One of the important functions of markets in a competitive economy is in generating signals about the relative value of different assets. These signals take the form of prices. Specifically, when market prices of different assets reflect the underlying fundamental values of those assets, markets provide accurate information to investors about the relative worth of the assets in question. This information helps investors allocate their capital efficiently. When prices deviate from fundamentals, this causes inefficient capital allocation, thus the extent to which prices deviate from fundamentals determines in part how efficient an economy’s allocation of resources may be.

It has long been argued that asset prices may become decoupled from fundamental values¹ (see Shiller 2003 for a review). In particular, asset markets may exhibit prices persistently

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¹ Some of the specific anomalies that have been detected that appear to be incompatible with fundamental prices are failure of price to exactly reflect dividend payouts (old refs, Barsky and...
much greater than fundamentals (Shiller, 1981; Froot and Obstfeld, 1991), a pattern which is referred to as a market bubble. Interest in such episodes of mispricing is heightened by spectacular incidents of price booms\(^2\), followed by subsequent rapid declines which have had dramatic effects on earnings of market participants. On the other hand, the suggestion that price bubbles and crashes are pervasive is unappealing to some economists because mispricing is at odds with classical economic and financial theory. Thus, it is hotly debated whether asset prices have a tendency to deviate from fundamentals as a matter of course (LeRoy, 2004), or whether deviations from fundamentals are a rare and relatively inconsequential phenomenon (Fama, 1970; Malkiel, 2003).

One approach to measuring market performance is to look at field data. This typically involves observing prices in the market, postulating a hypothesis about the fundamental value of the asset, and then measuring how well prices track fundamentals under the assumption that the hypothesis governing fundamentals is correct (Fama, 1970). Thus tests of market efficiency are in fact joint tests about market efficiency and the postulated process about fundamentals. Ideally one would separate the two tests, however this is impossible with field data because fundamentals are unobservable. Were fundamentals observable, market mispricing could be measured directly.

For the price of studying a highly artificial setting, laboratory experiments allow the fundamental value to be directly controlled and observed. Hence a substantial body of work, beginning with Smith et al. (1988), has studied experimental markets for long-lived assets. This literature has yielded consistent results about market structure and mispricing for assets whose value falls monotonically over time. This structure is studied for its simplicity and the substantial and sustained mispricing it exhibits when populated with inexperienced traders. A consistent pattern of price booms, episodes of pricing at greater than fundamentals, and crashes, rapid decreases in prices, reminiscent of those believed to occur in field markets, is generally observed. Since these markets are prone to severe mispricing, this allows researchers to subsequently analyze how various environmental factors increase the pricing performance of the market.

Experimental studies of long-lived asset markets have focused almost exclusively on the case of monotonically decreasing fundamental values, with a few exceptions (Camerer and Weigelt, 1993; Noussair et al., 2001; Ball and Holt, 2005) that study assets with constant

\(^2\) Well-known examples include Dutch tulip mania of the 1600s: the prices of tulip bulbs increased by 5000% in three years (1634-1637), and then rapidly lost almost all of their value. Another example is the South Sea Company, whose stock price increased by 600% in one year (1719-1720), and lost more than that entire gain the following year. More recently, the NASDAQ index increased by 85% in 1999, and then over the next three years fell from 5048 to under 1400.
fundamental values. Thus, the current results from long-lived experimental markets arise from studies of markets with a very particular parametric structure. The monotonic fundamental value parameterization, due to its simplicity, provides a structure that is easy to explain to subjects and analyze. Its study provides insights into the performance of markets during times of strictly appreciating or depreciating values. However, restricting attention to the case of monotonic fundamentals precludes the study of several issues of interest. These concern how well markets relay information when the trend in fundamentals changes direction.

A common feature of many economic series is that they experience periods of rising value followed by periods of decline. A common example of this is the business cycle pattern thought to be followed by output. Studies of assets with monotonic fundamentals are able to shed light on the performance of markets during times of expansion or times of contraction, but are unable to comment on market efficiency during the periods of transition from one state to the other. This study reports the results of an experiment that allows us to directly contrast the efficiency of markets for assets that move from a period of increasing values to a period of falling fundamentals versus markets in which fundamentals are first falling and then rising.

A simple asset that allows the study of these relationships is an asset whose value increases over one interval of the asset’s life, and decreases over the rest. The experiment reported here consists of two simple cases of such an asset. In the first treatment, called Peak, the fundamental value of the asset increases for the early part of the asset’s life, reaches a peak at mid-life, and then decreases for the remainder of the life of the asset. In the second treatment, Valley, the fundamental value decreases for the early part of the asset’s life, bottoms out, and then increases for the remainder of the life of the asset.

This design allows us to measure the asymmetry between the two cases by focusing on several sets of issues. The first is the amount of mispricing in the market. Is mispricing worse in one treatment than the other? Or are price levels similarly close to fundamentals in the two treatments? A second measure of market efficiency is the relationship between price trends and trends in fundamentals. An efficient price trend signal reflects changes in the asset’s value (for example, if fundamentals increase, prices increase). Thus a further question we ask is whether a difference exists in the relationship between price trends and trends in fundamentals in the two treatments. The third area of interest for us is how well market prices accurately reflect the timing of peaks and troughs in fundamental values. Together, these three measures serve as an indicator of the relative price efficiency of markets at different points in the business cycle. Our design also allows us to study whether any differences disappear with repeated interaction among traders in subsequent markets.
We find evidence that markets behave asymmetrically with regard to the time path of fundamental values. In particular, markets that experience a downturn are more efficient than markets that experience an equivalent upswing. This suggests that the likelihood that an asset market tracks fundamental values depends on the process that fundamentals follow. In other words, some environments may be more conducive to pricing at fundamentals than others, simply because of behavioral factors. This would provide a rationale for differing conclusions on whether asset markets display price efficiency.

