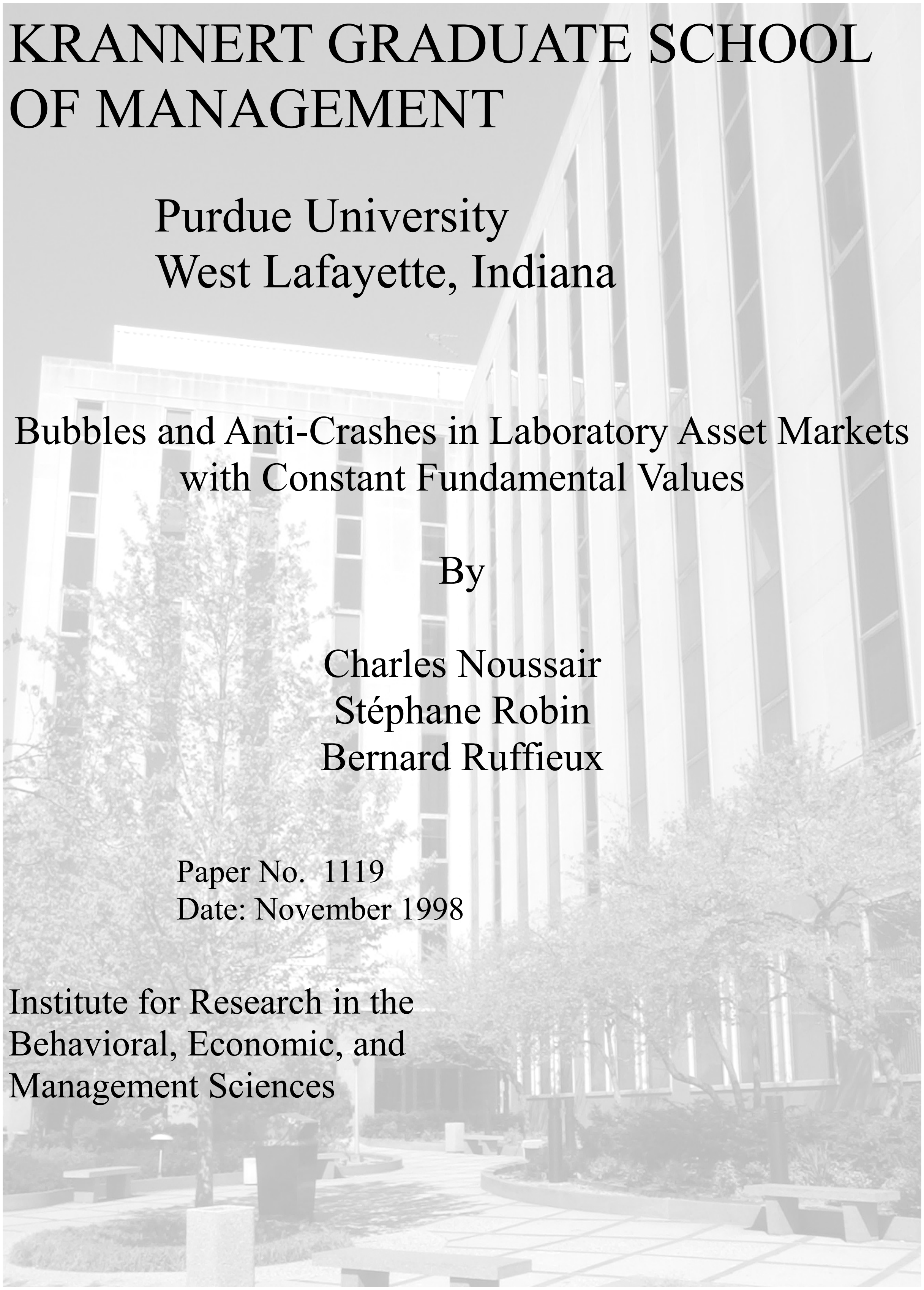

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## Bubbles and Anti-Crashes in Laboratory Asset Markets with Constant Fundamental Values

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# Bubbles and Anti-Crashes in Laboratory Asset Markets with Constant Fundamental Values

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## Abstract

We construct asset markets, that are similar to those studied by Smith, Suchanek and Williams (1988), in which bubbles and crashes tended to occur. The main difference between the markets studied here and those studied by Smith et al. are that in the markets studied here, the fundamental value is constant over time. In our data we observe bubbles, which are sometimes at prices lower and sometimes at prices higher than fundamental values. Anti-crashes, which are rapid, sudden, large increases in prices toward fundamental values are observed.

## 1. Introduction

Smith et al. (1988) created laboratory asset markets in which they observed that market prices consistently differed from the fundamental value of the asset, and labeled the price patterns as "bubbles"

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and "crashes". In subsequent work, laboratory asset market bubbles have been given the definition "trade in high volumes at prices that are considerably at variance from intrinsic values" (King et al. 1993). A market crash can be defined as a rapid drop in transaction prices. The markets studied by Smith et al. (1988) traded assets with a lifetime of a known finite number of periods, in which the asset paid a dividend in each period, and the dividend was typically the only source of intrinsic value.[1] The dividend paid was identical for each trader and the dividend process was common information to all traders. When subjects participated in this type of market for the first time, the prices tended to climb to levels higher than the fundamental value, and then to crash toward the fundamental value near the end of the time horizon. A typical time series of prices in a market with this structure can be found in figure 1. In the figure, the bold step-function indicates the fundamental value over time. The other time series graphs the price of each transaction.[2] The figure shows that prices increase to a level greater than the fundamental value, and then a crash occurs. After the crash, prices closely track the fundamental value.

[Figure 1: About Here]

The sharp differences between the observed prices and the fundamental values have motivated several extensions of the original Smith et al. (1988) experiment. The extensions examine the robustness of the bubble and crash phenomenon. King et al. (1993) study the effect of allowing short selling, allowing margin buying, having an equal initial endowment of the asset for each agent, imposing a fee on transactions, limiting the extent of price changes and using businesspeople as subjects. They observe

[1] In some of the experiments of Smith et al. (1988), there was a final buyout value paid for each unit at the end of the session in addition to the dividends. This increases the fundamental value of the asset at any time during the experiment by an amount equal to the buyout value.

[2] In the figure, the vertical axis represents price and the horizontal axis represents time. The connected time series indicates the time and price at which transactions occurred. The squares are offers to buy and the diamonds are offers to sell. The dotted vertical lines indicate the opening and closing of trading periods. The bold time series indicates the fundamental value. The data in figure 1 comes from a session conducted at the Ecole Nationale Supérieure de Génie Industriel in Grenoble, France in the spring of 1997. In the experiment, there were 15 periods. In each period, each unit of the asset paid a dividend of either 0, 8, 28, or 60 units of experimental currency, and all dividend levels were equally likely, so that the expected dividend was 24 in each period.

bubbles in all of their treatments. Fisher and Kelly (1998) construct two asset markets operating simultaneously and observe bubbles and crashes in both markets. Porter and Smith (1995) study the effect of futures markets and of removing the uncertainty in the dividend process, and find that the futures market reduces the bubble to some extent, but that the removal of uncertainty does not dampen the bubble. Van Boening et al. (1993) study asset markets in which trade occurs using call markets (two-sided sealed-bid auctions), rather than the continuous double auction used in the other papers, and also observe price bubbles and crashes. The only manipulation that has been shown to eliminate bubbles and crashes is prior experience with a bubble and a crash. When the subjects have participated in an asset market of this type twice previously, bubbles and crashes are less likely to occur than when the subjects are inexperienced (Smith et al. 1988).

In this paper we describe the results of a new robustness test, which extends the original experiment in a different direction than the papers listed in the last paragraph. In all of the studies mentioned above, the fundamental value of the asset includes (or in most cases consists entirely of) a stream of positive dividends paid to the owner of the asset over a finite time horizon. This payment of positive dividends at regular time intervals captures a structure found in many assets traded in the field, such as dividend-paying stocks. However, the existence of a dividend in each period coupled with the finite lifetime of the asset has the consequence that the fundamental value is declining in each market period (where a market period typically lasts 3-5 minutes), as illustrated in figure 1. For the prices to track the fundamental value, prices must readjust to the new fundamental value in each period. In this paper we consider whether these frequent changes in the fundamental value are necessary to produce the bubble and crash pattern.

