Contagion and return predictability in asset markets: An experiment with two Lucas trees

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Abstract: Using a laboratory experiment, we investigate if contagion can emerge between two risky assets even though their fundamentals are not correlated. To guide our experimental design, we use the 'Two trees' asset pricing model developed by Cochrane et al. (2007). The model makes time-series and cross-section return predictions following a shock to one of the assets' dividend share. Consistent with the predictions of the model, we observe positive autocorrelation in the shocked asset, a positive contemporaneous correlation between the two risky assets, and time-series and cross-sectional return predictability using the dividend-price ratio. In line with the rational foundation of the model, the model's predictions have higher support in markets with more sophisticated agents.

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1. Introduction

Asset comovement is a central notion in international finance and is crucial to portfolio allocation and asset pricing as it determines market risk.

Standard asset pricing theory postulates that an assets' price equals its expected discounted cash flows. Consequently, comovement between two risky assets can be caused either by common cash flow shocks or shocks to investors' discount rates.

In this paper, we examine a rational channel for asset comovement by conducting a laboratory experiment that tests discount rate dynamics in a consumption-based asset pricing model. The experimental setting is based on the 'Two trees' asset pricing model developed by Cochrane, Longstaff and Santa-Clara (2007), an extension of the 'One tree model' by Lucas (1978). The 'Two trees' model provides a rational account of how return comovement can arise between two risky assets whose fundamentals (cash flows) are uncorrelated. In the 'Two-trees' model, contagion appears via the discount rate channel and is driven by a diversification motive.

This study focuses on several implications of the 'Two trees' model. The model describes asset return dynamics and provides predictions for the cross-sectional and time-series pattern of asset returns following changes in the dividend share. To our knowledge, we are the first to study a market with two Lucas trees in an experimental setting.

In the literature, various studies attributed the increase in equity market co-movement to correlated information (King and Wadhwani, 1990), correlated liquidity shock (Calvo, 2004), and market integration (Bordo et al. 2014). However, these rational explanations don't seem to fully capture the equity comovement observed empirically. As a result, several behavioral factors have been suggested: market overreaction due to coordination failure which can lead to self-fulfilling crises (Diamond and Dyvbig, 1983); a "wake-up call" for investors to reassess vulnerabilities in other markets as well (Goldstein, 1998; Goldstein et al 2000), information mirages regarding correlation between assets (Camerer and Weigelt, 1991)[1], and asymmetric information between informed and uninformed traders (Kodres et al. 2002)[2].

Even though market contagion has the connotation of being 'irrational', the contagious return patterns generated in this study, appear in a setting where all market participants are fully rational.

There are two Lucas trees which can be traded over a number of periods, and whose fundamental values are subjected to dividend shocks. Comovement between asset returns emerges due to (1) a diversification motive with respect to aggregate consumption, and (2) the market clearing mechanism.

In the model, consumption comes only from consuming the fruit of the trees (dividends). Therefore, the diversification motive can be intuitively understood through an example where one of the assets undergoes a dividend shock. As the dividend shock increases the shocked asset's share in total wealth, the relative share of the non-shocked asset becomes smaller. Consequently, the non-shocked asset becomes less correlated with aggregate consumption. As a result, the diversification benefit of the non-shocked asset increases, which leads to a higher demand for the asset that raises its current price. Therefore, a positive, permanent dividend shock to one asset is associated with a price appreciation of the non-shocked asset and a positive contemporaneous correlation between their returns.

After a positive shock, the price of the shocked asset is expected to continue to drift upward. This occurs as the shocked asset has a larger share of dividends and therefore has lower diversification benefits and higher future returns in equilibrium. In other words, the returns of the shocked asset exhibit autocorrelation.

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[1] Noussair and Xu (2015) study the effect of information mirages in the lab and find that asset contagion appears in an asymetric information setting where investors overreact to mispricing in one market by extrapolating information from other market movements.

[2] Cipriani et al. (2013) using portfolio rebalancing as a mechanism, implement in the lab the effect of asymmetric information on asset price comovement by imposing a portfolio imbalance penalty in the traders' trade-off function.

Furthermore, after a positive shock to an asset, the expected return of the non-shocked asset is expected to be lower in the future, as its price has increased in the period of the shock while its dividend has remained constant. Therefore, we expect a negative cross-serial correlation of returns in the period following the shock.

When analyzing the aggregate price behavior observed in the lab, we find strong support for the Two-tree model. There is a contemporaneous correlation between the two assets, indicating contagion of the form predicted by the model. Momentum persists in the returns of the shocked asset as expected. However, it is also present in the returns of the non-shocked asset which is contrary to the model's predictions. Though we do not have direct evidence, we conjecture that the observed momentum in the non-shocked asset is due to backward-looking expectations.

In addition, the model's predictions are better supported in markets with more sophisticated agents. This is important as the intent of the model is to capture the dynamics of markets that are populated by rational, sophisticated agents, with strong incentives.

The paper is organized the following. Section 2 briefly discusses related work. Section 3 presents the adjusted asset pricing model that serves as the inspiration for our experiment. Section 4 characterizes the laboratory implementation of the model and the challenge of translating the model's assumptions into an experimental framework. Section 5 analyses the experimental data, and Section 6 concludes.

2. Previous Literature

The experimental asset pricing literature, that focuses on testing general equilibrium models in the lab, is scarce. Several experimental studies have evaluated equity asset pricing models such as the Arrow and Debreu complete-markets model, capital asset pricing model (CAPM) and augmented CAPM (Bossaerts and Plott, 2004; Bossaerts et al. 2007; Asparouhova et al. 2014)[3]. More recently, the formation of a bond price, when interdependencies exist between initial public offering (IPO) prices and the default risk, has been carefully examined using a lab experiment. Based on the bond pricing model of Merton (1974), Weber, Duffy and Schram (2018) find that even with limited experience, investors seem to learn to set an IPO price for the bonds whose price is close to what the theory predicts.

To our knowledge, the experimental research that is most closely related to ours, is the work of Asparouhova et al. (2016) and Crockett et al. (2018), who test the aggregate predictions of the Lucas (1978) model, the predecessor of the 'Two trees' asset pricing model studied in this paper.

Asparouhova et al. (2016) study a setting with two assets, a tree yielding uncertain dividends depending on the state of nature, and a bond with a specific dividend. There are two types of agents, one endowed with bonds and the other with trees, interacting in multiple indefinite horizons. Cash (which comes from dividends and trading income) disappears at the end of each period, and only assets carry over to the next period. Cash held at the end of the final period is credited as consumption. Because this consumption constitutes the entire earnings for the experiment, an equivalent optimization problem is created to that of maximizing a discounted stream of dividends. Asparouhova et al. observe that the tree trades at lower prices than the bond, prices move with fundamentals and expected returns vary across states as predicted (they are higher in the low state). Agents smooth consumption and hedge fundamental risk by buying trees when income is high and selling them when it is low.

Crockett et al. (2018) study a similar setting in which one asset could be traded in a double auction market. There are two types of traders, each type receiving income at different periods across a market, following a two-period cycle (income vs. shares), to

[3] For a review of the experimental asset market literature, see Bossaerts (2009), Noussair and Tucker (2013), Powell and Shestakova (2016) or Morone and Nuzzo (2017).

stimulate trade and consumption smoothing. The study follows a 2x2 design, with traders having either concave or linear utility, and the dividend being either high or low. They find that under concave utility, consumption smoothing and relatively low prices are observed and that prices are higher the greater the dividends are.

The empirical finance literature provides mixed findings when it comes to dividend yield return predictability. Early studies, such as Campbell (1990) and Cochrane (1992), find that dividend yields predict returns. Furthermore, Cochrane (2007) argues that the power of the test can be increased by testing the joint hypothesis that either returns or dividend growth must be predictable. On the other hand, authors such as Goyal and Welch (2007) argue that there is limited out-of-sample return predictability. We can test this contentious hypothesis in our experiment. Given the predictable price dynamics after a shock, the model postulates that dividend to price ratios should have some explanatory power in terms of returns in the cross-section and time-series.

3. The model and hypotheses

While not inspired by the specific goal of explaining contagion, the Cochrane et al. (2007) model provides a formal account of how contagion in asset prices can arise even when fundamentals are uncorrelated.

The model assumes continuous time; we describe here an adjusted version of the model in discrete time. The setting is as follows. There is a stationary endowment economy with an infinite horizon. There is a fixed supply of two assets (called trees), indexed with $i = 1,2$, that have tradable shares that yield dividends (which can be viewed metaphorically as fruit from a tree). The dividends/fruits are not storable, but rather must be consumed in the current period. Therefore, aggregate consumption, C_t, is equal to the sum of the two stochastic dividend streams, $D_{i,t}$, multiplied by the percentage of shares that come from each tree:

$$C_t = x\,D_{1,t} + (1-x)\,D_{2,t} \qquad [1]$$

In [1] x is the percentage of shares that are of asset 1. A state variable for this economy is constructed from the relative contribution of each asset to consumption. The share in consumption of the dividend contribution of one asset, $s_{1,t}$, can be written as:

$$s_{1,t} = \frac{x\,D_{1,t}}{x\,D_{1,t} + (1-x)\,D_{2,t}} = \frac{x\,D_{1,t}}{C_t} \qquad [2]$$

The assets are in positive net supply[4]. There is also a riskless asset in zero net supply and the interest rate is constant. No short selling is allowed.

Investors are modeled as a representative agent, who maximizes the discounted expected utility of consumption, with a logarithmic utility function, and a rate of time preference of β :

$$\max\ \mathbb{E}_t\left[\sum_{k=0}^{\infty} \beta^k \ln(C_{t+k})\right] \qquad [3]$$

If we apply the Euler equation, derived by Lucas (1982), as in the two-country setting of Lucas (1982), the price of a tree yielding a given a dividend stream equals:

$$P_{1,t} = \mathbb{E}_t\left[\sum_{k=0}^{\infty} \beta^k \frac{C_t}{C_{t+k}}\ D_{1,t+k}\right] \qquad [4]$$

The dividend streams generated by each asset follow a random walk:

[4] If an asset were in zero net supply, then every long position in the asset must be offset by a compensating short position. On the other hand, if the asset is in positive net supply, there need not be corresponding short positions. Indeed, in the Cochrane et al. (2007) model, short positions in the risky asset are not permitted.

$$\mathrm{D}_{1,t+1} = \mathrm{D}_{1,t} + \varepsilon_{i,t}, \qquad [5]$$

where the length of the time discretization interval is $\Delta t = 1$, and the stochastic process is $\varepsilon_{i,t} \sim N(0,1)$.