One mechanism whereby differences could arise is through loss aversion (Kahneman and Tversky, 1979), a tendency to resist selling assets at losses. Such a phenomenon has been documented in real estate markets (Genesove and Mayer; 2001; Engelhart, 2003), and an analogous property in financial markets is referred to as the disposition effect (Shefrin and Statman, 1985; Odean, 1998). Such loss aversion would slow the market response to declining fundamentals while exhibiting no effect when fundamentals are increasing. Indeed, Alan Greenspan, former chairman of the U.S. Federal Reserve, recently made the following comments suggesting asymmetries in market price adjustment:

“There’s an implicit judgment that the coefficients [of an econometric model] work symmetrically on the upside and downside. I’m beginning to question whether that premise is true.” 3 - interview on Stockhouse.com, Sept. 17, 2007.

One interpretation of this comment is that asymmetries exist in the reaction of an asset’s market price to changes in the determinants of the asset’s fundamental value. Such an asymmetry is not possible for prices if they are tracking fundamental values, and thus the comments presuppose pricing at variance with fundamentals. Our experimental design allows us to identify such an asymmetry in the particular markets we study.

The paper is organized as follows. Section 2 describes the experimental design and procedures. Section 3 presents our hypotheses, section 4 reports the results and section 5 briefly summarizes the main points of the study and provides some concluding remarks.

II. THE EXPERIMENT

a. General structure and treatments

3 http://www.stockhouse.ca/mediascan/news.asp?newsid=9166050
The experiment consisted of ten experimental sessions conducted in the dedicated experimental economics laboratory at Tilburg University, the Netherlands. The sessions were conducted in English and participants were all students enrolled at Tilburg University. Sessions averaged 3 hours in duration and average earnings were 36 euros. In each session, nine subjects traded in a sequence of four markets, each identical in parametric structure. Each market consisted of 15 periods, during which individuals could trade units of an asset. The asset’s lifetime equaled the 15 periods during which the market was in operation. An experimental currency called “francs”, which was converted to Euros at the end of the experiment, was used for all payments and transactions within the experiment.

The experiment had two treatments, a Peak treatment and a Valley treatment. The Peak treatment was characterized by a time path of fundamentals that was increasing during the first half of each market and decreasing in the later periods. The fundamental value attained a peak value in period 8 of each market in the Peak treatment. The Valley treatment consisted of markets in which the fundamental value was decreasing in the early periods of the market, and increasing in later periods. In two of the Valley sessions (V1 and V2), the trough of fundamentals occurred in period 9, whereas the trough occurred in period 8 for the other three sessions (V3 - V5). Figure 1 illustrates the time path of fundamentals in the two treatments.

**Figure 1:** Time path of fundamental value in Peak (panel a) and Valley (panel b). Timing of dividends, taxes, and final buyout are indicated on the horizontal axis.

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4 To make the treatments as similar as possible, Valley sessions should reach a trough in period 8. V1 and V2 mistakenly troughed in period 9; this was corrected in the other Valley sessions. In the analysis that follows, we use actual fundamentals in a session for various measures. The results we present are not affected by this one period difference.
b. Fundamental values

The fundamental value of the asset arose from three sources: dividends, taxes, and a final buyout. At any point in time the fundamental value was the sum of the expected future payments from all three sources: specifically, the fundamental value of a unit of the asset during any period was equal to the sum of the expected dividends and final buyout it would generate, minus any taxes that remained to be paid on the unit. Thus, the fundamental value of one unit of the asset at any point in time was the expected value of the stream of payments that resulted from holding the unit for the remainder of the current market. The three different sources of value were included in the design merely to induce the appropriate dynamic patterns in fundamental values.5

After every period in both treatments, each unit of the asset paid a dividend to its current owner. Dividends were drawn independently for each period from a four-point distribution with equal mass at 0, 8, 28, and 60 francs. This is the same distribution that was used in the original study of Smith et al. (1988) and a number of later studies that extended this work (Haruvy and Noussair, 2006). The expected dividend in any period was thus equal to 24 francs and the expected future dividend stream equaled 24 multiplied by the number of remaining periods in the current market. A die roll after each period determined the common dividend for all units in the just-ended period. The payment of a dividend at the end of a period reduced the fundamental value following the payment by 24 francs, since the number of future dividend payments had decreased by one.

Certain periods of each market were tax periods. After every tax period, subjects paid a fixed tax of 48 francs for each unit in their possession. Thus, the tax may be thought of as an inventory tax. In the Peak treatment, the first seven periods of each market were tax periods. In the Valley treatment, the last seven periods of each market were tax periods in sessions V1 and V2. The last eight periods were tax periods in sessions V3 - V5. The purpose of the tax periods was to create an increasing fundamental value for the periods the tax was in effect. The number and timing of future tax periods in the current market was always common knowledge. During a tax period, the difference between the expected dividend to be received and the tax to be paid that period was always equal to –24. Thus, after each tax period the fundamental value increased by 24 francs, as the future liability on each unit of the asset had decreased by 24 francs.

