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## Non-Speculative Bubbles in Experimental Asset Markets: Lack of Common Knowledge of Rationality and Actual Irrationality

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# Non-Speculative Bubbles in Experimental Asset Markets: Lack of Common Knowledge of Rationality vs. Actual Irrationality

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## Abstract

We report the results of an experiment designed to study the role of speculation in the formation of bubbles and crashes in laboratory asset markets. In a setting in which speculation is not possible, bubbles and crashes are observed. The results suggest that the departures from fundamental values are not caused by the lack of common knowledge of rationality leading to speculation, but rather by behavior that itself exhibits elements of irrationality.

## 1. Introduction

One of the most remarkable results from research on experimental asset markets<sup>1</sup> is the discovery, due to Smith et al. (1988), of a particular class of asset market that tends to generate price “bubbles”. A bubble is operationally defined as “trade in high volumes at prices that are considerably at variance from intrinsic values”.<sup>2</sup> The result has been replicated and shown to be robust to several changes in the experimental design (see for example King et al., 1993; Fisher and Kelly, 1998; Porter and Smith, 1995; Van Boening et al., 1993).<sup>3</sup> In all of these studies, markets are created for assets with a lifetime of a finite

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<sup>1</sup> See Sunder (1995) or Duxbury (1995) for surveys of the experimental research on asset markets.

<sup>2</sup> This definition is given by King et al. (1993).

<sup>3</sup> The robustness tests conducted by these authors are the following. King et al. (1993) study the effect of allowing short selling, allowing margin buying, having equal initial endowments for each agent, imposing a fee on

number of periods (typically 15 or 30 periods). The asset pays a dividend in each period, and the dividend (apart from possibly a fixed terminal buyout value) is the only source of intrinsic value. The dividend paid is identical for each trader and the dividend process is common knowledge to all traders. Rather than tracking the fundamental value, the market price time series is usually characterized by a “boom” phase, a period of time in which prices are higher than fundamental values, often followed by a “crash”, a sudden rapid drop in price.

Several typical time series of transaction prices in this type of market can be found in figure 1 of this paper. The figure illustrates the contrast between the observed prices and the fundamental value of the asset. For example, in the series NoSpec1, a boom occurs in periods 4-11 and a crash occurs in period 12. The results of Smith et al. (1988) have been described as striking (Sunder, 1995) because of their sharp contrast with theoretical predictions.

Explaining the patterns in the data presents a theoretical challenge.<sup>4</sup> One way to reconcile the departures of prices from fundamental values with economic intuition is to postulate that the bubbles are speculative in nature, that is, that the prices reflect the pursuit of capital gains. Smith et al. (1988) interpret their data in the following manner: “What we learn from the particular experiments reported here is that a common dividend, and common knowledge thereof, is insufficient to induce initial common expectations. As we interpret it, this is due to agent uncertainty about the behavior of others.” We understand the conjecture implicit in this quote to suggest that the bubbles can occur when traders are

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transactions, limiting the extent of price changes, adding insiders who are familiar with previous research on the topic and using businesspeople as subjects. None of these treatments successfully eliminated the bubble, though the treatment with informed insiders had some effect. 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 dividend payouts and find that the futures market somewhat reduced the extent of the deviations from fundamental values but the certain dividend payouts did not. Van Boening et al. (1993) study asset markets organized as call markets (two- sided sealed-bid auctions), and also observe price bubbles and crashes. The only manipulation which has been shown to reliably eliminate bubbles and crashes is prior participation in at least two sessions in the same type of asset market.

<sup>4</sup> Because of the finite time horizon, backward induction implies that risk neutral agents must trade at the fundamental value, which is the expected dividend flow for the remainder of the time horizon. Risk aversion can lead to prices below fundamental values. The hypothesis that risk aversion was the cause of the deviations from fundamental values was tested by Porter and Smith (1995). In this study the uncertainty about the dividend process was removed by

uncertain that future prices will track the fundamental value, because they doubt the rationality of the other traders, and therefore speculate in the belief that there are opportunities for future capital gains.<sup>5</sup> In this paper, we will refer to this conjecture as *the speculative hypothesis*.

To see how a bubble and crash might come about if it is not common knowledge that traders are rational, consider a rational trader who believes that there may be “irrational” traders in the market, who are willing to make purchases at very high prices. The rational trader might make a purchase at a price greater than the fundamental value, believing that he will be able to realize a capital gain by reselling at an even higher price, either to an irrational trader or to a trader who also plans on reselling. Thus trading prices may be much higher than the fundamental value when the end of the time horizon is sufficiently far in the future, even when all agents are rational. However, as the end of the time horizon approaches, the probability of realizing a capital gain on a purchase declines, the incentive to speculate is reduced, and the price falls (crashes) to the fundamental value. It need not be the case that irrational traders actually exist, but only that their existence be believed to be possible. Notice that the ability of traders to speculate, that is to buy for the purpose of resale, is necessary to create these price dynamics.

The speculative hypothesis can be precisely stated as follows: *The bubbles occur because of the possibility of the realization capital gains*. An implication of the speculative hypothesis is that, if there were no possibility to realize capital gains, there would be no bubble. The first two groups of experiments reported in this paper consider this prediction of the speculative hypothesis. Markets are constructed which have a structure similar to those in which bubbles and crashes have been observed. There are two different treatments, called *CapTax* and *NoSpec*. In the *CapTax* treatment the incentive to speculate is weak relative to previous studies and in the *NoSpec* treatment, the ability to speculate is completely removed. In sessions in which the *CapTax* treatment is in effect, a capital gains tax of 50% is levied on all

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having each unit of the asset pay a fixed amount after each period. Even if risk aversion is present, the asset should trade at the fundamental value. The authors continue to observe the bubble and crash pattern.

<sup>5</sup> A similar argument was also offered as an explanation of laboratory asset market bubbles by Plott (1991).

traders. In the NoSpec treatment, the role of each agent is limited to that of *either* a buyer or a seller, completely eliminating the ability of any agent to buy for the purpose of resale.

In the NoSpec treatment, the only source of benefit from a purchase is from the dividends that the asset pays out, since the unit can never be resold. Thus, a rational risk-neutral or risk-averse trader would *never* make a purchase at a price higher than the fundamental value in NoSpec, even if he expects the future price to be higher than the current price. If bubbles do not occur under NoSpec, it can be concluded that the desire to acquire capital gains is at the root of the deviations from fundamental values. If bubbles do occur under NoSpec, any explanation which relies on the possibility of the realization of capital gains, such as the lack of common knowledge of the rationality of market participants leading to speculation, can be ruled out as being the *only* cause of the bubble phenomenon. The extent to which bubbles occur under CapTax indicates how responsive the bubble is to a strong disincentive to speculate. An absence of bubbles under CapTax would provide evidence that speculation is essential in causing the bubble, and the presence of bubbles under CapTax would suggest that the formation of bubbles does not require a speculative motive.

