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Enrica Carbone, Tibor Neugebauer, Angelo Ventrone

Information Processing in an Asset Market Experiment with Algorithmic Arbitrage Trading

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Information Processing in an Asset Market Experiment with Algorithmic Arbitrage Trading*

Enrica Carbone[1]
Tibor Neugebauer[2]
Angelo Ventrone[3]

Abstract

In a novel laboratory setting in which scheduled information changes the expected asset value, we test the efficient market hypothesis. The scheduled information contains either good or bad news. The data show that average prices are not different from the fundamental value. However, asset prices underreact to news; we observe asset prices below fundamentals after good news and above after bad news. There seems to be a behavioral asymmetry; absolute price deviations are larger after bad news than after good news. In the course of a period, the asset price drifts towards the fundamental value. Following the literature that hypothesizes arbitrage trading would push asset prices towards fundamentals, we have an arbitrage robot trader interacting with human subjects in the experimental market to find no support for this hypothesis.

Keywords: experimental asset market; information; robot trader; underraction; drift; price discovery; fundamental value.
JEL codes: C92

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[1] Correspondence: Università degli studi della Campania "Luigi Vanvitelli", Dipartimento di Scienze Politiche, Email: Enrica.CARBONE@unicampania.it
[2] Correspondence: Department of Finance, University of Luxembourg, Tel.: (+352) 46 66 44 6285, Email: tibor.neugebauer@uni.lu
[3] Correspondence: Phd Student, Università degli studi di Salerno, Dipartimento di Scienze Economiche e Statistiche, Email: aventrone@unisa.it

1. Introduction

The standard finance literature and in particular the literature that proposes efficient markets (Malkiel 2003) presumes that asset prices account for all publicly available information. Asset prices should adjust instantaneously incorporating any newly available information. The fundamental assumptions are two-fold.

1. The average investor is rational and prices assets at intrinsic value. Even if some investors are not rational, they trade randomly, and their decisions cancel each other out.

2. If investors are irrational 'in similar ways', their influence is eliminated by rational arbitrageurs.

In the paper we propose an experimental test of these assumptions. In the experiment, subjects receive periodical updates on the intrinsic value. In the control treatment we investigate how experimental subjects price the asset given the publicly available information. In the arbitrage robot trader –ART– treatment additionally to subjects an algorithm exploits arbitrage opportunities. We test how close prices are relative to intrinsic asset values, and if price efficiency is enhanced with arbitraging.[4]

We are not the first to test the efficient market hypothesis. There is a huge literature both theoretical as well as empirical. Barberis and Thaler (2003) and Hirschleifer (2016) survey the literature on behavioral anomalies. Early experimental tests were Smith (1962), Plott and Sunder (1982), Plott and Sunder (1988) and Smith et al. (1988). These experiments showed that markets for short-lived assets are able to converge to the competitive equilibrium (Smith 1962), disseminate (Plott and Sunder 1982) and aggregate (Plott and Sunder 1988) information, and thus the data supported the hypothesis of efficient markets.[5] We study market efficiency of short-lived assets with one liquidation dividend at the end of the round. Differently from the standard experimental

[4] Another treatment variation is the announcement of the potential participation of an algorithmic trader. Farjam and Kirchkamp (2016) found that subjects price assets closer to fundamental value already if the potential participation of an algorithmic trader is announced.

[5] For long-lived assets, however, mispricing can be significant (Smith et al. 1988). In a recent study, Carbone et al. (2021) confirmed the divergence in efficiency between long-lived and short-lived assets.

paradigms where all information is contained in the market from the beginning, our design focuses on periodical news updates about the state of the economy. Good news corresponds to a rise of the intrinsic value and bad news to a decline of the intrinsic value. The news affects the values of two twin shares which are traded in two continuous double auction markets. The astute investor can arbitrage between the twin shares when price discrepancies arise. We know from earlier studies that subjects in the laboratory do not prominently engage in arbitraging. Therefore we focus on the ART treatment to see how arbitraging helps towards efficient market pricing as subjects exhibit biases.

We contribute to the behavioral and experimental finance literature, which observes a deviation from the efficient market hypothesis. The underreaction of asset prices to news and the post-earnings announcement drift (Bernard and Thomas 1989). Bernard and Thomas (1989) observed an underreaction of stock market prices to earnings surprises followed by a drift over the following months to fully incorporate the information content of the earnings surprise. That observation violates the efficient market hypothesis, which assumes instantaneous assimilation of the news content in the market price. Grinblatt and Han (2005) explain such price inertia and the post-earnings announcement drift as an anchoring effect. Investors anchor on a past price, for instance, on the price of the past period. In the model of Grinblatt and Han (2005), asset prices equal the weighted average of fundamental value and reference price and converge only with time on the new fundamental value. In this paper, we observe such a dynamic pattern of price inertia and drift towards fundamental value over time in our laboratory experiment. We also observe an asymmetric price inertia effect; after bad news, initial price changes are smaller in magnitude than after positive news.

The rest of the paper is organized as follows. Section 2 introduces the experimental design. In section 3, we allude to theoretical considerations, derive our testable hypotheses and present the measures that we apply to the data. Section 4 reports the experimental results. Finally, section 5 summarizes the findings and concludes the paper.

2. Experimental Design

2.1. Experimental treatments

The experiment was designed to evaluate asset market behavior in the presence of news announcements, and the impact of arbitrage robot trading (ART) on the market. To study the behavioral effect of news announcement we introduced a random tree structure involving three trading stages followed by scheduled news. Corresponding to positive or negative news scheduled after the trading period, the underlying asset values moved up or down the tree with probability ½, thus increasing or decreasing the asset value by 50 cash units. The current states of asset values were identified by colors (grey, orange, green, red, yellow, and blue), as shown in Figure 1.[6] The final realizations of the value were paid to the asset holders in form of liquidation dividends per share at the end of a round of three stages. The experiment involved 10 rounds of three trading stages (each of 180 seconds). To enable arbitrage robot trading, the twin assets X and Y could be traded simultaneously;[7] the Y asset paid always 50 cash units more than the X asset in liquidation at the end of the third stage. In the first (i.e., the grey) stage of each round, subjects were endowed with 2 shares of the X asset, 2 Y shares, and 1300 cash units. Within a round, shares and cash units carried over from one stage to the next.

The experimental design included four variations combining ART participation (ART condition) and the announcement of potential participation of an algorithmic trader (Ann condition), as shown in the Table 1. The experimental instructions, which are appended to the paper, were identical up to the reference on potential algorithm participation in the announcement condition. Even if announced, subjects were never informed about the ART trading strategy and the ART participation was not confirmed at any time.

[6] The box used for the communication of news in each trading stage, for the entire duration of the trading period, takes on the color of the corresponding state of the world in which the trading takes place and reports the information on the states of the world that may occur in the subsequent stage and the corresponding potential dividends paid by the two securities.

[7] As in Charness and Neugebauer (2019), Angerer et al. (2023) and Neugebauer et al. (2023) the fundamental values were identical modulo a shift. So, one asset could be interpreted as the leveraged asset of the same company.

