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# NONSPECULATIVE BUBBLES IN EXPERIMENTAL ASSET MARKETS: LACK OF COMMON KNOWLEDGE OF RATIONALITY VS. ACTUAL IRRATIONALITY

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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. Much of the trading activity that accompanies bubble formation, in markets where speculation is possible, is due to the fact that there is no other activity available for participants in the experiment.

KEYWORDS: Experiment, bubble, asset market, speculation.

## 1. INTRODUCTION

ONE OF THE MOST REMARKABLE RESULTS from research on experimental asset markets[2] is the discovery, due to Smith, Suchanek, and Williams (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."[3] 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 (2000), Porter and Smith (1995), Van Boening, Williams, and LeMaster (1993).[4] In all of these studies, markets are created for

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[2] See Sunder (1995) or Duxbury (1995) for surveys of the experimental research on asset markets.

[3] This definition is given by King et al. (1993).

[4] 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 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 (2000) 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 payoffs and find that the futures market somewhat reduced the extent of the deviations from fundamental values but the certain dividend payoffs did not. Van Boening, Williams, and LeMaster (1993) study asset markets organized as call markets (two-sided sealed-bid auctions), and also observe price bubbles and crashes. The only manipulation that has been shown to reliably eliminate bubbles and crashes is prior participation in at least two sessions in the same type of asset market.

assets with a lifetime of a finite 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, Suchanek, and Williams (1988) have been described as striking (Sunder (1995)) because of their sharp contrast with theoretical predictions and with experiments in which shorter-lived assets are traded.[5]

Explaining the patterns in the data presents a theoretical challenge.[6] 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, Suchanek, and Williams (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 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.[7] 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

[5] See the survey by Sunder (1995) and the references therein.

[6] 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. Porter and Smith (1995) tested the hypothesis that risk aversion was the cause of the deviations from fundamental values. In this study the uncertainty about the dividend process was removed by 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.

[7] A similar argument was also offered as an explanation of laboratory asset market bubbles by Plott (1991).

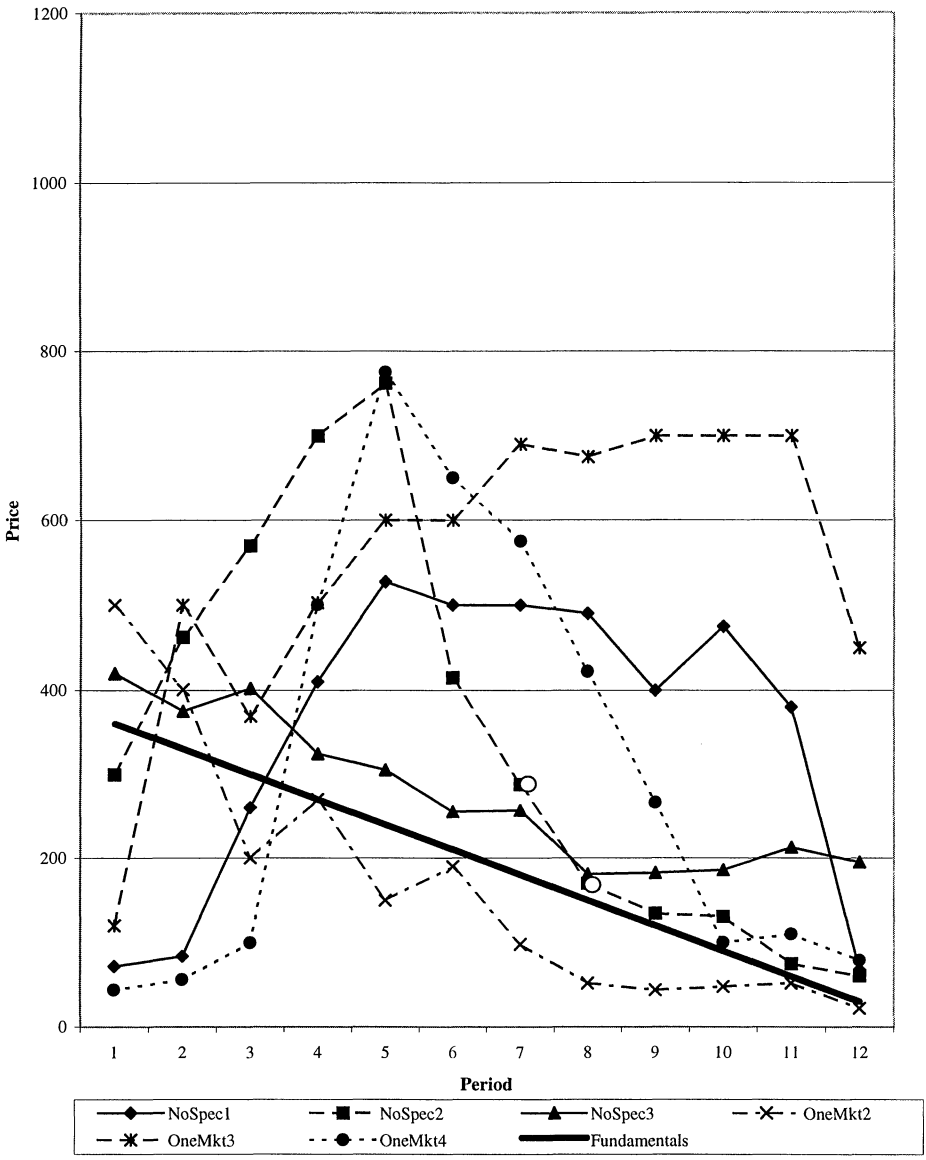


FIGURE 1.—Time series of median transaction prices by period: NoSpec and 12-Period OneMarket sessions.

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 of 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 group of experiments reported in this paper, called the NoSpec treatment, considers this prediction of the speculative hypothesis. Markets are constructed that have a structure similar to those in which bubbles and crashes have been observed. In the NoSpec treatment, the ability to speculate is completely removed. 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 possible 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 would be consistent with the argument 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 that 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.

As we report below in detail, large departures of prices from fundamental values at high volumes are observed in NoSpec. Furthermore, the pattern of prices has the boom and crash features observed by Smith, Suchanek, and Williams (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 fact that the rationality of participants is not common knowledge is well-founded, in that systematic errors in decision making tend to occur, such as purchases at prices higher than the maximum possible dividend stream and sales at prices lower than the minimum possible dividend stream. It is the actual presence of "irrational" behavior and not the lack of common knowledge of rationality that causes the bubbles we observe in NoSpec.

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 4 of this paper, we report on two series of follow-up experiments, called the TwoMarket and TwoMarket/NoSpec treatments, which were designed to explore the origin of this "excess volume." These two treat-

ments test the *Active Participation Hypothesis*, a hypothesis that much of the trading activity in the asset market is due to the fact that the protocol of the experiment encourages subjects to participate actively in some manner. Since no activity is available other than to participate in the asset market, excess trade occurs.

In the TwoMarket treatment there is another market operating simultaneously along with the asset market and buying for resale is permitted in the asset market. The instructions are modified to emphasize to the subjects that participation in the asset market is optional. In TwoMarket, the volume of trade in the asset market is low relative to benchmark experiments in which the asset market is the only market operating, supporting the hypothesis. However, in TwoMarket, prices also deviate considerably from the fundamental values in a majority of the sessions, 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 all factors that can cause price bubbles to arise.

