Rate of Return Parity in Experimental Asset Markets

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1. Introduction

The theories of international macroeconomics are quite diverse. They range from simple Keynesian models of open economies to modifications of the Mundell-Fleming small open economy model and more recently to real business cycle models. Whether considering international capital flows in monetary economics, modelling currency crises, or proving the impotence of monetary policy with fixed exchange rates, one simple and seemingly innocuous assumption is made time and time again. The assumption is that international capital markets are integrated in such a way that arbitrage is complete so that the rate of return on an asset in one country will equal the rate of return on a similar asset in another country once expected changes in the exchange rates are taken into consideration. The realization of this result is given the name of interest rate parity and is often expressed as

$$i = i^* - E(\Delta e) \qquad (1)$$

where i is the domestic interest rate, i* is the foreign interest rate, E is the standard expectations operator, and Δe is the percentage change in the exchange rate between the domestic and foreign currencies. The same idea can be applied to more general asset markets, and for the purposes of this essay this will be referred to as rate of return parity. In such a case *i*, in equation (1), represents the rate of return on investing in a domestic asset and *i** would represent the rate of return on a comparable foreign investment.

Given the prominence of the assumption of this outcome in open economy macroeconomics, it is reasonable to be concerned with its validity. The most obvious source for confirmation of this outcome is empirical work using field data from international capital markets.

There is no general agreement as to the validity of this prediction in field data, particularly in the modern period of floating and imperfectly fixed exchange rates. This lack of consensus may be caused by factors that confound the relationship between capital markets in the available field data. There are four major confounding factors in this system. The first is the difficulty in estimating expectations due to the large number of potentially relevant factors (Froot and Frankel 1989). Estimates of expectations are fraught with difficulties. Therefore the problems of estimating the expectations of the change in the exchange rate makes testing models of rate of return parity difficult (Fama 1984, Mayfield and Murphy 1992). The second confounding factor is the lack of perfectly identical financial instruments. If the instruments being considered are not perfectly identical in fact and are not seen as being perfectly identical by investors, rate of return parity cannot be confirmed without first measuring and acounting for these imperfections. The third possible confounding factor is that of frictions in capital and goods markets (Obstfeld and Rogoff 2000). The final confounding factor is that of exogenous shocks to capital markets. International politics, prices of fundamental inputs, and the mood of investors both domestic and foreign are likely to have an impact on the viability of rate of return parity, through changes in the underlying economies.

The confounding factors mentioned above will have different impacts on different data sets and will likely have to be dealt with in different ways. Instead of attempting to address the problems *ex post* in field data, the alternatives of surveys or laboratory experiments can be used.

Some researchers have attempted to use survey data to resolve some of the problems found with observations of market outcomes. Benzion *et al.* (1994) provide a direct attempt to capture the expectations and discount rates of individuals with respect to real assets. The results of this investigation do not support rate of return parity. The weakness of the survey approach is that individuals have very little incentive to report honestly or perform the calculations necessary to give a realistic response on a survey.

A successful survey will reduce, but not necessarily eliminate, the need to apply complex econometric techniques to eliminate or reduce the problems in a given data set. However, an environment may be designed to generate data in which these problems never arise. If rate of return parity holds in an environment in which the confounding problems do not occur, then some support can be lent to the basic principle behind both interest rate parity and rate of return parity as real phenomena.

Fisher and Kelly (2000) report the only attempt thus far to try to evaluate the existence of rate of return parity in a laboratory environment in which two asset markets are open for trade simultaneously and these markets are joined by a *common currency*. Subjects could buy and sell either asset, or both assets, in double auction markets. The authors argue that the relative asset prices constitute the exchange rate in this environment, and support for rate of return parity can be observed if the relative asset prices conform to the value predicted by the nature of the two assets. This work builds on the fairly large body of literature on experimental asset markets. Sunder (1995) offers a slightly dated survey of the experimental asset market literature and more recent results are surveyed in papers on the dynamics of market adjustment in Plott and Smith (Section 1.3, 2004).

One of the characteristics common to almost all experimental asset markets is the existence of price bubbles. In these laboratory markets the price of the asset tends to be below its fundamental (risk neutral expected dividend) value in early trading periods, rises well above the fundamental value in the middle periods of the session, and finally the price often falls back to or below the fundamental value shortly before the end of the session. These bubbles are greatly reduced in size and frequency when subjects are experienced in the environment (Smith, Suchanek, and Williams 1988). These asset markets are not fully appropriate for testing for the validity of rate of return parity. The assets which traders have to choose between are either an asset which pays an uncertain dividend, and which carries some level of risk, or cash, which pays no dividend, and is riskless. Rate of return parity is usually described within the context of identical assets (identical returns and identical levels of risk) denominated in different currencies. After accounting for expected exchange rate changes, rate of return parity is consistent with complete arbitrage in a risk neutral environment.

Within this context, the Fisher and Kelly (2000) experiment is novel, for it is the first studying environments in which identical assets with uncertain dividends are traded simultaneously. They find both bubbles and some support for rate of return parity. There are, however, some design features which can be improved upon. First, to the extent to which rate of return parity underlies much of the modelling of international financial markets, denominating the price of the assets and the dividends in the same currency may frame the problem that participants face in a way that induces a higher degree of integration between the asset markets than if the markets were denominated in different currencies. Second, Smith *et al.* (1988) show that trader experience affects the magnitude and period of bubbles in laboratory asset markets. In many of Fisher's and Kelly's sessions experienced and inexperienced traders were mixed. This makes it difficult to conclude that the emergence of rate of return parity was not driven by experience, rather than the incentives of the environment itself. Finally, Fisher's and Kelly's design was not balanced. This affects statistical evaluation of the resulting data.

The research presented in this paper is a systematic examination of a multiple asset environment to evaluate the prediction that arbitrage will be complete and that rate of return parity will result when capital is freely mobile, the expected nominal returns to assets and their variances are known and identical, and the exchange rate is perfectly fixed, and to discover the effects of different expected nominal returns and variances across assets. The maintained hypothesis of this essay is that all gains from arbitrage will be realized when the assets may be traded simultaneously. The general findings of this investigation are that arbitrage is complete in simple laboratory environments, but that as the assets become more differentiated, the completeness of arbitrage, within the context of risk neutral trading, falls. This suggests that in a world much more complex than the laboratory, the successful utilization of the assumption of compete arbitrage and rate of return parity may lead to erroneous predictions unless information about risk attitudes and motives for speculation are well known.

The remainder of this paper is organized as follows. Section 2 presents the experimental design and laboratory environment in which rate of return parity (used synonymously with complete arbitrage) is tested. This section is presented before the closer examination of the theory in order to provide a frame of reference when discussing the theory. Section 3 presents a closer examination of some theory behind rate of return parity, and will explain the specifics of how rate of return parity may be observed in the experimental environment. Section 4 presents the results of the laboratory sessions. Section 5 draws conclusions from the data.