The third determinant of the fundamental value was the final buyout, or terminal, value.

5 The same pattern could have been achieved solely through an appropriate dividend structure, however this would have required a non-stationary dividend distribution that included negative “dividends”.

6
Units yielded a final payment at the end of period 15, in addition to any dividends and taxes that were collected and paid, of 216 francs per unit of asset in the Valley treatment. In the Peak treatment, the final buyout value was implicitly zero. The final buyout value increased the fundamental value of the asset for the entire life of the asset. The purpose of the final buyout value was to ensure that the asset always had a positive fundamental value. Dividends and final buyout payments were added to individuals’ cash balances at the time they were paid, and taxes were subtracted from cash balances at the moment they were incurred. This meant that dividend payments added to and taxes subtracted from the cash that could be used for subsequent purchases.

c. Initial endowments

At the beginning of each market, subjects were endowed with units of the experimental currency and units of an asset. In each period of a market, subjects could exchange units of the asset for francs among each other. At the beginning of each 15-period market, the environment was reinitialized, so that a given individual began each market with the same initial endowment of asset and cash, although these initial endowments differed across individuals. Within a market, however, inventories of assets and cash carried over from one period to the next so that for each individual, the quantities of cash and assets held at the beginning of period \( t+1 \) were the same as those held at the end of period \( t \).

Each subject was assigned one of three different trader types (I, II, or III) for the duration of the session. There were three traders of each type in each session. A trader type was defined by the initial endowment of units and cash that a subject of that type began each 15-period market with. The initial asset endowments of type I, II, and III traders were one, two and three units of the asset, respectively. In the Peak treatment, the initial cash endowments of the trader types (I, II, and III) were 1281, 1257, and 1233 francs, respectively, whereas the initial endowments were 1113, 921, and 729 francs for the three types in the Valley treatment. These cash and asset endowments were chosen to equalize expected earnings across all trader types and treatments.\(^6\)

d. Market organization and timing

The markets were computerized and used continuous double auction trading rules (Smith, 1962)\(^6\)

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\(^6\) Expected earnings are equal under the assumption that individuals hold their initial endowment for the entire trading horizon. Clearly realized earnings at the individual level depend on the distribution of asset holdings, the dividend realizations, and the trading strategies employed.
implemented with the z-Tree computer program (Fischbacher, 2007) developed at the University of Zurich. In a continuous double auction, the market is open for a fixed interval of time. At any time, any agent may submit an offer to the market, specifying a quantity of units he is willing to buy or sell and a unit price offered for the transaction. At any moment, any trader who has sufficient cash or units to conclude the transaction may accept any standing offer. All offers were displayed to all agents on their computer screens. Upon acceptance of an offer, a trade was conducted and the asset and cash transferred between the transacting parties. No short sales or borrowing were allowed.

The sequence of events in a session was as follows. The experimenter first distributed and read instructions (Appendix A) that consisted of a step-by-step explanation of how to make and accept offers with the electronic trading interface. This took approximately five minutes. For the next ten minutes subjects practiced trading using the interface. Activity during this phase did not count toward final earnings. After the practice phase was completed, the rest of the instructions (Appendix B), which described all other aspects of the experiment, were handed out and read aloud by the experimenter. Subjects then received their initial endowments of the asset and cash and the first of the four 15-period asset markets began. Each period lasted two minutes, and during these two minutes a market was in operation.

A subject’s earnings over a 15-period market were equal to the amount of cash they held at the end of the final period of that market, after the last dividend, tax and final buyout value were paid. This was equal to their initial endowment of cash, plus any earnings from dividends, minus any taxes paid, plus proceeds from sales of shares, minus expenditures on purchases of shares, plus any final buyout received. A subject’s earnings for the entire experiment were equal to the sum of their earnings from each of the four markets, plus an additional show-up fee of five euros. Francs were converted to euros at a rate of 200 francs to 1 Euro and subjects were paid in cash anonymously at the end of the session.

III. HYPOTHESES

We organize our analysis of the data in the form of tests of a number of hypotheses. They are grouped along the lines of two distinct issues. The first issue has to do with differences between treatments with respect to market efficiency. To compare efficiency, we consider observed price levels relative to fundamental values, price trends within a market and their consistency with trends in fundamentals, and the period during which prices reach a maximum or minimum and how they relate to the timing of the turning point in fundamentals. Next we consider the effect of
repetition in our environment, first considering whether repetition induces stronger market efficiency in both treatments, and second whether it provides any clues regarding specific trading strategies.

a. Price Efficiency

The first set of issues deals with the efficiency of the price signals. Let $p_t^V$ and $p_t^P$ denote the observed period median transaction price in period $t$ of Valley and Peak treatments, respectively, and let $f_t^V$ and $f_t^P$ denote the fundamental values in period $t$ in the Valley and Peak treatments, respectively. The most basic question to pose is whether price levels track fundamental value differently across treatments.