The TwoMarket/NoSpec treatment is identical to the TwoMarket treatment, except that, as in NoSpec, buying in the asset market for resale is not permitted. In TwoMarket/NoSpec, the volume of trade is not significantly different from the level that would be observed if buyers and sellers had equal risk attitudes, indicating the absence of excess volume. Adding the second market reduces the incidence of the types of errors observed in NoSpec, though it does not eliminate the possibility of a bubble. The results from TwoMarket and TwoMarket/NoSpec indicate that much of the trading activity in the asset markets, including many of the errors that are observed under NoSpec, is related to the Active Participation Hypothesis.

In Section 2 we describe the design and procedures of the NoSpec and TwoMarket treatments. In Section 3 we report the results from the NoSpec treatment. In Section 4 we describe the results of the TwoMarket and TwoMarket/NoSpec treatments, and in Section 5 we list and explain our conclusions.

## 2. THE EXPERIMENTAL DESIGN

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

Summary information about each of the sixteen sessions of the experiment is given in Table I. 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 in a given session and known to the subjects in advance. The conversion rates in each session are indicated in Table I. All of the sessions were conducted at Purdue University, Indiana, USA, between September, 1995 and June, 1999. All of the subjects were undergraduate students, who had not participated in any previous research experiments, though all had previous experience with the

TABLE I

SUMMARY OF BASIC INFORMATION ABOUT THE SESSIONS

| Session | Initial Working Capital | Initial Asset Endowment | Number of Subjects | Conversion Rate | Possible Dividend | Number of Periods[a] |
|---|---|---|---|---|---|---|
| NoSpec1 | 7,200/buyer | 20/seller | 8 | 300fr/$ | 20, 40 | 12 |
| NoSpec2 | 7,200/buyer | 20/seller | 7 | 300fr/$ | 20, 40 | 12 |
| NoSpec3 | 7,200/buyer | 20/seller | 8 | 300fr/$ | 20, 40 | 12 |
| TwoMkt1 | 100,000/trader | 10/trader | 6 | 200fr/$ | 0, 8, 28, 60 | 18 |
| TwoMkt2 | 100,000/trader | 10/trader | 8 | 200fr/$ | 0, 8, 28, 60 | 18 |
| TwoMkt3 | 100,000/trader | 10/trader | 7 | 200fr/$ | 0, 8, 28, 60 | 18 |
| TwoMkt4 | 100,000/trader | 10/trader | 8 | 200fr/$ | 0, 8, 28, 60 | 18 |
| TwoMkt5[b] | 100,000/trader | 10/trader | 7 | 200fr/$ | 20, 40 | 15 |
| TwoMkt6 | 100,000/trader | 10/trader | 8 | 200fr/$ | 20, 40 | 15 |
| TMkt/NS1 | 100,000/trader | 20/seller | 14 | 200fr/$ | 20, 40 | 15 |
| TMkt/NS2 | 100,000/trader | 20/seller | 7 | 300fr/$ | 20, 40 | 15 |
| TMkt/NS3 | 100,000/trader | 20/seller | 15 | 300fr/$ | 20, 40 | 15 |
| OneMkt1 | 100,000/trader | 10/trader | 7 | 200fr/$ | 0, 8, 28, 60 | 15 |
| OneMkt2 | 100,000/trader | 10/trader | 7 | 200fr/$ | 20, 40 | 12 |
| OneMkt3 | 100,000/trader | 10/trader | 7 | 200fr/$ | 20, 40 | 12 |
| OneMkt4 | 10,000/trader | 10/trader | 7 | 500fr/$ | 20, 40 | 12 |

[a] The number of periods given in the table does not include the one practice period in each session, which did not count toward subjects' final earnings.
[b] In the session TwoMarket5 there existed a final buyout value of 80 units of experimental currency.

MUDA software in classroom exercises.[8] None of the subjects had any previous experience with asset markets, in either a classroom or a research setting. The sessions described in Table I lasted on average approximately 2 hours and 45 minutes.

### 2.2. *Procedures Specific to the NoSpec Sessions*

Each of the three NoSpec sessions consisted of 12 trading periods, not including one practice period, and each period lasted 4 minutes. 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 either buy 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

[8] In session TwoMarket/NoSpec2, four of the subjects had participated in a previous experiment for a different research project, which did not involve asset markets.

$X$ 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. (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 I, at the beginning of period 1, and then the market periods of the experiment took place.

In the NoSpec sessions, each subject was randomly assigned to be either a buyer or a seller.[9] 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 on hand at any point in time. The final earnings of each subject were equal to the total dividends he received from periods 1–12 plus the working capital he had remaining at the end of the experiment.

### 2.3. *Procedures Specific to the TwoMarket Treatment*

The six sessions conducted under the TwoMarket treatment had a duration of either 18 or 15 periods, depending on the session, not 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 at any time. 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

[9] Upon arriving at the session, subjects were told that they could be seated at whichever computer terminal they wanted. The computer terminals to be used by buyers and sellers had already been specified before the arrival of the subjects.

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 the $Y$ market and the other function was disabled. Each buyer was endowed with an inverse demand curve and each seller was endowed with an inventory of 10 units of $Y$ and an inverse supply curve.[10] 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.

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 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. A roll of a four-sided die determined the dividend 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.

[10] All buyers were endowed with one of two possible demand curves and all sellers were endowed with one of two possible supply curves. The actual marginal valuations for some buyers were 780, 730, 690, 670, 630, 600, 570 for the first through seventh units they purchased. For the rest of the buyers, the marginal valuations were 790, 730, 680, 670, 630, 600, and 570 for the first through seventh unit they purchased. The sellers had either marginal cost of 570, 620, 660, 690, 720, 750, and 780 for their first seven units or 560, 620, 670, 680, 720, 750, and 780 for their first seven units. In each session there was at least one buyer of each type and one seller of each type. If the number of buyers and sellers was equal, the competitive equilibrium quantity traded equaled three times the number of sellers and any price in the range 670–680 was a competitive equilibrium price. In the equilibrium, each buyer purchased three units and each seller sold three units. These same marginal valuations and costs were used in all sessions of the TwoMarket and TwoMarket/NoSpec treatments except for session TwoMarket1, in which the inverse demand and supply curves used in the experiment were identical to those above except that they were shifted downward by 40 units of currency. Competitive equilibrium profits in the $Y$ market, assuming a price of 675, the midpoint of the range of equilibrium prices, 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.

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. Final earnings equaled the sum of the earnings in the two markets minus initial working capital. 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.[11] (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 took place. These periods counted toward subjects' earnings. 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.

### 2.4. *Procedures Specific to the TwoMarket/NoSpec Treatment*

The three sessions conducted under the TwoMarket/NoSpec treatment consisted of 15 periods, not including the practice period. All of the procedures and timing of activity were identical to the TwoMarket treatment, except for the following differences. In the market for $X$ each agent was either a buyer or a seller of $X$ but not both, as in NoSpec. Subjects had the same role in both markets; a subject who was a buyer (seller) in the $Y$ market was also a buyer (seller) in the $X$ market. Each seller received an initial endowment of 20 units of $X$. The conversion rate was 300 francs to \$1 in sessions 2 and 3, and 200 francs to \$1 in session 1. Buyers were privately informed during period 4, the first period of operation of the asset market, that they would be given a bonus of \$24 (\$25 in session 1) on paper, in addition to their earnings in the markets. The bonus was designed to equalize expected earnings between buyers and sellers. The sellers' endowment of 20 units of $X$, each with an expected lifetime dividend stream of 360 francs, yielded an expected value of 7200 francs or, at a conversion rate of 300 francs = \$1, an expected value of \$24. The dividend process in the asset market was either 20 or 40 francs per period as in the NoSpec sessions, TwoMarket5, and TwoMarket6. Initial endowment of $X$ was

[11] Before the beginning of each session, each subject was required to sign a consent form indicating that if he finished the experiment with negative earnings, he would be required to pay the experimenter the amount of his losses. The design of the NoSpec treatment and session OneMarket4 ensured that losses were impossible in those sessions. Because bubbles occurred in those sessions, we are confident that the bubbles observed in this study are not caused by the possibility that subjects may have perceived their liability as limited.