As we report below in detail, in both the CapTax and NoSpec treatments, large departures of prices from fundamental values at high volumes are observed. Furthermore, the pattern of prices has the boom and crash features observed by Smith et al. (1988). We conclude that the bubbles and crashes are not caused by attempts to buy and to resell at a higher price. We do not claim that speculation does not occur in asset markets of this type, merely that speculation is not *necessary* to cause the departures from fundamental values. The absence of common knowledge of rationality is well founded, in that we observe systematic errors in decision making, such as purchases at prices higher than fundamental values in NoSpec. However, it is the actual presence of irrational behavior and not the lack of common knowledge of rationality that causes the bubbles we observe.

The fact that agents systematically make unprofitable transactions suggests that there may be some particular aspect of the methodology of the experiment that encourages such behavior. One

indication that subjects have difficulty making correct decisions in our asset markets is that much more trade occurs than would be expected if buyers and sellers had on average the same risk attitudes. In section four of this paper, we report on a series of follow-up experiments, called the TwoMarket experiments, which was designed to explore the origin of this “excess volume”. The TwoMarket experiments test the hypothesis that much of the trading activity in the experiment is due to the fact that no alternative activity is available for subjects other than to trade in the asset market. In the TwoMarket treatment, in which there is another market operating simultaneously along with the asset market, the volumes in the asset market are low relative to benchmark experiments, supporting the hypothesis. However, in TwoMarket, prices also deviate from the fundamental values, and tend to follow a boom and crash pattern. The presence of boom and crash price dynamics indicates that the TwoMarket treatment fails to eliminate the cause of the differences between prices and fundamental values.

In section two, we describe the design and procedures of the NoSpec, CapTax and TwoMarket treatments. In section three we report the results from the NoSpec and CapTax treatments. In section four we describe the results of the TwoMarket treatment and in section five we list and explain our conclusions.

## **2. The Experimental Design**

### **2.1 Procedures Common to All Sessions**

Summary information about each of the fifteen sessions of the experiment is given in Table 1. Trade in all of the markets followed continuous double auction rules that were implemented with the MUDA software package (see Plott and Gray, 1990, for a description). Trade was denominated in an experimental currency, called “francs,” which were converted to US dollars at the end of the experiment at a predetermined rate. The rate was common for all subjects and known to subjects in advance. The conversion rates in each session are indicated in table 1. All of the sessions were conducted at Purdue University, Indiana, USA between September, 1995 and February, 1998. All of the subjects were

undergraduate students who had not participated in any previous research experiments, though all had previous experience with the MUDA software in classroom exercises. None of the subjects had any previous experience with asset markets, in either a classroom or a research setting. The sessions described in Table 1 lasted on average 2 hours and 45 minutes.

[Table 1: About Here]

## **2.2 Procedures Common to the CapTax and the NoSpec Sessions**

Each of the CapTax and NoSpec sessions consisted of 13 trading periods and each period lasted 4 minutes<sup>6</sup>. The initial period of each session, to which we refer as period 0, was for practice only and earnings in period 0 did not count toward final earnings. Earnings in periods beginning in period 1 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 “francs”, the name used for the experimental currency. 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 in the market, which we call “working capital”, was also carried over from period to period. Working capital was denominated in “francs”. Both working capital levels and inventories were reinitialized only once: after period 0, before the beginning of period 1.

After the end of trading in each period, each unit of the asset paid a dividend of either 20 or 40 francs, depending on the outcome of a coin flip. Every unit of X paid the same dividend, regardless of the identity of the owner. Thus the expected dividend paid on each unit of X was 30 per period and 360 over the course of a session. The expected value of the dividends from holding a unit from the current period until the end of the experiment was given by  $30t$ , where  $t$  was the number of periods remaining including the current period.

The timing of activity in a session was as follows. (1) When subjects arrived at the experiment, they were given approximately fifty minutes of instruction that focused exclusively on the use of the

software. (2) The instructions for the asset market experiment were read for the subjects, who followed along with their own copy of the text, and could ask questions at any time. Subjects then took a quiz about the dividend process. The text of the instructions and the quiz can be found in the appendix. (3) The market was opened for period 0, which did not count toward subjects' final earnings. (4) Inventories of cash and X were reinitialized to the values in table 1 at the beginning of period 1, and then the market periods of the experiment took place.

### **2.3 Procedures Specific to the CapTax Treatment**

In the CapTax treatment, *each* subject was endowed with 5,000 francs of working capital and 10 units of X at the beginning of period 1. Since there were no trading rules to prevent subjects from buying and reselling X, there were two potential sources of earnings, capital gains and dividends. There was a tax of 50% on capital gains in effect, which was levied at the end of each period on the total net capital gain for the period. The tax rate was 50% when capital gains were positive, and it was zero for capital losses. Taxable capital gains were measured as net capital gains for an entire period, so that capital losses within a period offset capital gains during the period. There was no tax imposed on earnings from dividends. Total period earnings were equal to dividends on all units held at the end of the period plus after-tax capital gains or minus capital losses. The final earnings, in terms of francs, for each subject were calculated as the sum of period earnings from periods 1-12.

Proceeds from sales of the asset added to working capital and expenditures on the asset subtracted from working capital. Earnings from dividends did not add to working capital, but were paper earnings only, and thus could not be used for purchases. Capital gains were calculated by subtracting working capital at the beginning from working capital at the end of each period. The capital gains tax was imposed on paper and did not reduce the working capital available for transactions.

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<sup>6</sup> This is with the exception of period 12 in CapTax2 which was two minutes in length.

## **2.4 Procedures Specific to the NoSpec Treatment**

In the NoSpec sessions, each subject was randomly assigned to be either a buyer or a seller. Buyers were not permitted to sell units and sellers were not permitted to buy units. In the sessions NoSpec1 and NoSpec3, there were 4 buyers and 4 sellers; in NoSpec2, there were 4 buyers and 3 sellers. Each seller was endowed with 20 units of X but no working capital at the beginning of period 1. Each buyer was endowed with 7,200 francs of working capital but zero units of X at the beginning of period 1.

In the NoSpec treatment, there was no possibility of realizing a capital gain, though it was of course possible to sell units at prices greater than their fundamental values. Because each unit of X paid on average 360 over the course of the session, the expected final dollar payment for buyers and sellers was identical, under the assumption that prices track the fundamental values. Dividends were paper earnings which did not add to working capital. Purchases and sales of X did affect working capital. The final earnings of each subject were equal to the total dividends he received from period 1-12 plus the working capital he had remaining at the end of the experiment.