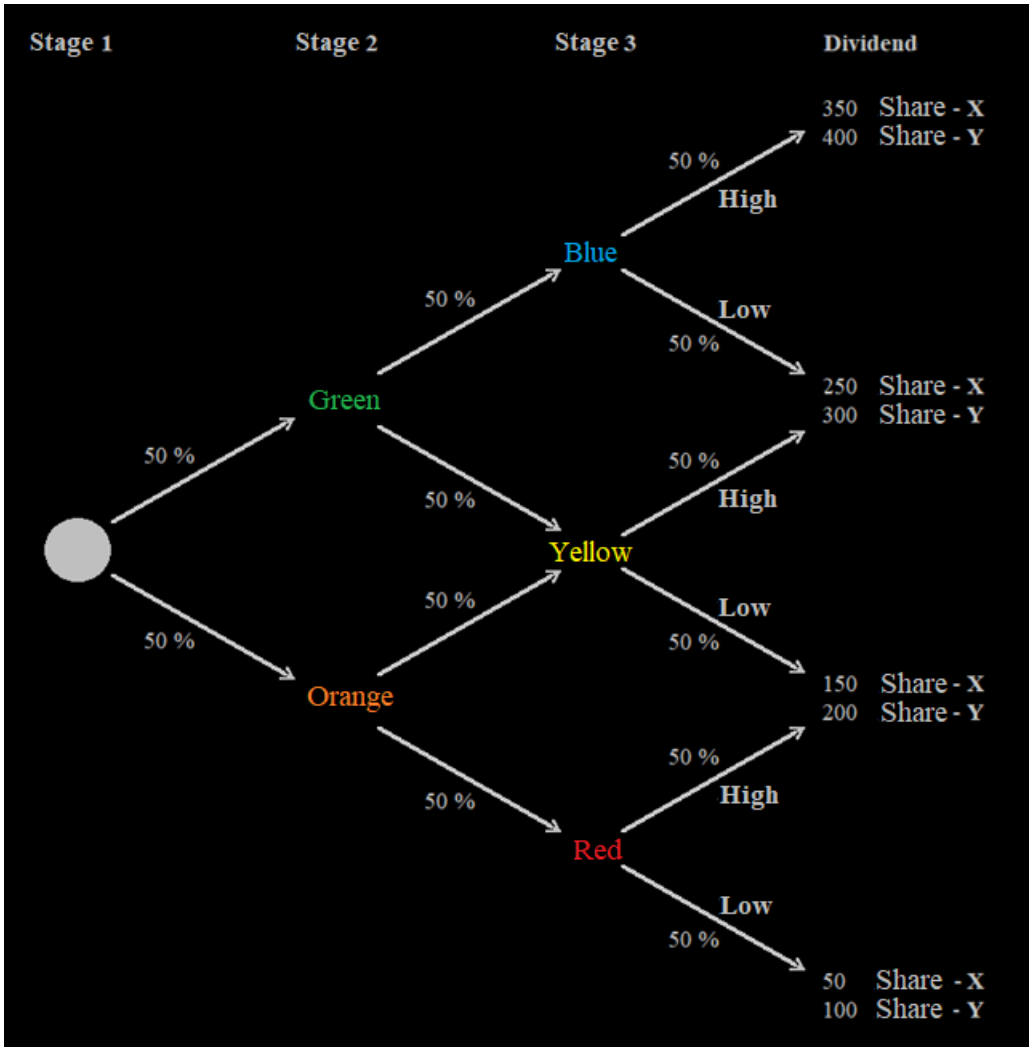

Figure 1. the three stages of the experiment

Table 1. Experimental treatments

Experimental variations	**No Announcement**	**Announcement of ART**
No ART participation	No Ann - No ART	No Ann + ART
ART participation	Ann - No ART	Ann + ART

2.2. Experimental procedures

The experiment was conducted between the 11th and the 15th of November 2019 at LUISS (Rome) CESARE experimental economics lab; 24 subjects participated in each of the 8 experimental

sessions, randomly divided into 4 different cohorts of 6 participants,[8] in total we had 32 cohorts and 192 participants. The sessions were computerized using zTree (Fischbacher 2007). By participating in the experiments, subjects earned an average of €25.30 including a fixed participation fee of € 5. All subjects were recruited among university students from three different departments at LUISS via the ORSEE platform (Greiner 2015).

Each session was completed within 2 hours and 30 minutes: 40 minutes for the assessment of risk aversion in an initial auction stage and the reading of the instructions at the beginning of the experiment; 90 minutes dedicated to trading in the 10 rounds of the main experiment; 20 minutes, at the end of the experiment, dedicated to assessing the participants' personal details including cognitive abilities via the CRT test (Frederick 2006) while processing the payment.

Before the asset market experiment started, all subjects were required to participate in second price auctions to assess their risk aversion in a context dependent elicitation task. Subjects were asked to state their willingness to pay for the assets X and Y given their potential high or low liquidation dividends in the blue, yellow and red state of the asset market. Subjects submitted on one screen six bids, one for each lottery. The high bidder would win the auction and pay the second highest bid in the auction. The task was incentivized; winning bidders received the additional income after the end of the asset market experiment.

3. Theoretical considerations and research hypotheses

3.1 Theoretical considerations

According to the efficient market hypothesis, the expected price in time *t* equals the intrinsic (or fundamental) value.

$$P_t = F_t$$

[8] A cohort is composed of six participants who interact in a market.

Rational investors buy at prices below fundamentals, $P_t < F_t$, and sell above fundamentals, $P_t > F_t$.

Grinblatt and Han (2005) assume that not all investors are rational, but some do exhibit behavioral biases. The so-called behavioral investors account in their evaluation for a reference price, R_t, which is known to the behavioral investor prior to period t.[9] The demand of the behavioral investor depends on the comparison of the price with both the fundamental value and the reference price. Given a mix of behavioral and rational investors, the price in time t equals a weighted average of fundamental value and reference price,[10]

$$P_t = w\, F_t + (1 - w)\, R_t$$

where w is the weight assigned to the fundamental value. The evolution of the reference price depends on the weighting of price innovations,

$$R_{t+1} = v_t\, P_t + (1 - v_t)\, R_t$$

which means the reference price moves in the direction of the price and, assuming value stability, the price converges on the fundamental value.[11] The price exhibits inertia as a positive weight of the reference price impedes an instantaneous approach. With this simple model in mind we next derive our testable hypotheses.

3.2 Testable Hypotheses and measures

In the experiment we distinguish good and bad news. The expected asset value increases upon good news and decreases upon bad news. Upon bad news, assuming the reference price is the prior fundamental value, inertia leads to a decrease of the asset price to an amount somewhere between

[9] R_t stands for reference price in t, which could be the purchase price of the investor or the price of the prior market period. Grinblatt and Han (2005) assume that the demand of behavioral investors depends on the weighted sum $(P_t - F_t) + \lambda(P_t - R_t)$, with λ measuring the capital gain component in the investment.

[10] As μ is the share of behavioral and $(1 - \mu)$ the share of rational investors, w equals $(1 - \lambda\mu)^{-1}$.

[11] In our maximum likelihood estimation, reported below, we assume that $R_1 = F_0$, and $R_{t+1} = P_t$, thus limiting the inertia effect.

the reference price and the fundamental value. The opposite inertia effect is expected upon good news. Our first four hypotheses are implications of Grinblatt and Han (2005).

Hypothesis 1 (underreaction): Asset prices move in the right direction, but underreact to news;

a. after good news, assets price below expected asset value,

b. after bad news, assets price above expected asset value.

c. After good and bad news (in the yellow state), asset prices are higher if bad follows good news than if good follows bad news.

With Hypothesis 1c we can test at once the inertia effect suggested in 1a and 1b in the yellow state after news was good one time and it was bad one time.

Since the experiment involves different fundamental values and twin shares, we make the deviations from the fundamental value comparable. To normalize the deviations we use the measures (absolute) deviation from fundamental, (*A*)*DF*, of Neugebauer et al. (forthcoming).

$$DF_{j\tau} = \frac{P_{j\tau}}{F_{j\tau}} - 1; \qquad ADF_{j\tau} = \left| \frac{P_{j\tau}}{F_{j\tau}} - 1 \right|$$

$$DF_t = \frac{1}{J} \sum_{j=1}^{J} \frac{1}{n_j} \sum_{\tau=1}^{n_j} DF_{j\tau}; \qquad ADF_t = \frac{1}{J} \sum_{j=1}^{J} \frac{1}{n_j} \sum_{\tau=1}^{n_j} ADF_{j\tau}$$

The measures account for various assets *j* and average the price in the time interval *t*. The absolute deviation is the distance, and the deviation from fundamentals takes in account if the average price is above or below the fundamental value. For the purpose of testing hypothesis 1 we employ the measure *DF*.