20 for each seller and 0 for each buyer. In all other respects the procedures were identical to those of the TwoMarket treatment.

### 2.5. *Procedures Specific to the OneMarket Treatment*

The four 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. In sessions OneMarket2, OneMarket3, and OneMarket4,[12] 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 these three sessions can be compared with the data from NoSpec, TwoMarket5, TwoMarket6, and TwoMarket/NoSpec. 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 NOSPEC SESSIONS

The time series of median transaction prices by period in each of the NoSpec sessions, as well as the three comparable benchmark sessions OneMarket2, OneMarket3, and OneMarket4, are given in Figure 1.[13] In period 1 of two of the three NoSpec sessions, the median price is below the fundamental value, as it tends to be in the previous studies cited in Section 1. 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 until 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 NoSpec1. Session OneMarket3 exhibits a boom and a crash during period 12. Though the median price in period 12 of OneMarket3 is 450, the last 12 trades of the period occur at prices between 15 and 30. In OneMarket4, prices surge above the fundamental value in period 4, and remain well above the fundamental value until period 10. In session OneMarket2 a bubble is not observed, and after period 3 prices remain somewhat lower than the fundamental value. The main conclusion we draw from the NoSpec data is stated below as Result 1.

[12] In sessions OneMarket1–OneMarket3, each subject had an initial cash balance of 100,000 francs, which could be viewed as a loan to be paid back to the experimenter, as in the TwoMarket sessions. In OneMarket4, each subject had an initial cash balance of 10,000, which was a gift to the subjects. In OneMarket4, subjects added their final cash balances to their earnings at the end of the experiment, as they did in NoSpec.

[13] In Figures 1–4, when no trade occurred during a period, the value indicated as the median price is the midpoint between the final offer to buy and the final offer to sell submitted during the period. In the figures, hollow circles indicate periods with no transactions.

TABLE II

TRANSACTION VOLUMES[a] BY PERIOD: THE NOSPEC TREATMENT, ALL SESSIONS

| | NoSpec1 | | NoSpec2 | | NoSpec3 | |
|---|---|---|---|---|---|---|
| Period | Volume | $a/b/c$[b] | Volume | $a/b/c$ | Volume | $a/b/c$ |
| 1 | 12 | 12/0/0 | 19 | 5/14/0 | 19 | 0/19/0 |
| 2 | 3 | 3/0/0 | 10 | 0/3/7 | 16 | 0/15/1 |
| 3 | 20 | 10/10/0 | 2 | 0/0/2 | 6 | 0/3/3 |
| 4 | 11 | 0/0/11 | 5 | 0/0/5 | 2 | 0/2/0 |
| 5 | 2 | 0/0/2 | 2 | 0/0/2 | 4 | 0/4/0 |
| 6 | 5 | 0/0/5 | 1 | 0/0/1 | 4 | 0/3/1 |
| 7 | 1 | 0/0/1 | 0 | 0/0/0 | 1 | 0/0/1 |
| 8 | 1 | 0/0/1 | 0 | 0/0/0 | 4 | 0/4/0 |
| 9 | 4 | 0/0/4 | 6 | 0/6/0 | 4 | 0/0/4 |
| 10 | 3 | 0/0/3 | 2 | 0/0/2 | 5 | 0/0/5 |
| 11 | 1 | 0/0/1 | 2 | 0/2/0 | 2 | 0/0/2 |
| 12 | 1 | 0/0/1 | 4 | 0/1/3 | 2 | 0/0/2 |
| Total[c] | 64 | | 53 | | 69 | |
| Turnover[d] (in %) | 80 | | 88 | | 86 | |

[a] Volume = total number of units traded during a period. NoSpec1–NoSpec3 are the three individual sessions of the NoSpec treatment.

[b] $a/b/c$: $a$ = number of transactions at $P <$ Min $D$; $b$ = number of transactions at Min $D \leq P \leq$ Max $D$; $c$ = number of transactions at $P >$ Max $D$.

[c] Total = total number of trades in the entire session.

[d] Turnover = (total number of trades in session)/(sum of the inventory of asset of all agents).

RESULT 1: *The speculative hypothesis is not supported in our data. The pursuit of capital gains is not the only cause of experimental asset market bubbles.*

SUPPORT FOR RESULT 1: Bubbles, defined as "trade at high volumes at prices considerably at variance with fundamental values," occur even when purchase for resale is not possible. By this definition, a bubble occurs in each of the three NoSpec sessions. The fact that prices deviate from fundamental values is apparent from Figure 1. Figure 1 shows the median transaction price in each period for all three NoSpec sessions as well as the three comparable OneMarket sessions, OneMarket2–OneMarket4. In every session of NoSpec, the median transaction price exceeds the fundamental value by at least 30 francs for at least 5 consecutive periods. In NoSpec3, the median price is closest to the fundamental value in period 8, during which it exceeds the fundamental value by 31 francs. Median period prices are either less than 50% or more than 200% of the fundamental value in 25% (9 out of 36) of the periods in NoSpec. Median prices in these nine periods are well outside the interval between the maximum possible realization (4/3 of the fundamental value) and the minimum possible realization (2/3 of the fundamental value) of the future dividend stream.

The volume of trade in each period of each session is given in Table II in the columns labeled *Volume*. Since it is impossible to buy for resale in NoSpec, the highest possible trading volumes over the course of the sessions are 80 in

NoSpec1 and NoSpec3 and 60 in NoSpec2 (20 per seller).[14] The actual total volumes were 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[15] at prices at variance from intrinsic values.

The NoSpec treatment reproduces the price bubbles observed in earlier studies and replicated in our OneMarket treatment. The bubbles in NoSpec cannot be due to speculation, because buying and reselling is not possible. We do not claim that speculation does not occur in previous studies, only that the boom and crash price pattern can 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 of rationality allows bubbles to form is refuted by the NoSpec data.

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. Smith, Suchanek, and Williams (1988), King, Smith, Williams, and Van Boening (1993), and Porter and Smith (1995), who observed that the effect occurred most prominently in markets in which bubbles were most pronounced, also identified this effect. 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, Suchanek, and Williams (1988), is that transaction volumes are greater during the boom phase of a market than during a crash phase. Result 2 shows that our 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: *Relationships between prices, quantities traded, and the number of offers to buy and sell, that were observed in earlier experimental studies of asset markets, do not require the presence of speculation.*

SUPPORT FOR RESULT 2: Empirical patterns that are found in earlier studies are also observed in NoSpec. Specifically, (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

[14] In NoSpec2 there were three sellers and four buyers, so that the total stock of $X$ was 60 units.

[15] In the experiments of Smith, Suchanek, and Williams, 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.

TABLE III

ESTIMATED VALUES FOR $a$ AND $b$ IN NOSPEC[a]

| | NoSpec1 | NoSpec2 | NoSpec3 | NoSpec | OneMkt | Pooled Data |
|---|---|---|---|---|---|---|
| $\hat{a}$ | −62.17 | −88.48 | −63.17 | −64.42[c] | −40.42 | −38.32 |
| | (47.59) | (55.92) | (49.72) | (6.69) | (22.8) | (8.95) |
| $\hat{b}$ | 0.58[b] | 0.82[c] | 0.71 | .59[c] | .22[c] | .24[c] |
| | (0.20) | (0.20) | (0.88) | (.05) | (.005) | (.03) |
| $n$ | 11 | 11 | 11 | 33 | 33 | 66 |

[a] NoSpec consists of the pooled data from the three NoSpec sessions. OneMarket consists of the pooled data from the three sessions of OneMarket with 12-period asset markets. The pooled data column consists of the data from the three NoSpec sessions and the three 12-period OneMarket sessions. The columns labeled NoSpec1–NoSpec3 contain OLS estimates of the coefficients. The numbers in parentheses are the first order autocorrelation-consistent Newey-West standard errors. The last three columns contain estimates from a population-averaged panel data linear regression model, in which the standard errors are corrected for first-order autocorrelation and heteroscedasticity within sessions.