We study the price patterns of a market for an asset similar to those of Smith et al., except in which the fundamental value is constant over the entire time horizon of the experiment. We consider whether prices differ systematically from the fundamental value, and if they do differ, whether they exhibit the bubble and crash pattern. We chose our design with the purpose of providing favorable conditions for the prices to track fundamental values, because if prices are tracking the fundamental value, there is no need for them to readjust in each period. We construct markets in which in any period the owner of the asset either receives a per-unit dividend or incurs a per-unit holding cost. The magnitudes and probabilities of the possible dividends and holding costs are specified so that the expected net dividend in each period is always equal to zero. A fixed positive per-unit terminal value is paid to the holder of each unit of the asset, at the end of the experiment. Thus the fundamental value of the asset is positive and constant over time. If the final buyout value were not included, the fundamental value would equal zero at all times, and since trading prices of less than or equal to zero are not possible, the proposition that prices equal the fundamental value would not be testable.

The only differences between the procedures used in the experiments reported in this paper and those used in the session shown in figure 1 are in the expected value of the dividend and the existence of the final buyout value. Therefore we are using procedures known to produce market bubbles when the fundamental value is declining over time. The next section describes the procedures of the experiment. Section three lists three hypotheses about price patterns in the data. Section four presents our results and section five discusses our findings.

## 2. The Experiment

The data for this study were gathered in seven sessions. Four of the sessions were conducted in English at Purdue University in West Lafayette, Indiana, the United States, and three of the sessions were conducted in French at the Ecole Nationale Supérieure de Génie Industriel (ENSGI) at the Institut National Polytechnique de Grenoble, France. Each of the seven sessions consisted of 16 trading periods and each period lasted between 3 and 5 minutes. The initial period of each session, which we refer to as period 0, was for practice only and earnings in period 0 did not count toward final earnings. Earnings in periods 1-15 did count toward final earnings. In each period, subjects were allowed to buy and/or sell units of an asset called X. Prices were quoted in terms of an experimental currency, which was convertible to French francs or to American dollars at the end of the experiment. Since X was an asset, inventories of X could be carried over from one trading period to the next. The cash balance available to traders to make purchases was also carried over from period to period. The cash balance was expressed in terms of the experimental currency. Trade followed continuous double auction rules which were implemented with the MUDA software package (see Plott and Gray, 1990, for a description).

The subjects at Purdue University had not participated in experiments previously. The subjects at the ENSGI were experienced in several sessions with MUDA, though none had previous experience with experimental asset markets. Before the sessions at Purdue began, subjects went through a training session in which they reviewed an interactive tutorial which acquainted them with the MUDA program. The interactive tutorial took about 30 minutes. Subjects then bought and sold in a practice market for 30 minutes in which each subject interacted with computer generated robots, who would buy and sell units in a random fashion. During the practice market they did not interact with other subjects. The Purdue subjects were closely supervised and required to each make several purchases and sales during the training session to demonstrate that they knew how to do so. Since the Grenoble subjects had previously participated in several experiments, the training sessions were omitted for them.

At the beginning of period 0, each subject was endowed with 10 units of X. Also, at the beginning of the sessions, subjects in the sessions at Grenoble received 100,000 units of experimental currency, and those in the sessions at Purdue received 5,000 units. At the beginning of period 1, cash balances and inventories of X were reinitialized at the same level as at the beginning of period 0. In both locations, the cash endowment was in the form of a loan, which had to be paid back at the end of the experiment. After the end of trading in each period, each unit of the asset paid a dividend of either 36 or 4, or incurred a holding cost of either -24 or -16. Dividends and holding costs were denominated in terms of the experimental currency. All four outcomes occurred with equal probability and depended on the outcome of a roll of a four-sided die, making the expected value of the dividend/holding cost equal to zero in each period. The die was rolled in the presence of subjects after each period. The dividends and holding costs were added and subtracted from the subjects' calculated earnings, but did not increase or reduce the amount of cash available for subsequent purchases.

Each unit of X paid a terminal value of 360 units of experimental currency to it's owner at the end of the session. Thus the fundamental value for each unit of X was 360 at any time during the session. The dividend process, the number of periods, and the existence and the amount of the final buyout value were common knowledge to all subjects. Great care was taken to ensure that the dividend process and the final buyout value were well understood. The instructions and forms used in the experiment are included in the appendix. Each subject had a copy of the table entitled "Average Holding Value for Units of X Table" with which they could calculate the expected dividend stream of X at any time.

Table 1 contains the abbreviations for the name of each session which will be used later in the paper, as well as the date and location of the sessions and the number of participants. Since each trader began his session with an inventory of 10 units of X, the expected payoff per agent for the experiment was 3600 units of experimental currency. The experimental currency was converted to US dollars at a rate to 200 units to 1 dollar and to French francs at a rate of 50 units to 1 franc, yielding expected profits from the market of $18 or FF72 over the session. Subjects received an additional participation fee of $5 or FF20. Sessions averaged approximately two hours in duration.

[Table 1: About Here]

# 3. Hypotheses

Smith et al. (1988) and Smith (1994) have attributed the phenomenon of bubbles in their experimental asset markets to the fact that subjects' expectations cannot be controlled by the experimenter. Though the experimenter controls the dividend structure, the initial inventories, and the time horizon of the experiment, subjects' expectations about future price movements are influenced by previous experience outside the laboratory as well as the activity they observe within the laboratory market. Uncertainty about the future behavior of other traders may cause subjects to believe that future prices will deviate from fundamental values and such uncertainty can make prices differ from fundamental values. For example, a speculative bubble and crash can be created in the following manner. Suppose the fundamental value is currently 360 and an offer to sell for 400 is currently on the market. Furthermore, suppose that one of the traders, say trader A, believes that there may exist another trader who is willing to pay a price higher than 400 in the future, possibly because the other trader is a risk seeker or does not fully understand the dividend process. Trader A might accept the offer at 400 in order to realize a capital gain by reselling later on at a higher price. The unit may then be resold to another trader, B, who in turn believes that he may be able to resell at a still higher price, and whose belief is reinforced by the fact that a trade has already occurred at 400. Near the end of the time horizon, the probability of realizing a capital gain decreases due to the diminishing time horizon, and the price crashes to the fundamental value as demand for the purpose of resale vanishes.

We formulate three hypotheses about the time path of market prices that our data allow us to evaluate. Each of the hypotheses is based on a different type of self-fulfilling expectation about future prices and predicts a different type of price pattern. The predictions of the hypotheses differ as long as there is sufficient time left in the session for expectations of future prices to affect current decisions. All three hypotheses predict that prices will be close to fundamental values at the end of the session, when there are no future expectations to affect current decisions. Examples of time paths of prices consistent with each of the three hypotheses are given in figure 2b. The first hypothesis is drawn from accepted theory of asset pricing and is stated as hypothesis 1. We refer to hypothesis 1 as the *fundamental value hypothesis*:

[Figures 2a and 2b: About Here]

**Hypothesis 1 (The fundamental value hypothesis): The price of the asset equals the fundamental value throughout the experiment. That is** $p_t = \sum_{s=t}^{T} E(D_s), \forall t = 1,...,T.$

where $p_t$ is the market price in period $t$, $T$ is the total number of periods in the session, and $E(D_s)$ is the expected dividend in period $s$. We assume that $E(D_T)$, the expected dividend in the last period, includes any terminal buyout value. If hypothesis 1 is satisfied, trade occurs at prices equal to the value of the stream of future dividends plus the eventual terminal buyout value. Traders act as if they and other traders have reservation values equal to the fundamental value of the asset at all times and will trade based on that reservation value. In our experiment, hypothesis 1 would predict prices of close to 360 for the entire session. Whereas hypothesis 1 suggests that traders take into account the entire future stream of income from the asset, hypothesis 2 suggests that they take a short-term view. Under hypothesis 2, they act as if they only take into account a time horizon of $k$ periods, where $k$ is shorter than the full length of the experiment.

**Hypothesis 2 (The myopia hypothesis): The price of the asset equals the expected total dividend payment on the asset in the current period and next $k$ periods of the session, where $k$ is less than the total number of periods in the session minus 1. That is** $p_t = \sum_{s=t}^{t+k} E(D_s), \forall t$, **and for some k** $\in$ **{0,...,T-2}.**

In a market, whose behavior is consistent with hypothesis 2, trade occurs at prices close to the expected sum of the dividend payouts of the current period and the next $k$ periods. Traders act and expect others to act as if the only take into account the expected dividend of the current period and the next $k$ periods. For our markets, this would imply a price close to 0 (trading at prices at or below 0 is prohibited by the trading technology) in every period until period 15 – $k$-1, and then a price equal to the terminal buyout value of 360 in the remaining $k+1$ periods. If all traders are risk neutral and expect such prices, they will be indifferent between purchasing in any period between the first and the 15 – $k$ –1st periods. If loss avoidance or risk aversion exists among the traders, that would lead them to strictly prefer to wait until the 15 – $k$ – 1st period to make their purchases, and to make sales early in the time horizon. A consequence of the myopia hypothesis is that prices should experience a very large and rapid increase between period 15 – $k$ – 1 and period 15 – $k$. In the special case of $k = 0$, prices remain close to 0 until period 14 and then rapidly rise to 360 in period 15. The next hypothesis also asserts that prices will differ from the fundamental value, but will follow a different pattern than under hypothesis 2.