2. Experimental Design and Laboratory Environment

This experiment consists of twelve simultaneous double auction asset market sessions run at the McMaster University Experimental Economics Laboratory. Four treatments are considered, with three sessions of each treatment. Ten subjects recruited from the student population of McMaster University participated in each session. The subjects who participated in each session had not participated in any other session of this experiment. Payoffs to the 120 subjects ranged from $12.25 to $104.50, with a mean of $38.45 and a standard deviation of $21.19. The key components of the laboratory environment are: the markets, the behaviour of the exchange rate, the nature of the assets, and the endowments of subjects. Each of these aspects as well as the overall experimental design will be discussed in turn below.

2.1. The Markets

International capital markets are double auction markets. Therefore the asset markets in this experiment are double auction markets. A market for Blue assets using Blue dollars as the medium of exchange and a market for Red assets using Red dollars as a medium of exchange were conducted simultaneously in a computer mediated environment. Each subject had the ability to act as a trader of assets in each of the two asset markets. The assets paid uncertain, but well-defined, dividends at the end of each trading period. The specific dividend structures are explained in section 2.3 below. Instructions were distributed to each subject and then read aloud at the beginning of each session. These instructions fully describe to subjects how to enter bids and asks, as well as how to accept an outstanding bid or ask.[1] Each session consisted of 20

[1] Instructions and a screen shot are posted at http:\\people.unbsj.ca\~jchilds\research.

three-minute trading periods.[2] At the beginning of every session each subject received an endowment of equal expected value, based on the expected dividends and trading at the assets' fundamental values in each trading period. Endowments consisted of some combination of Red assets, Blue assets, Red dollars ($R), and Blue dollars ($B). The specific endowments used are presented in part section 2.4. Having received their initial endowments, subjects' inventories of currency and assets were carried over from period to period. At the end of each session, subjects' holdings of Blue dollars were converted into Red dollars at the exchange rate of the last period. Subjects' holdings of Red dollars were then converted into Canadian dollars ($C) at a previously announced conversion rate.[3]

2.2. Exchange Rate Behaviour

In order to limit the number of possible confounding factors in the laboratory environment the exchange rate between the two currencies was fixed and not subject to change. The exchange rate was fixed at 1 Red dollar for 1 Blue dollar. This creates an environment comparable to that created by Fisher and Kelly (2000). The existence of separate currencies and a fixed exchange rate can be thought of as a comparable environment but one that is framed differently than an environment in which the Red and Blue assets and their dividends are denominated in the same currencies. In this environment, traders must exchange currencies, and have sufficient Red or Blue dollars to engage in a transactions. Converting to the proper currency is never a binding constraint in this environment, in which there was no possibility of the

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[2] Session 1.3 ran for 18 periods and session 2.3 ran for 19 periods due to problems with the computer network (these session numbers correspond to the numbers in Figures 1 and 2).

[3] $C1 = $R66 in Treatments 1 and 2; $C1 = $R77 in Treatments 3 and 4. The different conversion rates kept expected payoffs to subjects approximately equal across sessions.

exchange rate changing.

2.3. The Nature of the Assets

The majority of Fisher and Kelly's (2000) treatments dealt with assets which had four possible dividends. The same is true of the seminal asset market work of Smith *et al.* (1988).[4] The experiment presented in this paper is intended to be as simple as possible while allowing sufficient opportunity for alternate models of behaviour. Accordingly, assets in each period of each session in this experiment could pay either a high or a low dividend. The likelihood of the high dividend was fifty percent in all treatments.

Four treatments, each consisting of three sessions, fully interacted expected dividend value and the absolute difference in the variance of expected dividends. In the Treatment 1 both the Red and Blue assets had the same high and low dividends. This treatment is the direct test of rate of return parity. The assets are identical and there is no expectation that the exchange rate will change.

In Treatment 2 the dividends of both the Red and Blue assets had the same expected value, but the expected dividend of the Blue asset had a higher variance, and consequently the Blue asset was riskier than the Red. This treatment tests the impact of asset specific risk on rate of return parity. In Treatment 3 the expected dividend paid to holders of both assets had the same variance but the Blue asset had a higher expected dividend than the Red asset. The absolute risk is the same across assets, but relative risk (relative to expected dividend) is greater

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[4] When asked about the choice of 4 possible dividends as opposed to another number of potential dividends Vernon Smith responded, "No reason. Four is good round number. The software accommodates up to a six point distribution as I recall." Personal correspondence: October 11, 2000.

for the Red Asset than the Blue. In Treatment 4 the expected dividend of the Blue asset was higher than that of the Red asset, but the dividend of the Blue asset also had a higher variance. The absolute difference between the variances is the same as in Treatment 2 and the difference between the expected dividends is the same as in Treatment 3. This treatment allows the consideration of the impact of very dissimilar assets on rate of return parity. The Blue asset was riskier than the Red, but also provided a greater expected return. The possible dividends by treatment are in Table 1.

The dividends and difference in variance reported in Table 1 are in terms of the Red or Blue currency respectively. From the expected dividend values the risk neutral expected dividend price can be calculated. The specific calculations are discussed in the Section 4 below.

- Table 1 Here -

In each of the four treatments the dividends paid to owners of Red and Blue assets are independent. In all treatments the dividend values are determined by the rolls of coloured dice. A red die was rolled to determine the dividend of the Red asset and a blue die was rolled to determine the dividend of the Blue asset. The rolls and respective dividends were recorded on a chalk board at the front of the laboratory in appropriately coloured chalk.

The treatments of the factorial design are summarized in Table 2. Each of the treatment parameters is fully interacted with the others.

- Table 2 Here -

2.4. Endowments

In each treatment there were two different endowment groups. One endowment group received more Red dollars than Blue dollars and received more Blue assets than Red assets. The other received more Blue dollars than Red dollars and received more Red assets than Blue assets. This was done to encourage subjects to participate in both asset markets. The specific endowments are shown in Table 3. In each treatment the endowments to each group of traders have the same expected values if subjects did not trade (or if arbitrage is complete for risk neutral traders).

- Table 3 Here -

3. Theory, Predictions and Hypothesis Tests

Typically, uncovered interest rate parity focuses on specific assets, with little or no opportunity for capital gains from holding such assets. Modifying uncovered interest rate parity to include the possibility of capital gains and no possibility of exchange rate change leads to the form of rate of return parity described by

$$E(y_1) + E(g_1) = E(y_2) + E(g_2) \tag{2}$$

where y_i is the dividend yield (as a percentage of the price paid for the asset) on asset 1 or asset 2 purchased in period t and held to the end of period T (after which the asset pays no dividends), g_i is the capital gain (again measured in percentage of the purchase price of the asset) from holding asset 1 or asset 2 purchased in period t and held until the end of period T, and E is the standard expectations operator. Rearranging Equation (2) leads to

$$E(y_1) - E(y_2) = E(g_2) - E(g_1) \tag{3}$$

If rate of return parity between two assets is to be observed, the difference in the expected yields of the assets must be equal to the difference in expected capital gains. Thus, rate of return parity places no restrictions on yields unless the expected capital gains are known.