[b] Significant at 5% level (different from −30 for $a$ and from 0 for $b$).

[c] Significant at 1% level.

than when they are decreasing. 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, Suchanek, and Williams (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 III contains estimated values of $a$ and $b$ for the three sessions. In the table, the standard errors of the estimates are given in parentheses.[16]

[16] In addition to the estimates in Table III, we estimated the same equations using feasible GLS estimation. For the first three equations we assume an AR1 process in each session. For the last three equations, we estimate a panel data model, in which we assume a common coefficient of first order autocorrelation in all sessions and heteroscedasticity across sessions. We assume homoscedasticity within each session. All of the estimated coefficients using this alternative technique have the same sign as the estimates reported in Table III. In the first three equations, corresponding to the three individual sessions, none of the three estimated coefficients of the constant term $\hat{a}$ is significantly different from $-30$ at the 5% level. All three estimated $\hat{b}$ coefficients are significantly greater than zero at the 1% level. For the last three equations that use the pooled data from multiple sessions, each of the $\hat{b}$ estimates is significantly greater than zero at the 1% level. For the pooled OneMarket data and the pooled data from the two treatments, we cannot reject the hypothesis that the constant term differs from $-30$ at the 5% level of significance. For the pooled data from the NoSpec treatment the coefficient estimate of the constant term, $-59.00$, is borderline significantly different from $-30$ at the 5% level ($p = 0.0478$).

Two out of the three individual sessions of NoSpec, as well as the pooled data from all three sessions have significantly positive estimates of $\hat{b}$. In all three sessions the coefficient is positive in sign. The two sessions in which $\hat{b}$ is significant at the 5% level, NoSpec1 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, Suchanek, and Williams (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, 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 for the individual sessions of NoSpec are significantly different from the expected single-period expected dividend of $-30$ at the 5% level, also in agreement with previous studies.

The table also contains the estimates for the pooled data from the three sessions of OneMarket that had an identical dividend process as the NoSpec treatment, as well as for the pooled data from both treatments together. The estimates show that our OneMarket data replicate the pattern obtained by previous studies. The estimated intercept of $-40.42$ is not significantly different from $-30$ and the $\hat{b}$ term of .22 is significantly positive at the 1% level. The last column in the table contains the estimates for the pooled data from the NoSpec and the OneMarket treatments (6 sessions). For the pooled data, the estimated intercept, $-38.32$ is not significantly different from $-30$ and the $\hat{b}$ term is significantly greater than 0.

Smith, Suchanek, and Williams also 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 $t$. In the pooled OneMarket data, the correlation is .17. The correlations are .5947, .6073, $-.1470$, and .4581 in NoSpec1, NoSpec2, NoSpec3, and the pooled data from all three sessions, respectively. The correlations for sessions NoSpec1, NoSpec2, and for the pooled data are significant at the 10% level. Thus, in NoSpec sessions, the volume transacted tends to be positively related to the direction of price movements.

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 NoSpec, and in previous studies. Agents are prone to errors in decision making, in the form of particular types of unprof-

itable transactions, and it is these errors themselves that create the boom and crash price dynamics in NoSpec. Result 3 below documents three phenomena, which are evidence of obvious errors in decision making.

The first two phenomena documented in Result 3 are the large number of purchases at prices higher than the maximum possible dividend stream, and sales at below the minimum possible dividend stream, in NoSpec. These purchases and sales result in certain losses to one of the parties to the transaction. The third phenomenon is an excess amount of trade occurring under NoSpec. 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 errors in decision making, 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: *In our data, systematic errors in decision making accompany the presence of bubbles.*

SUPPORT FOR RESULT 3: Table II shows the total number of transactions in each of the three sessions of the NoSpec treatment in the row labeled *Total*. The percentage of the total stock of units exchanged during the session is given in the row labeled *Turnover*. The transactions are divided up into three groups in the table, those transactions that occurred (a) at prices below the minimum possible dividend stream, (b) at prices between the minimum and maximum possible dividend streams, and (c) at prices greater than the maximum possible dividend stream. The table shows that 30 of 186 total transactions (16.1%) occurred at prices below the minimum possible dividend stream and 70 of 186 (37.6%) occurred at prices greater than the maximum possible dividend stream. Overall, 9 of the 12 buyers in the three sessions made at least one purchase at a price higher than the maximum possible realization of the future dividend stream. 3 of the 11 sellers made sales at a price lower than the minimum possible realization of the future dividend stream. 5 agents made at least one dominated transaction in the last six periods of the session.

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 each 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 thus 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 any seller did.

The large volume of trade and purchases and sales at prices outside the feasible range of the future dividend stream observed in NoSpec may appear highly unusual to the reader. However, these patterns are very consistent with a substantial body of previous experimental research by other authors, who have studied the behavior of inexperienced subjects in experimental asset markets. The difference is that here, these transactions are inconsistent with the presence of speculation. Because the data are difficult to reconcile with theory, it is natural to conjecture that aspects of the methodology of this particular type of asset market experiment are the sources of the errors in decision making. The fact that a greater number of trades are made in NoSpec than are predicted, and that some of the trades are not individually rational for one side of the market, is consistent with a conjecture called *The Active Participation Hypothesis*. The Active Participation Hypothesis, discussed in Section 4, is a conjecture that subjects conclude trades in the asset market even when it is not in their best interest to do so, merely because trading in the asset market is the only activity available, and they are predisposed to participate actively in the experiment in some manner. Two experimental treatments, called the TwoMarket and the TwoMarket/NoSpec treatments, in which the asset market is one of two markets operating and the instructions are modified to emphasize that participation in the asset market is optional, are designed to test this conjecture. The Active Participation Hypothesis suggests that there would be less trade in the asset market in the TwoMarket treatment than in the OneMarket treatment.

## 4. THE TWOMARKET AND TWOMARKET / NOSPEC SESSIONS

### 4.1. *The Active Participation Hypothesis*

One possible explanation for the presence of such large volumes of trade lies 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, and to the fact that the protocol of the experiment encourages them to participate in some manner.*

The Active Participation Hypothesis implies that changes in the protocol of the experiment, which have no impact on theoretical predictions, but allow the subjects to engage in an alternative activity, would reduce the amount of trade in the asset market. We test this hypothesis for markets in which purchase for resale is possible with our TwoMarket treatment, which permits subjects to participate actively in the experiment outside of the asset market. We also test the hypothesis for markets in which purchase for resale is not possible with our TwoMarket/NoSpec treatment. In the TwoMarket and TwoMarket/NoSpec treatments, as described in Section 2, we embed the asset market in a larger experimental economy. In the TwoMarket and TwoMarket/NoSpec treatments, 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 makes two to four profitable transactions.

In the other market an asset was traded. In TwoMarket, all subjects could both buy and sell units in the asset market. In TwoMarket/NoSpec, each subject had the role of either a buyer or a seller in the asset market. 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 or TwoMarket/NoSpec 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 and TwoMarket/NoSpec Treatments*

Figures 2 and 3 show the time series of transaction prices in the TwoMarket treatment and in comparable OneMarket sessions. Tables IVA and IVB show the actual volumes by period in the ten sessions. In the tables, we include the quantities transacted in the baseline OneMarket experiments, in which the asset market was the only market operating, 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.