**Hypothesis 3 (The bull market hypothesis): Prices will exhibit an upward trend (relative to the fundamental value) in the early part of the experiment. Near the end of the experiment, prices will equal the fundamental value. That is:**

$$[p_t - \sum_{s=t}^{T} E(D_s)] > [p_{t-1} - \sum_{s=t-1}^{T} E(D_s)], \forall t \le t^*; and \;\; p_t = \sum_{s=t}^{T} E(D_s), \forall t > t^{**} for \;\; some \;\; t^{**} \ge t^*$$

Hypothesis 3 states that prices in the market will increase monotonically relative to the fundamental in every period until some period $t^*$, but track the fundamental value from some period $t^{**}$ until the end of the session. This particular pattern is consistent with the presence of speculation. Suppose prices increase, relative to the fundamental value, from one period to the next early in a session, say between the first and the second period. The fact that prices have already increased can create expectations of further prices increases, causing excess demand at current prices, and prices may continue to increase. Thus an early increase in prices causes speculation in anticipation of future price increases to occur. Hypothesis 3 is the only one of the three hypotheses which allows (but does not require) prices to exceed fundamental values. Speculators may make purchases at prices higher than fundamental values as long as they believe that they can resell units at even higher prices to other speculators or to traders who do not understand the dividend process. Under hypothesis three prices revert to the fundamental value at the end of the experiment because there is no possibility for future resale. Therefore if prices have increased beyond the fundamental value they will decrease before the end of the experiment.

Four remarks are in order here. The first remark is that not all price patterns consistent with Hypothesis 3 are necessarily speculative bubbles in the sense that they are caused by the intent of traders to realize capital gains. Our design does not allow us to determine whether subjects make purchases with the *intent* of resale. The second remark is that speculation can be present, but not necessarily generate the pattern described in hypothesis 3. Rejection of hypothesis 3 would not constitute a claim on our part that buying with the intent of realizing a capital gain is not occurring. The third remark is that a bull market in the sense of hypothesis three is not the same as a bubble in the sense of King et al. (1993). For our data, a bull market, in the sense of hypothesis 3, if it is accompanied by substantial trading volume, implies a bubble in the sense of King et al. (1993). A price pattern consistent with hypothesis 2, if accompanied by enough volume, is also a bubble in the sense of King et al. The fourth remark is that each of the three hypotheses will be held to a low standard when compared to the data, so that we claim that the data "support" the hypothesis, even when the data merely exhibit a general pattern resembling the predictions of the hypothesis. To hold the hypotheses to a higher standard would mean certain rejection in markets such as ours, in which the variance of transaction prices tends to be high.

Our prior belief was that the constant fundamental case would induce favorable conditions for hypothesis 1 to be supported, and thus for prices to track fundamental values. The reason for this, as mentioned earlier, is that there is no need for the prices to adjust to a new fundamental value in each period. The fundamental value in our design is very easy to calculate. In our design, a convergence process leading prices to the fundamental value need occur only once in the session, whereas in the declining fundamental case, a new price must be discovered each period in order for prices to track the fundamental.

Each of the three hypotheses can also be applied to the declining fundamental case and examples of price paths consistent with each of the three hypotheses are shown in figure 2a. Hypothesis 1 predicts that prices track the fundamental value throughout the life of the asset. Hypothesis 2 predicts that prices remain constant and lower than the fundamental value throughout the early part of the session, and track the fundamental late in the session. Hypothesis 3 predicts that prices increase over the course of the session, relative to the fundamental, and then fall abruptly near the end of the session. Hypothesis 3 is roughly consistent with previous data generated by inexperienced subjects, and hypothesis 1 is roughly consistent with data generated by twice experienced subjects.

## 4. Results

The time series of the median transaction prices in each period of each of the seven sessions are given in figures 3-5. In each of the figures, the horizontal line indicates the fundamental value, which was constant over time and equal to 360. Each of the other lines represents the median contract price in each period for one of the sessions. The data are displayed in three figures to emphasize the differences between the sessions, which are discussed later in this section. The figures also suggest the level of support for hypotheses 1-3. In none of the sessions does the time series exhibit the precise price dynamics predicted by any of the three hypotheses.

[Figures 3-5: About Here]

However, if we consider the general patterns predicted by hypotheses 1-3 and compare them to the figures, similarities are evident. Figure 3 shows that the prices in session 1G track the fundamental value fairly closely in accordance with hypothesis 1. In the other two sessions shown in figure 3, 1P and 4P, prices remain much closer to 0 than to the fundamental value for most of the session, rise rapidly late in the experiment, and are close to the fundamental value at the end of the sessions. The patterns of 1P and 4P are roughly consistent with hypothesis 2. Figure 4 shows the data from two sessions in which prices rise to levels above the fundamental value, and then fall to a level near the fundamental at the end of the time horizon. Figure 5 contains the data from the remaining two sessions, in which prices exhibit an upward trend throughout the session, but do not exceed the fundamental value for more than one period. The data in figures 4 and 5 are fairly consistent with hypothesis 3. Our findings concerning price movements are described more precisely in results 1-3 below.

**Result 1: a) Prices closely track the fundamental value in only one of the seven sessions. Therefore only one session is consistent with the fundamental value hypothesis (hypothesis 1).**

**b) The other six of the seven sessions are characterized by trade at high volumes at prices far away from fundamental values. Thus a "bubble", in the sense of King et al. (1993), occurs in six of the seven sessions.**

**c) Of the six markets in which prices differ from fundamentals, two are consistent with the myopia hypothesis (hypothesis 2).**

**d) Of the six markets in which prices differ from fundamentals, four are consistent with the bull market hypothesis (hypothesis 3).**

**Support for result 1:** a) The data are shown in figures 3-5. Only in session 1G, shown in figure 2, do prices track 360 closely throughout the session.

b) In each of the other six sessions, the median price differs from the fundamental value by at least 50 units of experimental currency for at least 5 consecutive periods. Thus prices differ substantially from the fundamental value for extended periods of time. The other component of a bubble is the large volume of trade. Total turnover in the sessions ranged between 2.8 and 10.4 times the total stock of units. The volumes are comparable to those of Smith et al. (1988), who report volumes of between 3.17 and 10.5 times the total stock of units for sessions with inexperienced subjects, and who considered such volumes as high enough to be considered a bubble. Overall, in the 60 minutes of trading time in each session, the number of units exchanged averaged at least 3.7 units a minute in every session. Based on the observed prices and quantities traded we are prepared to claim that a bubble occurred in six of the seven sessions.

c) Figure 3 shows the data from 1P and 4P, two sessions in which prices are at levels far below the fundamental value early in the session and then rise to levels near the fundamental value at the end of the session. In session 1P, median transaction prices are below the highest possible single-period dividend of 32 for the first six periods and slowly climb to 80 in period 11 and 108 in period 12. Then there is a very large increase in price between periods 12 and 13 from 108 to 300. The data from the session are roughly consistent with hypothesis 2 and k = 2 (traders take into account payments for the current period and two periods into the future, so they begin to take the final buyout value into account in period 13). In session 4P, prices remain below 29 in 12 of the first 13 periods, with only a single period spike in period 4. In period 14 prices rise to 50 and then surge rapidly to 310 in period 15. Thus the data are roughly consistent with hypothesis 2 and k = 0.

d) The four sessions shown in figures 4 and 5 are all consistent with hypothesis 3. In session 3G and 3P, which are shown in figure 4, prices climb in the early part of the session to values well above fundamental values, peaking in periods 6 and 8 in 3G and 3P respectively. In both sessions the price drops late in the experiment to a level very close to 360. In both sessions, the existence of prices higher than the fundamental value suggests that there is speculative demand for the asset. Sessions 2G and 2P are shown in figure 5. In these two sessions, there is a strong trend for prices to be rising. In session 2G prices remain below the fundamental value until period 6, climbing steadily over the course of periods 1-5. From period 6 on, they track the fundamental value fairly closely. In session 2P, prices change unevenly from period to period throughout the session, but the trend is consistently upward.