**Hypothesis 1:** Price levels track fundamentals equally well in the two treatments.

While hypothesis 1 is concerned with the level of prices, hypothesis 2 asks a similar question about the relationship between trends in prices and underlying fundamentals. In an efficient market, price trends send accurate signals to investors about the extent to which an asset is increasing or decreasing in value. In the case of monotonically-changing fundamentals, the trend in fundamentals always has the same sign, thus rendering the study of price trends relative to trends in fundamentals a moot point. The case where fundamentals rise and fall presents a challenging scenario for the efficiency of market prices. The issue we are concerned with here is whether prices are equally likely to move in the same direction as fundamentals in the two treatments, and thus whether an observer of price trends can discern the direction of current fundamental value trends.

**Hypothesis 2:** Price trends are equally good at tracking trends in fundamentals in the two treatments.

Another piece of potentially useful information in the markets we study is the point in time at which prices reach their most extreme value (maximum in Peak, minimum in Valley). We refer to this time period as the *turning point of prices*\textsuperscript{7} and compare it to the turning point in fundamentals. In an efficient market, there is no difference between the two, so that a price peak,

\textsuperscript{7} We require the turning point to be a period other than period 1 or period 15.
for example, signals that the asset’s value has also reached a maximum. Inefficiency then exists to the extent that the two turning points differ. Hypothesis 3 makes the conservative claim that inefficiency, as measured by the difference between turning points in prices and fundamentals, is similar in the two treatments.

**Hypothesis 3:** The difference between turning points of prices and turning points of fundamentals is the same in the two treatments.

b. Repetition

The markets we examine, while simple from a theoretical standpoint, can be somewhat confusing for the subject pool we consider. To allow for noise in the data, we perform robustness checks with respect to the market efficiency hypotheses to verify whether the same differences among treatments exist both initially (in the first market) and once subjects are more familiar with their trading environment (in the fourth market).

Additionally, we wish to analyze differences between sequential markets to observe how prices in one market depend on prices observed in the previous market. One possibility is that the pattern of prices reflects expectations of (a) a repetition of the price time series that occurred in the prior market, and (b) the use of profitable strategies given those expectations. This would cause a tendency for previous prices levels or deviations to be reproduced in the current market, but at an earlier market period. For example, suppose that the price peaked in period 8 of market 1. Then, in period 7 of market 2, prices may be bid up to the level of period 8 in market 1, in anticipation of a similar path of prices. Whether or not this is an entirely rational strategy to follow depends (in part) on whether the trader takes into account the fact that fundamentals differ from period 7 to period 8. For this reason, a best-response strategy suggests that the time series of price deviations be repeated, whereas a myopic best-response implies that prices are repeated in the following market. Haruvy et al. (2007) have documented a similar pattern in markets with monotonically decreasing fundamentals, in which such a pattern of “best responding” to an anticipated repetition of the price patterns of the preceding market is consistent with convergence to fundamentals. In the setting we study here, such a pattern is not necessarily associated with convergence. We consider whether a difference between treatments exists to the extent that the patterns hold for both prices and price deviations in testing hypotheses 4 and 5.

**Hypothesis 4:** The extent to which prices reflect a myopic best-response to
expectations that previous market prices will be repeated is the same in both treatments.

**Hypothesis 5:** The extent to which prices reflect a best-response to expectations that previous market prices will be repeated is the same in both treatments.

IV. RESULTS

The panels in Figure 2 show the time series of median transaction prices by period in the Peak and Valley sessions, respectively. In markets 1 and 2 of the Peak treatment (panel a), prices usually exhibit booms in the early periods of the market. The markets then operate at close to fundamentals in the latter part of the market. In later markets, the boom occurs earlier and earlier. By market 4, prices track fundamentals fairly closely in all Peak sessions.

In contrast, Valleys (panel b) begin the first market, in which traders are inexperienced, with prices substantially below fundamental value. The prices then typically exhibit booms, increasing to levels above fundamentals by the middle of the market and remaining fairly constant until the end of the market. In subsequent markets, prices exceed fundamentals at the beginning of the market but continue to exhibit their greatest deviations from fundamentals around the middle of the life of the asset. Later in the markets, prices tend to crash down to fundamentals, which they then track for the remainder of the market. In market 4, prices continue to deviate from fundamentals over much of the life of the asset. In those markets that exhibit a price trough and rebound, the time of the turnaround in prices is generally later than the turnaround point of fundamentals.

Overall the figures indicate that (1) prices are usually higher than fundamental values, (2) prices deviate less from fundamentals as traders become more experienced, (3) prices track fundamentals more closely in later than in earlier periods within a market, (4) deviations from fundamentals are larger in the Valley than in the Peak treatment and (5) repetition of a market appears to decreases deviations more in Peak than in Valley.

**Figure 2:** Median prices relative to fundamentals in the four markets of Peak sessions (panel a) and Valley sessions (panel b).
Observations (1), (2) and (5) are confirmed and summarized as Result 1:

**Result 1:** Hypothesis 1 is rejected. Price levels in Peak sessions are more closely
related to fundamentals than they are in Valley sessions.

Support for Result 1: To support this result, we turn to three related pieces of evidence. First we show that prices are on average farther away from fundamentals in Valley.