Estimates of the effects of the different treatments on turnover by period and on the deviation of median period price from the fundamental by period are

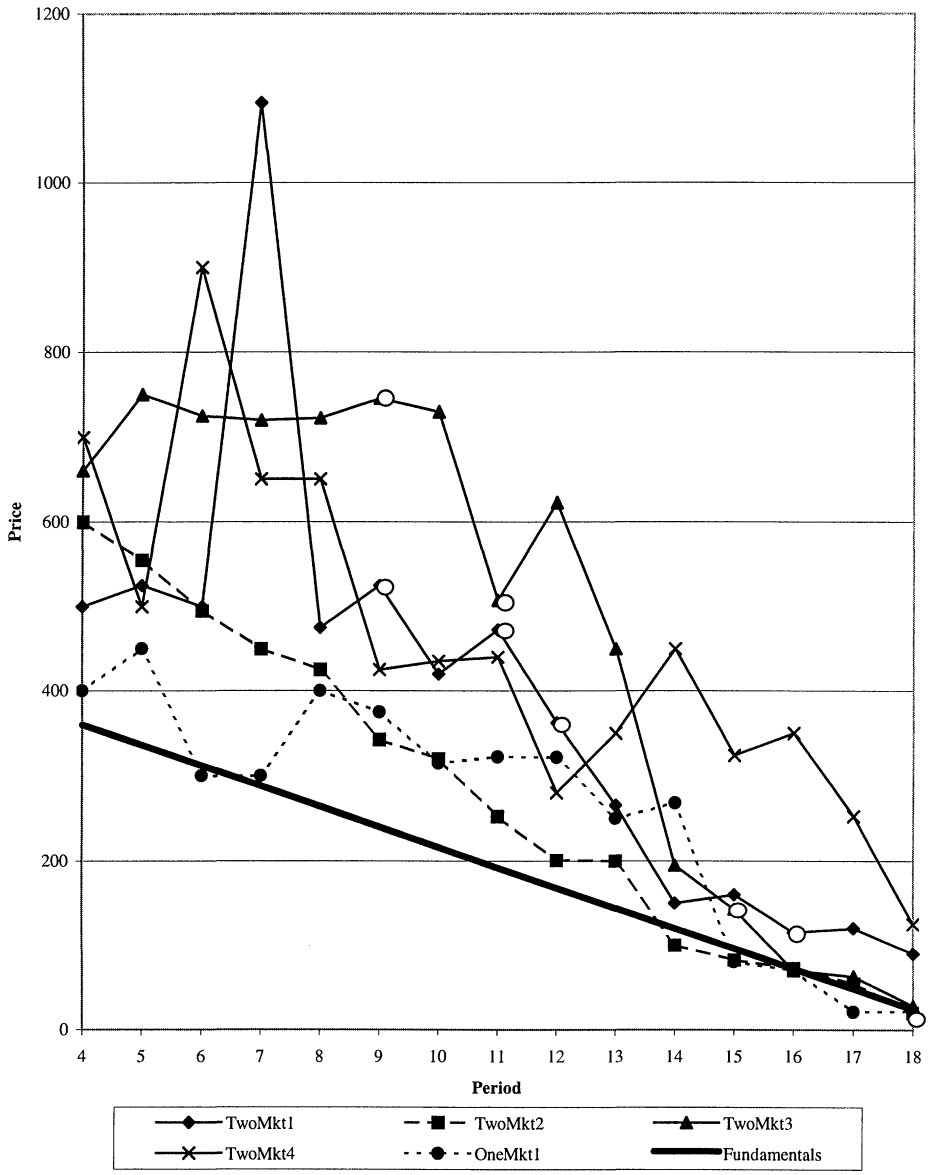


FIGURE 2.—Time series of median transaction prices by period: 15-Period Asset Markets, OneMarket and TwoMarket treatments.

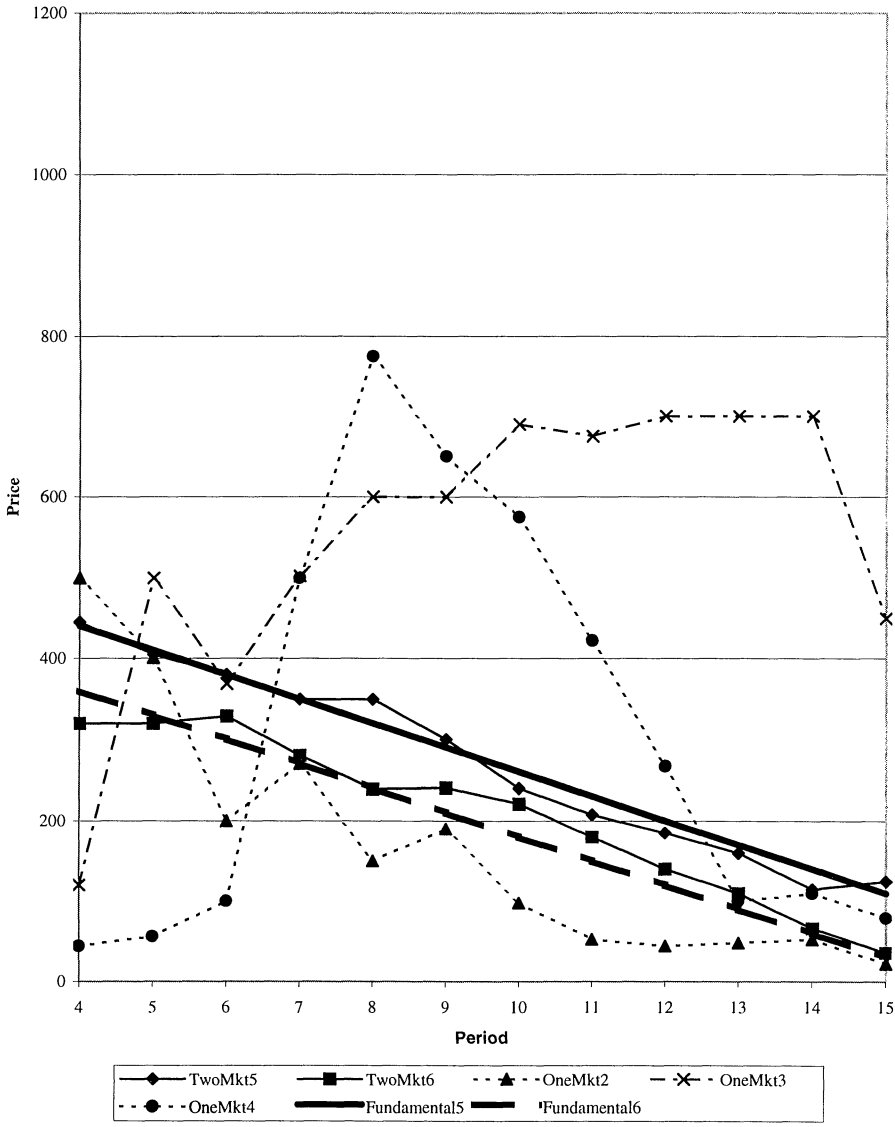


FIGURE 3.—Time series of median transaction prices by period: 12-Period Asset Markets, OneMarket and TwoMarket treatments.