Result 1 indicates that the data are highly diverse in the early part of the sessions and prices tend to differ dramatically from the fundamental value. However, at the end of the sessions, as is described in result 2, the data are rather similar across sessions, and prices tend to be close to the fundamental value.

**Result 2: At the end of the sessions, prices are close to the fundamental value**.

**Support for Result 2:** As can be seen in figures 3-5, in period 15, median prices in five of the seven sessions are very close to the fundamental value of 360. In each of the three sessions conducted in Grenoble, prices are very close to the fundamental value of 360. The prices are equal to 360, 361 and 370 in the three sessions. In two of the sessions conducted at Purdue, 1P and 3P, the median prices in period 15 are 360 and 363, at or very close to the fundamental value. The two sessions in which period 15 median prices are far from the fundamental value are sessions 2P and 4P, in which median prices are 310 and 500 in period 15. These two sessions are also characterized by a high variance of prices in period 15 and, in our view, the period 15 median price tends to overstate the deviation from the fundamental at the end of these sessions. The last trade in the two sessions occurred at prices of 330 and 320, relatively close to 360.

Figures 1, 3, 4, and 5 also show that prices may not converge to the fundamental value in a smooth manner, such as might be described by an exponential model. Rather the adjustment to the fundamental value often tends to occur through a large sudden price change. This is consistent with previous results for the declining fundamental case, in which previous researchers have observed crashes, rapid downward price changes which abruptly end bubbles. Here we also observe rapid upward adjustments in prices toward the fundamental value. Whereas a large, rapid decrease in prices is referred to as a crash, we will refer to a large, rapid increase in prices as an *anti-crash*. Crashes and anti-crashes are concepts whose precise operational definition is by necessity somewhat arbitrary. For purposes of this paper, we will say that a crash occurs in period *t*, if the median price in period *t* is at least 180 lower than in any of the preceding periods of the session. Similarly an anti-crash occurs in period *t*, if the median price in period *t* is at least 180 higher than in any of the preceding periods of the session. The number 180 is chosen because it equals 50% of the value of the asset. This definition is very conservative, and allows us to focus on the properties of those price changes, which are obvious regime changes. The extent of crashes and anti-crashes in the data are described in the support of result 3.

**Result 3: Anti-crashes, which are large, abrupt, upward adjustments in prices toward the fundamental value, are observed in two of the sessions.**

**Support for Result 3:** An anti-crash is observed in two of the sessions shown in figure 3. In session 1P, the median price increases from 108 in period 12 to 300 in period 13, and the median price is lower than 108 in each of the first eleven periods. The session 4P exhibits an anti-crash in period 15, in which the median price increases from 50 in period 14 to 310 in period 15. In periods 1-13 of 4P, the median price never exceeds 99. In periods 4-8 of session 3P and in period 15 of session 2P, there are rapid price increases but they do not satisfy the definition of an anti-crash given above. In session 3G prices fall rapidly in the final two periods, in a pattern reminiscent of the bubble and crash pattern in the declining fundamental case shown in figure 1. However, the fall in price is not enough to constitute a crash by the definition given above.

Anti-crashes appear to be similar phenomena, though moving opposite in direction, to the crashes that have been observed in the declining fundamental value case. A detailed example of an anti-crash is given in figure 6, which shows the complete time series of transaction prices in the session 1P. A bubble occurs in periods 1-12, and an anti-crash toward the fundamental value occurs in period 13. From the figure it is clear that there is a regime change between periods 1-12 and 14-15. Both of the sessions in which an anti-crash occurred, were sessions in which the myopia hypothesis was supported, and this support suggests an interpretation of anti-crashes. The anti-crashes occur during the period in which it first becomes common knowledge that traders are taking into account the final buyout value in making their purchase and sale decisions.

[Figure 6: About Here]

To establish whether the anti-crashes we observe here are a symmetric phenomenon to crashes we consider other patterns that have been observed to accompany crashes in other studies and consider whether analogous patterns accompany anti-crashes. One such pattern is a decline in the quantity exchanged. Smith et al. (1988) observed that volume tended to be lower during a crash than during the boom phase (during which prices are typically higher than fundamental values) in their experiments. We ask whether the same occurs in our anti-crashes. Another pattern observed by Smith et al. was that, just before a crash, the number of bids (offers to buy) relative to the number of asks (offers to sell) decreased. For our data we ask whether the opposite occurs, whether the number of bids exceeds the number of asks in the periods immediately preceding and during an anti-crash. Our findings are given in result 4.

**Result 4: Anti-crashes have the following four properties:**

**(a) Anti-crashes occur on a volume of exchange lower than during the preceding periods.**

**(b) In the market period immediately preceding an anti-crash there are more bids than asks submitted to the market.**

**(c) In the period during which an anti-crash occurs there are more bids than asks submitted to the market.**

**(d) The variances of bid prices and ask prices increase in the period before an anti-crash occurs.**

**Support for Result 4:** (a) The first two lines of table 2 below show the volume during the periods of the two anti-crashes we observed as well as the average volume in the *t*-1 periods of the session before the anti-crash. Also included in the table are the data for the three other instances of price increases of greater than 120, or 1/3 of the asset's value. These three price increases are included because we recognize that our definition of an anti-crash is somewhat arbitrary. Their inclusion allows us to evaluate whether the relationships we find in our two anti-crashes also occur with other large price increases, or whether our findings rely on our particular definition of an anti-crash. In the table, *t* refers to the period of the anti-crash. For example *1P, t = 13* refers to the anti-crash occurring in period 13 of session 1P. *Volume in t* refers to the total quantity of units of X exchanged on the market in period t. *Volume in < t* refers to the average volume exchanged in the *t-1* periods of the session preceding period *t*. The volume of exchange in the period of each anti-crash is less than 25% of the average of the volumes in the previous periods of the session. The same is true for the three other price increases, except for period 15 of session 2P, in which there is only a very small difference.

[Table 2: About Here]

(b,c) The third and fourth lines of the table illustrate the difference between the numbers of offers to buy and offers to sell in the period of the anti-crash and the period immediately preceding the anti-crash. $B_t$ and $O_t$ represent the number of offers to buy and offers to sell in period *t*, respectively. In four of the five cases the differences in both periods are positive. Again the exception is in session 2P.

(d) The result is shown in the last four lines of the table. In both sessions 1P and 4P, the variance of both bids and asks are at least 80% greater in the market period immediately preceding the anti-crash then the average of all previous periods in the session. Not including offers to sell in 4P, the variances increase by over 1,000%. There are substantial increases in the variance of bids and asks preceding the two large price increases in session 3P, but not in session 2P.

Anti-crashes behave in an analogous manner to crashes. Both occur on low volume. Anti-crashes are preceded by a decline in the number of offers to sell relative to the number of offers to buy, the opposite pattern from the crashes of the declining fundamental case. We also observe that the variance of both bid prices and ask prices increases before the price increase. The results indicate that there are warning signs that an anti-crash is about to take place in these markets. An increasing variance of bid and ask prices suggests a large change in price is imminent, and the number of bids relative to asks indicates the direction of the price movement. The failure of period 15 in session 2P to exhibit any of these characteristics is noteworthy. Inspection of figure 5 suggests that the price increase in period 15 of 2P was part of a general pattern of increasing prices over the course of the session. Thus it did not represent a regime change from the previous activity on the market and reflects a phenomenon different from the anti-crash phenomenon.

In addition to relating the number of bids and asks to crashes, Smith et al. (1988) also studied the general relationship between the number of bids and asks and price movements. They established that when a bubble occurred in their markets, the price movements were related to the difference between the number of bids and the number of asks in the markets. An excess of offers to buy over offers to sell was correlated with future price increases, and an excess of offers to sell over offers to buy was correlated with future price decreases. One of the models estimated by Smith et al. is the equation:

$$P_t - P_{t-1} = a + b(B_{t-1} - O_{t-1});$$

where $P_t$ and $P_{t-1}$ are the median transaction prices in periods $t$ and $t-1$, respectively; $B_{t-1}$ is the total number of offers to buy and $O_{t-1}$ is the total number of offers to sell in period $t-1$. The coefficient $a$ indicates the overall trend in prices. The coefficient $b$ indicates the effect of the difference between the number of bids and the number of asks in a period on price movements. The variable $B_{t-1}$- $O_{t-1}$ is a measure of excess demand in period *t-1*. Smith et al. (1988) tested the hypothesis that $b > 0$, which means that the median price in period $t$ increases more (decreases less) from the median price in period $t-1$, the greater the excess demand in period $t-1$. In the declining fundamental case, they found that (1) $a$, which was an estimate of the average decline in price per period, was generally not significantly different from the change in fundamental value from one period to the next, and (2) $b$ tended to be significantly greater than 0 when a bubble was observed.