Using equation [2], we can rewrite equation [4] to provide the price/consumption ratio for the first asset:

$$\frac{P_{1,t}}{C_t} = \mathbb{E}_t \left[\sum_{k=0}^{\infty} \beta^k \ s_{1,t+k} \right] \qquad [6]$$

Equation [6] can be used to show that the price-dividend ratio of the first asset can also depend on the share of the second asset in aggregate consumption:

$$\frac{P_{1,t}}{D_{1,t}} = \frac{x}{s_{1,t}} \frac{P_{1,t}}{C_t} = \frac{x}{1 - s_{2,t}} \frac{P_{1,t}}{C_t} \qquad [7]$$

Under this price process, the return of each asset equals:

$$R_{1,t} = \frac{P_{1,t} - P_{1,t-1}}{P_{1,t-1}} + \frac{D_{1,t}}{P_{1,t-1}} \qquad [8]$$

We can rewrite equation [8] as:

$$R_{1,t+1} = \frac{\left(\frac{P_{1,t+1}}{D_{1,t+1}} + 1\right) \frac{P_{1,t}}{D_{1,t}}}{\frac{P_{1,t}}{D_{1,t}}} - 1 \qquad [9]$$

Replacing the dividend yield $\frac{D_{1,t}}{P_{1,t}}$ by $d_{1,t}$ and using equation [5], equation [9] becomes:

$$R_{1,t+1} = \left(\frac{1}{d_{1,t+1}} + 1\right) \left(d_{1,t}\right) \left(1 + \frac{\varepsilon_{i,t}}{D_{1,t}}\right) \qquad [10]$$

Taking the expectation of equation [10], we obtain the expected return as a function of dividend yield:

$$\mathbb{E}_t(R_{1,t+1}) = \left(\frac{1}{d_{1,t+1}} + 1\right)(d_{1,t}) \qquad [11]$$

Thus, the price of an asset is a function of consumption, which can be rewritten as a function of the state variable, which is the share of the asset in aggregate consumption. This property leads to several notable predictions. These predictions constitute the hypotheses for our experiment.

Hypothesis 1: There is a positive contemporaneous correlation in the returns of the two assets.

If the dividend share of one of the assets increases, then the return of the other risky asset also increases as the asset becomes more valuable from a diversification perspective. This happens because of the increased correlation of the appreciating asset with aggregate consumption. Similarly, a decrease in the expected dividend of one of the assets lowers the price for both assets.

Specifically, the dividend share changes when the dividend stream has a permanent shock. In the model, this is due to the random nature of the dividend process. The change in dividend share, along with the assumptions that the agent holds both assets, and that the market clears instantaneously generate the contagion dynamics of the model. A shock to one of the assets leads to contagion, as prices of both assets adjust immediately to reflect the change in return due to demand for diversification.

The relationship between the return of the shocked asset (R^S) and non-shocked asset (R^{NS}) can be summarized as follows:

$$\mathrm{corr}(R^S, R^{NS}) > 0 \qquad [12]$$

Hypothesis 2: Time series predictability – there is momentum in the returns of the shocked asset

For the asset whose dividend distribution gets positively and permanently shocked, its current price and return increases. However, there is an underreaction of the price to the dividend shock as the asset becomes a larger part of total consumption, and therefore needs to offer higher expected returns to compensate for its reduced diversification benefit. Prices do not immediately fully adjust to the shock, but rather drift upward over time. A similar pattern is observed in case of a negative shock. The underreaction leads to positive autocorrelation in expected returns of the shocked asset:

$$\mathrm{corr}\,(R_t^S,\ R_{t+1}^S) > 0 \qquad [13]$$

Hypothesis 3: After a shock, the expected return of both assets can be predicted by the dividend yield of either asset.

The third pattern is that dividend yields forecast future returns as in equation [11]. However, because expected return is a function of dividend yield, which can be rewritten as a function of the dividend share of the other asset, the dividend yield can also forecast returns cross-sectionally. Therefore, the return of each asset can be predicted by its own dividend yield or the dividend yield of the other asset.

$$\begin{cases} \mathrm{corr}\,(\frac{D^S}{P^S}\ ,\ R^S) > 0 \\ \mathrm{corr}\,(\frac{D^S}{P^S}\ ,\ R^{NS}) > 0 \end{cases} \qquad [14]$$

4. Implementation in the lab

4.1. General description of the experiment

Participants were bachelor's and master's students at Tilburg University, the Netherlands and bachelor's students at The University of Arizona, USA. Each subject could participate in at most one session of the experiment. A session lasted approximately 3 hours, and eight participants took part in each session. A show-up fee of 5 Euros/7 Dollars was awarded to each participant. At the beginning of each session, the three-question Cognitive Reflection Test (CRT, Frederick, 2005)[5] was administered to all participants. For each CRT question correctly solved, 1 Euro/Dollar was awarded. Afterward, subjects participated in markets, in which they could trade two assets. A continuous double auction mechanism (Smith, 1962) was employed, implemented with the z-tree platform (Fischbacher, 2007), to enable trade.

The markets used an experimental currency called ECU, convertible to Euros or Dollars at the end of the session. The session was divided into several consecutive *markets*. At the beginning of each market, the environment, including the endowments of traders, was reinitialized. Each market lasted an uncertain number of *periods*. At the end of each period, the market closed, and the asset paid a dividend, but asset holdings carried over to the next period.

At the beginning of the first period of a market, participants received a portfolio of assets and cash. Two risky assets called Asset A and Asset B could be traded in each period in a centralized marketplace. In each period, the asset yielded a dividend, which was stochastic. All participants were aware of the dividend process of each asset. They did not know the portfolio holdings of other individual participants during each market,

[5] The cognitive reflection test (CRT), described in Frederick (2005), is widely used in the experimental asset market literature (Corgnet et al., 2014; Breaban et al., 2015; Noussair et al., 2016). The CRT is a test that consists of three verbally formulated questions of an algebraic nature and is designed to observe the willingness and capacity of the agents to override an intuitive response that is incorrect. It is sometimes interpreted as a measure of cognitive ability. The papers cited above find that individual CRT scores correlate positively with trading profits, and that a cohort's average CRT score correlates negatively with the difference between market prices and underlying fundamentals.

but the aggregate endowment of each asset was known to all participants, as required by the Two-tree model. The contagion effect in the model also requires that subjects are aware that all participants are holding a similar number of assets. Therefore, the aggregate number of assets for each security was made common knowledge and their initial endowments were identical.

4.2. Timing of events within a market

Each participant began period 1 of each market with 10 shares of asset A and 4 shares of asset B. At the start of each of the first two periods, Asset A and Asset B paid a stochastic dividend of either 200ECU or 300ECU, each with probability 0.5. At the beginning of every fourth period starting with period 3, that is, in periods 3, 7, 11, etc…, a permanent shock to one of the dividend distributions occurred. The dividend shock happened with certainty and the timing was known beforehand by market agents[6]. However, they did not know in advance which asset would be subject to the dividend shock or whether the shock would be positive or negative. It was explicitly stated that the shock to one asset would not affect the dividend distribution of the second asset, and thus, the dividends on the two assets were uncorrelated.

There was a 50% probability that the dividend shock would be positive or negative. There was also a 50% probability that any one of the assets would be shocked. In case of a negative shock, the distribution of the shocked asset changed to (150ECU, 250ECU)[7], with each realization occurring with equal probability. In case of a positive shock, the distribution of the shocked asset changed to (250ECU, 350ECU), each occurring with equal probability. Thus, there was a 50 ECU increase in the distribution

[6] An alternative would be for the dividend shock to happen unexpectedly during the experiment, participants having no previous knowledge of the distribution. Such a design choice would not have been in line with the model and would have added another layer of fundamental value uncertainty.

[7] In the experiment, dividends are stationary in levels rather than growth rate. This design feature is important as it does not allow more cash to come into the market, which itself is associated with higher prices.

from a positive shock, and a 50 ECU decrease from a negative shock. The adjusted dividend distribution remained in effect until another shock occurred[8].

At the beginning of each period, a loan was provided to each trader. The loan was automatically repaid at the end of the period by subtracting it from the cash obtained from dividends and from selling assets in the current period. This ensured that consumption was only equal to dividends and that there was no other income entering the market, but also that there was still enough cash in the market to meet liquidity needs. The loan amounted to 17500ECU[9]. To further increase the liquidity in the market, dividends were paid at the beginning of each period, including the first period of the market. Since all traders were holding the same portfolio initially, all traders had the same starting wealth.

At the end of every period, after the loan was paid back, the remaining cash each trader held (denominated in terms of experimental currency), was transformed into consumption (in terms of Euros/Dollars). This cash came from dividends, and any net capital gains from transactions performed during the period. The translation into consumption was done according to a logarithmic exchange rate of Euros/Dollars= 0.112* ln (ECU) [10]. Cash was not transferred across periods, and thus savings were not possible. Asset holdings carried over from one period to the next.

During the trading period, each participant could see, on her screen, how much Euros/dollars she has consumed in each previous period and could potentially use the history information to facilitate consumption smoothing.

[8] $D_{i,1}$, is the dividend of asset i at period 1.
$D_{i,1} \in \{200,300\}$; $\mathbb{E}[D_{i,t}]_{|t=1} = 250$; $\mathbb{p}(D_{i,1} = 200) = \mathbb{p}(D_{i,1} = 300) = 0.5$;
$Var(D_i) = \mathbb{E}[(D_i - \bar{D}_i)^2] = \mathbb{E}(D_i^2) - \bar{D}_i^2 = 0.5[200^2 + 300^2] - 250^2 = \sigma^2; SD(D_i) = 50 = \sigma$;
$D_{i,t+1} - D_{i,t} = \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ is a random walk with $\varepsilon_{i,t} \sim N(0,50)$ and i =1,2;
[9] Using simulations, the fundamental value of each asset is calculated to be on average 751.06 ECU in expectation. For more details see APPENDIX B. This corresponds to a cash/asset ratio of 0.79.
[10] A payoff table with many rows corresponding to possible cash levels in ECU and the Euros/dollars that they converted to, was provided for the participants' reference during the experiment (see APPENDIX A).

In case of negative cash holdings at the end of the period, which could occur if a trader had insufficient cash to repay her loan, the conversion rate was ECU/5100. That is, individuals had 1 Euro/dollar subtracted from their earnings balance for every 5100 ECU that their holdings were negative at the end of a period.

4.3. Timing of events in a session

After the experimenter read the instructions, there was a seven-minute practice period in which participants could become familiar with the mechanics of making purchases and sales in the computerized market. A practice market was then played to allow the participants to get used to the market setting, assets, and dividends. To test the understanding of participants, a quiz was administered[11].

Subjects then traded in a succession of markets. Each time a market finished, and a new market begun, the holdings of the participants were reset to the initial levels. The dividend distribution was also reinitialized to the starting distribution[12]. Within each market, each trading period lasted 2 minutes.

The block termination rule (Frechette and Yuksel, 2017)[13] was employed to end the market. The probability that the market would end during any given period was ¼. Ending the market meant that no subsequent activity after the market ended counted toward earnings. Blocks of four periods were played without interruption. Participants

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[11] The quiz was checked on the spot, in private. If there was a question answered incorrectly, the correct response was given and explained to the participant.

[12] We informed participants that they would participate in one or more markets, each consisting of an unknown number of periods. If one of the markets ended with more than 25 minutes of the 3-hour session remaining, another market was conducted. If there were fewer than 25 minutes remaining, the participants were informed that the market they just finished playing was the last market, and the session was ended. The experiment did not surpass the 3-hour limit in any session.