TABLE IVA

TRANSACTION VOLUMES BY PERIOD: 15-PERIOD ASSET MARKETS, ONEMARKET AND TWOMARKET TREATMENTS

| Period | TwoMkt1 | TwoMkt2 | TwoMkt3 | TwoMkt4 | OneMkt1 |
|---|---|---|---|---|---|
| 4 | 5 | 20 | 4 | 5 | 41 |
| 5 | 2 | 5 | 5 | 3 | 27 |
| 6 | 1 | 2 | 11 | 2 | 27 |
| 7 | 2 | 3 | 3 | 5 | 34 |
| 8 | 1 | 1 | 2 | 7 | 31 |
| 9 | 0 | 2 | 0 | 9 | 10 |
| 10 | 1 | 1 | 4 | 4 | 16 |
| 11 | 0 | 2 | 0 | 3 | 16 |
| 12 | 0 | 1 | 2 | 4 | 20 |
| 13 | 1 | 5 | 2 | 10 | 10 |
| 14 | 2 | 3 | 5 | 3 | 11 |
| 15 | 1 | 8 | 0 | 7 | 15 |
| 16 | 0 | 2 | 4 | 3 | 5 |
| 17 | 1 | 3 | 5 | 6 | 1 |
| 18 | 0 | 14 | 15 | 50 | 0 |
| Total | 17 | 72 | 62 | 121 | 264 |
| Turnover (%) | 28 | 90 | 89 | 151 | 377 |

TABLE IVB

TRANSACTION VOLUMES BY PERIOD: 12-PERIOD ASSET MARKETS, ONEMARKET AND TWOMARKET TREATMENTS

| Period | TwoMkt5 | TwoMkt6 | OneMkt2 | OneMkt3 | OneMkt4 |
|---|---|---|---|---|---|
| 4 | 6 | 3 | 33 | 76 | 40 |
| 5 | 3 | 5 | 27 | 104 | 29 |
| 6 | 2 | 1 | 37 | 31 | 42 |
| 7 | 3 | 1 | 5 | 42 | 22 |
| 8 | 3 | 1 | 16 | 32 | 36 |
| 9 | 1 | 6 | 9 | 32 | 27 |
| 10 | 3 | 2 | 21 | 75 | 22 |
| 11 | 2 | 8 | 9 | 94 | 14 |
| 12 | 2 | 8 | 11 | 81 | 28 |
| 13 | 3 | 9 | 8 | 58 | 39 |
| 14 | 5 | 1 | 7 | 96 | 27 |
| 15 | 2 | 4 | 11 | 67 | 7 |
| Total | 35 | 49 | 194 | 788 | 333 |
| Turnover (%) | 50 | 61 | 277 | 1126 | 476 |

given in Table V.[17] $P_t$ is the median price in period $t$; $f_t$ is the fundamental value in period $t$. The variable $|P_t - f_t|$, the dependent variable in regression

[17] We have also estimated the models presented in Table V using feasible GLS estimation of a panel data model under the assumption of a first-order autocorrelation coefficient that is common to all sessions. The estimation assumes heteroscedasticity between sessions but homoscedasticity within a given session. The estimates are similar to those reported in Table V with some minor differences. All coefficients have the same sign as in Table V. However, in equation (2), the coefficient of the constant term is significant at the 5% level but not at the 1% level. The coefficient of the variable *Complex Dividend* is significant at the 5% level (but not at the 1% level) in both equations (1) and (2). All of the coefficients that are significant (insignificant) at the 5% (1%) level in equations (3) and (4) in Table V remain so under the feasible GLS estimation.

equations (1) and (2) in Table V, measures the absolute deviation of median price from the fundamental value in period $t$. The variable *Turnover*, the dependent variable in equations (3) and (4), is the percentage of the total stock of units (the sum of the holdings of $X$ of all agents) that is traded during a period. *OneMarket* is a dummy variable that equals 1 if the data are from the baseline OneMarket treatment and 0 otherwise. *NoSpec*, *TwoMarket*, and *TwoMarket/NoSpec* are analogous dummy variables for the three other treatments. *Complex Dividend* equals 1 if dividends are drawn from the four-point distribution and 0 if they are drawn from the two-point distribution. In all of the regressions the unit of observation is an individual period in a session. Result 4 and it's supporting argument give our characterization of the quantity patterns in the data, and the differences between the TwoMarket and the OneMarket data.

RESULT 4: *The Active Participation Hypothesis is supported in markets in which speculation is permitted. Volume in the asset market is significantly lower in TwoMarket than in OneMarket.*

SUPPORT FOR RESULT 4: In the TwoMarket treatment the volumes traded in the asset market are lower than under OneMarket. The data in Tables IVA and IVB indicate that the volumes in TwoMarket are between 28 and 151 percent of the total stock of units, much lower than in the OneMarket data reported in the tables. The estimates in regression equation (3) of Table V show that the addition of the second market reduced volume traded in the average market period by 34.68% of the total stock of units. The constant term is the estimated turnover per period in the baseline OneMarket treatment (with the simple two-point distribution of dividends), and the coefficient on TwoMarket equals the effect of adding the second market. Only data from markets with speculation are included in regression (3). The standard error of 13.02 indicates that the amount of the reduction is highly significant.

However, adding a second market does not eliminate bubbles in the asset market. The price patterns in TwoMarket are illustrated in Figures 2 and 3. The prices from OneMarket are included for comparison. In Figure 2, in all four sessions of TwoMarket, the median transaction prices are higher than the fundamental values in each period until at least period 14.[18] 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. Figure 3

[18] In session TwoMarket1, there are 7 trades (for a total of 11 units exchanged since one trade was for 5 units) in periods 4 and 5 at very high prices. These trades were due to two subjects failing to understand the distinction between a total price and a per-unit price. For example, one of them purchased 5 units at 2,000, believing that he was paying 400 for each unit. Their losses from periods 4–6, the first three periods of the asset market, were written off by the experimenter to avoid the possibility of their behavior being influenced by the possibility of receiving negative overall earnings in the experiment. These data are not included in the figures, tables, or analysis of the data in the paper.

shows that the data from TwoMarket5 and TwoMarket6 tend to track the fundamental value fairly closely throughout the session.

The TwoMarket treatment did not significantly reduce the average deviation of median price from the fundamental value. Regression (1) of Table V contains the estimated effect of the TwoMarket treatment on the absolute deviation of median transaction price from the fundamental value by period. The constant term is the estimate for the OneMarket treatment. The dummy variable TwoMarket has a coefficient of −57.40, and was not statistically significant.

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 differed between the OneMarket and the TwoMarket sessions. In an average period of OneMarket, 88% of the subjects bought or sold at least one unit, and 61% did both. In contrast, in an average period in the TwoMarket sessions, 45% made some kind of transaction and 9% made both purchases and sales. Thus, subtle features of the experimental design influence the level of participation in the asset market. However, because the boom and crash price dynamics are observed in the majority of the TwoMarket sessions, "excess volume" is not at the origin of the boom and crash price pattern.