## **2.5 Procedures specific to the TwoMarket treatment**

Sessions conducted under the TwoMarket treatment had a duration of either 19 or 16 periods, depending on the session, including the practice period. There were two markets, both organized as continuous double auctions, and a different commodity was traded in each market. Each agent had the ability to participate in both markets. In one of the markets, a commodity called Y, with a life of one period, and which therefore can be thought of as a service (as in Smith, 1962) rather than an asset, was traded. The market for Y consisted of a one-period supply and demand market repeated under stationary conditions. Each participant was assigned as either a buyer or a seller in Y market and the other function was disabled. Each buyer was endowed with an inverse demand curve approximated by  $870 - 90Y$  and sellers was endowed with an inventory of 10 units of Y and an inverse supply curve function approximated by  $460 + 90Y$ . Inventories of Y were reinitialized at the end of each period. The market for

Y was open for every period of the session. The profits in the competitive equilibrium were between 50 cents and 1 dollar per period for each subject.<sup>7</sup>

In the other market an asset called X was traded. All agents could both buy and sell X. The asset market opened for the first time in period 4. In sessions TwoMarket1 – TwoMarket4, the asset had a life of 15 periods, and in TwoMarket5 and TwoMarket6, the asset had a life of 12 periods. As in the CapTax and NoSpec sessions, each period lasted 4 minutes. In sessions TwoMarket1 – TwoMarket4, the dividend distribution used was the following: each unit of X paid a dividend of either 0, 8, 28, or 60 francs in a given period, each dividend occurring with probability .25. The dividend was determined by a roll of a four-sided die at the end of each period. In TwoMarket5 and TwoMarket6, the dividend was either 20 or 40, each occurring with probability .5. The market for X was opened for the first time in period 4 and remained open every period for the remainder of the session. The instructions were written in a manner, that was intended to provide no bias toward action or toward inaction in the asset market and stressed that participation in either market was optional and not necessarily expected. The following sentence was written in bold block letters in the instructions: *“You are not required to participate in either of the markets if you choose not to. It may be to your advantage not to participate in either or it may be to your advantage to participate in one or both. You should decide what might be in your best interest and make your choice accordingly.”* The instructions for the service market were given and read to subjects before period 0, and the instructions for the asset market were given and read to subjects before period 4.

In the TwoMarket sessions, the working capital available was 100,000, a very large amount relative to the prices in the markets. The dividends earned were paper earnings that did not affect working capital. Purchases in either the X or the Y market reduced available working capital and sales in either the X or the Y market increased the amount of working capital.<sup>8</sup> Final earnings for the traders who were

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<sup>7</sup> Competitive equilibrium profits in the Y market are identical for each agent when there are an equal number of buyers and sellers, as there were in all of the TwoMarket sessions with an even number of participants. With an equal number of buyers and sellers, each agent makes three profitable trades in the competitive equilibrium.

<sup>8</sup> The high level of cash balance ensured that buyers in the Y market were not cash constrained late in the experiment in the X market.

buyers in the X market was determined by four totals. Final earnings equaled (1) the total value of the Y they purchased, plus (2) the total of the dividends received on units of X in their inventory at the end of each period, plus (3) the amount of working capital they had at the end of the experiment, minus (4) the amount of working capital at the beginning of the experiment. The earnings of agents who were sellers in the X market were given by (1) the total of the dividends on units of X, plus (2) the amount of working capital they had at the end of the experiment, minus (3) the amount of working capital at the beginning of the experiment, minus (4) the cost of the units of Y they sold over the course of the session. Thus, the initial working capital can be viewed as a loan from the experimenter to the subject to be paid back at the end of the experiment.

The timing of activity in each session of TwoMarket was the following. (1) Subjects were given instruction in the use of the software. (2) The instructions for the Y market, the service market, were read for subjects, who were allowed to ask questions. (3) The market for Y was opened for period 0, which did not count toward subjects' final earnings. (4) Market periods 1-3 of the experiment were run, which counted toward subjects' earnings, and during which only the market for Y was open. (5) After the end of period 3, the instructions for the X market were read. Subjects then took a quiz about the dividend process. (6) Periods 4-18, in which both markets were open and which counted toward subjects final earnings, took place.

## **2.6 The OneMarket Treatment**

The OneMarket sessions provided a benchmark with which all of the other treatments could be compared. At any time, there was one market open in which an asset, identical to those described above, was traded. Buying for resale was possible and there were no capital gains taxes in effect. In sessions OneMarket2 and OneMarket3, the procedures were identical to those described in section 2.2. In these two sessions the asset had a life of 12 periods and the dividend in each period had a 50% chance of equaling 20 francs and a 50% chance of equaling 40 francs. Thus the data from two sessions can be

compared with the data from CapTax, NoSpec, TwoMarket5 and TwoMarket6. In session OneMarket1, the asset had a life of 15 periods, and the dividend process was identical to sessions TwoMarket1 – TwoMarket4, enabling clear comparisons between those four sessions and OneMarket1.

### **3. Results for the CapTax and NoSpec Sessions**

The time series of median transaction prices by period in each of the six CapTax and NoSpec sessions are given in figure 1. In period 1 of five of the six sessions, the median price is below the fundamental value, as it tends to be in the previous studies cited in section 1. In CapTax1, the median price exceeds the fundamental value from period 2 until period 10. In CapTax2, the median price is greater than the fundamental from period 7 until the end of the experiment. In CapTax3, a boom, a period in which prices are higher than fundamental values, lasting 7 periods, begins in period 4. In NoSpec1, the median price was higher than the fundamental value from period 4 until the end of the session. In NoSpec2, a boom lasts from period 2 to period 6. During periods 7 and 8, no transactions occur. The median price is again higher than the fundamental value between periods 9 and 12. In NoSpec3 the median price in every period of the session is greater than the fundamental value. A crash, a sudden large drop in price toward the fundamental value, occurs in period 12 of CapTax2 and in period 11 of CapTax3. A crash also occurs in period 12 of NoSpec1. The main conclusion we draw from the CapTax and NoSpec data is stated below as Result 1.

**Result 1: Bubbles are not due to speculation. The speculative hypothesis is refuted. Bubbles occur even when speculation is not possible.**

**Support for Result 1:** For the purposes of this paper, we will follow King et al. (1993) and define a *bubble* as “trade at high volumes at prices considerably at variance with fundamental values”. By this definition, a bubble occurs in each of the six CapTax and NoSpec sessions. The fact that prices deviate

from fundamental values is apparent from Figure 1. In every session, the median transaction price exceeds the fundamental value by at least 30 francs for at least 5 consecutive periods. Median period prices are either less than 50% or more than 200% of the fundamental value in 50% (36 out of 72) of the periods.