[13] Participants took part in a block of four periods and only at the end of the last period of the block did they find out if the market ended in any of the previous periods. If the market continued, another block containing four more periods was played and so forth. This procedure allows the creation of the same incentives that exist in an infinite horizon with discounting, but unlike the standard random termination method proposed by Roth and Murninghan (1978), it allows a minimum of four periods of data from each market to be gathered.

were only informed after every block of four periods, whether the market had ended and if so, in which period. If the market continued beyond four periods, then another four period-block would be played and so on. To our knowledge, this block termination strategy has never been previously used in an asset market environment.

Consumption in all periods and across all markets constituted total earnings, except for the initial practice market. The instructions used during the experiment can be found in APPENDIX A.

4.4. Discussion of implementation challenges

We draw on the model of Cochrane et al. (2007) for hypotheses about market behaviour in the experiment, and we recognize that the experimental environment contains substantial departures from the model. We do not intend to reproduce the exact environment described in the model. Instead, we consider whether some predictions of the model are observed in our environment, in which we have an opportunity to find (or fail to find) some of these predictions. Our environment contains some of the essential features of the model. These include an asset market with two uncorrelated assets, an indefinite horizon, and shocks to the dividend distribution.

To be tractable, a model typically needs simplifying assumptions. For example, the two-tree model assumes two assets, no share repurchases, logarithmic utility, etc. The different assumptions of the model can impede empirical testing. The core intuition of the model is, nevertheless, valuable, despite the obstacles faced when testing with real-world data. A laboratory experiment allows us to enforce the simplifying assumptions of the model and is, therefore, a natural way to examine the model's predictions. The experimental approach enables researchers to control and observe many parameters that are difficult to impose and observe in non-laboratory financial markets; such as uncorrelated dividend shocks.

Consumption: In the experimental asset pricing literature, which tests consumption-based models in the laboratory, several methods have been used to create incentives to consume. Asparouhova et al. (2016) use an endogenous consumption smoothing mechanism. They do not include a concave exchange rate and rely on subjects' homegrown risk aversion, where consumption is considered to occur only at the end of the last period of the market. It is up to the participants to avoid holding too much cash in one period instead of investing it in assets. In contrast, Crockett et al. (2018) exogenously impose concave utility with a concave exchange rate from experimental currency to US dollars. Like Crockett et al. (2018), and in line with Cochrane et al. (2007) model, we impose a logarithmic ECU-dollar/EURO exchange rate to motivate consumption smoothing and trading.

At the end of each period, the end-of-period ECU balance is converted to Euro/Dollars and placed in a private account that cannot be used to purchase assets. This constitutes consumption for that period. Assets are long-lived, and inventories of assets are carried over to the next period. Assets only perish at the end of the market and do pay their dividends in the final period of the market.

The trade-off that investors have to make every period involves how much to consume now versus tomorrow. They then have to obtain the asset portfolio that is suitable to achieve their target. If they want to consume more in the current period than they would need to sell some of their assets. If they want to consume more in future periods, then it would be in their interest to save by investing in assets, as assets can be carried across periods. In this respect, assets are the only intertemporal store of value. However, due to the concavity of the logarithm function, gathering a lot of cash to be converted will not amount to much Euros/Dollars. The conversion function incentivizes participants to spread out consumption across time to avoid the low marginal values associated with large conversions. Thus, participants have an incentive to smooth consumption.

Risk-free asset: A risk-free asset could be introduced in the experiment by incorporating an additional market where the asset prices of the risk-free asset would be determined by supply and demand. However, the 'Two trees' model assumes that the risk-free asset is in zero net supply. In a multi-agent environment, zero-net supply implies that either no agent is holding risk-free assets or that some agents are shorting the risk-free asset, while some others are holding the asset.

Adding an additional market where participants are either a borrow or a lender, can lead to two additional complications. First, the borrower-lender market will require the price of the risk-free asset to be set by the market. However, within the model, the risk-free rate is determined exogenously, and it depends on the dividend shock of the risky asset and not by the market itself. Second, the market will add additional complexities to an already complex experimental environment.

Given all these extra complexities created by the introduction of a risk-free asset, we do not incorporate a risk-free asset. Instead, in line with the model, we assume that there is a zero-net supply of risk-free asset, as no market participant is neither a borrower nor a lender. In equilibrium, investors will have weights only in risky assets and not in cash.

Liquidity: In the two-trees model, prices adjust automatically. In reality, prices in markets adjust by investors selling and buying the assets. Even though the two-tree model abstracts from the traders' need to have cash as prices adapt instantaneously, the creation of a functioning market demands that the participants have cash at their disposal so that trade can take place. Therefore, a loan at zero interest is introduced at the beginning of each period which is repaid automatically at the end of the period. This ensures that the loan is not used to smooth consumption and hence does not enter the utility function. The loan is intended only to guarantee that there is sufficient liquidity for trading to take place.

5. Results

A total of 51 markets were conducted. The total number of dividend shocks across all sessions was 66, out of which 37 were for asset A (19 positive and 18 negative) and 29 for asset B (16 positive and 13 negative). If we consider only the first shock in a market as an observation, the total number of dividend shocks is 51 out of which 29 were for asset A (16 positive and 12 negative) and 23 for asset B (13 positive and 10 negative)[14].

The maximum number of periods played in any market was 12. This particular number was due to the block termination feature that ensured that blocks of four periods would be played despite the market possibly ending before the termination of the block. Consistent with the theory, the price of asset B was higher on average by 60 ECU than the price for asset A. Also, as the model predicts, the return on asset A was on average greater than B. This is illustrated in Figure 1 as the number of assets B is smaller than the number of assets A, the dividend share of asset B in the economy is smaller. Therefore, asset B has a greater value due to its diversification potential and a lower expected return.

We now evaluate the hypotheses discussed in section 2[15]. We organize the analysis as a series of results corresponding to each hypothesis.

Result 1: There is strong contagion, that is, significant positive contemporaneous correlation is present in the returns of the two assets.

Figure 2 illustrates a strong positive correlation between the returns of the shocked and non-shocked asset in the period of the shock.

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[14] In session 3, market 4, period 3, one of the assets B was traded at a price of 10000 which was 10 times the maximum fundamental value across all markets. It is very likely to be an error made by one individual. However, it drives the average price for that asset in that period as there only a few transactions in that period. We omit this observation from our analysis.

[15] To perform our analysis, for each asset, we average the price across the traded shares in each period. If no asset was traded in the period, the average of the bid-ask spread over the period is used.

The presence of positive contemporaneous contagion in returns is confirmed when using the following regression specification:

$$\mathrm{R}^{\mathrm{NS}}_{t_{shock}} = \beta_0 + \beta_1 \mathrm{R}^{\mathrm{S}}_{t_{shock}} + \varepsilon^{\mathrm{NS}}_{t_{shock}}, \qquad [15]$$

where *NS* stands for non-shocked asset and *S* is the asset that experiences a dividend shock; t_{shock} represents the period over which the return is calculated; $\varepsilon^{\mathrm{NS}}_{t_{shock}}$ represents the error, β_0 is the intercept and β_1 is the slope of the regression.

We pool observations across the two assets, as either of them can receive a dividend shock, and perform a pooled OLS regression. Markets within a session are concatenated. We estimate the models on two subsets of data: (1) all shock periods for all markets and sessions, and (2) only the periods of the first dividend shock in all markets and sessions. For this subset of the data, each observation is independent. As in Frechette (2012) and Petersen (2009), we cluster the errors at the session-level.

Table 1 shows that, in line with the model, we find a positive contemporaneous correlation between shocked and non-shocked assets. The magnitude of the relationship is quite large; a 1% increase in shocked asset returns is associated with a 0.4% increase in the returns of the non-shocked asset for pooled OLS (Panel (a)). We also test for autocorrelation in the panel and we find none (Wooldridge test, p= 0.1246, F= 3.043)[16].

A critical determinant of the pricing behaviour in experimental asset markets, is the cognitive sophistication of traders, as measured by the cognitive reflection test (CRT). On average, the CRT score across sessions was 1.5[17]. In Table 1, we estimate the model

[16] After testing whether session-level fixed or random effects are more appropriate (Hausman test, p= 0.0001; $chi2(1)$= 14.97) we find that fixed effects should be used. We must be careful as there are quite few observations to include 8 session effects. For fixed effects, we find that there is heteroskedasticity (Modified Wald test for GroupWise heteroskedasticity yields p = 0.00). We assume that something within a session may impact or bias the predictor and we should control for this. These time-invariant characteristics are assumed to be unique to each session and are not correlated across sessions. Under the fixed-effect specification, the economic significance decreases to 0.12%, but remains significant. A 1% decrease in the shocked asset is associated to a 0.12% decrease in return for the non-shocked asset as well.

[17] Summary statistics of CRT scores are detailed in APPENDIX C.

separately for those sessions in which the average CRT score was greater to, and less than or equal to, 1.5. We find that those sessions with high average CRT scores exhibit significant cross-sectional correlation in returns, while those with low scores do not have a significant relationship. More sophisticated groups show greater adherence to the model's predictions.

The following result shows that Hypothesis 2, which concerns momentum in returns, is also supported.

Result 2: There is strong momentum in the return of the shocked asset

Figure 3 illustrates the return of the shocked assets in the shock period, plotted against the returns of the shocked asset in the following period. The line of best fit represents the estimates of a robust pooled OLS regression. The line is strongly positively sloped suggesting autocorrelation in returns.

To more formally evaluate the hypothesis, we estimate regression specifications of the following form:

$$R^{S}_{t_{shock}+1} = \alpha + \beta R^{S}_{t_{shock}} + \varepsilon^{S}_{t_{shock}+1}, \qquad [16]$$

where S indicates that the asset experienced a dividend shock; t_{shock} is the period when the shock occurred; α is the intercept; β represents the sensitivity of next period return to previous period return; and $\varepsilon^{S}_{t_{shock}+1}$ are the residuals for the shocked asset.

The model predicts a positive coefficient on lagged returns. The results are presented in Table 2.

The estimates reveal significant momentum, supporting Hypothesis 2. A 1% increase in the return of the shocked assets is associated with a 0.46% increase in the next period's return[18]. The last two columns report estimates separately for sessions with relatively

[18] Serial correlation in the error term is absent (Wooldridge test, p= 0.11, F= 3.54). After testing for fixed effects (Hausman test, p= 0.1201; chi2(1)= 2.42) and whether random or pooled OLS should be used (LM test, p= 0.014, chibar2(1)= 4.74) we find the random effect model should be used. In this

high and low average CRT scores. As for Hypothesis 1, the groups with a relatively high level of sophistication are those that support Hypothesis 2 at a greater level of both economic and statistical significance.

We now turn our attention to a more subtle implication of the first two hypotheses of the model: negative cross-serial correlation in returns. That is, a dividend shock to one asset moves the return of the other asset in the opposite direction in the period after the dividend shock. As noted in the first hypothesis, both assets should have positive returns in the period following a positive dividend shock to one of the assets. The non-shocked asset experiences a one-time increase in demand (its price increases) during the shock period because of its increased attractiveness due to an increase in diversification potential. Thus, in the period after the shock, the return of the non-shocked asset will be lower, as the price remains at the same higher level given the shock, but the dividends stay at the same level as before the shock. Consequently, the expected return of the non-shocked asset decreases, while for the shocked asset, the return continues to be greater than before the shock due to momentum in returns. The opposite pattern is at work after a negative shock occurs.