Consider the random-effects regression of median price in period $t$ of market number $m$ in session $s$ (denoted by $p_{s,m,t}$) on market number, a dummy variable $vall_s$ that takes a value of unity if session $s$ is a Valley treatment, and an interaction term. This implicitly gives equal weighting to all periods and assumes that median prices in a period are independent of one another.

Table 1: Estimation of the Equation

\[ p_{s,m,t} = \beta_1 + \beta_2 \cdot m + \beta_3 \cdot vall_s + \beta_4 \cdot m \cdot vall_s + \epsilon_{s,m,t} \]

<table>
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<th>constant</th>
<th>m</th>
<th>vall</th>
<th>m * vall</th>
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</thead>
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<td>3.18</td>
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</tr>
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<td></td>
<td>(17.74)</td>
<td>(4.66)</td>
<td>(25.01)</td>
<td>(6.53)</td>
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<td>R2</td>
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<tr>
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<td>571</td>
<td>571</td>
<td>571</td>
</tr>
</tbody>
</table>

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Standard deviations in parentheses. Unit of observation is the trading period.

The table illustrates several points. First, prices in all markets of both treatments are significantly higher than underlying fundamentals. Predicted prices in the first market are roughly 180 in Peak and 200 in Valley, in contrast to the average fundamental value of 100. The difference between treatments increases by around 20 francs with each subsequent market. This suggests that with repetition Valleys converge (if at all) towards fundamentals in an average sense at a much slower rate than Peak markets.

Next we turn to market-level measures of mispricing. Table 2 displays the values of several bubble measures that previous author have proposed (King et al., 1993; Haruvy and Noussair, 2006). For all measures, larger values indicate more mispricing in a market. First, there is a strong tendency for market mispricing to decrease with repetition. This is consistent with other findings of convergence for repetition in stationary environments (Haruvy and Noussair, 2007).

The Amplitude measure differs from previous literature in two respects: 1) median, rather than mean, prices are used, simply because medians are used in all the other measures; 2) absolute, rather than deviations proportional to fundamental value, are used – this is done because deviations tend to occur earlier in markets, causing proportional deviations to be artificially higher in Peaks than in Valleys (only because Peaks have relatively low fundamentals in early periods).
The table also shows that mispricing in Valleys is consistently higher than in Peaks. The difference is somewhat smaller in the initial market, but grows larger with repetition. An asymmetry clearly exists by market four, where most measures of mispricing in Valley are double what they are in Peak.

**Table 2** – Bubble Measures per treatment, averaged over sessions, with Peak – Market 1 normalized to unity.

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Normalized Deviation</th>
<th>Turnover</th>
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<tr>
<td>0.0</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>1.2</td>
<td>1.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**NOTES:**

Amplitude = \( \max_t \left( P_t - f_t \right) - \min_t \left( P_t - f_t \right) \), where \( P_t \) and \( f_t \) equal the median transaction price and fundamental value in period \( t \), respectively. Normalized Deviation = \( \sum_i \sum_j |P_i - f_j| / (100 \cdot TSU) \), where \( P_i \) is the price of the \( i^{th} \) transaction in period \( t \). TSU is the total stock of units that agents hold. Turnover = \( \sum_t q_t / TSU \), where \( q_t \) is the quantity of units of the asset exchanged in period \( t \). The boom duration is the greatest number of consecutive periods median transaction prices are above fundamental values, respectively. Total Dispersion = \( \sum_t |P_t - f_t| \). Average Bias = \( \sum_t (P_t - f_t) / 15 \).

In summary, the various bubble measures indicate that Valleys experience larger bubbles than Peaks, and that the Peak treatment has a much stronger tendency to converge toward fundamentals. Result 2 shows that in the initial market with inexperienced subjects, the fundamental value has little influence on prices, in that prices levels follow a similar time
path in the two treatments despite the very different paths followed by fundamentals.

**Result 2:** Hypothesis 2 is rejected. In the initial market, price changes are correlated with changes in fundamentals, but price increases in *Peaks* signal increases in fundamentals, whereas price changes in *Valleys* are negatively correlated with fundamentals. The difference between treatments persists after repetition, although by the last market both correlations are positive.

**Support for Result 2:** The results of a random-effects regression of changes in fundamentals on changes in prices, controlling for treatment effects, is presented here. The idea is whether an observer can identify the current trend from observation of the current change in the direction of fundamentals. Specifically, the model is:

\[
\Delta f_{m,t} = \beta_1 + \beta_2 \cdot \Delta p_{m,t} + \beta_3 \cdot vall + \beta_4 \cdot vall \cdot \Delta p_{m,t} \\
+ \beta_5 \cdot incr_t \cdot vall + \beta_6 \cdot incr_t \cdot vall \cdot \Delta p_{m,t} + \epsilon_{m,t}
\]

where \(\Delta f_{m,t}\) and \(\Delta p_{m,t}\) represent changes in fundamental value and price, respectively, *vall* is a dummy treatment variable, and *incr_t* is a dummy variable that takes a value of unity when fundamentals are increasing. The results of estimating the model for the initial market (Model 1) and the final market (Model 2) are given in Table 3.

**Table 3:** Regression of change in fundamentals on change in prices, initial market (Model 1) and final market (Model 2).