Here we estimate the same model for our data. In our data, if prices were to track the fundamental value and price movements were not related to the number of offers to buy and sell, $a$ would equal 0 and $b$ would equal 0. If the same effect discovered by Smith et al. is present in our markets, we would observe $a = 0$ and $b > 0$.The results of the estimation are given in table 3. The model is estimated for each session separately and the results are summarized in result 5. In the table the standard errors of the estimates in the table are given in parentheses and coefficients significant at the 10 and 5 percent levels are superscripted with one and two asterisks respectively.

[Table 3: About Here]

**Result 5: Changes in prices from one period to the next are related to the relative number of bids and asks in the market. Once the variation that is related to the relative numbers of bids and asks is taken into account, there is no trend in price movement.**

**Support for Result 5**: In none of the sessions is $a$ significantly different from 0 at the 5% level, indicating that once the effect on price movements of the difference between bids and asks is taken into account, the trend in prices is flat. The coefficient $b$ is significantly positive at the 10 percent level in four of the seven sessions, and at the five percent level in two of the sessions. $b$ is positive in sign for all sessions except for 2P. A bubble occurs in each of the four sessions in which $b$ is significant. Thus we observe the same effect as in previous studies, that price movements in the current period are related to the number of bids and offers in the previous period.

## 5. Conclusion

In this paper we constructed markets similar to those studied by Smith et al. (1988) and subsequent papers in which bubbles and crashes have been extensively observed. In our data, we also observe bubbles, defined as trade at high volumes at prices that differ from the fundamental value, in six of the seven sessions. In only one session do prices track the fundamental value closely for the entire session. Our data show that a frequently changing fundamental value is not necessary to produce a bubble. It appears to us that it is natural consequence of human behavior in asset markets with a long time horizon and a common dividend, rather than an anomaly specific to the declining fundamental design, for prices to tend to become de-coupled from intrinsic values.[3]

Our data generalize many of the findings of Smith et al. (1988) and the subsequent papers mentioned in section 1. The resemblance between our data and those from the declining fundamental value case is much stronger than merely the superficial property that prices differ from fundamental values in both cases. We also reproduce subtle relationships observed in the declining fundamental case. The direction of the price change in the next period is related to the number of bids and the number of asks in the current period. The greater the number of bids relative to asks, the more positive the price change. Rapid changes in price that end bubbles occur. These rapid changes are accompanied by lower volume than in the bubble phase. Prices usually closely track fundamental values at the end of the time horizon. Thus all of these phenomena are general beyond the particular design studied by Smith et al.

Unlike Smith et al., we observe that the market "crashes" can also occur in an upward direction, and for lack of a better term we called these price movements *anti-crashes*. Anti-crashes exhibit many of the same properties as crashes. Both phenomena appear to be part of the adjustment process whereby prices converge to the fundamental value. Unlike repeated single-period double auction markets in which price adjustments occur early on in the trading process, in the asset markets we observe here, the convergence process can take a long time before it begins, but can then occur very swiftly. The existence of anti-crashes suggests that the crashes in the declining fundamental cases should be interpreted as an endgame phenomenon, a convergence process brought on by the impending end of the lifetime of the asset. Like the crashes of the declining fundamental case, anti-crashes tend to be preceded by several observable phenomena, and thus anti-crashes are, in principle, predictable to the observer. An anti-crash is preceded by an excess of bids over asks as well as by a very large increase in the variance of both bids and asks.

The anti-crash seems to coincide with the beginning of a backward induction process, which changes the nature of trading activity in the sessions. There appear to be two distinct phases in each session. In the second phase, prices are close to the fundamental value. During this phase a backward induction appears to be taking place. The data suggest that the capacity for backward induction is limited in length, corroborating existing intuition from experiments on games and individual decision making. The first phase of the markets is heterogeneous across sessions. We have classified the sessions by price patterns, according to whether they are more consistent with the fundamental value, the myopic, or the bull market hypotheses. More than half of our sessions were consistent with the bull market hypothesis and two of the remaining three were consistent with the myopia hypothesis, indicating that in 6 of the 7 markets, the prices early in the experiment were not determined by the final buyout value. It seems that, in the early periods of the experiment, period 15 is too far into the future to be included in many traders'

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[3] Ball and Holt (1998) construct asset markets for instructional purposes, which share some properties of our asset markets. In their markets, an asset, yielding a dividend of 1 US dollar each period, is traded. Each unit has a 1/6 chance of destruction after each period. At the end of period 10, there is a terminal buyout value of $6 for any surviving assets. The fundamental value is always constant at $6. Ball and Holt observe prices below fundamental values early in their sessions. This is followed by increases in prices to levels higher than fundamental values, a pattern consistent with hypothesis three. However, because their experiments were conducted for instructional purposes, their markets had a random ending rule for terminating the life of the assets, and it was not possible for

calculations of reservation prices. Myopic markets enter the backward induction phase with an anti-crash, while bull markets may enter the backward induction phase with a crash.

The anti-crashes we observe here, like the crashes observed in previous studies, because they take place near the end of the time horizon, appear to be a price adjustment process which occurs as a consequence of the finite lifetime of the asset. Therefore, we do not believe that they necessarily have the same cause as the "stock market crashes" observed in the field for assets without a fixed terminal date. In contrast, we find it striking that prices can differ greatly from fundamental values in such simple environments so readily. We would conjecture that price bubbles are a quite general phenomenon, which might be observed in a wide class of potential laboratory environments as well as in field environments, including in markets for assets without a fixed terminal date.

# Appendix

This Appendix contains the English version of the instructions and forms used in the experiment.

## A. General Instructions

This is an experiment in the economics of market decision making. 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 will consist 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 in terms of francs. The cash payment to you at the end of the experiment will be in dollars. The conversion rate is ..... francs to 1 dollar.

The experiment will consist of 15 trading periods. In each period, there will be a market open, in which you may buy and sell units of a good called X. X can be considered an asset with a life of 15 periods, and your inventory of X carries over from one trading period to the next. At the end of the experiment, each unit of X in your inventory pays a one time dividend of 360 francs to you. However, you may also receive additional dividends or pay a holding cost for each unit of X in your inventory at the end of each of the 15 trading periods.

At the end of each trading period, the experimenter will roll a four-sided die to determine the dividend or the holding cost for that period. Each period, each unit held by you at the end of the period:

costs you a holding cost of 24 francs if the die reads 1,

costs you a holding cost of 16 francs if the die reads 2,

earns you a dividend of 4 francs if the die reads 3,

---

dividends to be negative in their study, it is difficult to compare our results with theirs.

and earns you a dividend of 36 francs if the die reads 4.

Each of the four numbers on the die is equally likely. The average dividend/holding cost in each period is 0.

## B. AVERAGE HOLDING VALUE TABLE

You can use your AVERAGE HOLDING VALUE TABLE to help you make decisions. There are 5 columns in the table. The first column, labeled Ending Period, indicates the last trading period of the experiment. The second column, labeled Current Period, indicates the period during which the average holding value is being calculated. The third column gives the number of holding periods from the period in the second column until the end of the experiment. The fourth column, labeled Average Dividend/Holding Cost per Period, gives the average amount that the dividend/holding cost will be in each period for each unit held in your inventory. The fifth column, labeled Average Holding Value Per Unit of Inventory, gives the average value for each unit held in your inventory 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 earn on average the amount listed in column 5. That is:

AVERAGE HOLDING VALUE PER UNIT = (NUMBER OF PERIODS REMAINING *
AVERAGE DIVIDEND/HOLDING COST PER PERIOD) + END OF EXPERIMENT DIVIDEND

Suppose for example that there are 7 periods remaining. Since the dividend/holding cost on a unit of X has a 25% chance of being -24, a 25% chance of being -16, a 25% chance of being 4 and a 25% chance of being 36 in any period, the dividend/holding cost is on average 0 per period for each unit of X. If you hold a unit of X for 7 periods, the total holding cost for the unit over the 7 periods is on average 7*0 = 0. Therefore, the total value of holding the unit over the 7 periods is on average 0 + 360 = 360.