This cross-sectional relationship can be summarized with the following equation:

$$\mathrm{R}^{\mathrm{NS}}_{t_{shock}+1} = \dot{\alpha} + \dot{\beta}\mathrm{R}^{\mathrm{S}}_{t_{shock}} + \varepsilon^{\mathrm{NS}}_{t_{shock}+1}, \quad [17]$$

where *NS* stands for non-shocked assets and *S* represents the asset with a shock; t_{shock} represents the period in which the asset suffered a dividend shock; $\dot{\alpha}$ is the intercept; $\dot{\beta}$

case, the economic significance remains, returns increase in the period after the asset experiences a shock. As before, these results should be viewed with caution as there are too few observations per session. For the random effect specification, the economic significance remains 0.4%, and significant. For the random effect model, we also test for cross-sectional dependence (contemporaneous correlation). We test whether the residuals are correlated across sessions, which should not be a problem in small panels. The results of the Pasaran CD test confirm this (Pasaran CD, p= 0.3510).

is the sensitivity of the return of the non-shocked asset to the return of the shocked asset. and $\varepsilon^{NS}_{t_{shock}+1}$ are the residuals.

As before, we pool the data across the two assets and estimate the model for all the dividend shock periods, across markets, as well as only including the first dividend shock.

The existence of cross-serial correlation is illustrated in Figure 4, but the direction of the cross-serial correlation is the opposite of the one predicted. We find positive, rather than negative, correlation between the two assets in the periods following the dividend shock. Table 3 shows that a 1% increase in the return of a shocked asset is associated with a 0.36% increase in the next period return for the non-shocked asset (column (a))[19].

The failure to observe cross-serial correlation in returns in the hypothesized direction is associated with the presence of momentum in the non-shocked asset. As seen in Figure 5, the returns of the non-shocked asset also seem to show positive momentum after the dividend shock. Table 4 provides estimates of the extent of the momentum of the non-shocked asset.

The estimates show that a 1% increase in returns for the non-shocked asset is associated with a 0.74% increase in the subsequent period's returns (Table 4, Panel(a)). What is surprising is that markets with more sophisticated agents display stronger momentum in returns, not only for the shocked asset but for the non-shocked asset as well. This is consistent with agents' expectations and projections being influenced by recent trends (Smith et al. (1988); Marimon and Sunder, 1993; Haruvy et al., 2007). Our findings regarding momentum are stated as Result 3.

[19] Serial correlation in the error term is not present (Wooldridge test, p = 0.4, F= 0.828). However, when only one shock per market is considered, we find no significance. After concluding that a fixed effects model should be used when one shock per market is considered (Hausman test, p = 0.000; $chi2(1)$ = 90.51), we find no significant correlation and a smaller economic significance.

Result 3: There is positive cross-serial correlation in the two assets' returns after the shock. There is momentum in returns for both assets in the same direction as the shock[20].

We now turn our attention to the third hypothesis, that dividend yields predict returns cross-sectionally and in the time series. Our main observation is stated as our fourth result.

Result 4: After a shock, the expected return of both assets can be predicted by dividend yields of either asset.

We investigate the prediction cross-sectionally, across all markets, and in all sessions. We test the hypothesis for each of the two assets:

$$\mathrm{R}^{\mathrm{i}}_{\mathrm{m,t+1}} = \alpha + \beta \frac{Div^{i}_{m,t}}{P^{i}_{m,t}} + \varepsilon^{\mathrm{i}}_{\mathrm{m,t+1}}\,, \qquad [18]$$

where i represents the asset; m stands for markets and t for periods; for each market t always begins with period three (after the shock).

As observed in Table 5, the estimated slope coefficient of 0.9 means that an increase of 1% in dividend yield, in the prior period, the return of *asset i* increases by nearly 1% in the current period. The return of *asset j* shows a similar pattern, though to a lesser extent. The positive sign on these coefficients is predicted by the model. The dividend yield for one asset also has predictive power for the subsequent return of the other asset. For both assets, the statistical significance is high, with a t-statistic greater than 6. The returns seem to be predicted by the dividend-price ratio in an environment where the only source of uncertainty comes from the dividend shock.

[20] In APPENDIX D we report regressions that consider Hypotheses 1 – 2 and their implications simultaneously. The results are in agreement with the analyses presented in this section.

5. Conclusion

The model of Cochrane et al. (2007) posits that some fundamental market dynamics are at work when more than one asset is trading simultaneously. These dynamics contrast sharply with the proposition that the price of an asset is only a function of its expected dividend stream and is unaffected by the dividend that is paid on other assets.

While the patterns predicted under the Cochrane et al. model required risk aversion and a resulting motive to diversify, which we have imposed in our experiment, it was by no means clear to us beforehand that the dynamics predicted by the model would be observed. For example, if we find that the expected dividend and hence the price of one of the assets increases, does that mean that we should invest in the asset? If our expectations are backward-looking, such as adaptive or trend-extrapolating expectations, as has been often documented in laboratory markets, we should invest in the shocked asset. However, the Cochrane et al. (2007) model proposes that the investment decision is made in consideration of the diversification potential of an asset rather than its past performance.

The model shows that a shock to the fundamental value of one asset causes momentum in returns, but also a change in the return of the non-shocked asset. A consequence of these patterns is that future returns exhibit some predictability based on the current dividend yield. The model provides a compelling account of how co-movement in returns can arise without correlation in fundamentals, even when all traders are fully rational.

The results of our experiment confirm that contagion can arise between two risky assets even if their fundamentals are not correlated, also when traders have only a modest level of experience and sophistication. Moreover, following a dividend shock, the shocked asset exhibits autocorrelation in returns. Thus, the basic predictions of the model are seen in the experimental data.

We also observe momentum in returns for the non-shocked asset, leading to an absence of cross-serial negative correlation. While the failure to follow this secondary and subtle prediction shows the limits of the model's ability to predict precisely, we find it impressive that the main patterns predicted by the model can be observed in such a complex environment when individuals are so inexperienced in asset trading and valuation.

Why is there momentum in the non-shocked asset and thus a failure to observe negative cross-serial correlation in our data? The model predicts that returns in the non-shock asset would change direction in the period after the shock. However, a body of evidence from experimental economics suggests that individuals' expectations are influenced by trends and adaptive components, that is, they are backward-looking (Marimon and Sunder, 1993; Haruvy et al., 2007). When the tendency of individuals is to believe that past trends are influencing future price trajectories, it makes it unlikely that a reversal in price momentum caused by a ripple effect if a prior shock, would be observed.

The model's predictions are better supported in the market with relatively sophisticated agents, where sophistication is measured with a cognitive reflection test. This is an important finding as the intent of theoretical asset pricing models is to capture the behaviour of rational, sophisticated traders. A pattern in which a model predicts better when agents are more sophisticated bodes well for the model. However, momentum in the non-shocked asset is also better supported for sophisticated people, suggesting that this unanticipated momentum is not a consequence of our use of naive expectations.

Perhaps the most important implication of the Cochrane et al. model is that dividend yields predict return both in the time series and cross-section. We find the same type of predictability in our data. This indicates that in our markets, trading based on these predictions is profitable, as it is in the model.

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TABLES

Table 1. Contemporaneous contagion hypothesis.

This table presents the results of the regressions of non-shocked asset returns on shocked asset returns in the shock period. Column (a) contains the results where all shocks in a market are included, and (b) includes only one shock per market. Column (c) contains the results from the sessions where the average CRT score of participants is above 1.5, which is the average CRT score across sessions. Column (d) reports the results from the sessions where the average CRT score is below 1.5. Standard errors are clustered at the session level for all regressions. ***, ** indicates significance at the 1% and 5% level, respectively. The *t*-statistics are reported in parenthesis.

	(a) Pooled OLS (All shocks)	(b) Pooled OLS (1^{st} shock per market)	(c) CRT > 1.5 (All shocks)	(d) CRT ≤ 1.5 (All shocks)
	$R^{NS}_{t_{shock}}$	$R^{NS}_{s,m}$	$R^{NS}_{t_{shock}}$	$R^{NS}_{t_{shock}}$
$R^{S}_{t_{shock}}$	0.4***		0.45***	0.13
	(4.68)		(7.41)	(1.01)
$R^{S}_{s,m}$		0.49***		
		(5.69)		
Constant	0.39***	0.34***	0.31***	0.71***
	(4.47)	(4.94)	(5.46)	(4.24)
R – squared	0.32	0.38	0.37	0.03
N	66	51	34	32

Table 2. Time series predictability - Momentum.

This table shows the results of regressing the shocked asset returns in the period after the shock on lagged returns in the shock period. Column (a) shows the results when all shocks in the market are included and (b) includes only one shock per market. Column (c) contains the results from the sessions where the average CRT score of participants is above 1.5, which is the average CRT score across sessions. Column (d) reports the results from the sessions where the average CRT score is below 1.5. Standard errors are clustered at the session level in all regressions. ***, ** indicates significance at the 1%, and 5% level, respectively. t-statistics are reported in parenthesis.

	(a)	(b)	(c)	(d)
	Pooled OLS	Pooled OLS	CRT > 1.5	CRT ≤ 1.5
	(All shocks)	(1st shock per market)	(All shocks)	(All shocks)
	$R^{S}_{t_{shock}+1}$	$R^{t_{shock}+1}_{s,m}$	$R^{S}_{t_{shock}+1}$	$R^{S}_{t_{shock}+1}$
$R^{S}_{t_{shock}}$	0.46**		0.5**	0.32**
	(3.00)		(3.76)	(1.27)
$R^{t_{shock}}_{s,m}$		0.53**		
		(3.27)		
Constant	0.41**	0.38**	0.37*	0.57*
	(3.08)	(2.42)	(2.60)	(2.95)
R – squared	0.29	0.31	0.23	0.11
N	66	51	34	32

Table 3. Cross-serial Correlation.

This table presents the results of regressing the non-shocked asset return in the period after the shock on the return of the shocked asset in the shock period. Column (a) contains the results where all shocks in a market are included and (b) includes only one shock per market. Column (c) contains the results from the sessions where the average CRT score of participants is above 1.5, which is the average CRT score across sessions. Column (d) reports the results from the sessions where the average CRT score is below 1.5. Standard errors are clustered at the session level for all regressions. ***, ** indicate significance at the 1%, 5% level, respectively. The t-statistics are reported in parenthesis.