[Table 2: About Here]

The volume of trade in each period of each session is given in table 2. The volume in the CapTax sessions is substantial equaling 136%, 361% and 317% of the total stock of X (10 units per subject) in CapTax1, CapTax2 and CapTax3 respectively, indicating widespread buying and reselling. The volume in the NoSpec sessions is lower than under Captax. However, since it is impossible to buy for resale in NoSpec, the highest possible trading volumes are 80 in NoSpec1 and NoSpec3 and 60 in NoSpec2 (20 per seller).<sup>9</sup> The actual total volumes was 64, 53, and 69, representing 80%, 88% and 86% of the maximum possible for the three sessions, close to the highest trading volumes that could have been observed. The data thus indicate “trade in high volumes<sup>10</sup> at prices at variance from intrinsic values”.<sup>11</sup>

[Figure 1 about here]

Both the CapTax and the NoSpec treatments reproduce the price bubbles observed in earlier studies. The bubbles in NoSpec cannot be due to speculation, because buying and reselling is not possible. The presence of bubbles in CapTax, in which speculation was possible but costly adds additional support for result 1. We do not claim that speculation does not occur in CapTax or in previous studies, only that the boom and crash price pattern would occur even without speculation. Since the formation of bubbles does not require speculation, the conjecture that all agents are rational but that the lack of common knowledge allows bubbles to form is refuted by the NoSpec data.

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<sup>9</sup> In NoSpec2 there were three sellers and four buyers, so that the total stock of X was 60 units.

<sup>10</sup> In the experiments of Smith et al., in which the subjects were inexperienced with a bubble and crash, total volume over the sessions ranged from 3.17 to 10 times the total stock of units.

Result 2 is concerned with two other empirical patterns in prices observed in earlier work. The first pattern is that the change in price from the current period to the next can be predicted by excess of the number of offers to buy over the number of offers to sell in the current period. This effect was also identified by Smith et al. (1988), Williams et al. (1993) and Porter and Smith (1995) who observe that the effect occurs most prominently in markets in which bubbles are most pronounced. They interpreted a positive difference between the number of offers to buy and the number of offers to sell as a reflection of capital gains expectations. The second pattern, observed by Smith et al. (1988) is that transaction volumes are greater during the boom phase of a market than during a crash phase. Result 2 shows that our CapTax and NoSpec data tend to reproduce subtle relationships between prices, volumes of exchange, and the number of offers to buy or sell, that were observed in previous studies.

**Result 2: Empirical patterns found in earlier studies are also observed in CapTax and NoSpec. Specifically, in both the CapTax and the NoSpec treatments, (a) we replicate the finding that, when a boom and crash occur, changes in prices from one period to the next are positively related to the excess number of offers to buy over offers to sell, and (b) we observe that the volume of trades is greater when prices are increasing than when they are decreasing.**

**Support for Result 2:** Consider 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 (bids) and  $O_{t-1}$  is the total number of offers to sell in period  $t-1$ . In the estimation, a multi-unit offer for  $k$  units is treated as  $k$  separate offers. The coefficient  $a$  is the overall trend in prices. The coefficient  $b$  indicates the effect of the difference between the number of bids and offers 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) the greater the excess demand in period  $t-1$ . For 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  $-30$  and  $b$  would equal  $0$ . Table 3 contains the OLS estimated values for  $a$  and  $b$  for the 6 sessions.

[Table 3: About Here]

Two out of six individual sessions, as well as the pooled data from both treatments have significantly positive estimates of  $\hat{b}$ . In the five of the six sessions the coefficient is positive in sign. The two sessions in which  $\hat{b}$  is significant, CapTax2 and NoSpec1, and the sessions in which  $\hat{b}$  is nearly significant at the 10% level, CapTax3 and NoSpec2, are the sessions in which the most pronounced booms and crashes were observed, as can be seen in figure 1. This is consistent with previous work (Smith et al. (1988) report a significantly positive  $\hat{b}$  in 12 of 22 sessions, but in 11 of 14 sessions which they classify as bubble-crash markets). Thus, for both of our treatments, we support the hypothesis that when a bubble occurs, the changes in prices from one period to the next are related to the relative number of bids and offers, in agreement with previous studies. None of our  $\hat{a}$  estimates are significantly different from the expected single-period dividend of  $-30$  at the 10% level, also in agreement with previous studies.

Smith et al. observed that the transaction volume tended to be greater during boom periods than during crashes. Because the definition of a crash is somewhat arbitrary, we evaluate the relationship between the direction of price movements and volumes by considering the correlation between the variable  $\langle P_t - P_{t-1} \rangle$ , the price change from one period to the next, and the volume of units exchanged in period  $t$ . This correlation equals  $.0768$ ,  $.1147$ , and  $.2078$  in CapTax1, CapTax2, and Captax3, respectively. The correlation is  $.5074$ ,  $.607$ , and  $-.1470$  in NoSpec1, NoSpec2, and NoSpec3. Thus, in five

of the six sessions, the volume transacted is positively related to the direction of price movements. Volume is higher when prices are increasing. □

The importance of result 2 lies in the fact that subtle empirical patterns observed in previous studies can be reproduced without the possibility of speculation. This lends further support to the idea that the patterns in the data observed in previous studies are not due to speculation. It also indicates that a positive difference between the number of offers to buy and offers to sell is not only a reflection of the expectation of future capital gains. Result 2 suggests that there are common underlying causes of the differences between transaction prices and fundamental values in CapTax, NoSpec, and previous studies. Agents are prone to exhibit irrational behaviors, in the form of unprofitable transactions, and these irrational behaviors themselves create the boom and crash price dynamics. Result 3 below documents two phenomena which are evidence of obvious errors in decision making.

The first phenomenon documented in result 3 is the large number of purchases at prices higher than the fundamental value in NoSpec. The second phenomenon is an excess amount of trade occurring under NoSpec, in that buyers purchased almost all of the units held by the sellers over the course of the session. To see why this excess trade is evidence of irrational behavior, recall that if all agents are risk neutral, the fact that the dividend is identical for each agent implies that there are no gains from trade. Therefore, the theoretical prediction is for no trade to occur (no trade if it is postulated that trade involves a small transaction cost, otherwise trade could occur at the fundamental value, but with no gains from trade resulting). If agents had heterogeneous risk attitudes, then trade would occur in NoSpec. However, one would expect that the final holdings of buyers and sellers would on average be approximately the same, because there is no reason to suppose that sellers would be more or less risk averse than buyers on average.

### **Result 3: Systematic irrational behavior accompanies the presence of bubbles.**

**Support for Result 3:** In NoSpec, many trades occurred at prices higher than fundamental values. In session NoSpec1 and NoSpec2, 60.94% and 64.15% of all trades occurred at prices greater than fundamental values. In session NoSpec3, every trade in the session occurred at a price greater than the fundamental value. In the pooled data from all NoSpec sessions, 76.3% of all transactions involved a purchase at a price higher than the fundamental value, which was dominated for risk averse or risk-neutral traders.