Weber and Welfens (2007) showed the existence of an asymmetry in the market response following good and bad news. The model of Grinblatt and Han (2005), nonetheless, makes no distinction between the domain of gains and the domain of losses despite the fact that the authors motivate the inertia effect by prospect theory.

Hypothesis 2 (symmetry): Underreaction is symmetric vis-à-vis the domain of gains and the domain of losses, i.e., *ADF* is the same after bad news than after good news.

In Grinblatt and Han (2005) the price moves closer towards the fundamental value over time, because the reference price evolves in the direction of the fundamental value. Drift has been observed in the literature on the post-earnings announcement drift (Bernard and Thomas 1989).

Hypothesis 3 (drift): The asset price drifts towards fundamentals, i.e. the price tends to fundamentals over time during the trading period, i.e., *ADF* decreases during a period.

The model suggests that the weight given to the fundamental value increases with the share of rational investors in the market. In the experiment we elicit investors' acuity. The literature suggests that cognitive abilities may impact asset pricing close to fundamentals (Bosch-Rosa and Corgnet 2022, Charness and Neugebauer 2019).

Hypothesis 4 (rationality): The higher the level of investors' acuity the smaller the absolute deviation of asset prices from fundamental value, *ADF*.

The theoretical literature (Friedman 1953) suggests that if investors trade irrational in similar ways, arbitragers will push prices towards fundamental value. In our experiment we implement arbitrage trading via a sniper algorithm.

Hypothesis 5 (ART): Arbitrage trading pushes prices sooner to intrinsic values. Announcement of algorithmic trading reduces mispricing.

4. Experimental results

In this section we report the experimental results. The observations are numbered correspondingly to the hypotheses.

Observation 1: Average pricing is not significantly different from fundamental value.

a. After good news, average prices are below fundamental value.

b. After bad news, average prices are above fundamental value (unless the yellow state).

c. In the yellow state, average prices are higher after good and bad news than after bad and good news.

Support: Figure 2 presents the distributions of deviations of price from fundamentals, *DF*, after good, bad or no news.

Without news, similar to the overall data also shown in Figure 2, asset prices are very close to fundamental value in the initial state and the distribution is symmetric. Overall independent

observations, the average *DF* values measured separately for the A asset and B asset are 0.005 and -0.008, and -0.003 for the joint *DF*. The differences from fundamentals are not significant for either asset according to the Wilcoxon signed ranks test, p-values being 0.844 and 0.477 for the A asset and B asset, and 0.454 for the joint *DF*.[12]

Figure 2 and Table 2 inform about the average *DF* values after good and bad news. After good news the average *DF* is negative, and after bad news the average *DF* is positive. Negative *DF* values have more support than positive ones (82.6% of *DF* values are negative) after good news, and less support (70.5% of *DF* values are positive) after bad news. The test results reported in the table show that the differences from fundamental value are significant as suggested in Hypothesis 1. In fact, the *DF* values after good and bad news are negative and positive in each treatment with the exception of the yellow state. In the yellow state, subjects received two pieces of news, one being positive and the other one negative. Even with bad news (after prior good news) we have that the average *DF* is negative, different from what Hypothesis 1b suggests. In line with Hypothesis 1c, nevertheless, the DF in the yellow state is larger following bad news (after prior good news) than following good news (after prior bad news). Hence, the data suggest that prices underreact to news supporting Hypothesis 1 (with the described exception in Hypothesis 1b).

Table 2. Deviations and absolute deviations of prices from fundamentals

	overall	stage 1	stage 2		stage 3			
news$^{\text{prior news}}$		/	Bad$^{/}$	Good$^{/}$	Bad^{Bad}	Good^{Good}	Bad^{Good}	Good^{Bad}
DF	-0.003	-0.014	0.085** $^{>>>}$	-0.093***	0.113*** $^{>>>}$	-0.121***	-0.068 $^{>>}$	-0.129***
ADF	0.155	0.231	0.256 $^{>>}$	0.190	0.272 $^{>>>}$	0.153	0.157	0.154

news $^{\text{prior news}}$ describes the second news after the first news, "/" indicates no such news are applicable.
$^{>>>,\ >>,\ >}$ significantly larger measure at .01, .05, .1, according to one-tailed Wilcoxon signed ranks test
***,**,* significant deviation *DF* measure at .01, .05, .1, according to one-tailed Wilcoxon signed ranks test

[12] There are significant differences of *DF* from zero in the control treatment with no algorithm and no announcement, particularly in the X asset. The *DF* is negative in more sessions than positive.