	(a) Pooled OLS (All shocks)	(b) Pooled OLS (1st shock)	(c) CRT > 1.5 (All shocks)	(d) CRT ≤ 1.5 (All shocks)
	$R^{NS}_{t_{shock}+1}$	$R^{NS,t_{shock}+1}_{s,m}$	$R^{NS}_{t_{shock}+1}$	$R^{NS}_{t_{shock}+1}$
$R^{S}_{t_{shock}}$	0.36**		0.48**	-0.107
	(3.24)		(3.19)	(-0.89)
$R^{S,t_{shock}}_{s,m}$		0.38***		
		(3.94)		
Constant	0.47**	0.44**	0.33**	0.71***
	(3.34)	(3.50)	(3.31)	(6.86)
R – squared	0.25	0.25	0.24	0.03
N	66	51	34	32

Table 4. Momentum in the non-shocked asset.

The table presents the results of regressing the non-shocked asset returns in the period after the shock, on lagged returns in the shock period. Column (a) contains the results where all shocks in a market are included and (b) includes only one shock per market. Column (c) contains the results from the sessions where the average CRT score of participants is above 1.5, which is the average CRT score across sessions. Column (d) reports the results from the sessions where the average CRT score is below 1.5. Standard errors are clustered at the session level for all regressions. ***, ** indicate significance at the 1%, 5% level, respectively. The t-statistics are reported in parentheses.

	(a)	(b)	(c)	(d)
	Pooled OLS	Pooled OLS	CRT > 1.5	CRT ≤ 1.5
	(All shocks)	(1st shock)	(All shocks)	(All shocks)
	$R^{NS}_{t_{shock}+1}$	$R^{NS,t_{shock}+1}_{s,m}$	$R^{NS}_{t_{shock}+1}$	$R^{NS}_{t_{shock}+1}$
$R^{NS}_{t_{shock}}$	0.7***		1.02**	0.12
	(4.51)		(5.59)	(2.05)
$R^{NS,t_{shock}}_{s,m}$		0.61***		
		(3.87)		
Constant	0.26	0.3*	0.02	0.81***
	(1.91)	(2.18)	(0.39)	(10.73)
R – squared	0.43	0.4	0.4	0.4
N	66	51	51	51

Table 5. Dividend-price ratios.

The table presents the results of regressing the return of the shocked asset on its lagged dividend-price ratio or the dividend-price ratio of the other risky asset. Columns (a) and (b) show the results for risky *asset A* and columns (c) and (d) give the results for *asset B*. Standard errors are clustered at the session level in all regressions. ***, ** indicates significance at the 1% and 5% levels, respectively. $R^{A}_{m,t+1}$ is the return of the risky asset A where m represents the market (group identifier), and t represents the period (time identifier); t-statistics are reported in parenthesis.

	(a)	(b)	(c)	(d)
	$R^{A}_{m,t+1}$	$R^{A}_{m,t+1}$	$R^{B}_{m,t+1}$	$R^{B}_{m,t+1}$
$\frac{Div^{A}_{m,t}}{P^{A}_{m,t}}$	0.90***		0.8***	
	(11.7)		(8.34)	
$\frac{Div^{B}_{m,t}}{P^{B}_{m,t}}$		0.88***		0.70***
		(5.6)		(6.32)
Constant	0.08	0.154	0.14	0.15
	(1.09)	(1.3)	(1.55)	(1.59)
R-squared	0.54	0.42	0.41	0.40
N	96	96	96	96

FIGURES

Figure 1. Stock returns across sessions.

This figure illustrates the return path of asset A and asset B averaged across sessions and periods. For each asset, we average the price across the traded stocks in each period and then across markets.

Figure 2. Contemporaneous contagion.

This figure presents the returns of the non-shocked asset plotted against the returns of the shocked asset during the shock period. The line of best fit represents a robust pooled OLS regression. *Panel (a)* illustrates that returns during all shock periods and *Panel (b)* illustrates the returns during the first shock in the market.

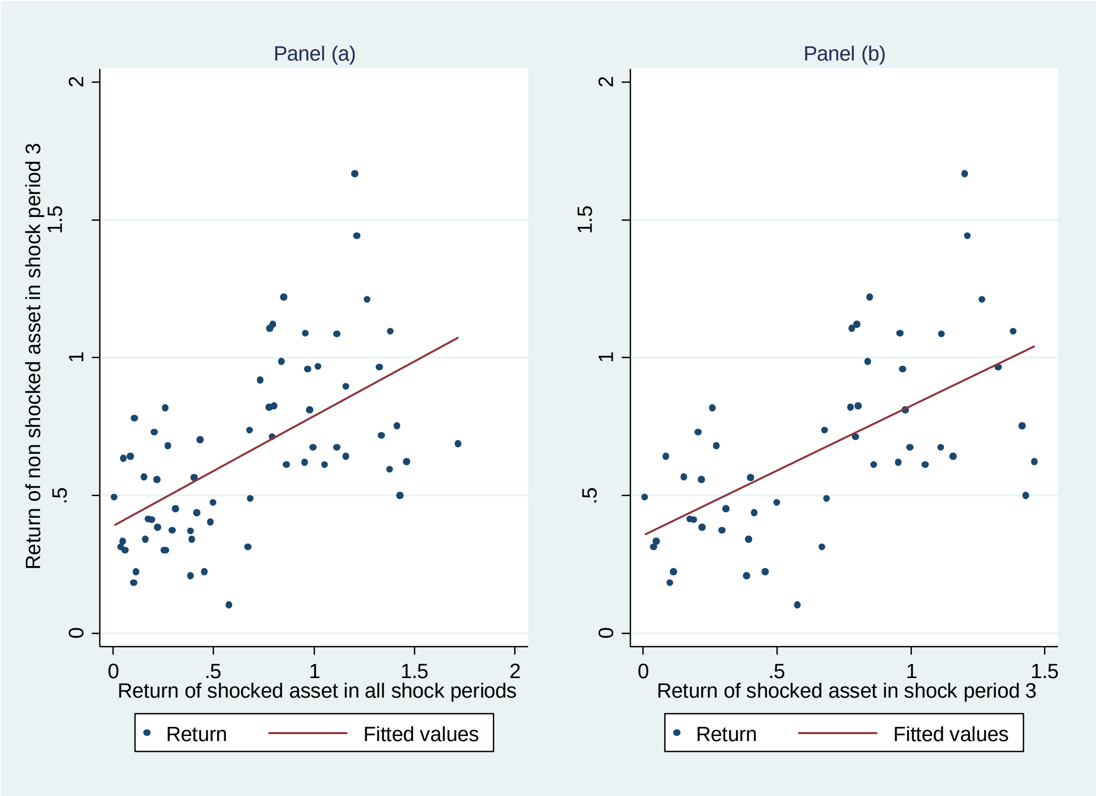


Figure 3. Time series predictability.

This figure illustrates the relationship between the returns of the shocked asset during all shock periods and its returns in the period following the shock. The line of best fit represents the estimate of a robust pooled OLS regression. *Panel (a)* includes the returns from all shocks in each market and *Panel (b)* contains only those returns corresponding to the first shock in each market.

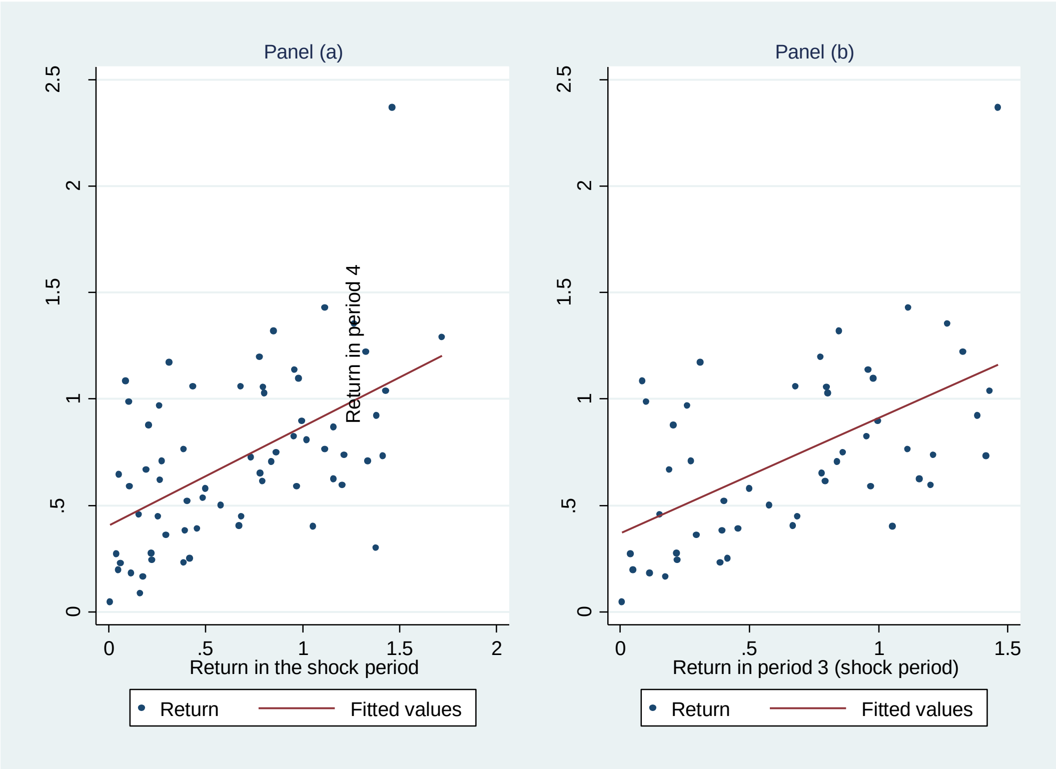


Figure 4. Cross-serial Correlation.

This figure shows the returns of the non-shocked assets in the period following a shock, plotted against the returns of the shocked asset during the shock period. The line of best fit represents the estimate of a robust pooled OLS regression. *Panel (a)* includes the returns from all shocks in each market, and *Panel (b)* contains only those returns corresponding to the first shock in each market.