In NoSpec1 and NoSpec2, the final inventory at the end of the experiment of every buyer exceeded the final inventory of every seller. Over the course of the session, every single buyer purchased a quantity of units which exceeded the total stock of units divided by the number of subjects, and therefore held more units at the end of the session than the average amount held by all subjects. Conversely each seller sold more than the average per-capita holding, and this had a final inventory less than the average amount. In session NoSpec3, the final inventory of buyers was 16, 20, 9 and 24 units of X for the four buyers respectively. For sellers, the final inventories were 0, 0, 11, and 0 units respectively, indicating that three of the four sellers had lower final inventory than any buyer and three of the four buyers had higher final inventory than and seller. □

The large volume of trade observed in NoSpec is difficult to reconcile with theory, and it is natural to look for the cause of the high volume in the methodology of this particular experiment. *The active participation hypothesis*, discussed in section four, is a conjecture that subjects are predisposed to participate actively in the experiment in some manner. Because trading in the asset market is the only activity available, subjects may conclude trades even when it is not in their best interest to do so. A series of experiments, called the TwoMarket experiments, in which the asset market is one of two markets operating, is used to test this conjecture. The active participation hypothesis suggests that there would be less trade in the asset market when two markets are operating than when the asset market is the only market operating.

## 4 The Two Market Sessions

### 4.1 The Active Participation Hypothesis

One possible explanation for the presence of such large volumes of trade is in the methodology of the experiment. Consider a human participant in this type of experimental asset market, who is recruited to participate in an experiment, and is trained in the mechanics of buying and selling. The subject may be predisposed to participate actively in the experiment in some manner and to use his training. That is, the subject may believe that he is “supposed” to buy and sell because he is placed in a market environment in the role of a trader. He does not believe that he was recruited for the experiment to do nothing. If that is the case, then a subject, when faced with a choice between an unprofitable transaction and not trading, may choose the unprofitable transaction. We will use the term *the active participation hypothesis* to refer to the hypothesis that *a fraction of the volume in the markets is related to the fact that participation in the asset market is the only activity available for subjects.*

The active participation hypothesis implies that changes in the protocol of the experiment, which have no impact on theoretical predictions, but which allow the subjects to engage in an alternate activity, would reduce the amount of trade in the asset market. We test this hypothesis with our TwoMarket treatment, which permits subjects to participate actively in the experiment outside of the asset market. In the TwoMarket treatment, as described in section two, we embed the asset market in a larger experimental economy. There exists a second market operating simultaneously with the asset market. In one of the markets, a service called Y is traded. The market for Y is repeated each period under stationary supply and demand conditions as in Smith (1962), and thus contained profitable opportunities for participation in each period. In the competitive equilibrium of the Y market each agent had either two or three potentially profitable transactions available.

In the other market an asset was traded. All subjects could both buy and sell units in the asset market and there was no capital gains tax in effect. The asset market opened after the service market was already in operation for four periods (one practice period and three periods that counted), to ensure that

subjects were already participating in the service market. As indicated in section 2, in our instructions to the subjects, it was emphasized that participation in the asset market was optional. A subject who felt compelled to make transactions could actively participate in the market for Y and not affect the market for X. The data are interpreted to support the active participation hypothesis, if the volume of trade declines in the asset market in the TwoMarket sessions relative to benchmark experiments in which the asset market is the only market operating. If the active participation hypothesis is false, there is no reason to suppose any difference in quantities transacted.

#### **4.2. Results from the TwoMarket Treatment**

Figure 2 shows the time series of transaction prices in the TwoMarket treatment.<sup>11</sup> Tables 4a and 4b below show the actual volumes by period in the four sessions. In the last two columns, we include the quantities transacted in baseline experiments, called OneMarket, in which the asset market was the only market, and the initial endowment of X and cash was the same as in TwoMarket. The OneMarket sessions provide a benchmark to establish whether the TwoMarket treatment lowers quantity traded. Result 4 gives our characterization of the price and quantity patterns in the data.

[Tables 4a and 4b: About Here]

**Result 4: In the TwoMarket treatment the volumes traded in the markets are lower than under CapTax or under OneMarket. In TwoMarket, the time series of transaction prices follows the boom and crash pattern.**

**Support for Result 4:** The data in tables 4a and 4b indicate that the volumes in TwoMarket are between 45 and 153 percent of the total stock of units, much lower than in the CapTax and the OneMarket data

reported in the tables. The price patterns are illustrated in figures 2 and 3. In figure 2, in all four sessions the median transaction prices are higher than the fundamental values in each period until at least period 14. In some of the sessions the prices fall rapidly toward the fundamental values in late periods. For example, a crash is observed in period 14 of session TwoMkt3 and TwoMkt4. In figure 3, the TwoMarket5 data shows prices higher than fundamental values in periods 3 and 4 as well as during periods 6-12. In TwoMarket6, there is a brief bubble in periods 5 and 6. □

Result 4 indicates that the existence of the second market and the changes in the instructions indicating that participation was optional, drastically reduced participation in the asset market, in a manner consistent with the active participation hypothesis. In addition to the total volume of trade, the number of buyers making purchases and sales in each period in the asset market differs between the OneMarket and the TwoMarket sessions. In an average period of OneMarket, 85% of the subjects bought or sold at least one unit, and 58% did both. In contrast, in an average period in the TwoMarket sessions, 41% made some kind of transaction and 8% made both purchases and sales. Thus the level of participation in the asset market is influenced by subtle features of the experimental design. However, because the boom and crash price dynamics are observed in TwoMarket, “excess volume” of the type observed in NoSpec is not at the origin of the boom and crash price pattern.

Result 5 considers patterns in the data in the market for Y. In previous studies, double auction markets for services have been shown to reliably converge to the competitive equilibrium. We observe the same pattern here.

**Result 5: In the market for Y, prices and quantities exchanged converge to the competitive equilibrium, despite the departures of prices from fundamental values in the X market. Irrational behavior in the asset market is a property of the market environment, not of the subjects.**

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<sup>11</sup> In figure 2, when no trade occurred during a session, the value indicated as the median price is a linear interpolation of the median prices of the immediately preceding and following periods.

**Support for Result 5:** The median transaction price by period in the market for Y in the pooled data of the six TwoMarket sessions are within 5% of the competitive equilibrium price for 98% of the periods after period 2 (88 out of 90 periods). The market-level quantity traded differed by one unit or less from the competitive equilibrium level after period 2 in 67% of the periods in the pooled data (60 out of 90 periods). At the level of the individual buyer and seller, end of period holdings differed from the competitive equilibrium level by one unit or less in 92% of the 628 individual level observations after period 2. □

Result 5 shows that, even while the service market converges to the equilibrium, the asset market, in which the same participants are interacting at the same time as in the service market, produces prices that are very far from the fundamental value of the asset. Prices in one market can correspond closely to the theoretical prediction while they differ greatly in another market. In the service market, individual behavior resembles behavior generated by optimizing agents. Thus the irrational behavior documented in result 3 lies not with the subjects themselves, but with properties of the asset market.

## **5. Summary and Concluding Remarks**

Why do bubbles occur in experimental asset markets? The existence of the phenomenon has been attributed to the lack of common knowledge of rationality and consequent speculation. If this theory is accepted, then the existence of speculative opportunities is a necessary condition for the existence of bubbles. The research reported here investigated the role of speculation in creating asset market bubbles.