When considering rate of return parity in the experimental environment described in Section 2, one should note that there are not simply two assets, but four, available to agents. The Red and Blue currencies along with the Red and Blue Assets are all assets from the perspective of the agents participating in the experiment. With the assumption of risk neutral agents, rate of return parity can be applied to any pairing of assets. In this sense, there are many experiments that have tested rate of return parity between a single asset and a currency. Most notable among these is Smith, Suchanek and Williams (1988). Applying equation (3) to an environment with a single asset and a single currency is actually quite simple. If asset 1 is the laboratory currency and asset 2 is the laboratory asset with uncertain dividends then

$$E(y_{currency}) - E(y_{asset}) = E(g_{asset}) - E(g_{currency}) \quad (4)$$

For all agents in this type of experiment, holding the laboratory currency means receiving no dividends with certainty, and therefore, the yield on the currency is 0. Furthermore, the conversion rate between the laboratory currency and the payment medium of subjects is constant, thus, the capital gain to holding currency is simply 0. In this type of experiment the price of the asset with uncertain dividends at the end of the session (after period T) is 0. Therefore if agents have time horizons that extend to the end of period T the expected capital gain from an asset purchased at time t will be

$$E(g_{asset}) = (0 - P_{asset,\, t})/P_{asset,\, t} \quad (5)$$

where $P_{asset,\, t}$ is the price of the asset with uncertain dividends purchased in period t. If there are T - t periods remaining in the session when an asset is purchased, the expected yield on the asset with uncertain dividends will be

$$E(y_{asset}) = (T - t + 1)[\, E(D_{asset})/P_{asset,\, t}\,] \quad (6)$$

where D_{asset} is the dividend paid to holders of the asset at the end of each period. Equation (4) can be written as

$$0 - (T - t + 1)[E(D_{asset})/P_{asset, t}] = - [P_{asset, t} / P_{asset, t}] - 0 \quad (7)$$

and further rewritten as

$$P_{asset, t} = (T - t + 1)[E(D_{asset})] \quad (8)$$

Equation (8) declares that with rate of return parity an asset should be purchased in period t at a price equal to the sum of the expected dividends for the T - t + 1 periods the asset is expected to pay dividends. This price is the asset's fundamental value in period t.

Typically, inexperienced asset traders generate bubbles in laboratory asset markets, such as in Smith *et al.* (1988).[5] Bubbles indicate that asset prices do not generally reflect fundamental values (as in equation (8)). Therefore, asset market experiments (with a single, uncertain dividend paying asset and money) generally do not support the observation of rate of return parity. But rate of return parity can have its best chance of being observed if the assets are identical, unlike a dividend paying asset and money.

3.1. Two Assets with Uncertain Dividends and either Risk Neutral Traders or Identical Assets

Consider an environment in which there are three assets. Two assets pay uncertain dividends and the third asset is cash. Considering the two assets which pay uncertain dividends, if traders are risk neutral or if there is no difference between the risk (absolute or relative) associated with the two assets, we can write, from equation (3)

$$E(y_{blue}) - E(y_{red}) = E(g_{red}) - E(g_{blue}) \quad (9)$$

If agents have time horizons that extend to the end of the session, then from equation (5),

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[5] See Sunder (1995) for a slightly dated survey of single asset market experiments.

$E(g_{red}) = E(g_{blue}) = -1$. Therefore the yield on the Blue asset will be equal to the yield on the Red asset.[6] Furthermore,

$$E(y_{blue}) - E(y_{red}) = 0 \;\; \mathrm{Y} \;\; E(y_{blue}) = E(y_{red}) \qquad (10)$$

Applying equation (6) to equation (10) yields

$$P_{blue} = P_{red}\,[E(D_{blue,\,t})/\,E(D_{red,\,t})] \qquad (11)$$

When there is no exchange rate uncertainty, then for risk neutral traders or for traders facing assets with identical expected dividends and identical risk characteristics (absolute and relative), equation (11) will characterize rate of return parity. For the parameters given in Table 1, this provides the predictions in the middle column of Table 4.

- Insert Table 4 Here -

3.1. Two Assets with Uncertain Dividends and Different Risk Characteristics

If traders are risk averse, or risk preferring then equation (2) does not capture the relationship between the assets in question. Many researchers attempting to find evidence of rate of return parity have posited that risk does in fact play a key role in actions of traders. If such is the case, equation (10) needs to be modified to include a risk premium for each asset. This leads to

$$E(y_i) - E(y_j) = \Theta_j - \Theta_i \qquad (12)$$

Where Θ_i is the risk premium on asset i and Θ_j is the risk premium on asset j3. Assets i and j, in equation (12) could be the Red asset and the Blue asset or either the Red or Blue asset and currency. Θ_i could depend on asset i's variance or on its variance relative to its price (absolute

[6] It should be noted that any behaviour that equates the expected capital gains of the two financial assets will lead to Equation (10).

or relative risk may be important). If agents are risk averse, the risk premium will be positive and increasing in the absolute or relative variance of expected dividends. In this case, the yield on the asset with the greater risk would be higher than the yield on the asset with the lower risk. Higher yield implies lower price. If agents were risk loving, the risk premium would be negative and falling in the absolute or relative variance of expected dividends.[7] In this case, the yield on the asset with the greater risk will be lower than the yield on the asset with the lower risk. Lower yield implies higher price.

This leads to different predictions with regard to the relationship between the price of the Red asset and the price of the Blue asset, depending upon the risk characteristics of the traders in the markets. If there are only risk averse traders, the prediction will be characterized by risk aversion. If there are at least two risk neutral traders and the remaining are risk averse, risk neutrality will characterize the prediction. If there are at least two risk loving traders, then the prediction will be characterized by risk loving behaviour. These predictions are presented in Table 4. The predicted prices of the Red and Blue assets in period t are less than or equal to or greater than $(T - t + 1)E(D_{asset})$ depending upon whether all traders are risk averse, at least two traders are risk neutral and all other are risk averse, or at least two traders are risk loving respectively. D_{asset} is the dividend paid to holders of the asset at the end of each period and T is the last period a dividend will be paid.

3.3. Hypotheses Tests

Except for testing *Hypothesis 1* that

[7] The risk premium will be negative, and as the measure of risk rises, the risk premium will rise in absolute magnitude, but fall in actual value (it will become a larger negative number).

rate of return parity will emerge in a simple environment with two identical assets, denominated in different currencies whose exchange rates are known with certainty to be fixed for the duration of the trading session,

it is important that something is known about the risk attitudes of the participants as traders in this experiment. The traders in each session may be characterized by their behaviour in the individual asset markets. Risk neutral traders would engage in transactions at or below the fundamental value of an asset. By observing the "bubble" patterns in the laboratory asset markets, we may be able to identify the overall risk attitude characterizing a market that can then be used when considering the relationships between the prices of the assets yielding uncertain dividends. If a session is characterized by Red asset prices and Blue asset prices exceeding their fundamental values, we would conclude that risk loving traders characterized this market session.