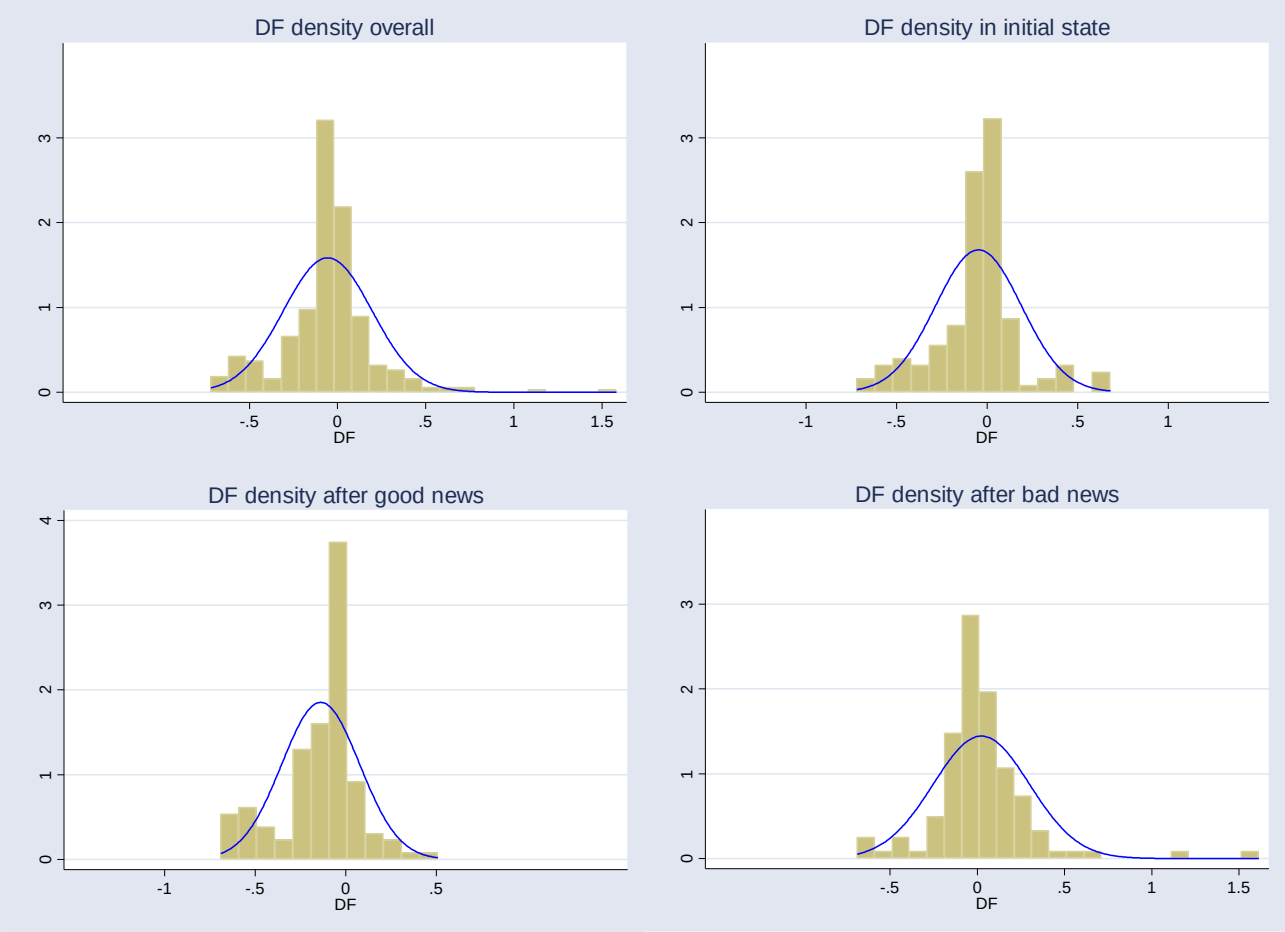

Figure 2. Deviations of average prices from fundamental value after good, bad or no news
Bar charts and continuous density approximations indicate the difference of the period's average price from the fundamental value, *DF*. The top panels display the *DF* over all periods and for the initial stage of the experiment, where the continuous density approximations suggest a symmetric distribution around zero. The bottom panels display the *DF* after good and bad news, where the density approximations suggest left and right skewed distributions respectively.

Observation 2: Underreaction seems to be asymmetric vis-à-vis the domain of gains and the domain of losses, i.e., *ADF* is larger after bad news than after good news.

Support: Table 2 also reports the *ADF* for good and bad news. Figure 3 displays the average price trajectory in stage 2 and stage 3 following news. The data in Table 2 show that the absolute

deviation from fundamentals is significantly larger in stage 2 after bad news (orange state) than after good news (green state). The data reject Hypothesis 2 except for the yellow state.

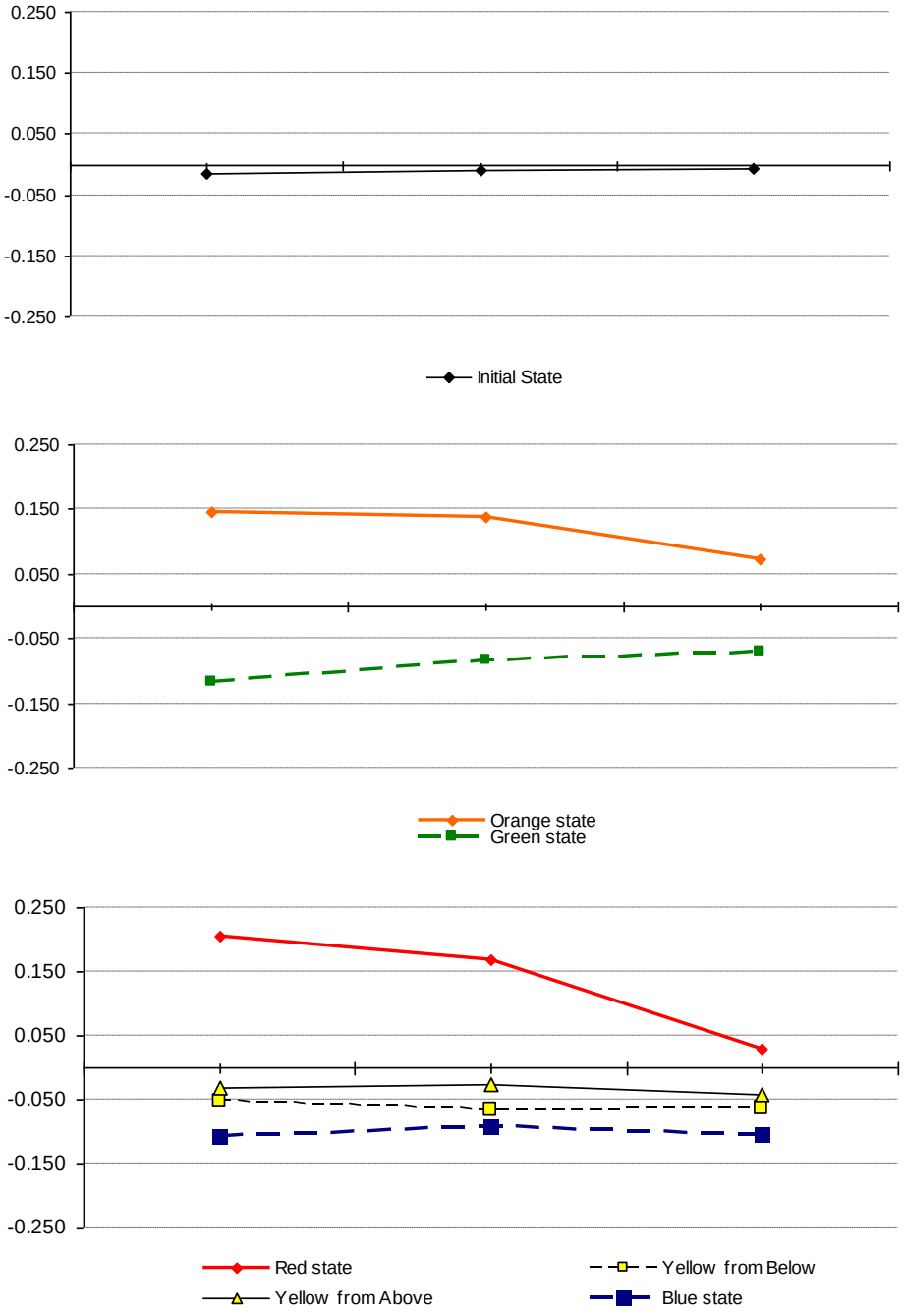

Figure 3. Distance from and convergence on fundamental value in the different states of a period
Diamonds indicate the average distance of the asset price from fundamental value, *DF*, in the 60 seconds time interval for the first, second and third minute of the period. The top panel displays the price behavior in the first period, the middle panel in the second period in, and the bottom panel in the final period of a round. The dashed lines in the middle and bottom panels indicate the price behavior following good news, and the solid lines indicate the price behavior following bad news relative to the prior stage fundamental value.

Comment. We have estimated the weight assigned to the fundamental value, *w*, over the three minutes interval. During the interval we hold *w* constant. We estimated with maximum likelihood different *w* values for different states using the following equations.

$$P_1 = w\,F_1 + (1\text{-}w)\,F_0$$

$$P_2 = w\,F_1 + (1\text{-}w)\,P_1$$

$$P_3 = w\,F_1 + (1\text{-}w)\,P_2$$

State	Orange	Green	Red	Yellow	Yellow	Blue
w	0.393	0.316	0.556	0.341	1.233	0.081

Our approach is different from Grinblatt and Han (2005) who estimated the (weekly) return as a function of past returns to show the inertia effect in data from real world exchanges.[13] They assumed changes across the different time horizons for the weight assigned to the fundamental value, *w*. The updating weight assigned to the current price *v* was estimated by turnover. Thus, Grinblatt and Han (2005) presumed that investors update their reference price depending on the trade volume.

Observation 3. The price drifts towards fundamentals over time during the trading period. ADF decreases during a period.

Support: Figure 3 displays the charts of average *DF* for the first, second and third minute of trading across all independent observations. The regression with robust standard errors of the *ADF*

[13] They considered the weeks of the past month, the preceding eleven months, and the preceding 24 months.

values on *t* (minute by minute during the period) shows that the absolute deviations from fundamentals decrease during a period (see Table 3), in support of Hypothesis 3.

Observation 4: The absolute deviation of asset prices from fundamental is lower the higher the level of investors' acuity.