Result 5 considers the TwoMarket/NoSpec treatment. The effect of adding the service market is evident. TwoMarket/NoSpec had a strong tendency to

TABLE V

THE EFFECTS OF DIFFERENT TREATMENTS ON AMPLITUDE OF BUBBLES AND ON TURNOVER[a]

| Treatment | (1) $\lvert P_t - f_t \rvert$ | (2) $\lvert P_t - f_t \rvert$ | (3) Turnover (in %) 1Mkt and 2Mkt Data | (4) Turnover (in %) NoSpec and 2Mkt/NS Data |
|---|---|---|---|---|
| Constant | 160.79[b] | 91.61[c] | 47.61[c] | 4.95[c] |
| | (74.51) | (27.46) | (16.02) | (1.4l) |
| OneMarket | | 69.18 | | |
| | — | (79.41) | — | — |
| NoSpec | −21.01 | 48.17 | | 2.56[b] |
| | (81.25) | (42.46) | — | (1.46) |
| TwoMarket | −57.40 | 11.78 | −34.68[c] | |
| | (91.68) | (72.35) | (13.02) | — |
| TwoMkt/NoSpec | −69.18 | | | |
| | (79.41) | — | — | — |
| Complex Dividend | 47.14 | 47.14 | −7.80 | |
| | (80.91) | (80.91) | (10.04) | — |
| $\chi^2$ | 2.50 | 2.50 | 7.11 | 3.07 |
| $p$ | 0.65 | 0.65 | 0.03 | 0.08 |
| $n$ | 207 | 207 | 135 | 72 |

[a] The coefficients are estimates from a population-averaged panel data linear regression model, where the standard errors, given in parentheses, are corrected for first-order autocorrelation and heteroscedasticity within sessions. $p$ is the significance level of a chi-squared test that all of the slope coefficients (those other than the constant term) are equal to 0.

[b] Significant at 5% level.

[c] Significant at 1% level.

reduce the number of dominated purchases and sales from the level in NoSpec. This suggests that many of the errors in decision making in NoSpec can be attributed to the Active Participation Hypothesis.

RESULT 5: *The existence of a second market reduces the incidence of dominated transactions in markets in which speculation is not possible. There is no evidence of excess trade in TwoMarket/NoSpec.*

SUPPORT FOR RESULT 5: Adding the second market reduces the number of dominated transactions. Table VI also shows the incidence of trading at prices above the maximum possible and below the minimum possible dividend stream. In the three sessions of TwoMarket/NoSpec 82.9%, 4.9%, and 8.3% of the transactions were of one of those two types, compared to 84.4%, 50.9%, and 27.5% in the three sessions of NoSpec. In TwoMarket/NoSpec5, 5 of the 17 buyers made a purchase at a price higher than the maximum possible realization of the future dividend stream and 1 of the 19 sellers made a sale at a price below the minimum possible future stream of dividends. Only 2 agents made dominated transactions in the last 6 periods. These are much lower percentages than under NoSpec.

The transaction volume in each session of the TwoMarket/NoSpec treatment is shown in Table VI. On average in the three sessions, 59% of the total stock of units changed hands, compared to 85% for the NoSpec treatment. Regression (4) in Table V shows the estimated turnover. In the equation, the data from NoSpec and TwoMarket/NoSpec are included in the estimation. The coefficient on the constant term is the mean turnover in TwoMarket/NoSpec and the coefficient on NoSpec measures the effect of removing the service market. The

TABLE VI

TRANSACTION VOLUMES: THE TWOMKT / NOSPEC TREATMENT

| | TwoMkt/NoSpec1[a] | | TwoMkt/NoSpec2 | | TwoMkt/NoSpec3 | |
|---|---|---|---|---|---|---|
| Period | Volume | *a/b/c* | Volume | *a/b/c* | Volume | *a/b/c* |
| 4 | 9 | 0/4/5 | 3 | 0/0/3 | 3 | 0/3/0 |
| 5 | 5 | 0/0/5 | 2 | 0/2/0 | 1 | 0/0/1 |
| 6 | 5 | 0/0/5 | 0 | 0/0/0 | 10 | 0/10/0 |
| 7 | 14 | 0/0/14 | 20 | 0/20/0 | 7 | 0/7/0 |
| 8 | 11 | 0/0/11 | 10 | 0/10/0 | 3 | 1/2/0 |
| 9 | 7 | 0/0/7 | 0 | 0/0/0 | 3 | 0/3/0 |
| 10 | 6 | 0/2/4 | 7 | 0/7/0 | 0 | 0/0/0 |
| 11 | 14 | 0/5/9 | 3 | 0/3/0 | 1 | 0/1/0 |
| 12 | 8 | 0/2/6 | 4 | 0/4/0 | 2 | 0/2/0 |
| 13 | 9 | 0/6/3 | 6 | 0/6/0 | 1 | 0/1/0 |
| 14 | 4 | 0/0/4 | 3 | 0/3/0 | 4 | 0/4/0 |
| 15 | 19 | 0/0/19 | 3 | 0/3/0 | 1 | 1/0/0 |
| Total | 111 | | 61 | | 36 | |
| Turnover (in %) | 79 | | 76 | | 23 | |

[a] *a/b/c*: *a* = number of transactions at $P <$ Min $D$; *b* = number of transactions at Min $D \leq P \leq$ Max $D$; *c* = number of transactions at $P >$ Max $D$.

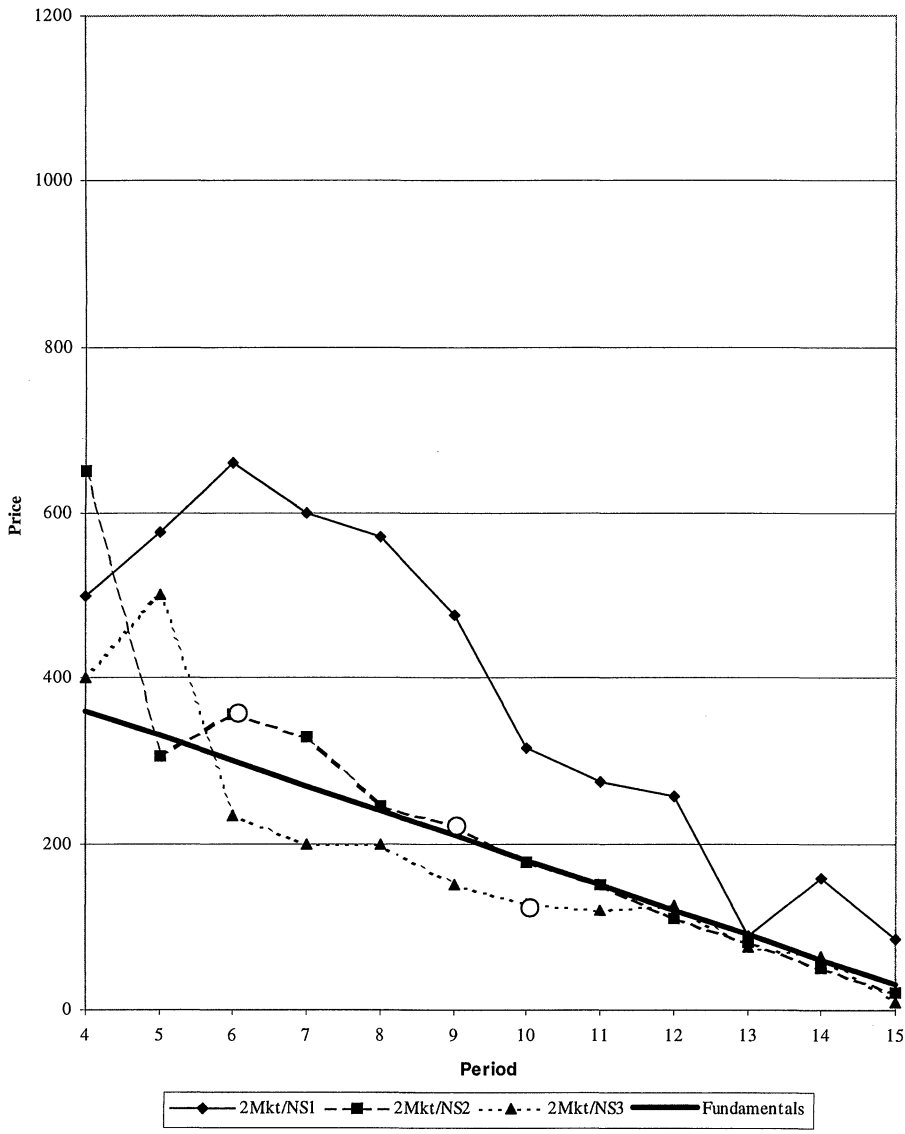


FIGURE 4.—Time series of median transactlon prices by period: TwoMarket/NoSpec treatment.

estimated constant is 4.95, not significantly different from 4.17, the per-period average if total turnover equals 50, or 50% of the total stock, over the 12 period life of the asset. The estimated turnover in NoSpec is not significantly different from the estimated turnover in TwoMarket/NoSpec, though it is significantly different from 4.17, at the $p < 5\%$ level.