Before considering hypotheses related directly to relative price performance in specific treatments, it would be useful to evaluate the performance of traders in the laboratory markets with respect to the effects of changing the most basic environment to incorporate assets with different expected dividends and assets whose expected dividends had different variances. This was the objective of introducing Treatments 2, 3 and 4 into this design. Several hypotheses follow directly from this design.

Hypothesis 2: Changing expected dividends and the variance of the expected dividends has no impact on the difference between the actual Blue asset price and its predicted price based on the Red asset price (the Treatment 1 relationship will be observed in all sessions).

If *Hypothesis 2* can be rejected in favour of an alternative that expected dividends and their variances matter, then two obvious hypotheses follow .

> *Hypotheses 3: Changing expected dividends has no impact on the difference between the actual Blue asset price and its predicted price (there is no difference in the market performance in Treatment 1 and 2 as compared with Treatments 3 and 4).*
>
> *Hypothesis 4: Changing the variance of the expected dividends has no impact on the difference between the actual Blue asset price and its predicted price (there is no difference in the market performance between Treatments 1 and 3 as compared with Treatment 2 and 4).*

Finally, if Hypothesis 2 can be rejected, three additional hypotheses can be considered regarding the relative price performance in each of Treatments 2, 3, and 4 with respect to the theoretical predictions and the implied risk characteristics of the markets associated with an inspection of their "bubble" patterns (Treatment 1 is included in *Hypothesis 1*).

4. Empirical Results

The laboratory sessions generate a large number of observations. Many contracts may be transacted in a trading period and there are twenty trading periods in each session. The data generated over time in a session are not independent. For analysis of these sessions, the average contract price in each period will be reported as the price in each trading period.[8] These prices are presented in the left panels of Figures 1, 2, 3, and 4. In addition, the difference between the mean Blue asset price in a period and the risk neutral predicted Blue asset price, a Blue asset

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[8] Average transaction prices in each period are often used in analyses of experimental asset markets. See Sunder (1995). In those periods in which no transaction occurred, the midpoint between the outstanding bid and ask was used as a proxy for the price.

price prediction error, based on equation (11), is computed for each period of each session. These data are presented in the right panels of Figures 1, 2, 3, and 4.

Each session will provide one observation to the analysis. The variable used for each session is the median of the Blue asset price prediction errors for the session. The mean of these data are not chosen as the unit of observation to avoid the effects of one or two extreme values in the twenty observations during a session. These data are summarized in Table 5.

4.1. Risk Attitudes

Figures 1, 2, 3, and 4 display the mean contract price data for each period in each of the twelve sessions in the experiment. Except for two of the twelve sessions, the patterns displayed by the mean prices of the Red and Blue assets are consistent with sessions run by others using traders inexperienced in the asset market environment. Mean prices begin below the risk neutral fundamental value of the assets, exceed this value after the sixth trading period and return to the fundamental value by the last few periods. The general characteristic in these markets is of assets trading above the risk neutral fundamental value. Because these price series describe a trade-off between the asset with an uncertain return and currency, this supports a characterization of these markets as being dominated by risk loving traders.[9] In session 4.2 (Figure 4), the price of the Red asset does not rise above its fundamental value and stay there for several periods until the ninth period. In session 1.2 (Figure 1), while the prices of both assets exceed their fundamental values from the eighth through fifteenth periods, this market is closest to being characterized as having risk neutral traders. Generally, however, when the alternatives

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[9] This could be as few as two traders who are risk-loving and who bid the asset's price above its fundamental value.

are an asset which returns an uncertain dividend and cash, the risky asset trades at a premium.

4.2. Giving Rate of Return Parity Its Best Shot

Treatment 1 is characterized by two identical assets denominated in different currencies whose exchange rate is fixed. The prediction, from Table 4, is that the price of the Blue asset will equal the price of the Red asset if there is complete arbitrage and rate of return parity prevails (this is *Hypothesis 1*, that the blue price prediction error will be zero). The three time series on the right panel of Figure 1 display the difference between the actual price of the Blue asset and the predicted price of the Blue asset. These time series are very close to zero. The median of these deviations, by session, are reported in Table 6. The mean is - 0.71. With one observation at 0, and one on either side, it is impossible to reject the null hypothesis that the difference between the actual price of the Blue asset and the predicted price of the Blue asset is zero in favour of the alternative that it is different from zero.[10] When given its best shot, rate of return parity is observed in the laboratory environment.

4.3. The Effects of Different Dividends and Different Variances

In a simple environment, rate of return parity holds. What happens when there is a change in the characteristics of the assets in this simple environment? How robust is this slightly more complex environment? The data in Table 5 are evaluated using analysis of variance. The analysis of variance results are presented in Table 6.

The analysis of variance indicates that the model is marginally significant (p = 0.066).

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[10] An OLS regression of the session median prediction errors in Table 5 on dummy variables in which Different Dividends equals unity, Difference Variances equals unity and the interaction of these two variables returns a p-value of 0.954 on the null hypothesis that the intercept of the regression (the Blue price prediction error in Treatment 1) is zero against the alternative hypothesis that the Blue price prediction error is not zero. See Table 7.

This permits the rejection of *Hypothesis 2* in favour of the alternative hypothesis that changing dividend and variance characteristics will have an effect on the Blue asset price prediction error. Accordingly, at least one of the treatments is significantly different from the others. By reviewing the data in Table 6, it is clear that there is an interaction effect between different dividends and different variances. When the expected dividends from the two assets are the same, increasing the difference between the variances of the expected dividends results in a reduction in the prediction error. The actual Blue asset price falls below the predicted price with an increase in the variance of the expected dividends of the Blue asset. However, when the expected dividends differed across the two assets, increasing the variance of the expected dividends of the Blue asset results in the actual Blue asset price rising above the predicted price. This interaction effect is significant ($p = 0.028$).

The significant interaction effect between the different dividend and different variance variables contributes to the rejection of *Hypothesis 4*. From Table 5, the effect of the different variance results in a reduction in the prediction error from Treatment 1 to Treatment 2. However, there is an increase in the prediction error from Treatment 3 to Treatment 4. The strength of the interaction effect results in a marginal rejection of the null hypothesis that different variances has no effect on the prediction error ($p = 0.0983$). *Hypothesis 3*, however, cannot be rejected. The data cannot reject the null hypothesis that different dividends have no effect on prediction error ($p = 0.745$). This is the case even though different dividends brings the changes consistent with the alternative hypothesis for Treatment 1 and 3 and for Treatments 2 and 4. These changes are in opposite directions. This results from the effect on prediction error in Treatment 3 from the increased relative riskiness of the Red asset following the increase in the expected dividend of the Blue asset. A more fruitful avenue of investigation is the three additional hypotheses which can be introduced following the rejection of *Hypothesis 2*.