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
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<tr>
<td></td>
<td>(dep. var = df)</td>
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<tr>
<td>constant</td>
<td>1.49 (3.09)</td>
<td>11.01*** (3.91)</td>
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<tr>
<td>dpm</td>
<td>0.10*** (0.04)</td>
<td>1.02*** (0.18)</td>
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<tr>
<td>vall</td>
<td>-1.20 (4.19)</td>
<td>-12.20** (4.90)</td>
</tr>
<tr>
<td>dpm_vall</td>
<td>-0.30*** (0.09)</td>
<td>-0.79*** (0.20)</td>
</tr>
<tr>
<td>incr_dpm</td>
<td>-0.02 (0.05)</td>
<td>-0.70** (0.29)</td>
</tr>
<tr>
<td>incr_dpm_vall</td>
<td>0.11 (0.16)</td>
<td>0.61* (0.33)</td>
</tr>
<tr>
<td>market</td>
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<td>4</td>
</tr>
</tbody>
</table>
For *Peak* sessions, the results suggest that fundamentals increase when prices are moving upwards: every 10 unit increase in prices is associated with a one unit increase in fundamentals. For *Valleys*, the effect is even stronger, but acting in the opposite direction: for every five units that prices increase, fundamentals *fall* by one unit. These estimates confirm the visual impression from *Figures* 2 and 3 that prices tend to rise and fall within a market of the *Valley* treatment, even as the fundamental value follows the opposite pattern.

Running a similar regression for market 4 (Model 2) suggests that the correlation between price changes and changes in fundamentals becomes more positive in both treatments with repetition, however the treatment difference remains.

We now turn to the relationship between the timing of the turning point of fundamentals and the turning point in prices. Our observations are summarized below as Result 3.

**Result 3:** *Hypothesis 3* is weakly rejected. In the first market, turning points in prices occur slightly before the turning point in fundamentals in *Peak* and *Valley* sessions. With repetition however, the turning point of prices occurs later and later in *Valley* sessions and does not change in *Peak* sessions.

**Support for Result 3:** The variable *TPD* is the *turning point difference* i.e. the difference between the turning point in prices and the turning point in fundamentals. For the *Peak* treatment, the turning point in a market is defined as the interior period with the highest median price. For the *Valley* treatment, turning point is the interior period with the lowest price. For periods in which no trades occurred, the midpoint between the highest bid and lowest ask in the period is used.

*Figure 3* shows *TPD* by market in each session. The turning points of prices are on average earlier than those for fundamentals in the Peak treatment in markets 1 – 3, but the difference is close to zero by market 4. Average turning points of prices in *Valley* are unbiased in market 1, but after the first market are consistently later than those of fundamentals, as well as those in the *Peak* treatment.
Result 4: Hypotheses 4 and 5 are rejected. The extent to which prices can be interpreted as best responses to expectations that previous market prices will be repeated is different in both treatments, both when disregarding (Hypothesis 4) and taking into account (Hypothesis 5) fundamentals.

Support for Result 4: First, we test whether changes in prices from one market to the next are explained by the difference between the previous market’s prices in period $t + 1$ relative to period $t$:

\[
p_{m,t} - p_{m-1,t} = \beta_1 + \beta_2 \cdot \text{vall} + \beta_3 \cdot \left(p_{m-1,t+1} - p_{m-1,t}\right) + \beta_4 \cdot \text{vall} \cdot \left(p_{m-1,t+1} - p_{m-1,t}\right) + \epsilon_{m,t}.
\]

When $0 < \beta_3 < 1$, this model allows for prices in the current market to be “best-responses” to expectations that the time series of transaction prices from previous markets will be repeated.

To see how this is possible, suppose a trader believes that prices in the current market will be the same as those in the previous market. Then when prices in the previous market were increasing from one period to the next ($p_{m-1,t+1} > p_{m-1,t}$), the trader’s myopic...
best-response in period $t$ of the current market is to purchase at (slightly less than) the high period $t+1$ prices of the previous market, in anticipation of selling at the high period $t+1$ prices in the next period. If all traders follow this strategy, all will purchase a period earlier at (slightly less than) the prices in the previous market, and none will purchase in the next period at the high price. In this sense, prices may be dampened and shifted backwards in time. $\beta_3$ measures the extent of this best-response to previous prices: it measures how much the period $t+1$ price in the previous market affects the period $t$ price in the current market. If all traders behave in this manner in both treatments, $\beta_3$ should equal unity and $\beta_4$ should equal nil.

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<td>(9.70)</td>
<td>(0.09)</td>
<td>(0.17)</td>
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</table>

Table 4 – Regression of change in price across markets on previous market period price differences, allowing for differences between treatments (Model 1).

Model 2 is for price deviations, rather than prices.

The results of the regression presented in Table 4 suggest that behavior is consistent with a certain amount of best-responding to beliefs that previous price patterns will be repeated. In Peak sessions, 60% of previous price increases are shifted backwards in time, but in Valley sessions previous price increases are (slightly more than) fully transmitted backwards in time.