The data provide strong evidence that the ability to speculate is not essential to creating the bubble-crash price dynamics. We make this claim based on the fact that we have been able to reproduce the empirical patterns of the previous studies discussed above even in the NoSpec treatment, in which there is no the possibility of speculation. As in Smith et al. (1988), we observe bubbles in our NoSpec and CapTax treatments, characterized by (a) prices lower than fundamental values at the beginning of all but

one of the sessions, (b) booms in every session and (c) crashes in some of the sessions. We also observe (d) that the movement of prices from one period to the next is related to the difference between the number of offers to buy and offers to sell, and (e) that trading volume is greater when prices are increasing than when they are decreasing. The final piece of evidence is (f) that the 50% capital gains tax in the CapTax does not reduce the tendency for bubbles to occur. Thus the pursuit of capital gains is not the *only* force driving the asset prices to deviate from fundamental values.

We observe behavior that has substantial elements of irrationality. In our NoSpec data, many traders make purchases at prices higher than fundamental values, but not because they are rational traders who expect to be able to sell at a higher price, since even if prices increase further later in the experiment, the purchaser is not better off. Of course, it may be the case that rationality is not common knowledge, in that traders believe that other traders make errors, such as making purchases at prices above fundamental values when it not in their interest to do so. However these beliefs appear to be justified in that many purchases at prices above fundamentals are observed under NoSpec.

In the NoSpec treatment, we also observe large transaction volume, which is difficult to reconcile with theory. To explain the high volume, we formulated a conjecture called the Active Participation Hypothesis, which asserts that some of trades in the asset market are related to the fact that there are no other activities available for subjects in the experiment. Subjects prefer making purchases and sales rather than doing nothing. The hypothesis is based on the common sense notion that if a participant is trained to buy and sell at the beginning of an experimental session, he may believe that buying and selling is in itself one of the objectives in the experiment. The TwoMarket treatment was designed to try to reduce the level of this phenomenon. Volume decreased sharply in TwoMarket, supporting the active participation hypothesis. Though the volume in TwoMarket was low, the prices continued to follow the boom and crash pattern.

We do not interpret our data as suggesting that the conscious pursuit of capital gains does not occur in experiments of this type. Our claim is merely that speculation is not *necessary* to create large

deviations from fundamental values, that follow the boom and crash pattern. The data show that any explanation of the bubble phenomenon, which relies on the possibility of speculation, does not provide a complete account. Thus, the hypothesis that the traders are rational, and that the bubble is due to the fact that this rationality is not common knowledge, can not be the whole story behind the bubbles.

A full investigation of the reasons behind the bubble phenomenon is far beyond the scope of a single set of experiments or a single paper. However, a brief description of what we think that we have seen might be useful. Bubbles and crashes have stages not previously recognized. The beginning involves some confusion and irrationality. Subjects may not fully understand the nature of the task or the structure of the asset, especially when first exposed to it. This lack of understanding facilitates particular types of irrational behavior, which allow for the formation of the bubble. Thus, when the asset market starts, not only is there a lack of common knowledge of rationality, there is a lack of rationality itself. When the experiment is modified, as in our TwoMarket treatment, so that subjects are not “compelled” to participate in the asset market, they avoid it, suggesting that subjects have difficulty in determining profitable strategies in the asset market.

Over the course of the experiment, the realization of lack of rationality promotes speculation as held by the existing theory. Then experience and practice removes the irrationality as subject confusion is reduced. Once the irrationality has been removed, this new information about the changes in the environment must be transmitted to the market. If our view is correct, that transmission takes the form of a crash. That is, the market crash is the vehicle through which the newly established rationality becomes common knowledge.

The duration of a bubble in the NoSpec treatment measures the length of time that irrationality is present among market participants. This is because bubbles in NoSpec must indicate actual irrationality, not the lack of common knowledge of rationality. Because there is no evidence that the length of time the bubbles last is any shorter in NoSpec, than in other treatments in which speculation is possible, the period of time in which rationality is present but is not common knowledge is likely to be at most very short.

Therefore, market crashes would indicate the beginning of the presence of rationality itself among all active market participants, rather than the beginning of the presence of the common knowledge of already-present rationality.

The importance of instructions and the issue of subject understanding has certainly not escaped the attention of experimental economists (see for example Hoffman et al., 1996). However, because the experimental procedures followed in asset market experiments were so carefully developed and because the theory of the lack of common knowledge of rationality is so compelling, the issue of procedures has not been closely scrutinized. The research reported here suggests that the phenomenon of bubbles and crashes could have such origins. If this assessment is correct, then the research is able to proceed along somewhat different theoretical lines to attempt to understand the general process of price discovery and the dynamics of market adjustments. In particular, the bubbles and crashes provide a rich opportunity to study the nature of learning and mistakes.