4.4. The Treatments 2, 3 and 4

Three additional hypotheses can be tested following the rejection of *Hypothesis 2*. The null hypotheses for *Hypotheses 5, 6 and 7* are that the mean Blue asset price prediction errors are zero. Because the conclusion from section 4.1 is that the markets conducted in this experiment tended to be characterized by risk loving traders, the predictions from the two right-most columns in Table 4 are relevant as alternative hypotheses against which the null hypotheses of Hypotheses 5, 6, and 7 are tested.

For Treatments 2 and 4 the alternative hypotheses are that the prediction error will be positive. For Treatment 3, the alternative hypothesis is that the prediction error will be negative. In the case of Treatment 3, it will be impossible to differentiate between risk neutral rate of return parity and the outcome in a market in which the risk premium depends upon the variance of the expected dividends. If the risk premium depends upon the variance *relative* to the price of the asset, then the Blue asset price should fall short of the risk neutral predicted price.

Referring to Table 5, the mean prediction error for Treatment 2 is negative (- 10.83), for Treatment 4 it is positive (18.51), and for Treatment 3 it is negative (-38.51). The prediction errors for Treatments 3 and 4 are consistent with the alternative hypotheses, the prediction error for Treatment 2 is not. The significance of these results can be derived from the regression presented in Table 7.

Hypothesis 5. The test that the regression constant plus the Different Variance coefficient equals zero cannot be rejected in favour of the alternative that this sum exceeds zero (p = 0.794). This means that we cannot reject the null hypothesis that risk neutral rate of return parity is realized when the assets' expected dividends did not change but their variance did. This is consistent with the right panels in Figure 2 which show slightly more variation than in Figure 1, but essentially show prediction errors very close to the risk neutral rate of return parity prediction.[11]

Hypothesis 6. The test that the regression constant plus the Different Dividend coefficient equals zero can be rejected in favour of the alternative that this sum is less than zero (p = 0.008). This means that we can reject the null hypothesis of risk neutral rate of return parity in favour of an alternative that the behaviour we observe is consistent with rate or return parity in a market characterized by risk-loving traders whose risk premia are determined by the a measure of relative risk. This is consistent with the data presented in the right panels in Figure 3 showing negative prediction errors dominating the time series data.

Hypothesis 7. The test that the regression constant plus the coefficients for the other three variables equals zero can be rejected marginally in favour of the alternative that this sum exceeds zero (p = 0.089). Again, we reject the null hypothesis of risk neutral rate of return parity in favour of an alternative that the behaviour we observe is consistent with rate of return parity in a market characterized by risk-loving traders. The marginal rejection of the risk neutral hypothesis is reflected by the mixed results in the right panels of Figure 4. Sessions 4.1 and 4.2

[11] This result appears contrary to the finding of much research using field data (Fama 1984, Mayfield and Murphy 1992). The failure to observe rate of return parity in the field data (specifically uncovered interest rate parity) has been attributed to risk aversion and differences in the risk associated with different assets. The analysis of the laboratory data do no support this finding. To the extent that the laboratory environment does not appear to characterized by risk aversion suggests a limitation of these results.

are consistent with the result, but session 4.3 shows a declining trend, with negative rather than positive prediction errors over much of the latter half of the session.

5. Conclusions

Overall, the analyses indicate that risk neutral rate of return parity is not observed between assets with uncertain dividends and currency. In the environment created for this experiment, the markets appear to be characterized by risk-loving behaviour. When the environment contains assets with identical expected dividends and risk characteristics, but these assets are denominated in different currencies which are linked by a fixed exchange rate, rate of return parity between the assets with uncertain dividends is observed. This is the specific case for which rate of return parity is expected to be observed, but which is difficult to find outside of a laboratory environment. This result is independent of the risk attitudes of the traders. This result is consistent with the finding of Fisher and Kelly (2000), but this experiment uses the frame of assets with different currencies and a fixed exchange rate, rather than a common currency.

Risk neutral rate of return parity between assets with uncertain dividends may not carry over to more complex environments. In particular, different expected dividends and different variances of expected dividends make risk attitudes important. The data suggest that even though the variance of expected dividends changes, as long as expected dividends are unchanged, risk neutral rate of return parity is maintained. This result, however, is puzzling, because of the underlying risk-loving behaviour that seems to characterize these markets.

When only expected dividends change or when both expected dividends and the variance of expected dividends change, the behaviour of the Blue asset price prediction errors are consistent with rate of return parity and risk-loving behaviour. Why these changes bring significant changes in prediction errors but changing the variance of expected dividends without changing expected dividends does not may be associated with the sensitivity of inexperienced traders to their environment. Inexperienced traders may focus on expected dividends and not their variances, unless the expected dividends are different. Once expected dividends differ, all aspects of the environment are considered more carefully. This is a conjecture which requires testing.

Whether arbitrage is complete cannot be evaluated in this environment. This requires having more specific information about the risk attitudes of each trader so that specific risk premia can be determined. In addition, throughout this analysis, these data are limited to the consideration of rate of return parity in which capital gains on assets are assumed to be identical.[12]

The results pertaining to changes in expected dividends and the variance of expected dividends, and the consistency of outcomes with rate of return parity that accounts for some form of risk attitudes, is new. Risk neutral rate of return parity is not generally supported. Applying rate of return parity in situations where assets are different would be ill advised, even in the

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[12] Many researchers using field data to consider rate of return parity have hypothesized that rate of return parity is observed as a long run phenomena. The empirical hypothesis in this case is that rates of return on two assets will be co-integrated. This technique was applied to the twenty periods of data generated in each session of this experiment. While the results of the augmented Dickey-Fuller tests generally provide support for the claim that the price series in each session are co-integrated, the failure to support this result is not conclusive because of the low power of this test when applied to relatively short time series. A demonstration that these series are co-integrated is not sufficient, however, to support the hypotheses introduced in this paper.

absence of exchange rate risk. Exchange rate risk is not the only problem that needs to be addressed if effective predictions for naturally occurring environments must be made.

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Table 1 Asset Dividends

Treatment	Red Asset Dividend	Blue Asset Dividend	Difference in Variance
1	D_R = (10,20): $E(D_R)$ = 15	D_B = (10,20): $E(D_B)$ = 15	0
2	D_R = (10,20): $E(D_R)$ = 15	D_B = (5,25): $E(D_B)$ = 15	75
3	D_R = (10,20): $E(D_R)$ = 15	D_B = (15,25): $E(D_B)$ = 20	0
4	D_R = (10,20): $E(D_R)$ = 15	D_B = (10,30): $E(D_B)$ = 20	75

Note: D_i indicates the possible dividends for the Red and Blue assets in terms of Red and Blue dollars, as the subscript indicates. E represents the standard expectations operator.