## C. RECORDING YOUR EARNINGS

At the end of each period, record your earnings on your PERIOD EARNINGS SHEET. At the end of period 1, record your cash on hand at the end of the period in column 2 in the row marked period 1. In column 3, record your cash on hand at the beginning of the period. Record your inventory of units at the end of the period in column 4 in the row marked period 1. Fill in the dividend/holding cost of each unit in column 5. Record your earnings for the period in column 6. Your earnings in each period equal the difference in your cash on hand from the beginning to the end of the period minus the holding cost paid at the end of the period for the units of X in your inventory at the end of the period. That is:

YOUR EARNINGS = END OF PERIOD CASH - BEGINNING OF PERIOD CASH +
(DIVIDEND/HOLDING COST PER UNIT * NUMBER OF UNITS IN INVENTORY AT END OF PERIOD)

Subsequent periods should be recorded similarly. Your earnings for the entire experiment are the total of your earnings for periods 1-15. It should be kept in mind that EACH UNIT OF X IN YOUR INVENTORY PAYS YOU 360 FRANCS AT THE END OF THE EXPERIMENT. Thus you may have negative earnings in one or more periods of the experiment yet still be earning money by the end of the experiment.

There will be a practice period, 0, which will not count toward your final earnings.

# PERIOD EARNINGS SHEET

| (1) PERIOD | (2) END CASH | | (3) BEGINNING CASH | | (4) END OF PERIOD INVENTORY | | (5) DIV./HOLD. COST PER-UNIT | | (6) PERIOD EARNINGS |
|---|---|---|---|---|---|---|---|---|---|
| 0 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 1 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 2 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 3 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 4 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 5 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 6 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 7 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 8 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 9 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 10 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 11 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 12 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 13 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 14 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| 15 | ______ | - | _______ | + | (_____ | * | _____) | = | __________ |
| TOTAL EARNINGS | | | | | | | | = | __________ |

## AVERAGE HOLDING VALUE FOR UNITS OF X TABLE

| Ending Period | Current Period | Number of Holding Periods * | Average Dividend Per Period = | Average Holding Value Per Unit of Inventory |
|---|---|---|---|---|
| 15 | 1 | 15 | 0 | 360 |
| 15 | 2 | 14 | 0 | 360 |
| 15 | 3 | 13 | 0 | 360 |
| 15 | 4 | 12 | 0 | 360 |
| 15 | 5 | 11 | 0 | 360 |
| 15 | 6 | 10 | 0 | 360 |
| 15 | 7 | 9 | 0 | 360 |
| 15 | 8 | 8 | 0 | 360 |
| 15 | 9 | 7 | 0 | 360 |
| 15 | 10 | 6 | 0 | 360 |
| 15 | 11 | 5 | 0 | 360 |
| 15 | 12 | 4 | 0 | 360 |
| 15 | 13 | 3 | 0 | 360 |
| 15 | 14 | 2 | 0 | 360 |
| 15 | 15 | 1 | 0 | 360 |

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Table 1: The Sessions of the Experiment

| Session | Date | Location | Number of Subjects |
|---|---|---|---|
| 1G | 4/23/97 | Grenoble | 10 |
| 2G | 2/25/98 | Grenoble | 10 |
| 3G | 2/26/98 | Grenoble | 10 |
| 1P | 5/29/97 | Purdue | 9 |
| 2P | 6/5/97 | Purdue | 8 |
| 3P | 7/22/97 | Purdue | 8 |
| 4P | 7/24/97 | Purdue | 8 |

Table 2: Quantities Exchanged, Quantities Offered, and Variance of Bid and Ask Prices

| | Anti-Crash Periods | | Other Periods with Large Price Increases | | |
|---|---|---|---|---|---|
| | 1P, t = 13 | 4P, t = 15 | 2P, t = 15 | 3P, t = 7 | 3P, t = 8 |
| Volume in t | 12 | 8 | 18 | 13 | 14 |
| Volume in < t | 48.58 | 58.64 | 17.14 | 26.5 | 23.8 |
| $B_t - O_t$ | +30 | +3 | -11 | +23 | +16 |
| $B_{t-1} - O_{t-1}$ | +21 | +13 | -5 | +13 | +23 |
| Var(B) in < t-1 | 29 | 45 | 5083 | 283 | 741 |
| Var(B) in t-1 | 877 | 6374 | 5254 | 778 | 11895 |
| Var(O) in < t-1 | 45 | 11453 | 10057 | 12157 | 15227 |
| Var(O) in t-1 | 7045 | 21619 | 6874 | 30400 | 21719 |

Table 3: Price changes from one period to the next as a function of the difference between the number of bids and asks in each period, all sessions

| Session | *a* | *b* |
|---|---|---|
| 1G | 1,24325422<br>(3,28666749) | 0,20501364<br>(0,33457394) |
| 2G | 12,4077744*<br>(6,49499775) | 1,09679878**<br>(0,45174542) |
| 3G | 9,45747971<br>(8,13900857) | 0,79119959*<br>(0,42271907) |
| 1P | 2,23012354<br>(20,0800044) | 1,75853782<br>(1,13279374) |
| 2P | 11,8409451<br>(34,0533256) | -2,58387972<br>(2,76208943) |
| 3P | 10,7551769<br>(18,7068987) | 2,89567497**<br>(1,49535609) |
| 4P | 9,45747971<br>(8,13900857) | 2,87714841*<br>(1,60919189) |