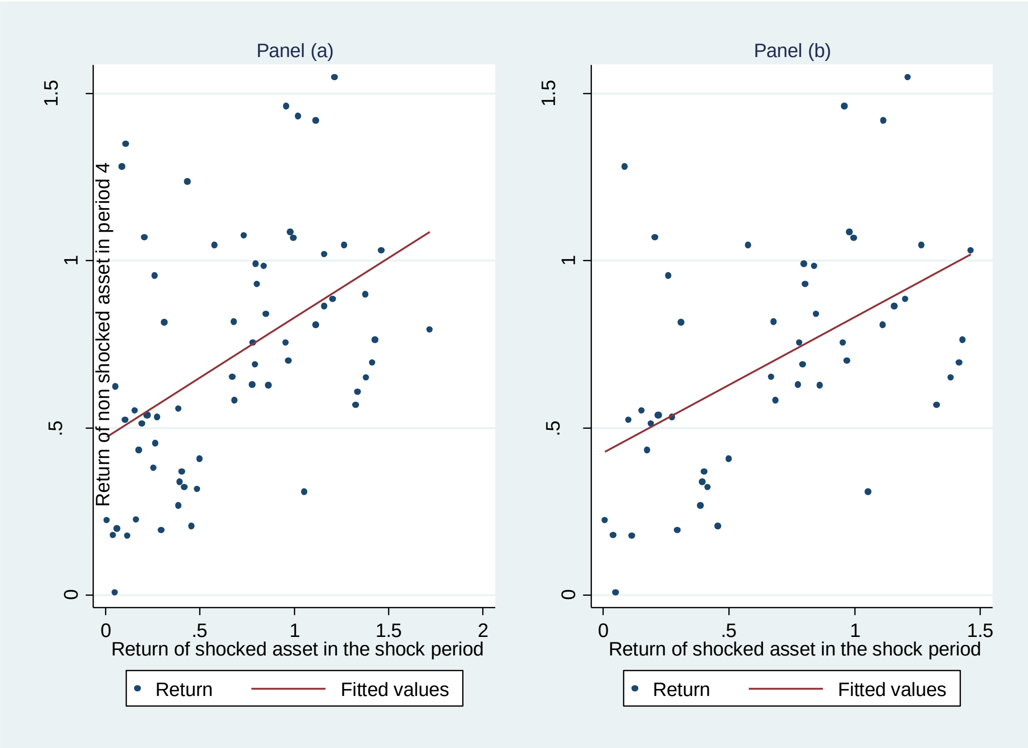
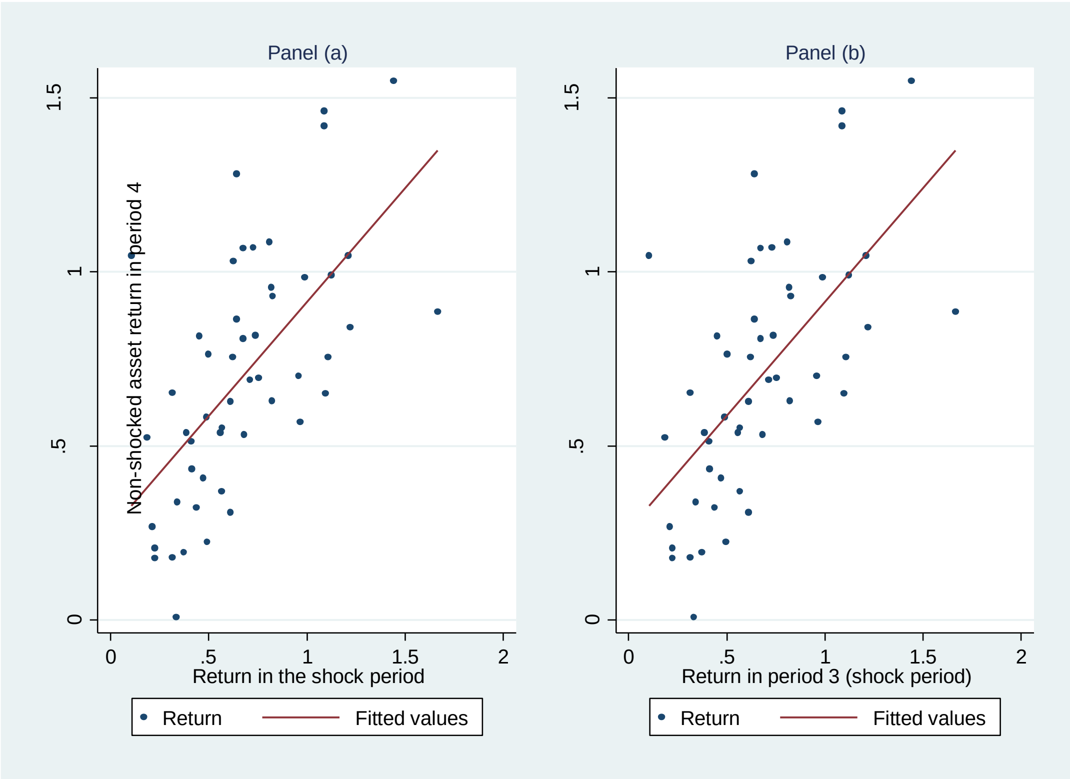


Figure 5. Momentum in the non-shocked asset.

This figure illustrates the returns of the non-shocked asset, in the period of the dividend shock, plotted against its returns in the following period. The line of best fit represents a robust pooled OLS regression. *Panel (a)* includes the returns from all shocks in each market, and *Panel (b)* contains only those returns corresponding to the first shock in each market.



APPENDIX A

Instructions Experiment:

1. General Instructions

Welcome to our experiment. If you follow the instructions and make good decisions, you might earn a substantial number of euros during the experiment. Please pay attention to the information provided and if at any time you have questions, please raise your hand and we will come to you in private. Communication between participants is prohibited during the experiment. The total earnings you have made will be paid to you via bank transfer within 48h. The experiment will consist of two parts. In the first part, you will be required to answer a few questions. In the second part, you will participate in several asset markets. The earnings for the entire experiment will count the number of euros won in both parts of the experiment. These are: (a) the total euros earnings that you won for answering correctly the questionnaire in the first part of the experiment, (b) the total euros earnings won in all markets played in the second part of the experiment and (c) the show-up fee of 5 Euros.

Part 1. Questionnaire

In the first part of the experiment, you will be asked to answer 3 questions. For each question answered correctly, you will receive 1Euro. You will have three minutes to complete the questionnaire. After you finish the questionnaire please wait until the second part of the experiment will begin.

Part 2. Asset Markets

1. **General structure**

In this part of the experiment, we will organize several asset markets in which you can buy and sell two assets. You will participate in the markets with seven other people who are here today. Each asset market will last for several trading periods. First, we will learn how to trade assets.

2. **How to use the computerized market**

In the top right-hand corner of the screen, you can see how much time is left in the current trading Period. The goods that can be bought and sold in the market are called assets. On the left side of your screen, you see the number of assets you currently have and the amount of cash you have available to buy assets. Let's take Asset A as an example. For Asset A, on the left side, you will find the number of Assets A units you have in the inventory and the income, called dividend, that one Asset A will pay. In our case, each of you has 10 assets A.

If you want to SELL one Asset A: You can do that by filling in the blue box on the left side of the screen, called "Enter offer to sell one asset A" with your desired price and then pressing the red button "Submit an offer to sell one asset A". The lowest offer-to-sell price will always be on the bottom of that list. Please do so now. You will notice that eight numbers, one submitted by each participant, now appear in the left side column, entitled "All offers to sell one asset A". Your offer is listed in blue and others in black. When you sell a share your Cash increases by the price of the sale. Try now the same procedure for asset B.

If you made an offer, but no one is willing to take your offer as, for example, it is too high, then you can submit a second offer with a lower price. You can submit as many offers as you want. All the prices will be listed, but as soon as one person accepts one offer from you, the other offers will disappear. So, only once you sold/bought one asset and there is still time left, you can sell/buy another asset by submitting again offers.

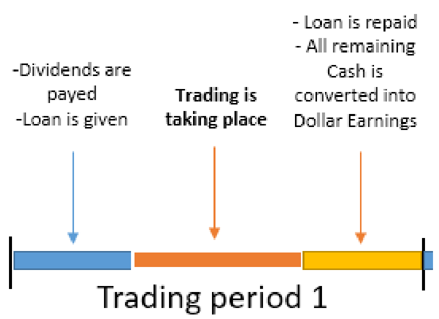
If you want to BUY one Asset A: Look at "All offers to sell one asset A" list and find the price at which you are willing to buy the asset. You accept the offer by clicking on one of the listed prices and then clicking the "Buy A" button. If you find the prices unacceptable, then you can submit your own price at which you are willing to buy one asset by filling in the blue box on the right side of the screen, called "Enter offer to buy one asset A" with your desired price. If you submit an offer it will be coloured in blue and will appear under the right-side column “All offers to buy one asset A”. When you BUY an asset, your Cash decreases by the price of the purchase. Try now the same procedure for asset B

In the middle column, labelled **“History of transaction prices for asset A”**, you can see the prices at which asset A has been bought and sold in this period. You will now have about 7 minutes to buy and sell asset A and Asset B. This is a practice period. Your actions in the practice period do not count toward your earnings and do not influence your position later in the experiment. The only goal of the practice period is to master the use of the interface. Please be sure that you have successfully submitted offers to buy and offers to sell. Also, be sure that you have accepted buy and sell offers. If you have any questions, please raise your hand and the experimenter will come by and assist you.

3. Specific instructions for this experiment

The experiment will consist of several asset markets where two assets can be traded, Asset A and Asset B. At the beginning of each market you will have several units of each asset. Every unit of Asset A and Asset B that you are holding will pay you an income, called a dividend, which will be given at the beginning of the next period.

- You can carry over your holdings of these assets from one period to the next within each asset market, but not across asset markets.
- In each trading period, you will also receive **a loan** of 17500 ECU (ECU=Experimental Currency) which you will need to repay at the end of the trading period.
- Each participant in the market will hold **10 Assets A** and **4 Assets B**. So, it is important to notice there are fewer Assets B available to trade in the market.



Each share of **Asset A** that you hold, for the first **two** periods, will:

earn you a dividend of 200ECU with a $\frac{1}{2}$ chance earn you a dividend of 300ECU with a $\frac{1}{2}$ chance

Each share that you hold of **Asset B**, for the first **two** periods, will:

earn you a dividend of 200ECU with a $\frac{1}{2}$ chance

earn you a dividend of 300ECU with a $\frac{1}{2}$ chance

- So if the result of a coin flip is head than 200ECU will be paid. If the result of a coin flip is tail than 300ECU will be paid. On average the dividend paid on each asset is $\frac{1}{2}$ * 200ECU+$\frac{1}{2}$ * 300ECU = 250 ECU.
- Whether the dividend on Asset A is 200 or 300 is unrelated to whether the dividend on Asset B is 200 or 300. It is also unrelated to the dividend the asset pays in past or future periods.
- After the market ends, time permitting, we will conduct other markets. We expect to be able to conduct several asset markets today. When a new market starts, each player's inventory of assets and cash will be **reset** to the same level that market 1 started out with.
- You will be randomly regrouped in a group of 8 people in each asset market.

4. When does the market end?

Each trading period lasts approximately 2 minutes. The exact number of periods in a market is not known beforehand. There is a **1/4 chance** that the market will end **in each trading period**. So, at the end of each period, the computer rolls an eight-sided die, if the die rolls a 1 or a 2, then the market ends at the end of that period. Otherwise, the market continues. If the market ends, one final dividend income will be received for the assets you hold when the market ended. So even, if the market ended the asset holdings in that last period will matter.

Even though the market might end at any time, we will play through four periods at a time as if the market continued. You will not know in which period the market ended until you have played through a **four-period block**. After the market has ended, the activity in the market from that point on will not count towards your earnings. For example, suppose you have played four periods, and then find out that the market ended after period 2. In this case, the activity from periods 1 and 2 will count and from period 3 will not count. It is possible that the market will continue for more than four periods if the die failed to come upon 1 or 2 any of the first four periods. In that case, we will play four more periods, and the market will have as before a chance of 1/4 of ending after anyone period.

So, playing the four-period blocks does not change the chance of ending. The chance of ending the market in each period is constant over time and is 1/4.