Support: As measure of investors' acuity we take the average *CRT score* of subjects in a market. The regression with robust standard errors of the *ADF* values on *CRT scores* shows that the absolute deviations from fundamentals declines with an increase in acuity (see Table 3), in support of Hypothesis 4.

Observation 5: We observe no effect of ART announcement or participation.

Support: We report a dummy regression in which the algorithm take value 1 if the algorithm participated and announcement takes value 1 if the potential participation of the algorithm was announced in the session, and zero otherwise. We include the interaction effect of the two in the regresssion. The regression with robust standard errors of the *ADF* values on time, *CRT scores, algorithm, announcement and* the interaction *ann* × *algo* shows that the absolute deviation from fundamentals is not amended through the participation or the announcement of the algorithm (see Table 3). We also conducted this regression for each state in our design separately to find confirming results. Thus, Hypothesis 5 is not supported by the data.

Table 3. Determinants of ADF_t

constant	0.267***	0.352***	0.393***
	[10.67]	[7.66]	[6.00]
time, i.e. minute	-0.025***		-0.025***
	[-5.00]		[-4.89]
crt score		-0.114***	-0.111***
		[-3.94]	[-3.59]
algorithm			0.038
			[0.73]
announcement			0.008
			[0.17]
ann × algo			-0.069
			[-0.97]
obserations	96	96	96
clusters	32	32	32
R squared	0.031	0.222	0.288

The reported regressions have the mispricing measure ADF_t as dependent variable, where *t* is the minute of the period and *ADF* is the average absolute deviation from the fundamental value in each observation.
***, **, * indicates signidicant results at 0.01, 0.05, 0.10

5. Discussion

Our results reject the efficient market hypothesis in favor of the hypothesis of underreaction to news. Our data reveal price inertia: prices move slower than news and drift over an extended period. In fact, the average prices confirm the fundamental value because bad and good news are equally probable, but the state depend prices reject the fundamental value. Therefore, we have provided evidence in favor of the first hypothesis suggested by the behavioral theory of Grinblatt and Han (2005). The second hypothesis, however, that suggests symmetry in underreaction is not confirmed. Mispricing or price inertia is more pronounced after bad than after good news. This asymmetry shares similarities to the disposition effect, i.e., the tendency of investors to sell their winners early and hold on to their losers for too long.

We also investigated the effect of algorithmic trading in the context of news announcements. Price drift was not significantly impacted through the participation of an arbitrage robot trader; the arbitrage trader did not impact a faster convergence on the fundamental value. The absence of a treatment effect may be rationalized with the fact that the arbitrager only takes advantage of price discrepancies between assets, and does not take account of the fundamental value.

If we had incorporated an algorithmic fundamental trader that purchases at prices above and sells at prices below the asset value, its influence would likely have been evident. For future research, exploring additional algorithmic trading strategies beyond arbitrage in this experimental design could provide insights into how convergence on the fundamental value may pick up pace.

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APPENDIX

Experimental Instructions

Welcome and thank you for participating in our experiment on decision-making in asset markets. If you read these instructions carefully and make good decisions, you might earn a considerable amount of money. This money will be paid to you in cash after the session. Do not use hand phones, laptop computers, or use the lab's desktop computer except for the experimental software application. Please refrain from talking for the duration of the experiment or looking at others' computer monitors. If at some point you have a question, please raise your hand and we will address it as soon as possible. You must observe these rules, otherwise we will have to exclude you from this experiment and all associated payments, and ask you to leave.

I. The structure of the round, shares, cash, and earnings

In this experiment, you will participate in a market of **6 participants**. The identities of the other market participants will not be revealed to you. You will interact with the same participants in **10 successive rounds** of **3 stages**.

At the beginning of each round we offer each participant the following endowment: **1300 cash units**, **2 "A"** shares and **2 "B"** shares. Each individual share generates a cash payment at the end of stage 3 to the shareholder, which we will refer to as dividend. The dividend of the round depends on the final state which will be either **high** or **low** and on the final stage. There are three possible **final stages** which we refer to as **Blue**, **Yellow** and **Red**. The high state and low state outcomes occur with **probability of** ½ each. You can think of the occurrence of the outcomes as a *flip of a coin*; *heads* you win the high outcome, *tails* you win the low outcome.

If the final stage of the round is Blue, the dividend payment per A-share will be 250 (low state outcome) or 350 (high state outcome) cash units with equal probability. The dividend payment per B-share will **always** be 50 cash units higher, that is, 300 if the state is low and 400 if it is high.

If the final stage of the round is Yellow, the dividend payment will be 150 per A-share and 200 per B-share in the low state outcome; it will be 250 per A-share and 300 per B-share in the high state outcome.

If the final stage of the round is Red, the dividend payment will be 50 per A-share and 100 per B-share in the low state outcome; it will be 150 per A-share and 200 per B-share in the high state outcome.

Preparation: Auction Experiment

Before we describe the first and the second stage of the round of the main experiment, we ask you to value the possible dividends to be received at the end of stage 3 in an auction. Thus, you will familiarize yourself with the possible dividends in the main experiment and you will earn additional money.

You are about to participate in an auction market of 6 participants. Each of you is endowed with 400 Eurocents and makes a **purchase proposal**, which we call **bid**. You win the auction if no other participant submits a higher bid than you. The winner receives the dividend outcome (which can be high or low) and pays a price that is fixed at the **second highest bid** submitted in the auction. If you do not win the auction you keep your endowment of 400 Eurocents.

On the screen, the possible dividends are described in parentheses for each possible final stage (see Figure I). For instance, the blue-framed window at the upper left of the screen represents the **Blue stage** of the A-share. BLUE: (L 250 ; H 350) means that the dividend is 250 Eurocent in the low state outcome or 350 Eurocent in the high state outcome. High and low state outcomes occur with the same probability of ½. Think of the flip of a coin; *heads* you win the high outcome, *tails* you win the low outcome.

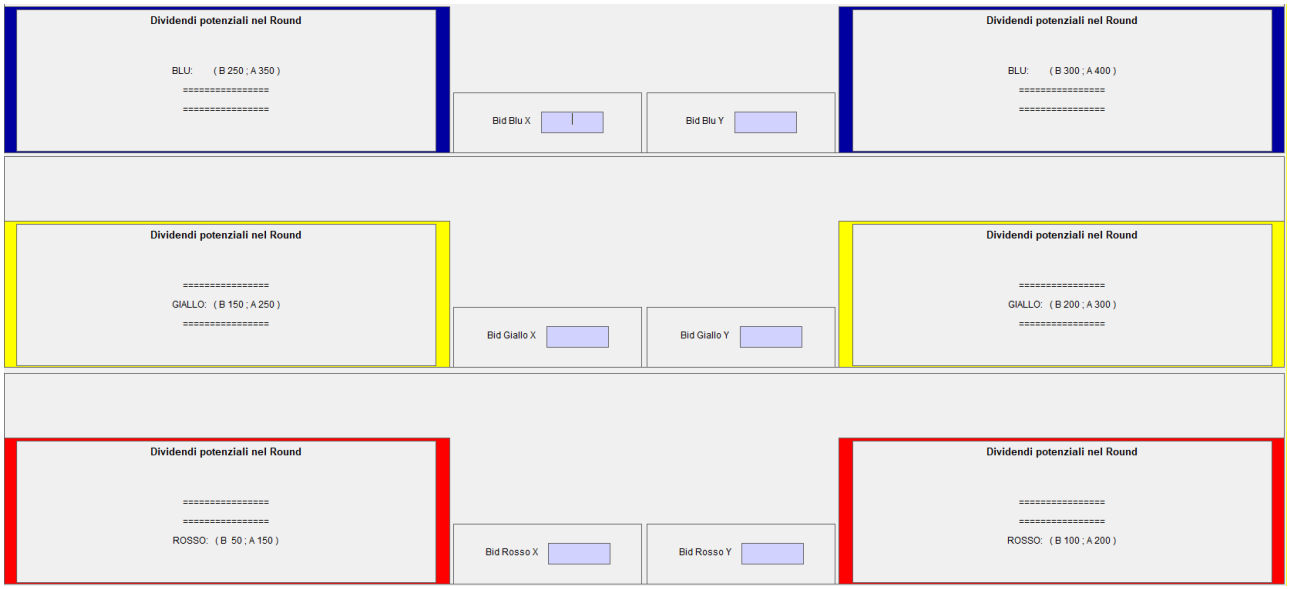


Figure I. Auction of Dividends in Possible Stage 3 – Blue, Yellow or Red

We ask you to submit a bid for each possible final stage of the round, for the A-share and for B-share separately; thus 6 auctions. Enter these 6 bids (price proposals) in the entries attached to the

color-framed windows and press the button “Submit all Bid prices”. All bids are real Eurocent money amounts that represent the price you are willing to pay at most for the dividend payment (which can be high or low with equal probability).