The median price time series for TwoMarket/NoSpec are shown in Figure 4. In session TwoMarket/NoSpec1, a bubble is observed, and in TwoMarket/NoSpec2, there are two transactions at high prices early in the session, but median prices track the fundamental value closely thereafter. In TwoMarket/NoSpec3, median prices are close to fundamental values beginning in period 6, the third period of the life of the asset market. The estimated coefficient on the constant term in regression (2) equals the average deviation of median period price from fundamental values in TwoMarket/NoSpec (in TwoMarket/NoSpec the value of all of the dummy variables other than the constant are equal to 0). Since the estimate is significantly different from 0 at the $p < .01$ level, the average value of $|P_t - f_t|$ remains significantly different from 0 under TwoMarket/NoSpec.

However, because adding the second market does reduce the number of errors made, we conjecture that it reduces the chance that a bubble will occur. We state this as a conjecture because of the fact that the coefficients on NoSpec and OneMarket indicate that the value of $|P_t - f_t|$ in NoSpec and in OneMarket are not significantly greater than that in TwoMarket/NoSpec at the 5% level of significance. We believe that the difference would become significant with more observations, and that with more data it would be possible to convincingly claim that, in markets without speculation, the probability of a bubble is lower when a service market is present. Result 6 considers patterns in the data in the market for $Y$ in both the TwoMarket and TwoMarket/NoSpec treatments. 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 6: In TwoMarket and TwoMarket/NoSpec, departures of prices from fundamental values are a specific characteristic of the asset markets that does not extend to the service markets.

SUPPORT FOR RESULT 6: In the market for $Y$, in both TwoMarket and TwoMarket/NoSpec, prices and quantities exchanged converge to the competitive equilibrium, despite the departures of prices from fundamental values in the $X$ market. The median transaction price by period in the market for $Y$ in the pooled data of the six TwoMarket sessions is within 5% of the competitive equilibrium price for 97% of the periods after period 2 (87 out of 90 periods). The market-level quantity traded differs 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). As for TwoMarket/NoSpec, the median price is within 5% of the competitive equilibrium level in 87% (34 out of 39) of the periods. The market

quantity traded is within one unit of the equilibrium level in 64% (25 out of 39) of the periods.[19]

Result 6 shows that, even as 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 "irrationality" documented in Result 3 is not a general property of the subjects themselves, but a property of their behavior in the asset market specifically.

## 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 possibility of speculation. As in Smith, Suchanek, and Williams (1988), we observe bubbles in our NoSpec treatment, 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 positively 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

[19] In 12 of the 30 periods of TwoMarket in which transaction volume in the service market differed from the competitive equilibrium by more than one unit, the volume was lower than the equilibrium level. In the other 18 of the 30 periods it was higher than at the equilibrium. In the TwoMarket/NoSpec data the volume was greater than the competitive equilibrium level in each of the eight periods in which the difference was greater than 1. Because the deviations from equilibrium volume did not tend to be negative, they do not suggest that time constraints played a major role in restricting the volume of trade. In fact, on average, the sum of the quantities exchanged in the two markets of TwoMarket was less than in the single market of OneMarket. That indicates that volume in TwoMarket was below the upper limit of the volumes that could by traded in a period. The relatively frequent incidence of departures from the equilibrium quantity traded in the service market of TwoMarket appears to be related to the fact that both the market demand and supply curves, which are described in footnote 10, are very elastic in the region of the equilibrium. This allows extramarginal buyers and sellers to frequently have opportunities to conclude profitable trades if some trading prices deviate only slightly from the competitive equilibrium.

decreasing. Thus the pursuit of capital gains is not the *only* force driving the asset prices to deviate from fundamental values.

We also observe behaviors that can be clearly classified as decision errors. In our NoSpec data, many traders make purchases at prices higher than the maximum possible realization of the dividend stream. However, they do not buy 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.

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 following 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, cannot be the whole story behind the bubbles. 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 and sales when it is not in their interest to do so. However, these beliefs appear to be justified in that many purchases at prices above the maximum possible dividend stream and sales below the minimum possible dividend stream are observed under NoSpec.

In Section 4 we investigated a possible methodological explanation for the errors in decision making observed in NoSpec. The explanation was suggested by the large observed transaction volumes, which are difficult to reconcile with theory. To explain the high volume, we formulated a conjecture called the Active Participation Hypothesis. The conjecture asserts that some trades in the asset market are related to the fact that there are no activities available for subjects in the experiment, other than to trade in the asset market, and that subjects prefer making purchases and sales to doing nothing. The hypothesis is consistent with 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 and TwoMarket/NoSpec treatments were designed to try to reduce the level of this phenomenon. In markets with resale, we observed that much of the turnover in the asset market was eliminated when an alternative activity was available. Volume decreased sharply in TwoMarket, a treatment in which buying for resale was permitted, supporting the Active Participation Hypothesis. Though the volume in TwoMarket was low, the prices continued to follow the boom and crash pattern. The TwoMarket treatment illustrates that the fact that only one market is available promotes activity in the market, and the Active Participation Hypothesis must be taken seriously in asset markets of the type studied here.

The TwoMarket/NoSpec treatment allowed us to consider whether the Active Participation Hypothesis was the source of the bubbles in NoSpec. The results are mixed. The incidence of dominated purchases and sales declined, as

did the proportion of the sessions in which bubbles were observed. However, a substantial number of dominated transactions still occurred in TwoMarket/NoSpec, and a bubble was observed in one session. We conclude that the lack of an alternative activity in the experiment explains some of the anomalous behavior in NoSpec, but does not account for it entirely.

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 we have seen in our experiment might be useful. The behavior exhibited by the asset markets over time appears to have stages not unlike the stages that have been postulated for other experiments (Plott (1996)). 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 decision errors, which allow for the formation of the bubble. Thus, when the asset market begins operating, not only is there a lack of common knowledge of rationality, there is a lack of rationality itself, in the sense that at least some traders tend to be confused by the particular environment of the asset market.

Over the course of the experiment, some traders come to realize that there is the possibility of irrational behavior on the part of other traders. This realization promotes speculation. Later, experience and practice reduce subject confusion and remove the irrationality of market participants. Once the irrationality has been removed, the new information about the change 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 whereby the newly established rationality of market participants 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 the 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, price crashes in markets with resale appear also to correspond to the beginning of the existence of rationality itself among all active market participants, rather than merely the beginning of common knowledge of rationality already present.

The importance of instructions and the issue of subject comprehension have certainly not escaped the attention of experimental economists. 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 in asset market experiments has not been closely scrutinized. The research reported here suggests that the phenomenon of bubbles and crashes could have origins in aspects of the methodology of the experiment. If this assessment is correct, then research is able to proceed along different theoretical lines in the attempt to understand

the general process of price discovery and the dynamics of market adjustments. In particular, the bubbles and crashes observed in experimental economies provide a rich opportunity to study the nature of learning and mistakes by individual traders in asset markets.

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