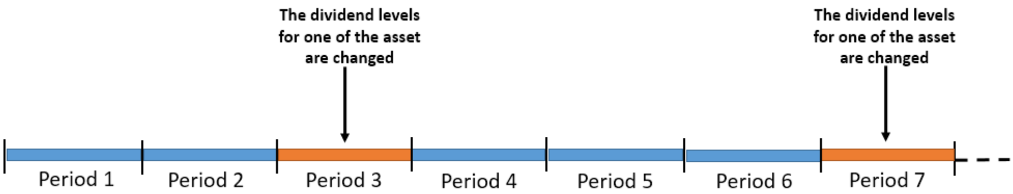
Trading assets: If there is a 1 in 4 chance that the market will end in each period, then the market on **average** ends after 4 periods, no matter which period you calculate from. So, if you

hold an asset for that long, you can expect that on average you would get **four** times the average dividends.

The experiment will last approximately three hours in total. If a market ends 25 minutes before the time limit, we will not start a new market. If a market is already underway when we hit the 25 minutes threshold mark, that market will continue until it finishes given the random draw of the dice. It will not be manually stopped. So, everything that you do during that time will still matter towards your final earnings.

5. Change to the dividend level

During the **third** period, the possible dividends, of one of the asset, will change with **certainty**. The possible dividends will change for only **one** of the two assets. The change may be **positive** or **negative**, and each direction is equally likely (1/2 chance). Once there is a change, the **new dividend level** will then remain in effect **in every period until** there is another change in the dividend level for that asset. The dividend level of each asset can only change every fourth period. Therefore, it can change in periods 3, 7, 11, etc… if the market does not end by then. If in the third period the change happens to asset A, for example, it doesn't mean that in period 7 the change will happen again to asset A. It has a ½ change that it can happen to asset A or asset B.



If the change is *positive*, the asset's dividend changes to be 250ECU or 350ECU, each equally likely (1/2 chance). On average, for each unit of the asset that you hold, you would receive 300ECU, 50ECU more than before in each period. So, every time there is a positive change to the dividend income to one of the assets, 50ECU are added to each possible dividend level.

If the change is *negative*, then the asset dividend becomes equally likely to be 150ECU or 250ECU. In this case, you will receive on average 200ECU for each unit of the asset, or 50ECU less than before. So, every time there is a negative change to the dividend income to one of the assets, 50ECU are subtracted from each possible dividend level.

Example: In period 6, Asset B pays either 150ECU or 250ECU, equally likely. Suppose in period 7 there is a negative change to its dividend income. As a result, Asset B will pay either 100ECU (150ECU-50ECU) or 200ECU (250ECU-50ECU).

6. Loan

At the beginning of each trading period, you will receive a loan of 17500ECU. The loan will have to be paid back at the end of the trading period. The repayment will be directly taken out of your cash at the end of the period. If you will not have enough ECU to repay the loan, it means that your ECU holding at the end of that period will be negative. As a result, you will have negative dollar earnings for that period. More on this in the following section. If the total of your dollar earnings over all periods is negative, then the negative dollar amount will be subtracted from the showup fee. We believe that this is a very unlikely outcome.

7. Earnings

At the end of each period, the cash you have after paying the loan is converted to euros. These are your euro earnings for the period. If you have a positive amount of Cash, the conversion formula from ECU to euros is the following: Euros= 0.112* ln (ECU), (where ln= natural logarithm). In the case of negative cash holdings at the end of the period, the conversion rate is the following: ECU/5100. The payoff table below shows the conversion for some of the possible amounts.

Table 1. Payoffs

ECU	€ Earnings	ECU	€ Earnings	ECU	€ Earnings	ECU	€ Earnings	ECU	€ Earnings
-17500	-3.431	-9700	-1.902	-1900	-0.373	5900	1.030	13700	1.096
-17200	-3.373	-9400	-1.843	-1600	-0.314	6200	1.034	14000	1.097
-16900	-3.314	-9100	-1.784	-1300	-0.255	6500	1.037	14300	1.099
-16600	-3.255	-8800	-1.725	-1000	-0.196	6800	1.040	14600	1.101
-16300	-3.196	-8500	-1.667	-700	-0.137	7100	1.043	14900	1.103
-16000	-3.137	-8200	-1.608	-400	-0.078	7400	1.046	15200	1.105
-15700	-3.078	-7900	-1.549	-100	-0.020	7700	1.049	15500	1.106
-15400	-3.020	-7600	-1.490	200	0.934	8000	1.052	15800	1.108
-15100	-2.961	-7300	-1.431	500	0.942	8300	1.055	16100	1.110
-14800	-2.902	-7000	-1.373	800	0.949	8600	1.057	16400	1.111
-14500	-2.843	-6700	-1.314	1100	0.956	8900	1.060	16700	1.113
-14200	-2.784	-6400	-1.255	1400	0.963	9200	1.063	17000	1.115
-13900	-2.725	-6100	-1.196	1700	0.969	9500	1.065	17300	1.116
-13600	-2.667	-5800	-1.137	2000	0.974	9800	1.068	17600	1.118
-13300	-2.608	-5500	-1.078	2300	0.980	10100	1.070	17900	1.119
-13000	-2.549	-5200	-1.020	2600	0.985	10400	1.072	18200	1.121
-12700	-2.490	-4900	-0.961	2900	0.990	10700	1.075	18500	1.122
-12400	-2.431	-4600	-0.902	3200	0.995	11000	1.077	18800	1.124
-12100	-2.373	-4300	-0.843	3500	0.999	11300	1.079	19100	1.125
-11800	-2.314	-4000	-0.784	3800	1.004	11600	1.081	19400	1.127
-11500	-2.255	-3700	-0.725	4100	1.008	11900	1.084	19700	1.128

-11200	-2.196	-3400	-0.667	4400	1.012	12200	1.086	20000	1.130
-10900	-2.137	-3100	-0.608	4700	1.016	12500	1.088	20300	1.131
-10600	-2.078	-2800	-0.549	5000	1.020	12800	1.090	20600	1.132
-10300	-2.020	-2500	-0.490	5300	1.023	13100	1.092	20900	1.134
-10000	-1.961	-2200	-0.431	5600	1.027	13400	1.094	21200	1.135

Euro Earnings per Period:

- **If Cash at the end of the period after repaying the loan ≥0 (positive number) then:**

Euro Earnings per period = Euro Earnings in ECU based on the payoff table above

- **If Cash at the end of the period after repaying the loan <0 (negative number) then:**

Euro Earnings per period = Cash at the end of the period after repaying the loan ECU /5100

Euro Earnings per Market:

- Euro Earnings Period 1+ Euro Earnings Period 2 + … + the Euro conversion of the dividend income for the trading in the last period=Total Euro earnings per Market

Euro Earnings for Part II of the experiment:

- Euro Earnings Market 1 + Euro Earnings Market 2 +…= Total Euro earnings part II

8. Trading rules for the current experiment

The market will start with a screen where you can find the number of assets you hold (10 assets A and 4 assets B). this is represented in Figure 1. Beginning Screen. Everyone will start with the same number of units of each asset. At the beginning of each period, you will receive the dividend income for the assets you are holding. On the last line, you will find the amount of cash that you can use during the trading period.

Figure 2. will present the trading platform is like the market you have played before.

The following screen is the actual trading platform. On the left side, you will find the number of Assets A units you have in the inventory and the income that one Asset A will pay.

Below the header in which the trading period is mentioned, you will find the amount of cash that you have available for the period. You can use the cash to buy assets or to keep as earnings to be converted at the end of the period, after repaying the loan.

On the upper-left corner, under the header that indicates the remaining trading time, you will find a **history of your cash balance** at the end of previous periods and the number of euros that they were converted to. This will provide you with a guide of how much you were able to earn in previous periods based on the trading you have done.

When the trading period ends, a new screen will appear. This is illustrated in Figure 3. On this screen, it will be displayed the number of assets that you have at the end of the trading period and the amount of cash that you have before and after paying back the loan received at the beginning of the trading period. Most importantly you will find out the number of euro earnings you will receive for that trading period.

Figure 1. Beginning screen.