One of these 6 auctions is randomly chosen for payment. Think of a six-sided die; if the die shows 1, the auction for the Blue A-share (upper left on the screen) is selected; if the die shows 2, the Blue B-share (upper right on the screen) is selected, …, if 6, the Red B-share (lower right on the screen) is selected. The winner in the selected auction receives the dividend and pays the second highest bid from the endowment. The dividend was randomly determined before the experiment. If you do not win the auction you keep your endowment of 400 Eurocents. We inform you about the result of the auction on your screen at the end of the main experiment.

The structure of a round

In the experiment you will interact with the same 5 other participants in **10 successive rounds** of **3 stages**. The final stage and the dividend outcome were determined before the experiment. The dividend payments to be received at the end of the third stage are shown in Figure II on the right. The dividend is **high** or **low** with equal probability. Think of the flip of a coin. For instance, if Stage 3 of the round is **Blue**, the dividend payment will be **250** per A-share and **300** per B-share in the low state outcome; it will be **350** per A-share and **400** per B-share in the high state outcome. … In the **Red** stage, the high state outcome is **150** per A-share and **200** per B-share and the low state outcomes are **50** per A-share and **100** per B-share, respectively. Note that the dividend per B-share is **always** 50 cash units higher than of the A-share.

Stage 2 can be Green or Orange. If the final stage is Blue or Yellow, Stage 2 is Green; if the final stage is Yellow or Red, Stage 2 is Orange. If the second stage is Green, the final stage is Yellow or Blue with equal probability; if the second stage is Orange, the final stage is Yellow or Red with equal probability. Think of the flip of a coin; *heads* you go up in the tree of Figure II, *tails* you down in the tree.

In Stage 1, each final stage of the world is possible. **Green** or **Orange** occur with equal probability of ½ in stage 2.

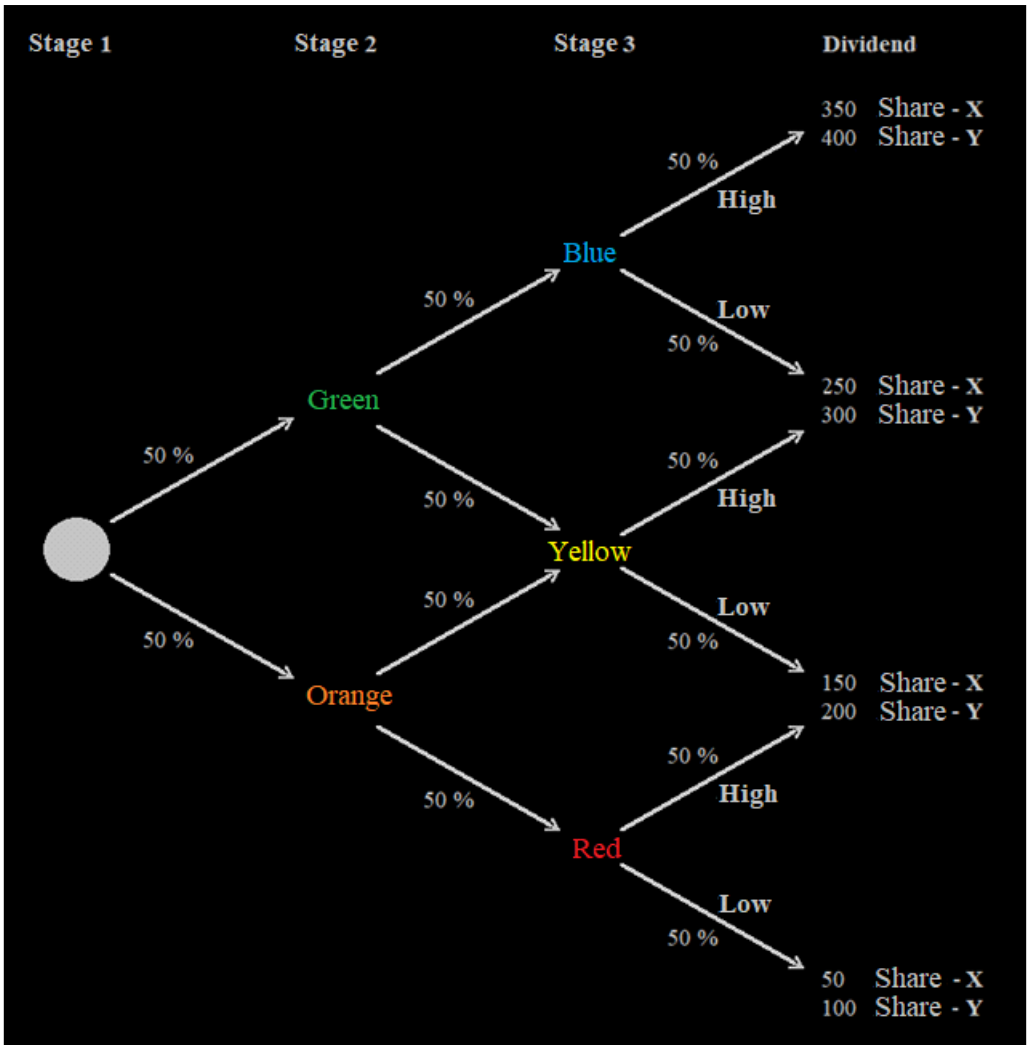


Figure II. – Structure of one round

Earnings

At the end of the round when the dividends are paid on the shares held, the amount is added to the cash balance.

Please note: the dividend of the B-share is always equal to the dividend of the A-share + 50 cash units.

You will end each round with a final cash balance. The final cash balance is the basis for your final earnings in this experiment.

At the beginning of each round you start Stage 1 with the identical initial endowment 2 A-shares, 2 B-shares and 1300 cash units. Cash and shares carry over from Stage 1 to Stage 2 to Stage 3.

How dividend payments and final earnings are determined:

Prior to the session, we have **pre-drawn the dividend series** for all rounds. At the end of the experiment, one round will be chosen for payment. One participant in the room will determine the decisive round for payment for everyone. You will earn your final cash balance in the decisive round.

II. How to Trade Shares?

The experiment is divided into ten rounds of **3** consecutive **stages**. In each of these stages you will be able to trade shares for cash with the other market participants. We refer to the period between stages as **trading period**. Each trading period will last 180 seconds. In each trading period, you will participate in a market where the **Shares** can be **bought and sold between participants**. You pay out of your Cash when you buy a share, and you get Cash when you sell a share. When a period is over, your Cash and Shares will carry over to the next period until the round ends.