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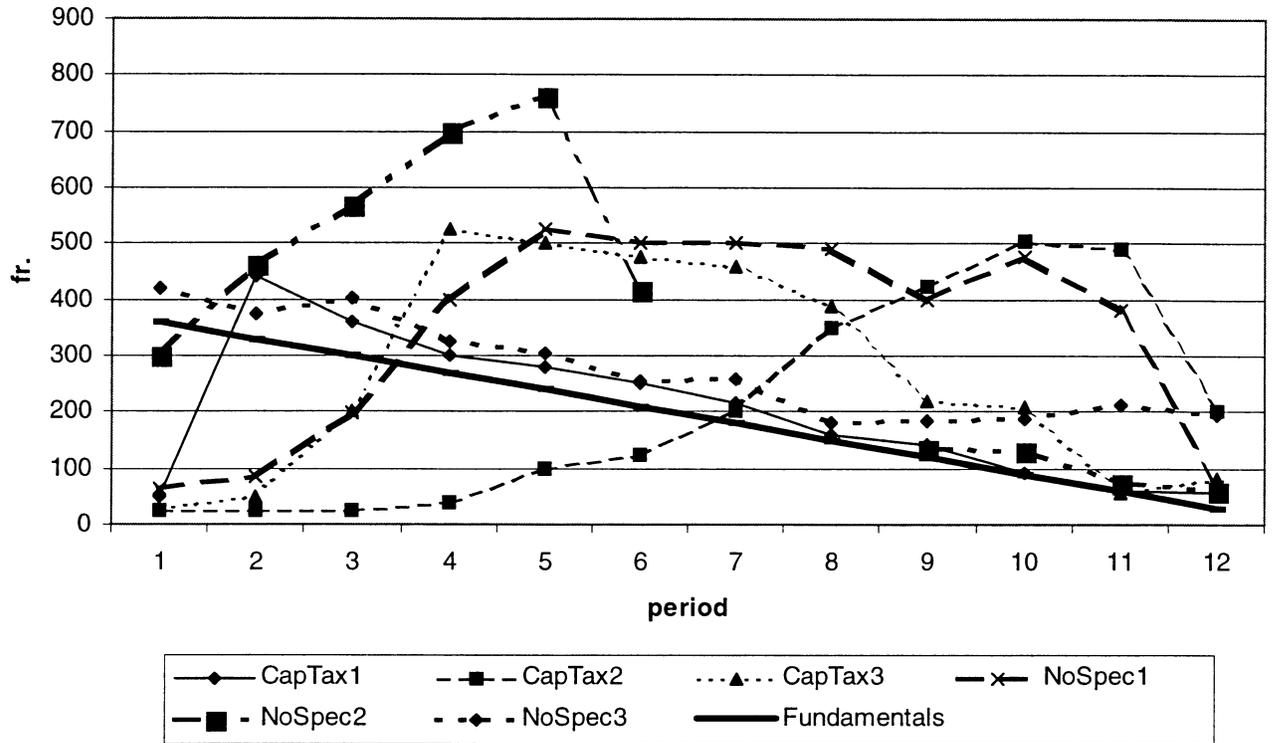
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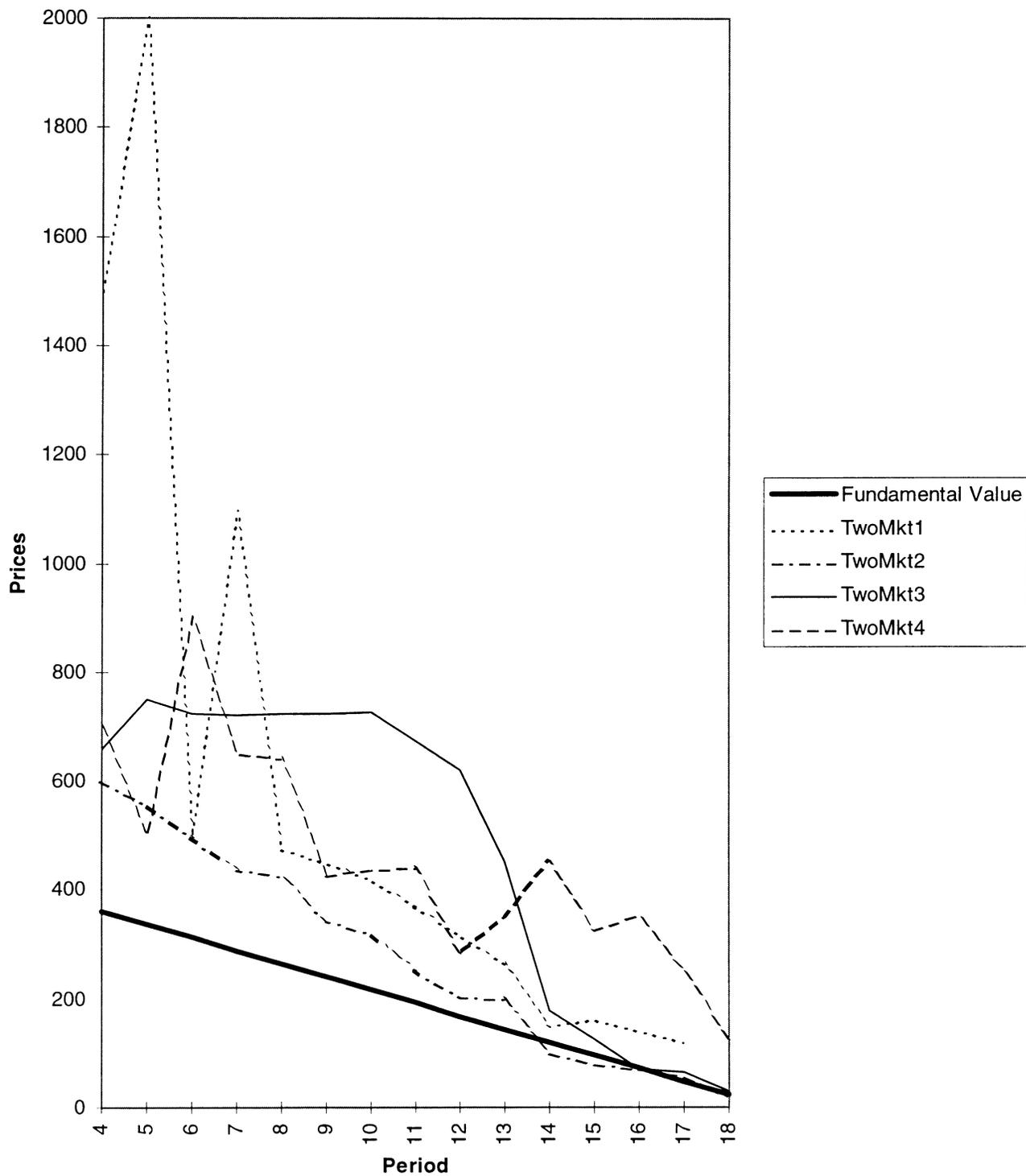
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**Figure 1: Time Series of Median Transaction Prices: Nopec and CapTax Treatments**



**Figure 2: Time Series of Median Prices by Period: Two Market Treatment: 15 Period Asset Markets**



**Figure 3: Differences Between Median Period Price and Fundamental Value: Two Market Treatment: 12 Period Asset Markets**