* significant at the 10% level

** significant at the 5% level

**Figure 1: Transaction Prices, Bids and Asks for an Asset with a Declining Fundamental Value**

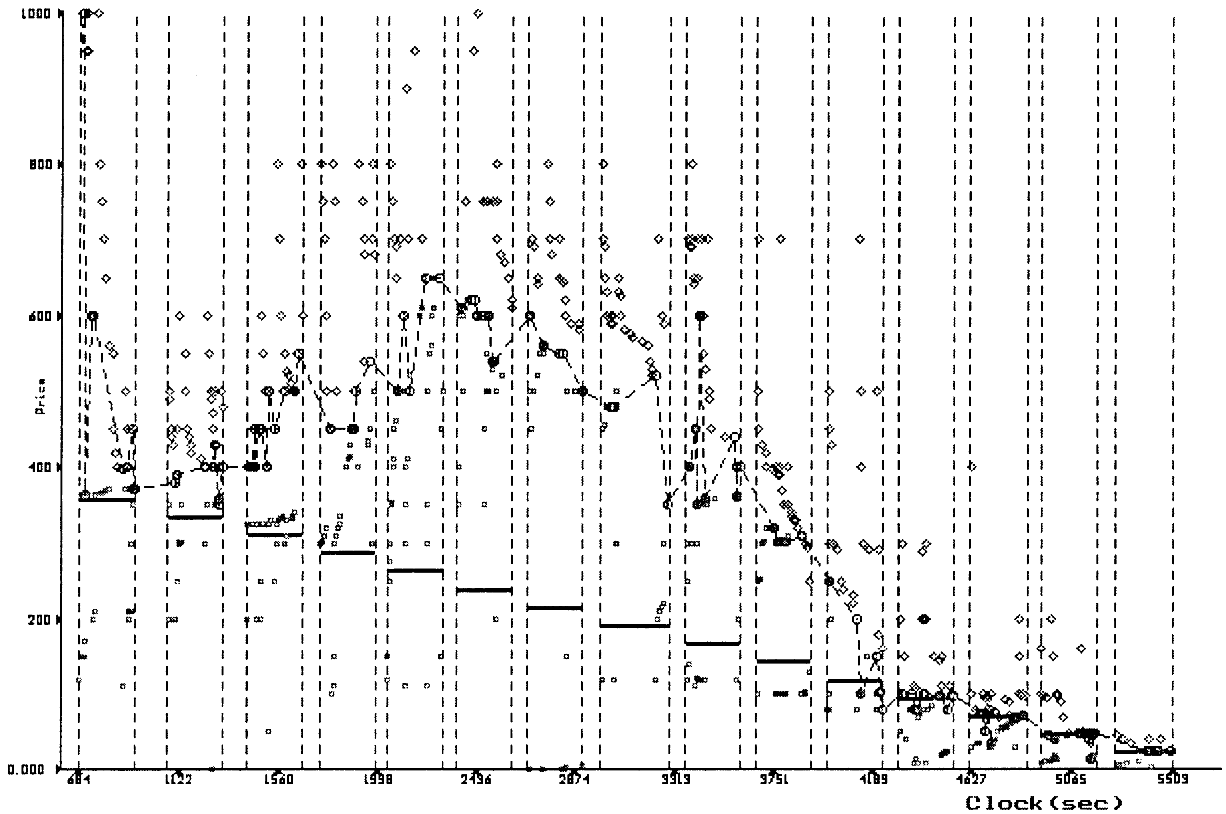


**Figure 2: Price Paths Consistent with Hypotheses 1-3**

**Figure 2a:**
**Predictions of Hypotheses 1-3**
**Decreasing Fundamental Value Case**

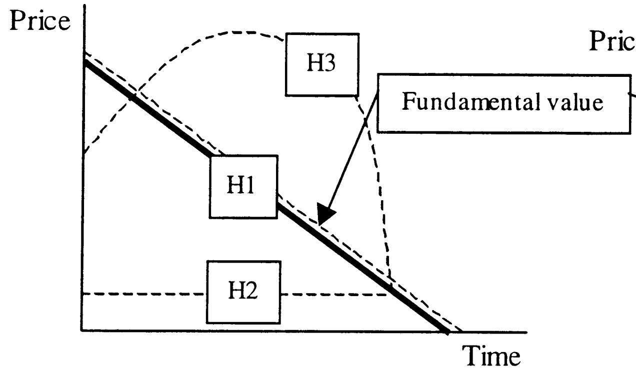
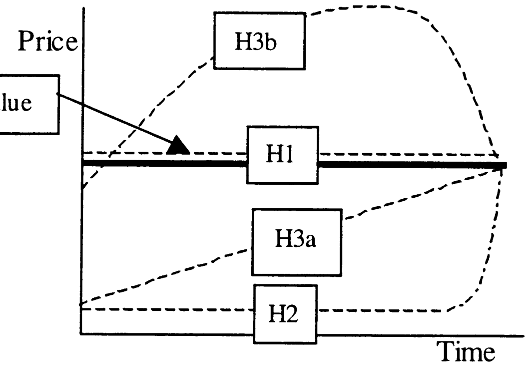



**Figure 2b:**
**Predictions of Hypotheses 1-3**
**Constant Fundamental Value Case**



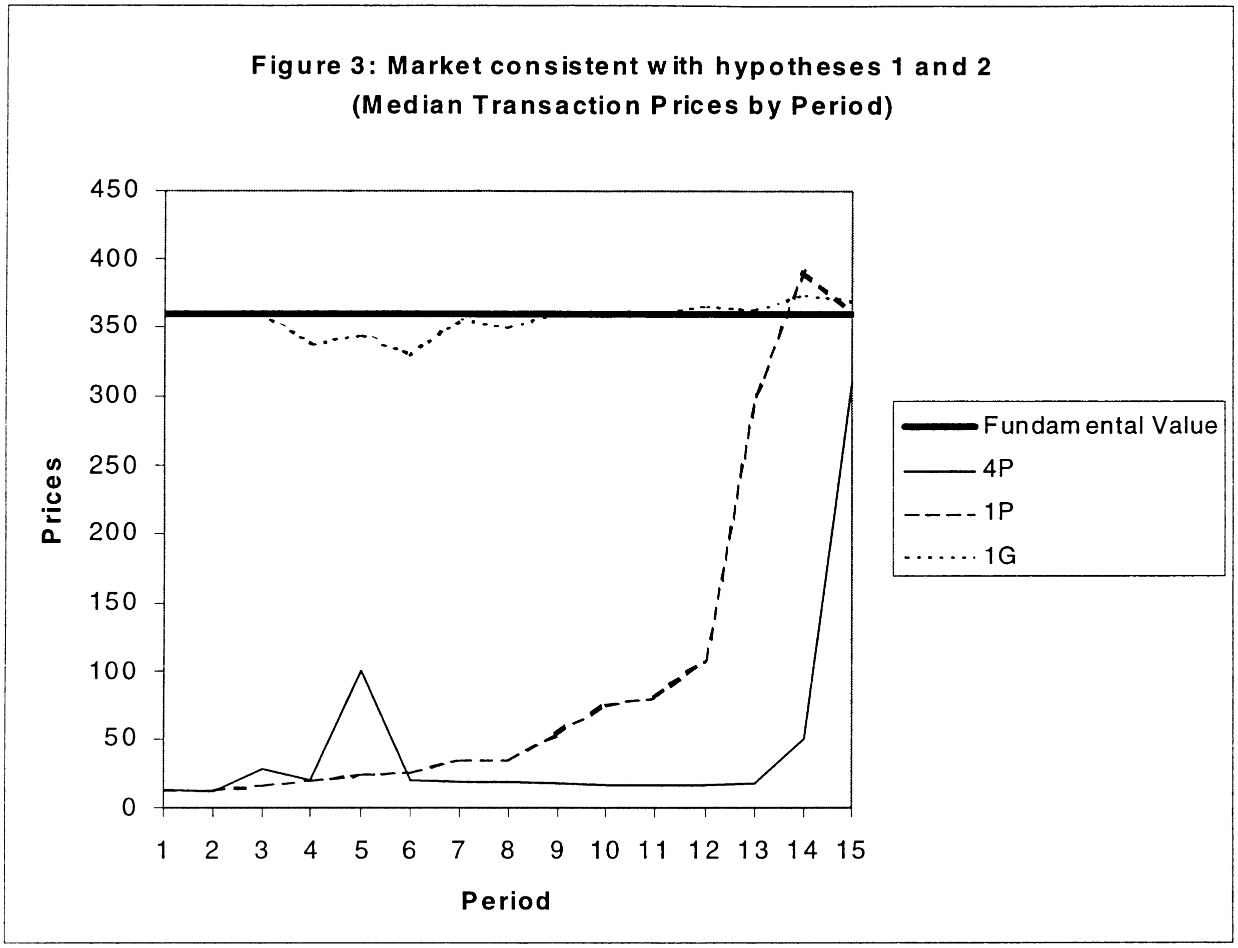


Figure 3: Market consistent with hypotheses 1 and 2
(Median Transaction Prices by Period)
450
400
350
300
250
200
150
100
50
0
Prices
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Period
Fundamental Value
4P
1P
1G

