Futures Markets and Bubble Formation in Experimental Asset Markets

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Abstract

We construct asset markets of the type studied in Smith et al. (1988), in which price bubbles and crashes are widely observed. In addition to a spot market, there are futures markets in operation, one maturing in each period of the life of the asset. We find that when futures markets are present, bubbles do not occur in the spot markets. The futures markets seem to reduce the speculation and the decision errors that appear to give rise to price bubbles in experimental asset markets.

1. Introduction

The prevalence of bubbles and crashes in experimental markets with inexperienced participants is a well-documented result in experimental economics.[1] Smith et al. (1988) were the first to observe the bubble and crash pattern. They studied markets with the following structure. The asset traded has a life of 15 periods. In each period, each unit of the asset pays a per-unit dividend that is common knowledge and independent of the identity of the agent holding the asset. Because of the finite time horizon and the fact that the dividends, whose distribution is common knowledge, are the only source of intrinsic value for the asset, the fundamental value at any point in time can be calculated. The fundamental value declines over time, decreasing in each period by the per-period expected dividend. However, Smith et al. find that, when participants have no or little previous experience in asset markets of the same type, the markets exhibit price

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[1] See Sunder (1995) for a survey of research on laboratory asset markets.

bubbles and crashes rather than tracking the fundamental value. For most of the time horizon, market prices greatly exceed fundamental values on high volume. Market crashes, rapid drops in price to fundamental values, often occur as the end of the life of the asset approaches.

These price bubbles have been found to be robust to environmental and institutional changes that might have been thought to eliminate them. King et al. (1993) show that bubbles occur even in the presence of a Tobin tax on transactions, of limits on price changes from one period to the next, of equal initial endowments of the asset for each agent, of margin buying capability, and of informed graduate students or businesspeople as participants. Fisher and Kelly (2000) show that if two asset markets are in simultaneous operation, bubbles and crashes occur in both markets and the crashes in the two markets occur nearly simultaneously. Van Boening et al. (1993) observe that a similar pattern occurs if trading is conducted with two-sided sealed-bid auctions in each period, thereby showing that the bubble and crash phenomenon is not specific to the continuous double auction trading system used in all of the other studies cited here. Camerer and Weigelt (1993), Smith et al. (2000), and Noussair et al. (2001), show that assets with constant rather than declining fundamental values also generate bubbles and crashes. This indicates that the bubble phenomenon is not particular to a fundamental value structure that declines over time. Porter and Smith (1995) observe that the existence of a futures market, in which contracts are realized at the half way point of the trading horizon, in period eight of fifteen total periods, does not remove the tendency for bubble formation.

To explain the occurrence of bubbles, Smith et al. (1988), and Smith (1994) argue that bubbles form because the rationality of participants is not common knowledge. Although the experimenter can explain to all agents the dividend process, he cannot convince participants that all other traders are rational. If an agent believes that others may be "irrational", in the sense that they may make purchases at prices greater than fundamental values, the agent may speculate in order to attempt to realize capital gains. As soon as speculative demand raises prices above fundamentals, speculative behavior is reinforced and prices continue to rise. Expectations of future capital gains can thus emerge endogenously if the rationality of participants is not common knowledge and lead to bubble formation. Prices remain above fundamental values until the end of the life of the asset is sufficiently close so that there are no further perceived opportunities to realize capital gains. As the end of the asset's life approaches, the speculative demand disappears and a crash occurs. Lei et al. (2001) argue that in addition to speculation, decision errors on the part of market participants also play a role in bubble formation. These errors appear to originate in an inability on the part of traders to correctly value the asset by linking the expected future dividend stream to a rational limit price, as well as in the procedures of the experiment, which encourage active participation in the market due to a lack of alternative activities. These effects, speculation and decision error, appear to us to provide the most reasonable account of the source of the bubble and crash phenomenon.

The formation of endogenous expectations and the tendency to err in the valuation of the asset both result from the dynamic multi-period structure of the market. Both arise from a failure of subjects to calculate an appropriate limit price using backward induction, or from a lack of common knowledge on the part of individuals that others are doing so. The bias toward active participation presumably arises from the existence of only one activity in the experiment, trading in the spot market. If the origins of bubble formation are those described above, none of the institutional and environmental manipulations mentioned in the second paragraph would prevent bubbles because they do not assist agents to backward induct or to form common expectations about future prices, nor do they provide alternative activities to trading in the asset market.