Table 2 Design Table: Treatments and Sessions by Dividend and Variance Characteristics

	var (D_B) = var (D_R)	var (D_B) > var (D_R)
$E(D_B) = E(D_R)$	Treatment 1 (3 sessions)	Treatment 2 (3 sessions)
$E(D_B) > E(D_R)$	Treatment 3 (3 sessions)	Treatment 4 (3 sessions)

Table 3 Endowments of Subjects

Treatment	Endowment	Red Dollars	Blue Dollars	Red Assets	Blue Assets
1	A	300	600	3	1
1	B	600	300	1	3
2	A	300	600	3	1
2	B	600	300	1	3
3	A	300	800	3	1
3	B	600	300	1	3
4	A	300	800	3	1
4	B	600	300	1	3

Table 4 Predictions for the Price of the Blue Asset (P_b) as a Function of the Red Asset Price (P_r) and Risk Attitudes and the Measure of Risk

	All Traders Risk Averse		At Least Two Traders Risk Neutral, All Others Risk Averse	At Least Two Traders Risk Loving	
	$\Theta_i(\sigma_i)$	$\Theta_i(\sigma_i / P_{i,t})$	$\Theta_i(\sigma_i)$ or $\Theta_i(\sigma_i / P_{i,t})$	$\Theta_i(\sigma_i)$	$\Theta_i(\sigma_i / P_{i,t})$
Treatment 1	$P_b = P_r$	$P_b = P_r$	$P_b = P_r$	$P_b = P_r$	$P_b = P_r$
Treatment 2	$P_b < P_r$	$P_b < P_r$	$P_b = P_r$	$P_b > P_r$	$P_b > P_r$
Treatment 3	$P_b = 1.33\ P_r$	$P_b > 1.33\ P_r$	$P_b = 1.33\ P_r$	$P_b = 1.33\ P_r$	$P_b < 1.33\ P_r$
Treatment 4	$P_b < 1.33\ P_r$	$P_b < 1.33\ P_r$	$P_b = 1.33\ P_r$	$P_b > 1.33\ P_r$	$P_b > 1.33\ P_r$

Note: $\Theta_i(\sigma_i)$ identifies a risk premium based on the variance of the expected dividends to asset i and $\Theta_i(\sigma_i / P_{i,t})$ identifies a risk premium based the variance of the expected dividends to asset I relative to the price of asset i at the time it was purchased.

Table 5 Median Blue Price Prediction Errors by Treatment and Session and Means and Standard Deviations by Treatment

	Same Variance		Different Variance		
	Session Medians	Means (Std. Dev.)	Session Medians	Means (Std. Dev.)	Row Mean (Std. Dev.)
Same Dividends	1.84 0 - 3.97	- 0.71 (2.97)	- 6.12 - 11.25 -15.13	- 10.83 (4.52)	- 5.77 (6.51)
Different Dividends	- 71.92 -18.97 - 24.63	- 38.51 (29.07)	35.28 38.41 - 18.16	18.51 (31.80)	- 10.00 (41.44)
Column Mean (Std. Dev.)		- 19.61 (27.75)		3.84 (25.90)	- 7.89 (28.37)

Notes: For each session a measure of bias is calculated for each period. This measure is $\beta_t = P_{blue, t} - [E(D_{blue, T-t+1})]/E(D_{red, T-t+1})]P_{red, t}$ and these terms are defined in Section 3.

Table 6 Analysis of Variance of Blue Price Prediction Error

Source	Partial SS	df	MS	F	p-value
Model	5083.667	3	1694.556	3.59	0.066
Different Dividend	53.594	1	53.594	0.11	0.745
Different Variance	1649.238	1	1649.238	3.50	0.098
Interaction	3380.835	1	3380.835	7.17	0.028
Residual	3771.110	8	471.389		
Total	8854.778	11	804.980		

Note: There are 12 observations, the root mean squared error is 21.711, the R-squared is 0.574, and the Adjusted R-squared is 0.414.

Table 7 Regression for Blue Price Prediction Error

Variable	Coefficient	Std. Error	t-statistic	p-value
Constant	- 0.710	12.535	- 0.06	0.956
Different Dividend	- 37.797	17.727	- 2.13	0.066
Different Variance	- 10.123	17.727	- 0.57	0.584
Interaction	67.140	25.070	2.68	0.028

Note: There are twelve observations; F(3, 8) = 3.59 and Prob > F = 0.066; the root mean squared error is 21.711, the R-squared is 0.574, and the Adjusted R-squared is 0.414.