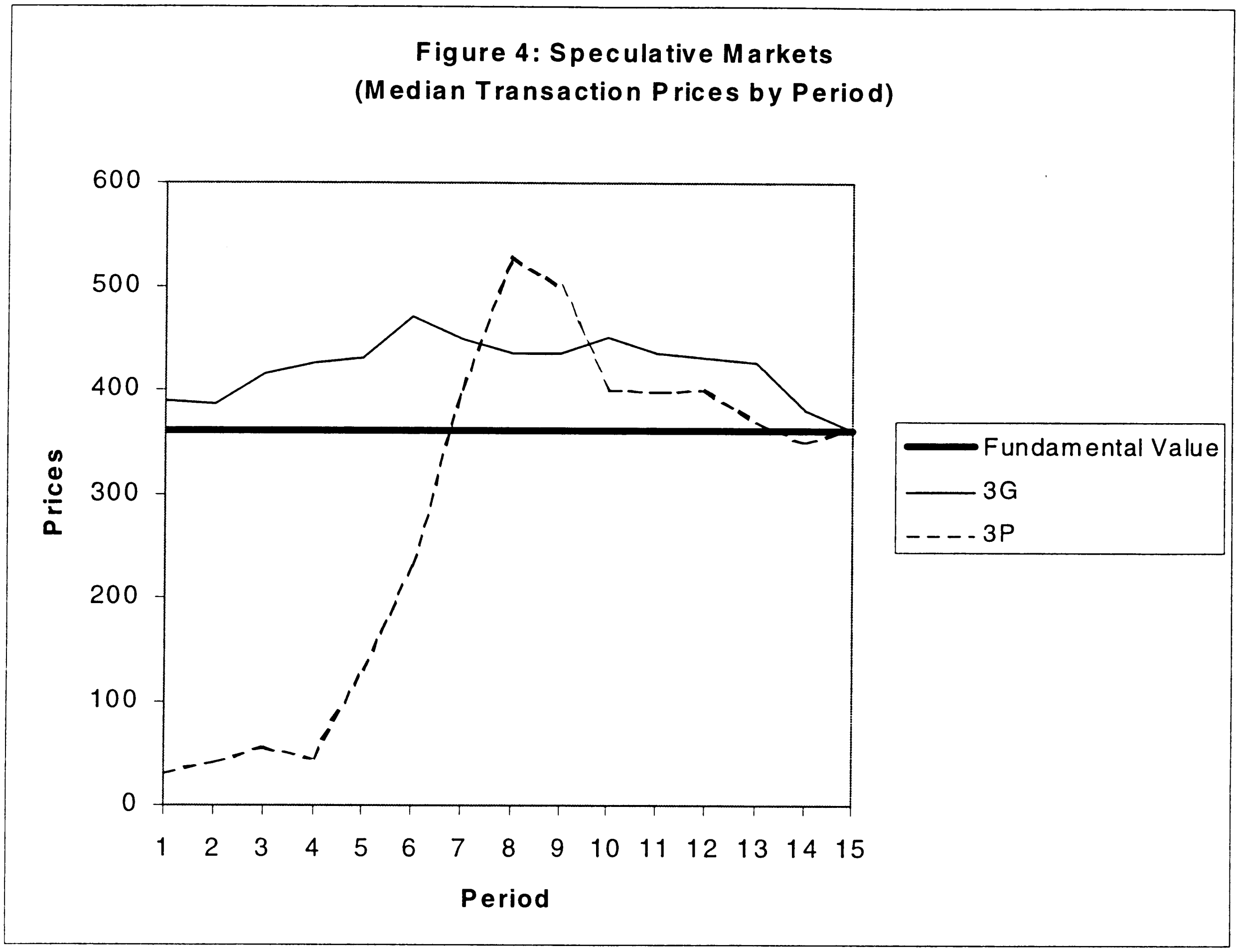


Figure 4: Speculative Markets
(Median Transaction Prices by Period)
600
500
400
300
200
100
0
Prices
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Period
Fundamental Value
3G
3P

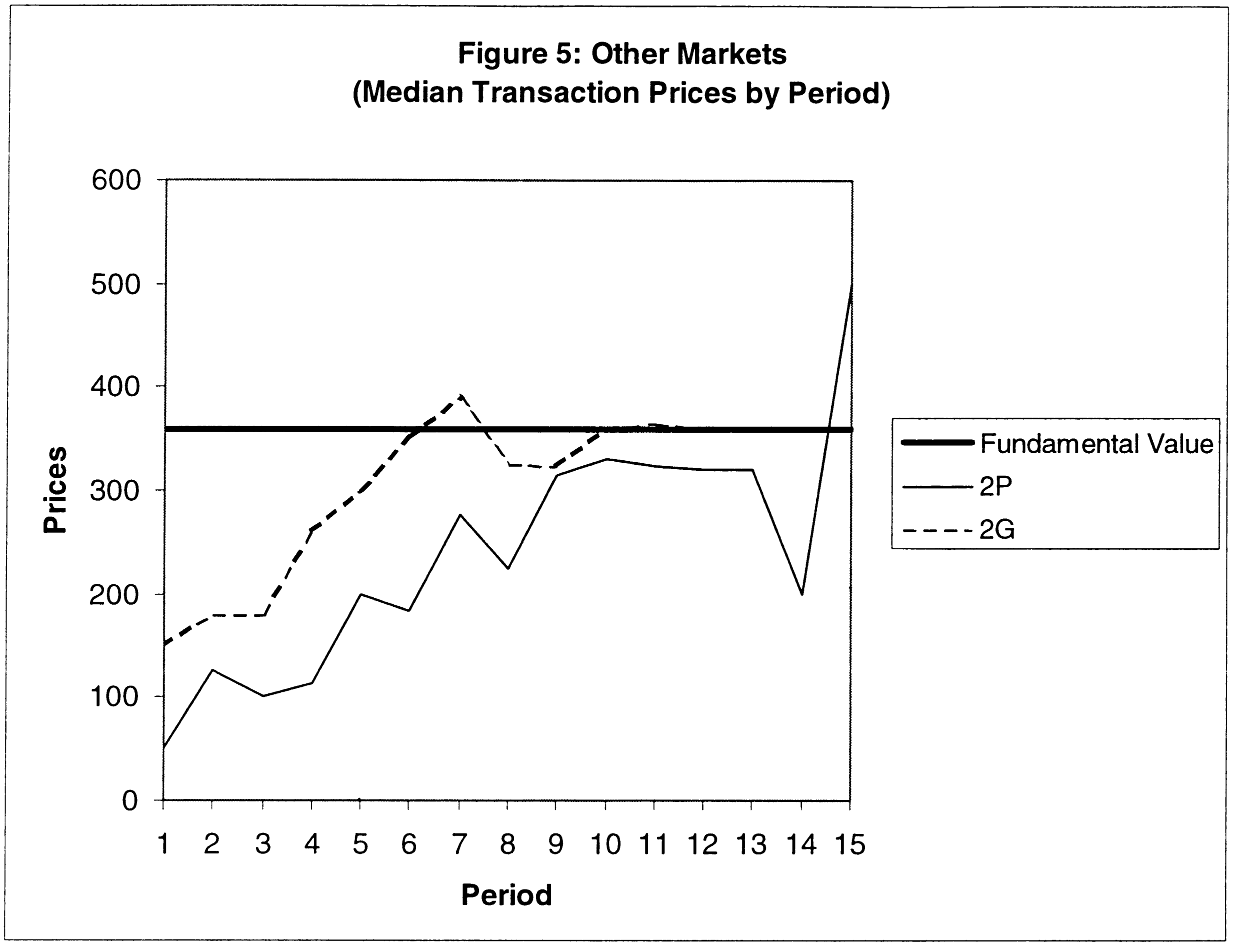
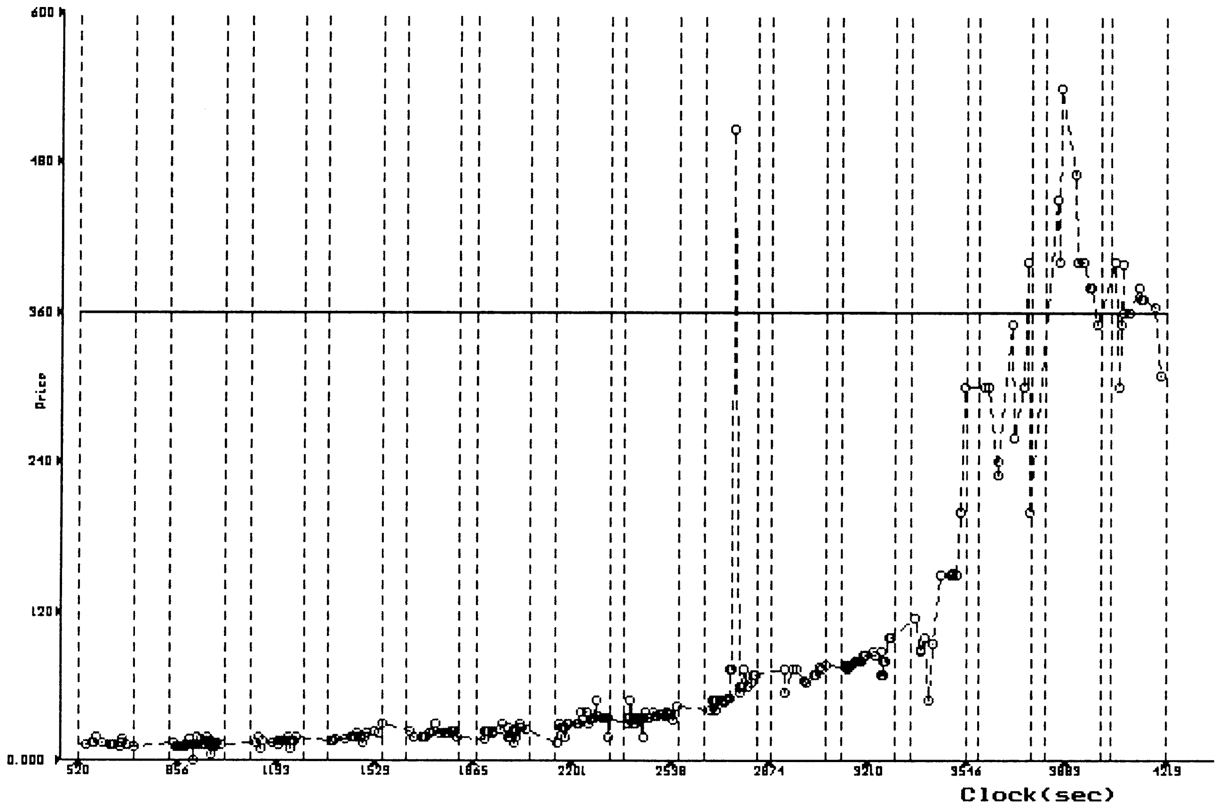


Figure 5: Other Markets
(Median Transaction Prices by Period)
600
500
400
300
200
100
0
Prices
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Period
Fundamental Value
2P
2G

## Figure 6: Time series of transaction prices (Session 1P)



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