We are interested in the price you are bidding to buy a share and the price you are asking to sell a share. To buy shares, you need cash. If you run out of cash, you can no longer trade, unless you sell the shares you own. The money you own is shown on the screen. In order to sell shares, you need shares. The number of shares you own is indicated at the top of the screen for "A" shares on the left and "B" shares on the right, respectively.

During a period, you may buy or sell shares. To buy a share you may **submit a bid** or **accept an outstanding ask** in the market (see Figure 2). To sell a share you may submit an ask or accept an outstanding bid in the market. **Note that you can only buy or sell one share at a time.**

1. Submit an ASK: An **ask is a proposed selling price** for one share. You offer a share from your **share holdings** for sale by entering the asking price to sell one share in the space underneath the button **ASK: proposed selling price** (see Figure 2). You confirm the ask by a click on the button. The ask is then added to the list of outstanding asks. The outstanding asks are publicly recorded in increasing order, i.e. the best outstanding ask (the cheapest proposed selling price) being placed at the top of the list. All market participants can see this list.

Note: you can submit as many asks as you like to sell one share. Upon selling one share, all your outstanding asks (for that **share class** "A" or "B") are cancelled. **To sell another share of that share class, you then must submit a new ask.**

2. Submit a BID: A **bid is a proposed buying price** for one share. You bid to purchase a share by entering your bidding price for one share in the space underneath the button **BID: proposed buying price.** You confirm your bid by a click on the button. The bid is then added to the list of outstanding bids. The outstanding bids are publicly recorded in decreasing order, i.e., the best outstanding bid (highest proposed purchase price) being placed at the top of the list. All market participants can see this list.

Note: If two or more orders (bids or asks) are the same, they are listed in the order of arrival, earlier orders being given priority over later ones. Upon purchasing one share, all your outstanding bids (for that share class) are cancelled. **To buy another share for this share class you then must submit a new bid.**

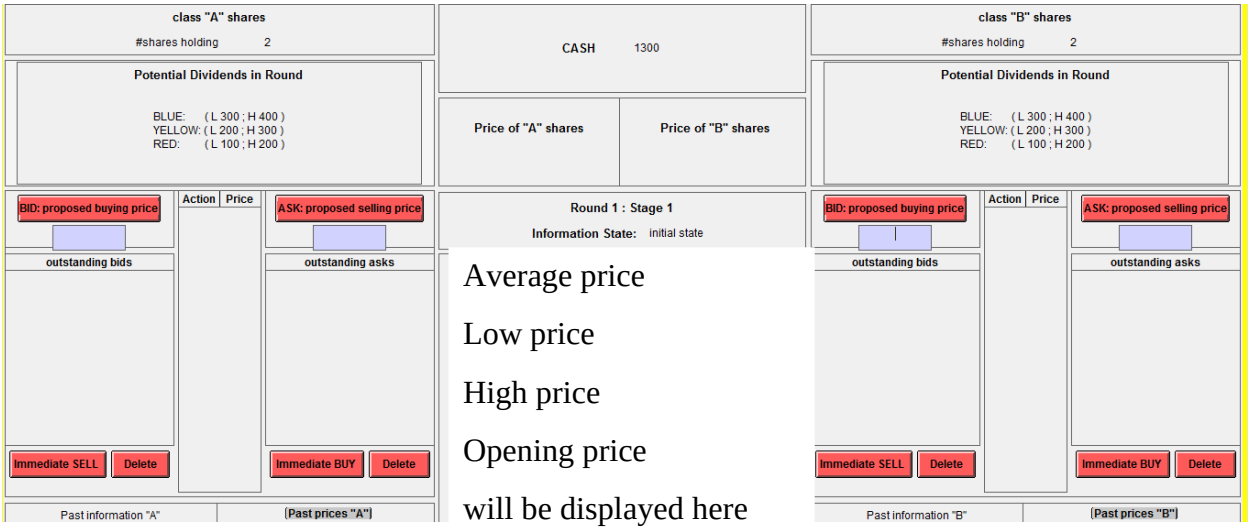


Figure 2. Trading screen

3. Immediate BUY – accept an ask: The best outstanding ask of the other market participants is marked on your screen. You can accept the asking price (i.e., entering in a purchase agreement of a share with the seller) by clicking the button **Immediate BUY**, which is placed at the bottom of the list of outstanding asks.

4. Immediate SELL – accept a bid: The best outstanding bid of the other market participants is marked. You can accept the bid (i.e., entering in a sale agreement of a share with the buyer) by clicking on the button **Immediate SELL**, which is placed at the bottom of the list of outstanding bids.

5. Delete – you can delete your outstanding bids and asks. To do so, select your outstanding bid or ask, which are displayed in the list in blue colour and click the button **Delete**.

Note: Your own orders are displayed in blue, while the other orders are visible to you in black. You cannot accept your own orders. You cannot delete orders of others. You cannot purchase shares if the ask exceeds your cash. If your holding of "A" shares is 0, you cannot sell any further "A" shares. If your holding of "B" shares is 0, you cannot sell any further "B" shares.

III. Transaction and price announcement

Upon acceptance of a bid or ask, via **Immediate BUY** or **Immediate SELL**, a transaction is completed. The accepted order is the transaction price. The transaction price is recorded on your screen in between the lists of bids and asks. Next to the price you are informed if you participated as buyer or seller in the transaction. The more recent prices are listed first. The most recent prices are also recorded for each share class in the middle of the screen below the cash amount.

Upon transacting, the price is debited from the buyer's cash balance and credited to the seller's cash balance. The purchased share is added to the buyer's share holdings and subtracted from the seller's share holding.

Note: You are now going to participate in a **Practice Session** of trading to familiarize yourself with the trading environment. You trade for 3 minutes on your screen with the other participants, in fact in stage 1. There are **NO payoff consequences** linked to trading in the **Practice Session**. During the Practice Session please practice submissions of bids and asks, immediate selling and buying, and deleting of your outstanding bids and asks. During the **Practice Session** none of your actions will have any payoff consequences. The payoff-relevant trading periods begin only after the Practice Session.

IV. Information

In each stage, the information on the final state changes. In line with the above explained **structure of a round**, we inform you about the current state of the round in every moment. The first stage is the initial state; Blue, Yellow and Red are the possible final states. The potential dividends are highlighted on your screen (see Figure 3: Information in Stage 1).

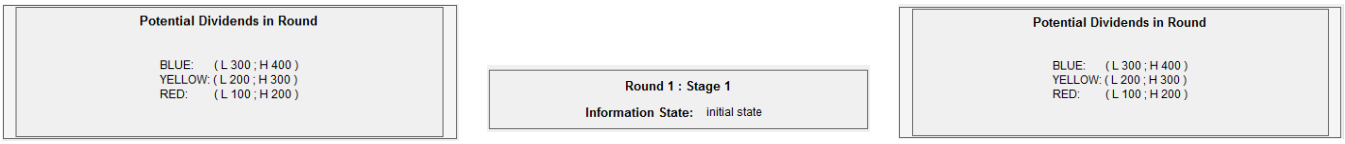


Figure 3: Information in Stage 1

In stage 2, the state of the round is either Orange or Green which both occur with probability ½. Onscreen you see the information in the center of the screen. The frame of the window of potential dividends is colored in the corresponding color, and the potential dividends are updated (see Figure 3: Information on Alternative States in Stage 2).

