis brought the complex and secretive world of high-frequency trading to the public in *Flash Boys*, his best-selling account of trading in the U.S. (Lewis 2014). Around the world, regulators' attention has also focused in HFT as evidenced by the U.K. Treasury project that reports on computerized trading (Available at https://www.gov.uk/government/publications/future-of-computer-trading-in-financial-markets-an-international-perspective).

[3] Typically, bubbles markets include dividend uncertainty. Traders are informed of the possible dividends and can compute expected values (e.g., Porter and Smith 1995). The uncertainty we refer to here is an unstable environment in which the distribution of possible dividends changes.

[4] The typical bubble and crash pattern has been replicated around the world, even with experienced business people and professional traders (e.g., King, Smith, Williams, and van Boening 1993). Our baseline sessions confirm the usual price path with our Chinese subject pool.

[5] This software is provided to experimental researchers by the University of Zurich, Institute for Empirical Research in Economics. See http://www.iew.unizh.ch/ztree/index.php.

[6] The instructions are included in the Appendix.

[7] The ratio of cash-to-assets is an important consideration in the bubbles design because researchers have shown that bubbles are encouraged in markets that are flush with cash (Caginalp, Porter, and Smith 1998, 2000a, 2000b, 2001).

[8] No participant raised concern about deception or manipulation of the draws at any time.

[9] Figures illustrating the experience based on median transaction prices give a similar view of treatment differences.

[10] Examination of the individual markets indicates that there is substantial variability across markets in the evolution of prices over time. While behavior in some sessions was not consistent with the typical bubble pattern, it is quite common to have a session or two that seem atypical. Recall that Smith, Suchenek, and Williams (1988) reported that bubbles were common, but not universal. They report that 37% of their markets did not exhibit the typical bubble pattern. See also Ackert, Charupat, Deaves, and Kluger (2009) who report that about half of their markets exhibit the usual bubble pattern.

[11] We also examined whether the shock affected the bid-ask spread. The spread actually narrows after the price shock, but this narrowing was observed in all treatments including those with no shock. Thus, the decline in the spread is likely due to experience in the trading environment. We do not observe significant differences in the spread across treatments.

[12] Inferences are similar using median values.

[13] See, for example, Ackert, Charupat, Church, and Deaves (2006).

[14] The one significant paired comparison is for Overpriced Transactions in the comparison between FV Uncertainty No Shock and the No Shock baseline. Though statistically significant, the difference is not economically significant as there are very few transactions that are overpriced, as Table 2 indicates.

[15] On the SEC’s limit up-limit down mechanism see http://www.sec.gov/investor/alerts/circuitbreakersbulletin.htm.