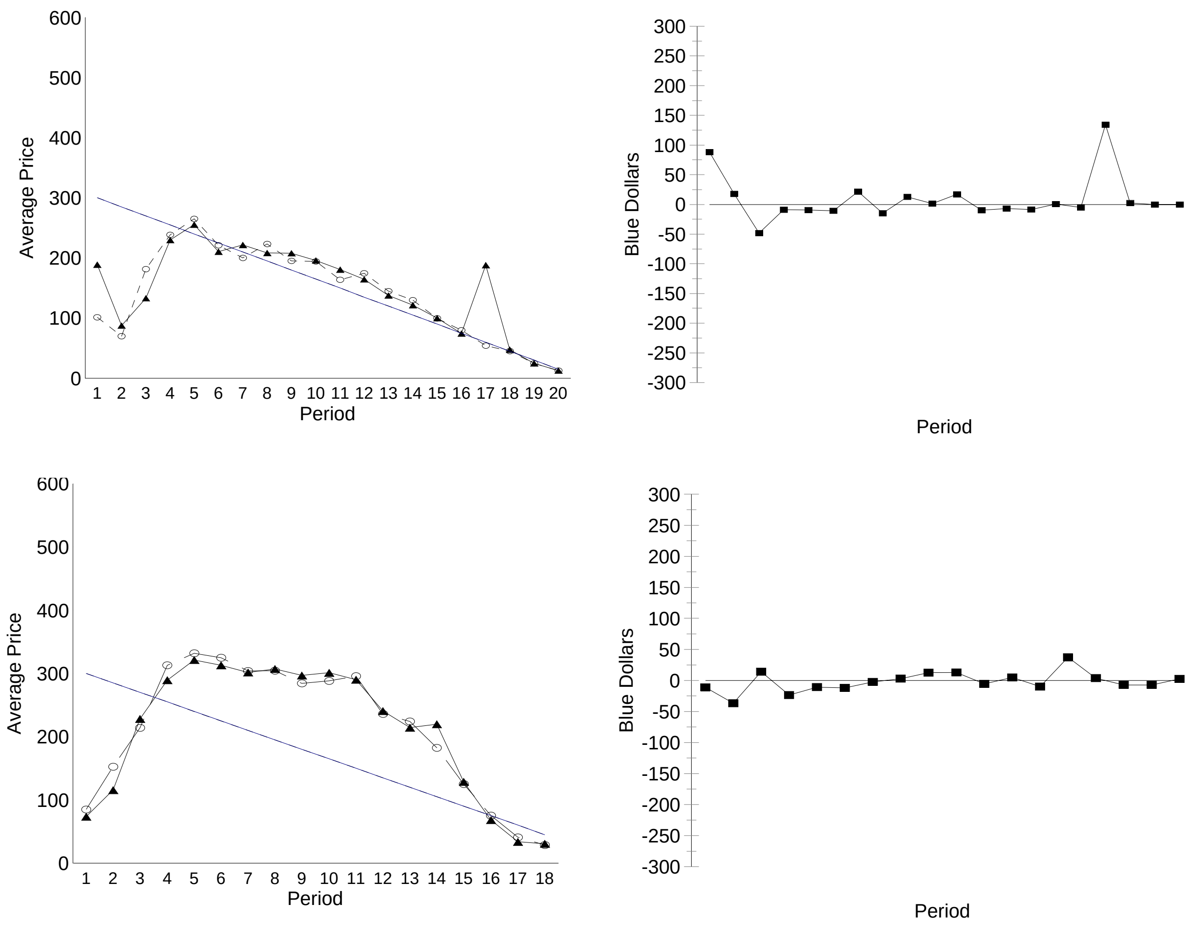

Fig. 1. Treatment 1, Sessions 1.1, 1.2 and 1.3 (Top to Bottom); Triangles are Blue Assets, Circles are Red Assets; Downward sloping lines in panels on the left identify fundamental asset values. Right-hand panels display differences between blue asset prices and the rate of return parity predicted value.

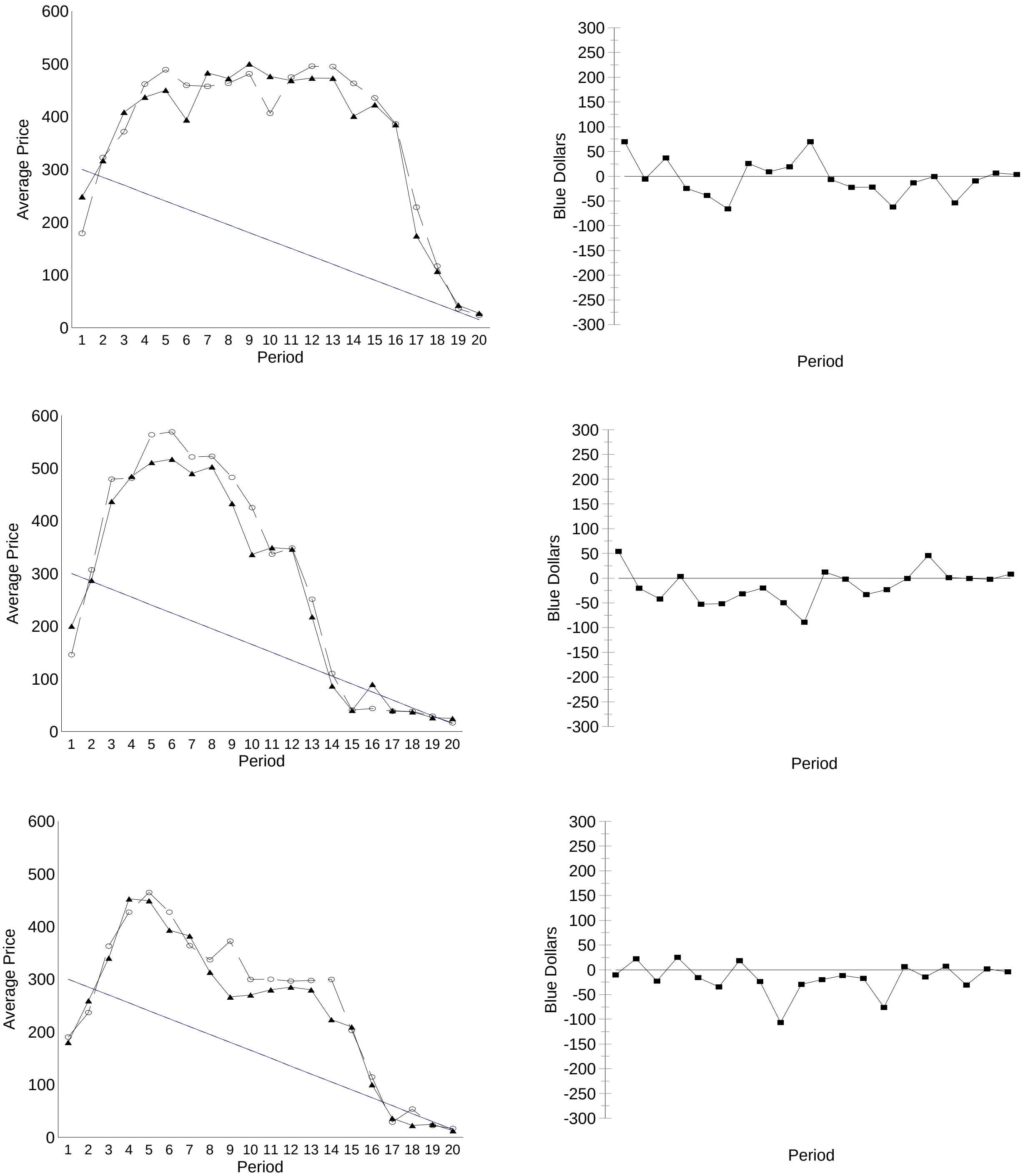

Fig 2. Treatment 2 Sessions 2.1, 2.2 and 2.3 (Top to Bottom); Triangles are Blue Assets, Circles are Red Assets; Downward sloping lines in panels on the left identify fundamental asset values. Right-hand panels display differences between blue asset prices and the rate of return parity predicted value.