In this paper, we consider whether an institutional feature, the existence of a futures market maturing in every period, prevents spot market bubbles. There is reason to believe that this particular institutional change might be effective. This is because (a) it fixes spot market price expectations at publicly observable levels for every future period, (b) it creates a series of futures market prices that can aid in the solution of the backward induction problem, and (c) it offers alternative activities to spot market participation, namely opportunities to trade in the futures markets. The existence of publicly available expectations of future spot prices would presumably dampen the incentive to speculate. Agents could use the futures prices to help them calculate the future value of the asset at any point in time, perhaps reducing the incidence of decision errors. If the prices in the futures markets reflect fundamental values, it may become common knowledge that traders are using the expected future dividend stream as a limit price. Thus, while the addition of futures markets does not discriminate between the sources of bubbles listed in (a) – (c) in the sense that it eliminates one but not the other sources, it has the potential to address each of them. There is encouraging previous experimental data that indicates that futures markets help markets for short-lived assets (of two and three periods in duration) to converge to rational expectations equilibria (Forsythe et al., 1984; Friedman et al., 1984).

Our experimental economies differ from those studied by Smith et al. (1988) in that in addition to the spot market, where the asset can be traded, there are 15 futures markets, one maturing in each period. To facilitate the solution of the backward induction problem and the comprehension of the decision environment, the futures markets begin to operate before the spot market. The futures markets are opened one at a time, with a fixed pre-announced time interval between openings, and in reverse order of maturity. That is, the futures market for period 15 is opened first. Then, after the time interval has elapsed, the futures market for period 14 is opened, and so on. After all of the markets are opened, the spot market begins operation. All futures markets remain open until maturity.

The observed market activity exhibits the following properties. Spot market prices closely track fundamental values, with no price bubbles or crashes observed. In contrast to the remarkably high volumes reported in previous studies, quantities transacted in the spot markets are moderate. Prices in futures markets typically converge to the rational expectations equilibrium prices in the last few periods before their maturity. We conclude that an institution, more precisely a system of futures markets, can be constructed that eliminates the bubble and crash phenomenon in experimental markets. As described in sections 3 and 4, it does so in an intuitive way: because it helps to counteract the biases in dynamic decision making and to reduce the speculation that appear to underlie price bubbles in experimental asset markets. The rest of the paper is structured in the following manner. Section two describes the procedures used to conduct the experiment. Section three presents the results and section four outlines our interpretation and conclusions.

2. Procedures

Four sessions were conducted between October 2002 and April 2003. Session 1 was conducted at Canterbury University, Christchurch, New Zealand, and sessions 2 - 4 took place at Purdue University, West Lafayette, Indiana, USA.[2] There were twelve traders participating in each session. Participants were undergraduate students at the two respective universities who were recruited from introductory economics and mathematics courses or online through Web-Lab, which is a dedicated website for subject recruitment and management.[3] In the experiment, two types of markets were in operation, one spot market and fifteen futures markets. Each futures market corresponded to one of the fifteen periods that comprised the life of the asset.

Traders were initially endowed with 10 units of the asset and a cash balance of 10,000 "francs", the experimental currency used in the market. The asset had a finite life of 15 periods. At the end of each of the fifteen trading periods, each unit of the asset in a trader's inventory paid a dividend. The dividend distribution was the following. In each period, each unit of the asset paid 0, 8, 28, or 60 francs to its holder, each value occurring with probability .25. Therefore, the average dividend per unit equaled 24 in each period. The dividend was independently drawn each period. The asset had no terminal value after the final dividend for period 15 was paid. Therefore, the fundamental value of the asset at any time equaled 24 francs times the number of periods remaining.

The structure determining the fundamental value was made common knowledge by the experimenter. More specifically, all participants were given a sheet entitled "Average Holding Value Sheet", within their packet of instructions. The sheet contained the value of the stream of dividend payments for the remainder of the experiment.[4] Furthermore, the maximum, minimum, and expected value of a unit of the asset held for the remaining periods of the experiment were calculated and made available to the

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[2] Several previous asset market experiments (in which there were no futures markets) with participants drawn from one of the same subject pools, Purdue University undergraduate students, exhibit market bubbles and crashes (see the studies of Lei et al., 2001, and Noussair et al., 2001). These previous experiments used instructions that were similar (except for the description of the futures markets) to the ones described here. Thus we are using a subject pool and procedures known to generate price bubbles in the absence of futures markets. No subject who took part in the current study had any previous experience in an asset market experiment.

[3] See Willer et al. (2002) for a description of the recruiting website.

[4] A copy of the instructions is provided in the Appendix.

subjects on a separate computer screen labeled Dividend Calculations. The screen was accessible by clicking on a field on the main screen. Although the dividend process was described in detail in the instructions, there was no suggestion that the dividend process had any relationship to the prices at which one ought to be willing to make transactions.