The previous best-response strategy was myopic in the sense that traders only considered previous prices when trading in the current period. A slightly more sophisticated best-response to beliefs that previous prices will be repeated is to take into account that fundamentals are also changing from period to period. Specifically, traders may have expectations that price deviations from the previous market will reoccur. If traders behave in this manner, it is price deviations, not absolute price levels, that are shifted backwards in time. The model:
allows for such an effect. $\beta_3$ measures the extent to which deviations in a previous Peak market predict deviations in the current market, while $\beta_4$ allows for differences between treatments. Complete adherence to this strategy in both treatments would imply $\beta_3 = 1$ and $\beta_4 = 0$.

Fitting the model suggests that 62% of deviation differences from the previous market are passed through to the current price in Peaks, whereas their effect is amplified (113%) in Valley sessions. (see Model 2, Table 4). Overall, the picture that emerges from fitting these models to the data is that the two treatments differ in the extent to which behavior is consistent with best-responding to beliefs that the previous market’s prices will be repeated. Both treatments are consistent with a leftward shift in prices, however only Peak prices (and deviations) become smaller over time. Prices and deviations in Valley sessions tend to increase with repetition, not at all consistent with the best-responding story outlined above.

V. CONCLUSION

We construct experimental markets to obtain the first empirical observations about the behavior of controlled, laboratory asset markets when they experience a peak or a trough in fundamentals. In our markets, the timing of the upcoming turning point in fundamentals is common knowledge, and we focus on how well the market tracks the fundamental value when it currently is undergoing an upward trend, a downward trend, or a turning point. The answers are not obvious ex-ante in light of the strong tendency of experimental asset markets to generate bubbles and crashes, a result that nonetheless has only been established for market environments with fundamental values that are monotonically decreasing or constant over time.

We observe that price booms and crashes are typical in markets populated with inexperienced subjects. Indeed, prices are similar between the two treatments despite the very different underlying processes of fundamentals. As individuals gain experience, prices move closer to fundamental values in the Peak treatment, in a manner similar to that observed in previous studies. However, in the time frame we are able to observe, four repetitions of a 15-
period market, the Valley treatment fails to move appreciably toward fundamentals. Prices have a tendency to average above fundamentals in both treatments, and this result may have to do with the fact that short sales were not permitted in our markets (see Haruvy and Noussair, 2006).

Prices changes from one period to the next are typically in the same direction as the change in fundamentals in the Peak treatment, but not in the Valley treatment. The price turnaround accurately reflects the timing of the turnaround in fundamental values in Peaks, but is systematically too late in Valleys.

Thus the evidence we find suggests strong asymmetries between the price efficiency of a market when the underlying fundamentals rise to a peak and then decline, and that of a market that declines to a trough and subsequently rises. In the Peak setting, while the market experiences bubbles and crashes when traders are inexperienced, the markets operate at close to fundamentals after participants have required experience in the environment. Overall, the Peak treatment behaves much like the declining fundamental value environment that has served as the focus of prior research. On the other hand, a trough in fundamentals appears to represent a challenging environment for the market to achieve price efficiency. Prices consistently fail to reflect the level, trend direction, and timing of the turnaround of fundamentals in the Valley treatment. To our knowledge, this is the first experimental environment in which markets populated by individuals with this much experience in their stationary environment do not track fundamental values closely.

There is considerable debate in the economics profession about the extent to which markets produce prices that reflect underlying fundamental values. The evidence we obtain here, from ten experimental sessions, suggests that the answer is that “it depends”. The likelihood that a market exhibits price efficiency depends on the properties of the process underlying fundamental values and the dynamics it exhibits over time. We identify a strong asymmetry between how asset markets respond to downturns and upswings in fundamentals. However, there may also be other characteristics of the time path of fundamentals that enhance or impede the ability of a market to track fundamentals. Our research indicates that characteristics of the fundamental value, in addition to the well-known influences of the institutional structure and the level of sophistication of traders, are determinants of market efficiency.
References


APPENDIX A – General Experiment Instructions

1. General Instructions

This is an experiment on decision making in a market. The instructions are simple and if you follow them carefully and make good decisions, you might earn a considerable amount of money, which will be paid to you in cash at the end of the experiment. The experiment consists of a sequence of trading Periods in which you will have the opportunity to buy and sell in a market. The currency used in the market is francs. All trading will be done in terms of francs. The cash payment to you at the end of the experiment will be in euros. The conversion rate is: 200 francs to 1 euro.

2. How to use the computerized market

In the top right hand corner of the screen you see how much time is left in the current Period. The goods that can be bought and sold in the market are called Shares. In the center of your screen you see the current Period and the amount of Money you have available to buy Shares. To the left of the screen, you see the number of Shares you currently have.

If you would like to offer to sell a share, use the text area entitled “Enter offer to sell:" in the second column. In that text area you can enter the price at which you are offering to sell a share, and then select “Submit Offer To Sell”.

Please do so now. Type in a number in the appropriate space, and then click on the field labeled “Submit Offer To Sell”. You will notice that nine numbers, one submitted by each participant, now appear in the third column from the left, entitled “Offers To Sell”. The lowest ask price will always be on the bottom of that list and will, by default, be selected. You can select a different offer by clicking on it. If you select “Buy”, the button at the bottom of this column, you will buy one share for the currently selected sell price.

Please purchase a share now by selecting “Buy”. Since each of you had offered to sell a share and attempted to buy a share, if all were successful, you all have the same number of shares you started out with. This is because you bought one share and sold one share.