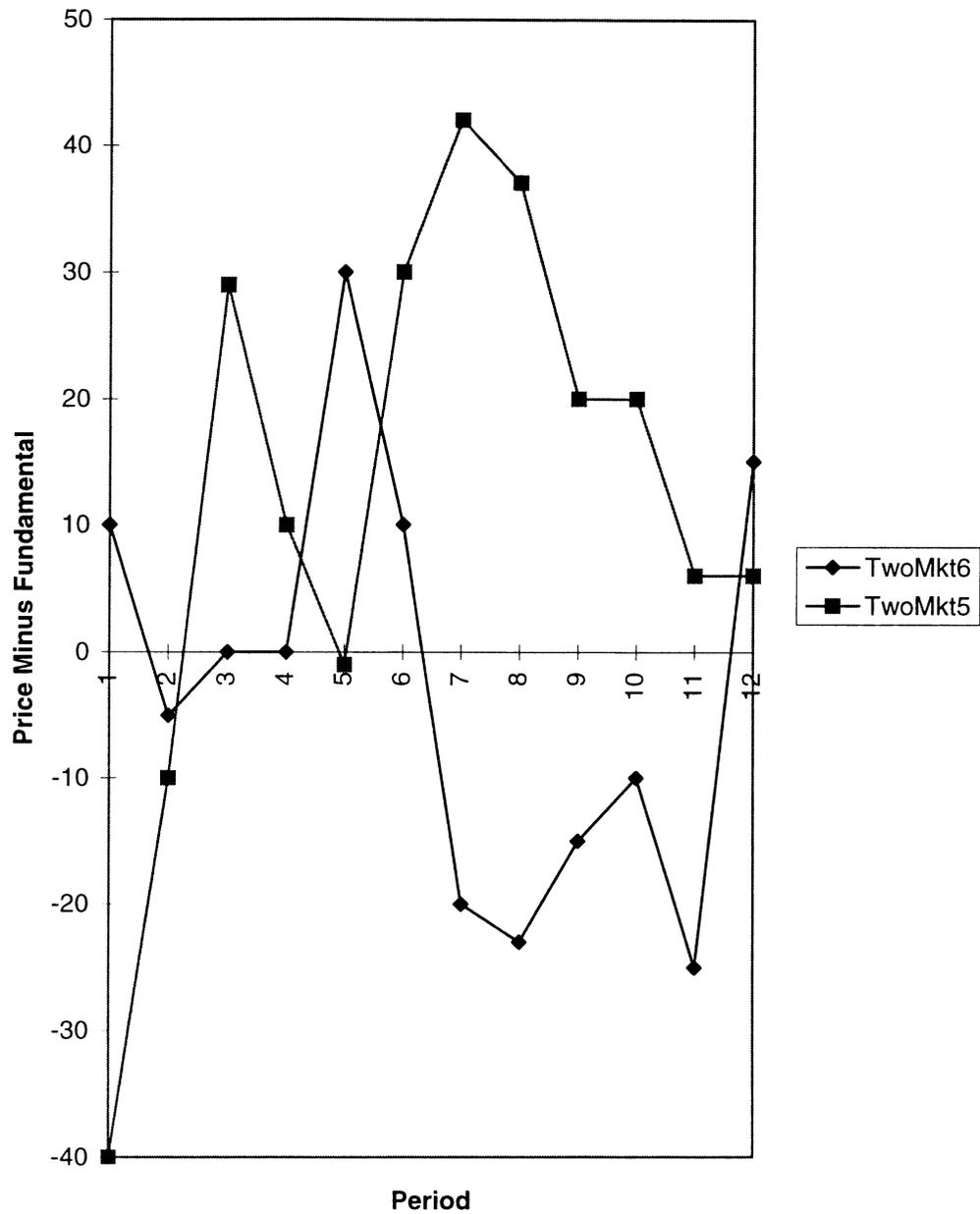


Table 1: Summary of Basic Information of the Six Sessions

<i>Session</i>	<i>Initial Working Capital</i>	<i>Initial Asset Endowment</i>	<i>Number of Subjects</i>	<i>Conversion Rate</i>	<i>Number of Periods</i> <sup>12</sup>
CapTax1	5,000/trader	10/trader	7	130fr/\$	13
CapTax2	5,000/trader	10/trader	7	130fr/\$	13
CapTax3	5,000/trader	10/trader	9	130fr/\$	13
NoSpec1	7,200/buyer	20/seller	8	300fr/\$	13
NoSpec2	7,200/buyer	20/seller	7	300fr/\$	13
NoSpec3	7,200/buyer	20/seller	8	300fr/\$	13
TwoMkt1	100,000/trader	10/trader	6	200fr/\$	19
TwoMkt2	100,000/trader	10/trader	8	200fr/\$	19
TwoMkt3	100,000/trader	10/trader	7	200fr/\$	19
TwoMkt4	100,000/trader	10/trader	8	200fr/\$	19
TwoMkt5	100,000/trader	10/trader	7	200fr/\$	16
TwoMkt6 <sup>13</sup>	100,000/trader	10/trader	8	200fr/\$	16
OneMkt1	100,000/trader	10/trader	8	200fr/\$	16
OneMkt2	100,000/trader	10/trader	8	200fr/\$	13
OneMkt3	100,000/trader	10/trader	7	200fr/\$	13

<sup>12</sup> The number of periods given in the table includes the one practice period in each session, which did not count toward subject's final earnings.

<sup>13</sup> In the session TwoMarket6 there existed a final buyout value of 80 units of experimental currency.

Table 2: Transaction Volumes

<i>Period</i>	<i>CapTax 1</i>	<i>CapTax 2</i>	<i>CapTax 3</i>	<i>NoSpec 1</i>	<i>NoSpec 2</i>	<i>NoSpec 3</i>
1	39	35	94	12	19	19
2	6	13	22	3	10	16
3	9	15	9	20	2	6
4	6	32	24	11	5	2
5	5	18	12	2	2	4
6	3	51	22	5	1	4
7	8	26	14	1	0	1
8	5	7	5	1	0	4
9	4	16	19	4	6	4
10	2	18	6	3	2	5
11	1	11	12	1	2	2
12	7	11	46	1	4	2
Total	95	253	285	64	53	69
As % of Total Stock	136	361	317	80	88	86

Table 3: OLS Estimated Values for  $a$  and  $b$

	<i>CapTax1</i>	<i>CapTax2</i>	<i>CapTax3</i>	<i>NoSpec1</i>	<i>NoSpec2</i>	<i>NoSpec3</i>	<i>CapTax</i>	<i>NoSpec</i>
$\hat{a}$	-1.34 (42.30)	-19.10 (34.64)	-29.15 (42.63)	-61.07 (41.75)	-88.48 (55.41)	-63.17 (58.89)	-14.01 (21.66)	-65.84 (21.77)
$\hat{b}$	-0.68 (3.12)	0.28* (0.14)	0.28 (0.16)	0.57** (0.23)	0.82 (0.48)	0.71 (0.96)	0.26** (0.10)	0.63** (0.17)
$R^2$	.0053	.3032	.2478	.4093	.166	.0573	.1657	.2883

\* Significantly positive at 10% level.

\*\* Significantly positive at 5% level.

*Table 4a: Transaction Volumes by Period: TwoMarket Treatment:  
15 Period Asset Markets*

<i>Period</i>	<i>TwoMkt1</i>	<i>TwoMkt2</i>	<i>TwoMkt3</i>	<i>TwoMkt4</i>	<i>OneMkt1</i>
4	11	20	4	5	54
5	7	5	5	3	43
6	1	2	12	2	39
7	2	4	3	5	42
8	1	1	2	8	34
9	0	2	0	9	16
10	1	1	7	4	16
11	0	2	0	3	16
12	0	1	2	4	22
13	0	5	2	10	10
14	2	3	5	3	11
15	1	8	0	7	16
16	0	3	4	3	5
17	1	3	5	6	1
18	0	14	15	50	0
Total	27	74	66	122	325
As % of Stock	45	106	94	153	464

*Table 4b: Transaction Volumes by Period: TwoMarket Treatment:  
12 Period Asset Markets*

<i>Period</i>	<i>TwoMkt5</i>	<i>TwoMkt6</i>	<i>OneMkt2</i>	<i>OneMkt3</i>
4	6	3	42	79
5	3	5	39	104
6	2	1	39	32
7	3	1	6	42
8	3	1	20	32
9	1	6	12	33
10	3	3	26	75
11	2	10	17	54
12	2	8	15	81
13	3	9	17	58
14	5	1	15	99
15	2	4	17	67
Total	35	52	265	756
As % of Stock	50	65	331	1080

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