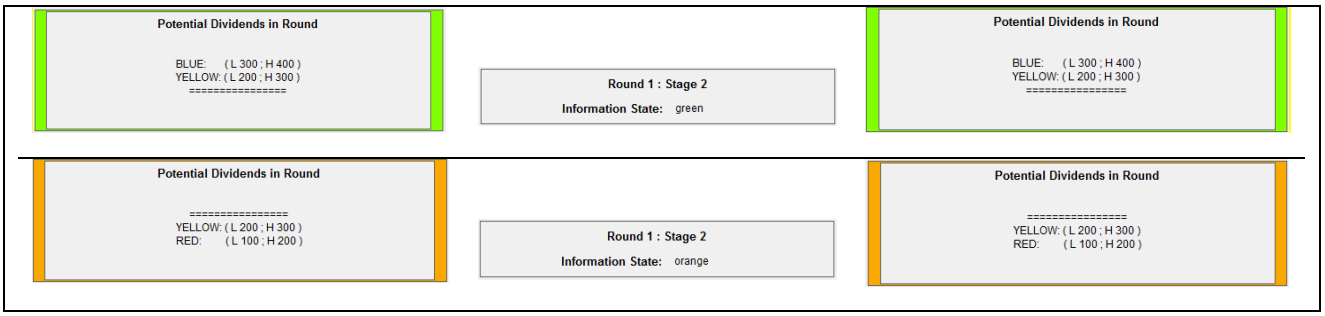
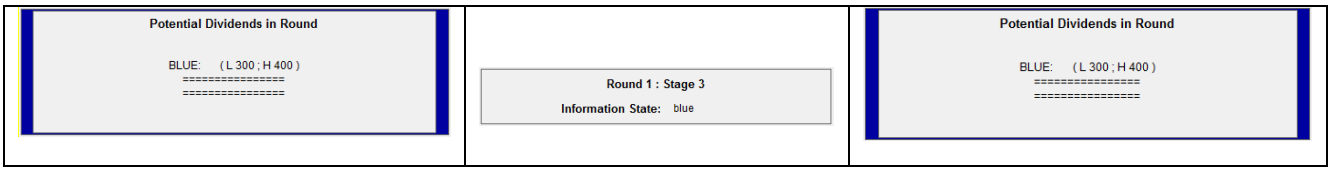


Figure 3: Information on Alternative States in Stage 2

In stage 3, the final state of the round is revealed to you. Following the Orange state, the final state is either Yellow or Red each occurring with probability ½. Following the Green state, it is either Blue or Yellow each occurring with probability ½. The frame of the window of potential dividends is colored in the corresponding color, and the potential dividends are updated (see Figure 3: Information on Alternative States in Stage 3).



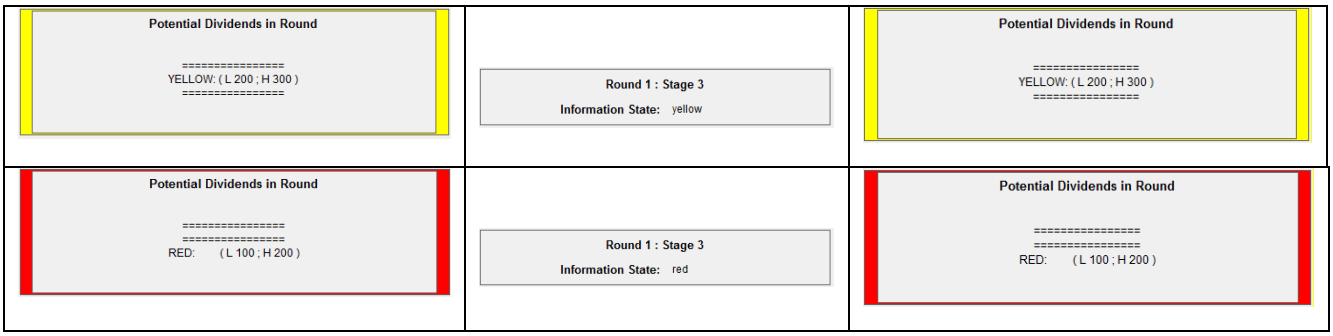


Figure 3: Information on Alternative Final States in Stage 3

You will receive real-time updates on bids, asks and prices for both A-shares and B-shares on the left-hand and right-hand side of the screen, respectively. You will receive summary information on prices at the opening of the period, the high, the low and the average price during the period.

The **past prices** are shown in a table on the bottom of the screen, including the prices at opening, closing, the high, low and **average** of past stages. **Alternatively to the past prices,** you receive past information on your share and cash holdings at the end of the period, buys and sells during a period, and the past period dividends. You can alternate the **past information** with the **past prices** by clicking on the button.

V. Endowment and earnings

Your earnings in this experiment will be based on your **final cash balance** at the end of a round. The final cash balance of **one of** the **ten rounds** will be paid out to you at the end of the experiment.

The experimenter randomly determined the sequence of high and low states for the ten rounds. Then the experimenter randomly determined the final states and the sequences of the corresponding information. Finally, the experimenter randomly determined one round for your payment and inserted this information in the software.

The **decisive round** to be paid out to you is chosen randomly. The result of this random draw has been determined before the session and has been recorded on a sheet of paper in the envelope on the wall, which will be revealed to you after the final round. You will also be informed about the decisive round on the screen to confirm that the two numbers match.

At the end of the experiment, cash units (CU) will be converted to Euro, at an exchange rate of €1 = 100 CU. Your final payment will be equal to your final cash balance at the end of the decisive round plus a €3 payment for your participation. The final payment will be made to you in private; you will receive an envelope delivered to your seat in exchange for your signed receipt.

V. Trading Algorithm

Besides the participants in the room, a computerized trading algorithm may participate in the market. The computerized algorithm can take the same actions as you, that is, it can buy and sell in the market. The details of the strategy followed by the algorithm are not revealed to you, and you will not be informed whether the computerized trading algorithm actually acts in the market or not.

VIII Summary

1. At the beginning of each round you will be given an initial endowment of 1300 cash units, 2 shares of "A" and 2 shares of "B". At the end of a round, you will be paid for each A-share and each B-share the dividend, depending on the final state of the round and whether the state is the low state or the high state.

2. At the end of the round, the final state can be Blue, Yellow or Red. In Blue, the high and low dividends of the B-share are (L 300 ; H 400), and the high and low dividends of the A-share are (L 250 ; H 350). In Yellow, the possible dividends of the B-share are (L 200 ; H 300), and the corresponding dividends of the A-share are (L 150 ; H 250). In Red, the possible dividends of the B-share are (L 100 ; H 200), and the corresponding dividends of the A-share are (L 50 ; H 150). The dividend of the A-share is **always** 50 cash units smaller than the dividend of the B-share.

3. In each period, the market will open for trading for 180 seconds. You can submit BIDs to buy shares and ASKs to sell shares. You can make immediate transactions by buying at the lowest ask (offer to sell) or selling at the highest bid (offer to buy). You can delete your offers while outstanding.

4. You are about to participate in 10 rounds of 3 stages. At the end of the experiment, one round is selected for payment. The decisive round is determined randomly and is recorded on a sheet of paper in an envelope which is taped on the wall, which will be revealed to you after the final round. The decisive round is the same for all participants in a market of six.

5. A computerized trading algorithm may participate in the market. However, you will never be told whether the algorithm acts in the market and, if it does, what it is programmed to do.

6. The instructions are over. If you have any question, raise your hand and consult the monitor. Otherwise, please wait for the start of the Round 1.

Note: We now invite you to participate in a Trading **Practice Session** to familiarize yourself with the trading environment. Practice trading for 3 minutes on screen with the other participants. **There are no payoff consequences** related to trading in the **Practice Session**. During the practice session, please practice submitting Bid Proposals and Ask Proposals, Instant Selling and Buying, and deleting pending Bid Proposals and Ask Proposals. During the **Practice Session** none of your actions will affect your bottom line. Payoff-relevant trading periods only begin after the practice session.

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LABSI EXPERIMENTAL ECONOMICS LABORATORY
UNIVERSITY OF SIENA
PIAZZA S. FRANCESCO, 7 53100 SIENA (ITALY)
http://www.labsi.org labsi@unisi.it