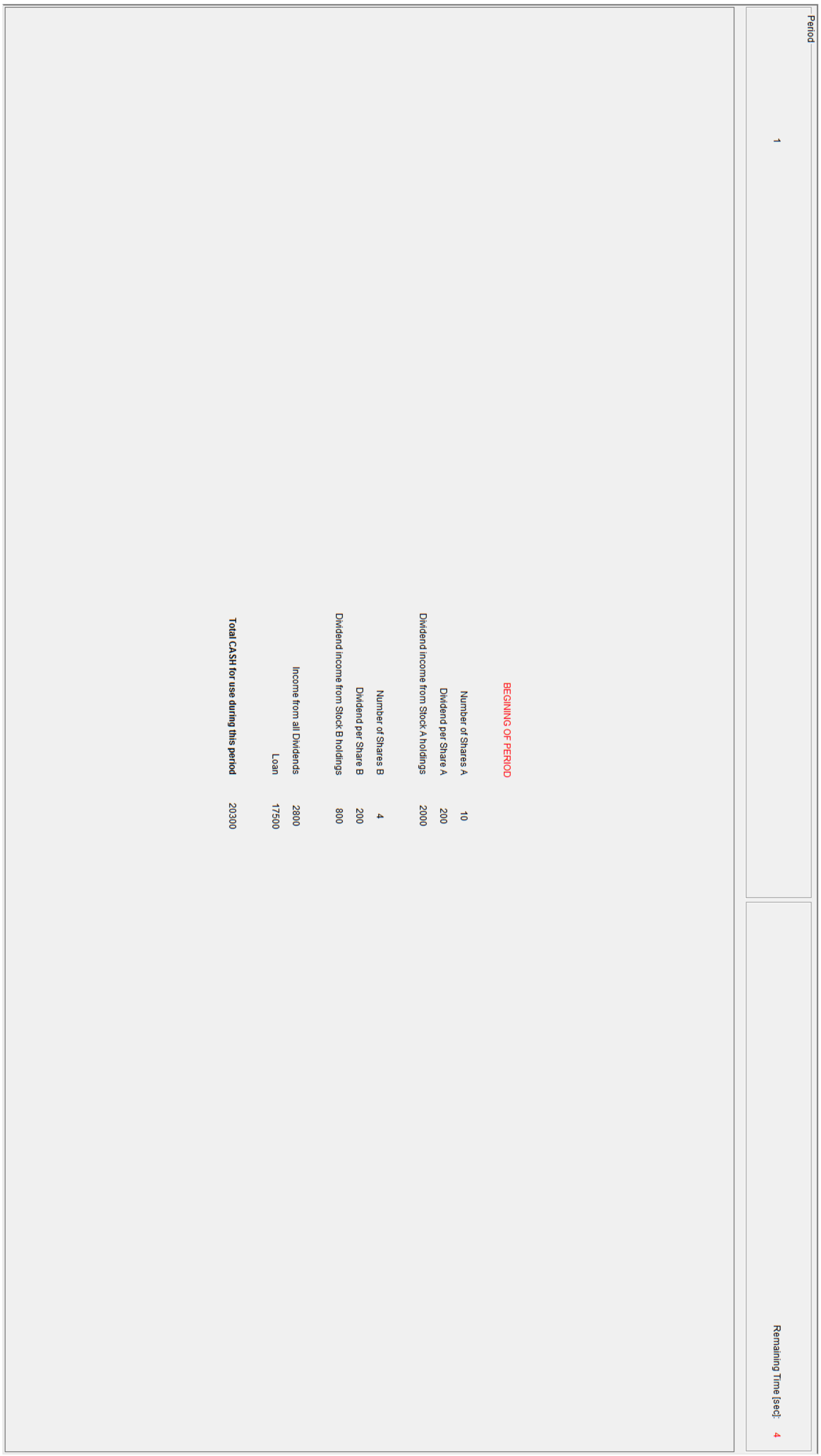
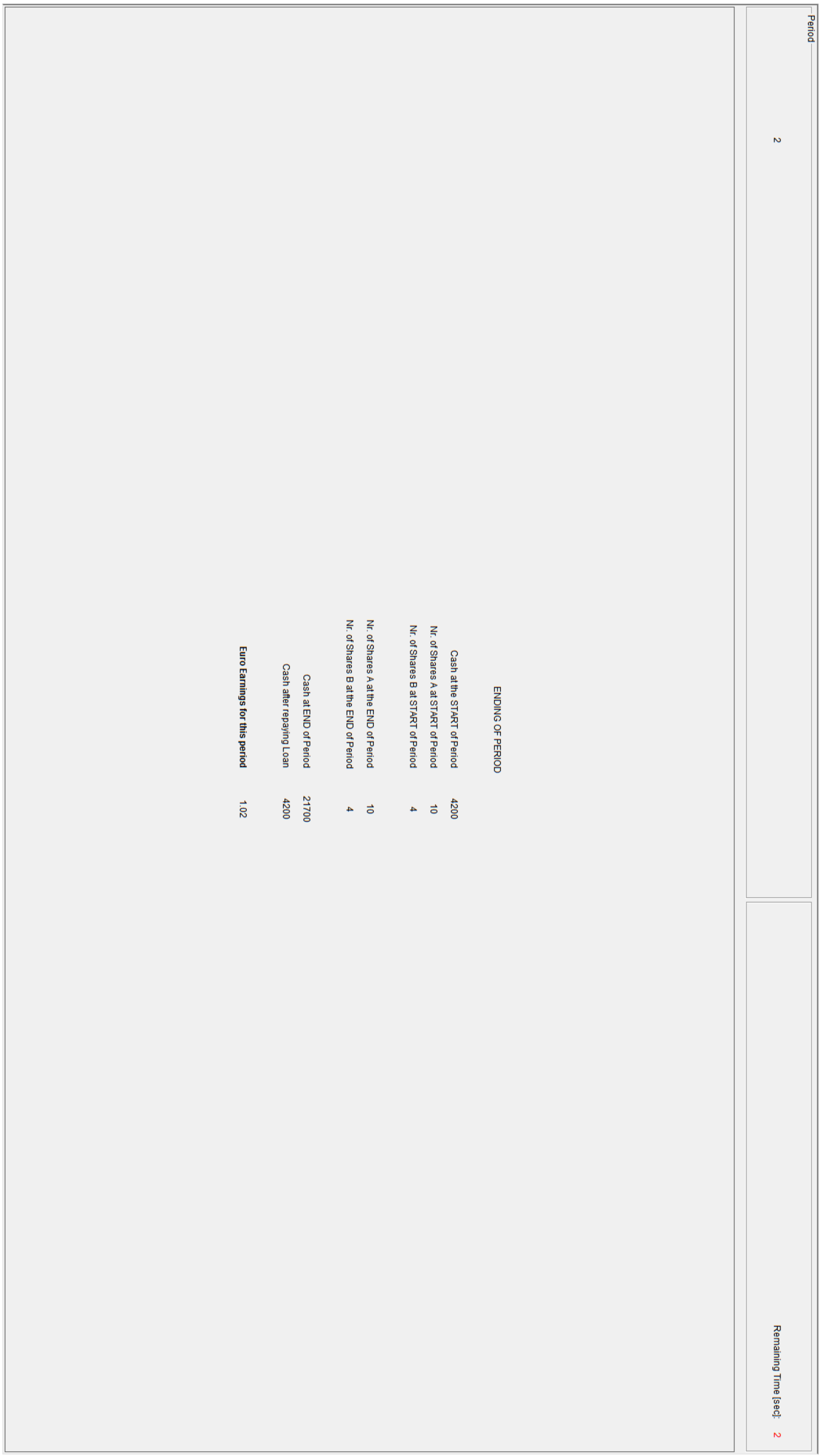


Figure 2. Trading screen

Figure 3. Ending screen



Before starting the asset market, please answer the following quiz bellow, and an experimenter will come and check the answers of the quiz. You have 10 minutes to finish the quiz.

Quiz

1. Suppose that there is 1340 ECU cash left after repaying the loan at the end of period 4 and the market will continue to period 5. Will the cash left be carried over to the beginning of the next period? Yes/No

2. Suppose that a dividend of either 200ECU or 300ECU is paid, each level is equally likely. What is the chance that the dividend payment will be 200ECU? _________chance. How about payment of 300ECU? _________ chance.

3. Suppose that the dividend paid by asset A is drawn from {200ECU, 300ECU} each level equally likely. The dividend paid by asset B is drawn from {100ECU, 200ECU}, each level equally likely. How much can you get on average as a dividend if you hold one asset A for one period? ___________ECU. How much will you get on average as a dividend if you hold one asset B for one period? _________ECU

4. Suppose you are in period 4, what is the chance that the market will continue to period 5?________ chance.

5. What is the chance that the market ends in period 6? How about period 2? ______chance

6. Suppose that in period 4 you find out that the market continues, would you be able to take with you to the next period the assets that you have at the end of period 4? Yes/No

7. If the market continues to the second period, and you have not sold or bought any of the assets during period 1, how much cash will you have at the beginning of period 2?
   (a) The amount of cash received as dividends at the beginning of period 2 from the assets that you hold at the end of period 1 plus the loan.
   (b) The amount of cash received as dividends minus the loan
   (c) The amount of cash received as dividends from the assets that you hold at the end of period 1 plus the cash that you had in your account at the end of period 1.

8. Suppose you hold 6 assets A and 2 assets B at the end of period 4 and the market continues to period 5. Suppose that the dividend that is drawn for asset A from the possible realizations is 200 and the dividend that is drawn for asset B is 150. How much dividend pay-out will you receive at the beginning of period 4?________ECU

9. Suppose that a change to the dividend distribution occurred for asset B. Is it true that in this case, a change will always occur to the dividend distribution of asset B? NO

10. What is the chance that asset A's dividend distribution is changed in period 3? ________chance. How about period 7 or in period 11 etc? ________ chance.

11. Assume that there was a change to the dividend levels of Asset A in period 3, what is the chance that the dividend levels of asset A will be changed again in period 7? ______chance

12. Suppose asset A will pay a dividend from the following distribution {100ECU,200ECU} in period 6. If a positive change to the dividend distribution occurs to asset A in period 7, then the dividend payout will increase on average by __________ECU. If the distribution increases on average by 50 ECU, what is the new distribution of dividends of asset A:

(a) {100ECU, 200ECU}
(b) {150ECU, 250ECU}
(c) {200ECU, 300ECU}

13. How many assets A are in total in the market, given that there are 8 participants in total? __________assets

14. How many assets B are in total in the market, given that there are 8 participants in total?
_____________ assets

Now that you have solved the quiz, we will play one trial market such that you get accustomed to the setting. Nothing that you will do during this trial market will matter in terms of your final earnings. After the trial market finishes, the earnings that you will receive in the subsequent markets will count towards your final earnings.

APPENDIX B

The random walk implemented in the lab had the following parameters:

$\Delta t = 1 \quad if\ t = 4s - 1\ \forall\ s = \overline{1;n}$; $\sigma = 50$; $\mu = 0$; $p = q = 0.5$;

$D_{i,1} \in \{200{,}300\}$; $\mathbb{E}[D_{i,t}]_{|t=1} = 250$; $\mathbb{p}(D_{i,1} = 200) = \mathbb{p}(D_{i,1} = 300) = 0.5$;

$Var(D_i) = \mathbb{E}\,[(D_i - \bar{D}_i)^2] = \mathbb{E}\left(D_i^{\,2}\right) - \bar{D}_i^{\,2} = 0.5[200^2 + 300^2\,] - 250^2 = \sigma^2$;

$SD(D_i) = 50 = \sigma$.

The probability that the market would end in period t was ¼ = 0.25. So, the continuation probability (induced discount factor) was $\beta = \frac{3}{4} = 0.75$.

Therefore, the price of asset i, $P_{i,t}$, can be calculated in the following manner:

$$P_{i,t} = D_{i,t} + \beta^1 \frac{D_{i,t} + D_{j,t}}{D_{i,t+1} + D_{j,t+1}} D_{i,t+1} + \beta^2 \frac{D_{i,t} + D_{j,t}}{D_{i,t+2} + D_{j,t+2}} D_{i,t+2} + \cdots$$

APPENDIX C

Table 6. Summary description of CRT, by CRT score.

The table presents the summary description of CRT scores across sessions.

CRT	Frequency	Per cent	Cumulative
0	11	17.19	17.19
1	22	34.38	51.56
2	18	28.13	79.69
3	13	20.31	100.00
Total	64	100	-

Table 7. Summary description of sessions by CRT score.

The table presents the mean and standard deviation of CRT scores across sessions.

Session	Mean	Standard Deviation
1	1.4	0.91
2	1.1	0.64
3	1.2	1.28
4	2	1.19
5	1	0.75
6	1.6	1.18
7	1.9	0.99
8	1.9	0.83
Total	1.5	1

APPENDIX D

Table 8. Testing multiple hypotheses

This table shows the result of the regression where the return of the shocked asset (in the period following the shock) is regressed on its past return and the return of the non-shocked asset (in the shock period). Panel (a) provides the results that take into account all dividend shocks, including the shock after the first block period. Panel (b) only considers one shock per market, namely the shock in period 3. Standard errors are clustered at the session level for all regressions. ***, ** indicates significance at the 1% and 5% level, respectively. *t*-statistics are reported in parenthesis.

	Panel (a) Multiple shocks per market	Panel (b) One shock per market		
	$R^{NS}_{t_{shock}+1}$	$R^{NS,t_{shock}+1}_{s,m}$		
Explanatory variables	Pooled OLS	Pooled OLS	Fixed Effects	Random Effects
$R^{NS}_{t_{shock}}$	0.6**			
	(3.44)			
$R^{S}_{t_{shock}}$	0.12			
	(1.24)			
$R^{NS,t_{shock}}_{s,m}$		0.5	0.29	0.37**
		(2.34)*	(1.47)	(2.10)
$R^{S,t_{shock}}_{s,m}$		0.13	-0.04	0.03
		(1.01)	(-0.81)	(0.32)
Constant	0.24*	0.27*	0.53***	0.42***
	(1.97)	(2.31)	(4.45)	(3.69)
R-squared	0.44	0.42	0.37	0.41
N	66	51	51	51