When you buy a share, your Money decreases by the price of the purchase. When you sell a share your Money increases by the price of the sale. You may make an offer to buy a unit by selecting “Submit offer to buy.” Please do so now. Type a number in the text area “Enter offer to buy.” Then press the red button labeled “Submit Offer To Buy”. You can sell to the person who submitted the highest offer to buy if you click on “Sell”. Please do so now.

In the middle column, labeled “Transaction Prices”, you can see the prices at which Shares have been bought and sold in this period.

You will now have 10 minutes to buy and sell shares. 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. You are free to ask questions during the practice period by raising your hand.
3. Specific Instructions for this Experiment [VALLEY treatment]

The experiment will consist of 15 trading periods. In each period, you are permitted to buy and sell shares. Shares are assets with a life of 15 periods. Your inventory of shares carries over from one period to the next. For example, if you have 5 shares at the end of period 1, you will have 5 shares at the beginning of period 2.

Dividends:

You may receive dividends for each share in your inventory at the end of each of the 15 trading periods. At the end of each trading period, including period 15, the experimenter will roll a six-sided die. The outcome of the roll will determine the dividend for the period. Each period, each share you hold at the end of the period earns you a dividend of:

- 0 francs if the die reads 1
- 8 francs if the die reads 2
- 28 francs if the die reads 3
- 60 francs if the die reads 4

If the roll is a “5” or “6”, the die is rolled again. Each of the numbers on the die is equally likely. This means that the average dividend is 24. We arrive at 24 by averaging the four equally likely dividends: 0, 8, 28, and 60. That is, we calculate $(0 + 8 + 28 + 60)/4 = 24$.

The dividends you earn from shares you own are automatically added to your money balance after each period.

After dividends and taxes have been paid out at the end of period 15, the experimenter will purchase back all the shares in the market for 216 francs each from their current owners. This buyout value will be added to any dividends received in period 15.

Holding Taxes:

At the end of the last eight periods, you must pay a holding tax of 48 francs for each share in your inventory. That is, a tax is paid at the end of period 8, period 10, … and period 15. No tax is paid at the end of each of the first seven periods (period 1, period 2, … and period 7).

The taxes you owe on shares are automatically subtracted from your money balance at the end of each of the last seven periods.

4. Average Holding Value Table

You can use the AVERAGE HOLDING VALUE TABLE (attached at the end of this document) to help you make decisions. It calculates the average amount of dividends and holding taxes you will receive and pay if you keep a share until the end of the experiment. It also describes how to calculate how much in future dividends and holding taxes you give up on average when you sell a share at any time.
1. **Current Period**: the period during which the average holding value is being calculated. For example, in period 1, the numbers in the row corresponding to “Current Period 1” are in effect.

2. **Number of Remaining Dividends**: the number of times that a dividend can be received from the current period until the final period. That is, it indicates the number of die rolls remaining in the lifetime of the asset. It is calculated by taking the total number of periods, 15, subtracting the current period number, and adding 1, because the dividend is also paid in the current period.

3. **Average Dividend**: the average amount of each dividend. As we indicated earlier, the average dividend in each period is 24 francs per share, except for the last period, which has an average dividend of $24 + 216 = 240$ francs.

4. **Average Remaining Dividends**: the average value of all the dividends you will receive for each share you hold from now until the end of the experiment. It is calculated by multiplying **Number of Remaining Dividends** by **Average Dividend**.

5. **Number of Remaining Tax Payments**: the number of times that a tax must be paid on a share from the current period until the end of the experiment. It is calculated by taking the total number of tax periods, 8, and subtracting the number of tax periods that have already passed.

6. **Tax Amount**: the amount that the tax payment per share will be. As indicated earlier, there is no tax in the first 7 periods, while the tax amount is 48 francs per share in the last 8 periods.

7. **Remaining Taxes**: the total value of the taxes remaining on a share from now until the end of the experiment. That is, for each unit you hold in your inventory for the remainder of the experiment, you will pay the amount listed in column 7 in holding taxes. It is calculated by multiplying **Number of Remaining Tax Payments** by **Tax Amount**.

8. **Average Holding Value**: the average value of holding a share for the remainder of the experiment. That is, for each unit you hold in your inventory for the remainder of the experiment, the difference between the dividends you earn and the taxes you pay will on average be the amount listed here. It is calculated by subtracting **Remaining Taxes** from **Average Remaining Dividends**.

Please have a look at this table now and make sure you understand it. Feel free to raise your hand if you have a question. When you feel comfortable with it, please go on and answer the following practice quiz:

**PRACTICE QUIZ**

1. Suppose it is period 10. How much will you pay in taxes on a share if you hold it for the remainder of the experiment?
   
   ANSWER: ________________

2. Suppose it is period 10. How much do you expect to receive in dividends on a share if you hold it for the remainder of the experiment?
   
   ANSWER: ________________
3. Suppose it is period 10. What is the average value of holding a share for the remainder of the experiment?

ANSWER: ________________

5. Your Earnings

Your earnings for the experiment will equal the total amount of money that you have at the end. More specifically, your earnings will be:

the money you begin with
+ any dividends you receive
- any taxes you pay
+ any money you receive from sales of shares
- any money you spend on purchases of shares.

6. Beginning the experiment

From now on your decisions will count toward your earnings, so please think carefully before making them.
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