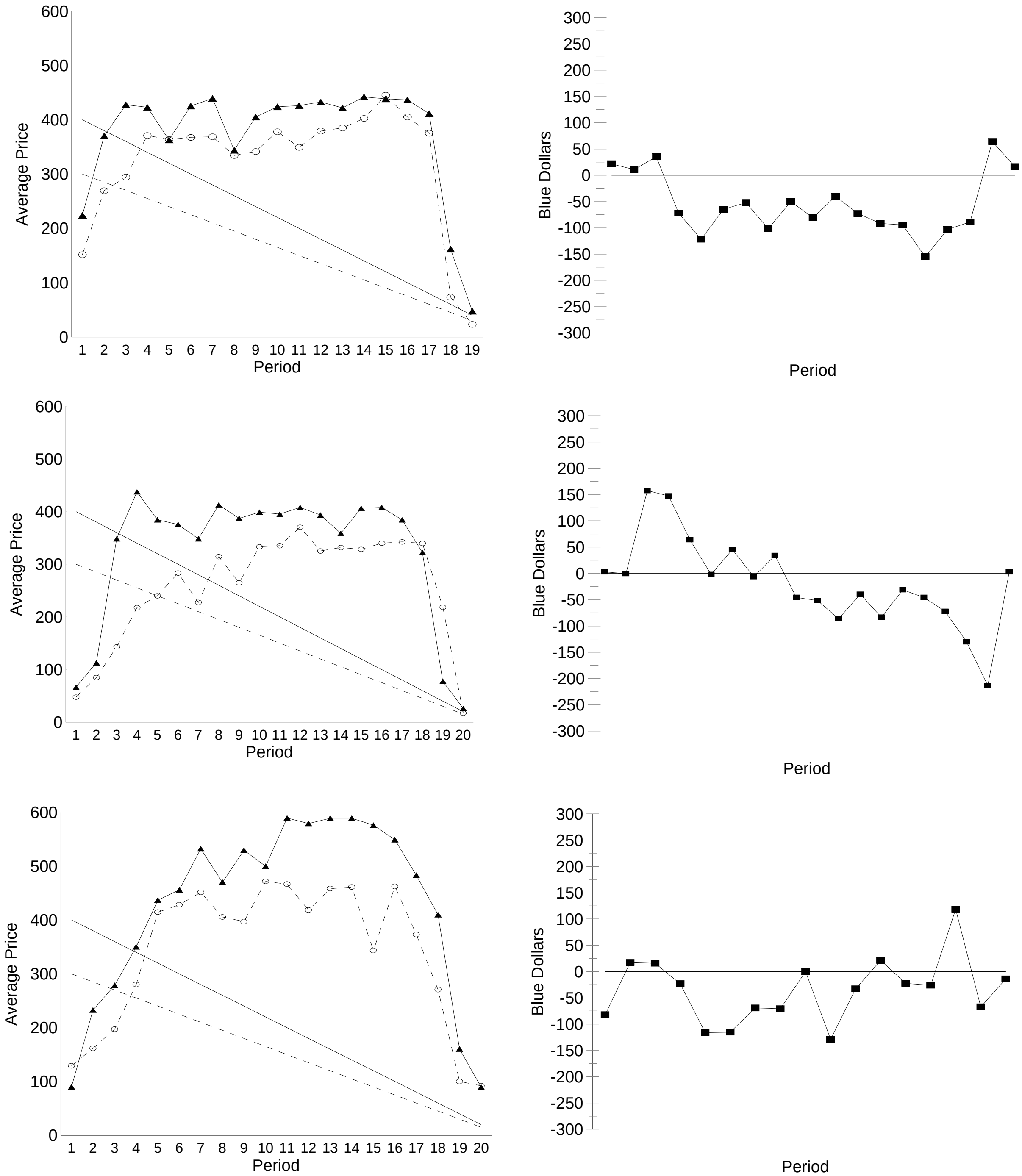

Fig. 3. Treatment 3, Sessions 3.1, 3.2 and 3.3 (Top to Bottom); Triangles are Blue Assets, Circles are Red Assets; Downward sloping lines in panels on the left identify fundamental asset values. Right-hand panels display differences between blue asset prices and the rate of return parity predicted value.

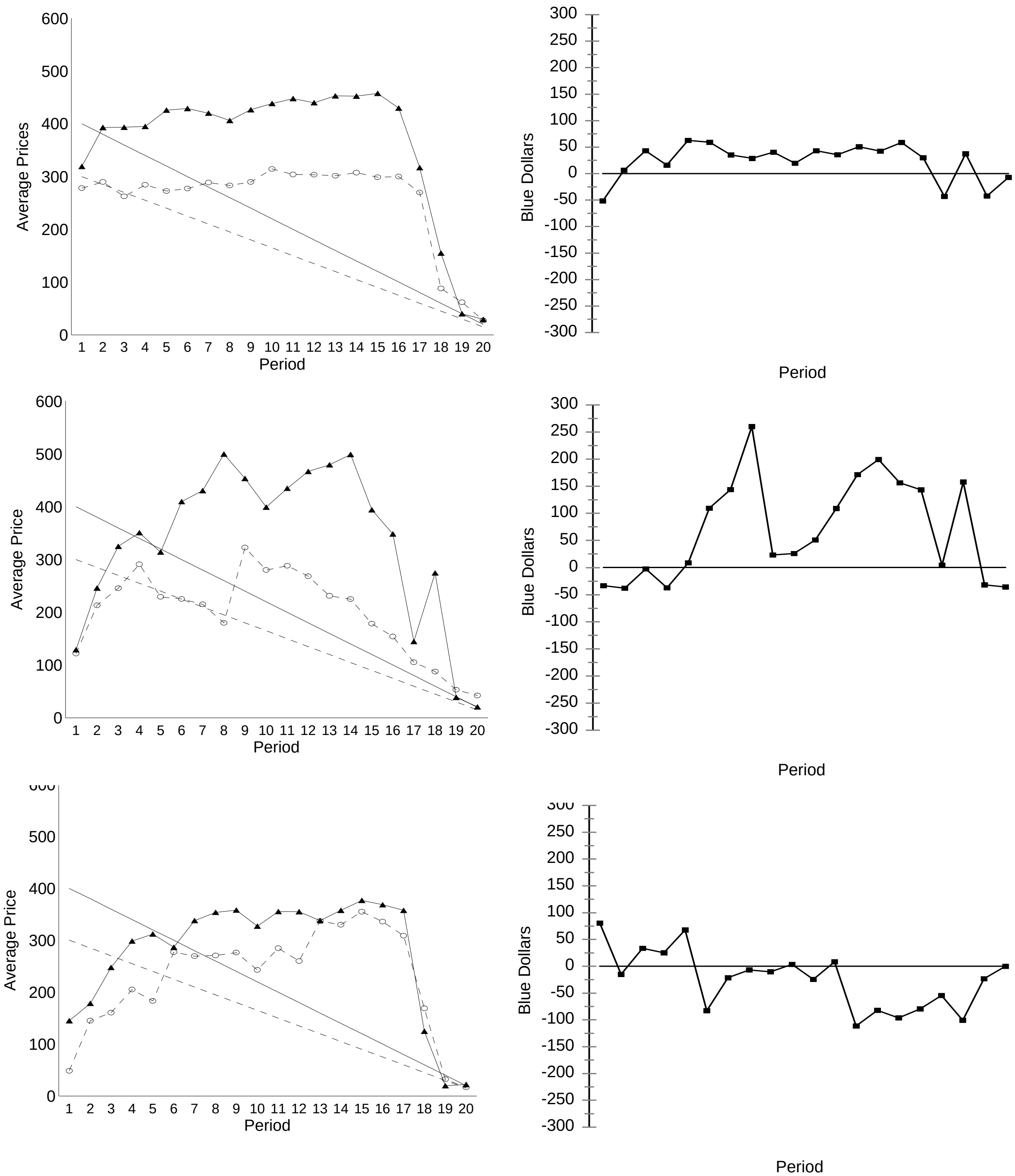

Fig. 4. Treatment 4, Sessions 4.1, 4.2 and 4.3
(Top to Bottom); Triangles are Blue Assets, Circles are Red Assets; Downward sloping lines in panels on the left identify fundamental asset values. Right-hand panels display differences between red asset prices and the rate of return parity predicted value.