In each trading period, traders were allowed to either buy or sell units of X as long as they held sufficient cash to purchase the asset or sufficient units of asset in their inventory to make the sale. The trading institution in all markets was the computerized continuous double auction (see Smith, 1962, or Plott and Gray, 1991, for a description). Under continuous double auction rules, the market is open for a fixed period of time, during which any potential buyer or seller can submit an order to buy or sell at a specified price. Acceptance of another trader's offer concluded a trade at the price specified in the offer. All trade took place in terms of the experimental currency. Traders' earnings were paid in dollars at the end of the experiment according to a predetermined conversion rate (equal to 485 francs = $1 of local currency, either $NZ or $US). Inventories of francs and units of X carried over from one period to the next.

In addition to the spot market in which the exchange of units occurred at the time of an offer's acceptance, there were 15 separate futures markets, one maturing at the beginning of each spot period. We will refer to the market maturing at the beginning of period 15 as Futures Market 15, etc. Continuous double auction trading rules were in effect in the futures market as in spot market, with one exception. In a futures market transaction, the unit, and the cash paid for the unit, was transferred between the buyer and seller at the beginning of the period of maturity. By making a contract to buy (sell) a unit of the asset in a futures market, the trader committed to buy (sell) a unit of the asset at the agreed upon price at the beginning of the corresponding spot market period. The actual trade, and thus the exchange of inventories of the asset and cash, occurred at that time. If a trader had committed to sell a unit of the asset in a future period, he continued to receive the dividends on the unit until the trade took effect.

The constraints individuals faced on their purchasing and selling activity in the markets were twofold. The first constraint was that they could not contract to sell more units, either on the spot or the futures markets, than the total of their current inventory plus the net amount they had already contracted to purchase in the future (net amount contracted equals contracted purchases minus contracted sales in the futures markets). That is, current inventory plus net future purchases, described as "available units" to the subjects, could not be negative. Notice that actual inventories could be negative, that is an agent could have a temporary net short position, but only if he had also previously contracted to repurchase the units in the futures markets in a later period. Thus, it was impossible to end the game in a net short position. If an agent had a net short position at the end of a period, he was required to pay the dividend on the number of units he was short. The other constraint was on purchases. A trader could not make a purchase unless his "available cash" remained positive after the purchase. An individual's available cash equaled his actual current cash balance, minus the expenditures he had committed to contracted purchases on the futures market minus the cash he had committed to current outstanding, but unaccepted, offers to purchase on any market, plus the revenue committed to him from sales contracts in the futures market.

The sequence of events in a session was the following. (1) The instructions for the experiment were read aloud for the subjects, who followed along with their own copy of the instructions. The subjects were encouraged to ask questions relating to the rules and the interface at any time. (2) After the experimenter read the instructions, a quiz was given to the subjects to ensure that they understood the dividend process. If a subject made any incorrect responses, the correct answers were given and explained privately to the individual. (3) Subjects traded in a two-period sequence of markets consisting of a futures market period followed by the corresponding spot market period. The purpose of this exercise was to allow the subjects to familiarize themselves with the software, the specific parameters of the market, and the market rules. Earnings in this phase did not count toward final cash payouts. (4) Inventories of asset and cash were reinitialized to their initial values of 10 units of asset and 10,000 francs for each participant. (5) The market periods that comprised the experiment took place. (6) Subjects were paid their earnings for the session.

During phase (5) above, the first market to open was Futures Market 15 (hereafter FMKT15). Three minutes after the opening of FMKTI5, FMKT14 was opened. All subsequent futures markets were opened in reverse order of their period of maturity and at 3-minute intervals until all 15 futures markets were open for trading. The staggered and reverse-ordered opening of the futures markets was intended to facilitate the backward reasoning that is required for agents to realize that the expected future dividend stream corresponds to a limit price for a rational trader. All futures markets remained open for trading until the beginning of their period of maturity, at which time all transactions in the markets were realized. Three minutes after the opening of FMKT1, the spot market opened for period 1. Each spot market period lasted for three minutes. After the close of the spot market for period 15, the session ended. Each subject's earnings equaled his final cash balance. This final balance represented the initial cash balance of 10,000 francs, plus revenue from sales of asset, minus expenditures on purchases of asset, plus the net dividends received on units of asset in inventory over the 15 period spot market horizon. The sequence of events during a session is illustrated in Figure 1, which shows that the 15 futures markets open in reverse order of their period of maturity, and the opening of all of the futures markets precedes the 15 spot market periods.

[Figure 1: About Here]

3. Results

3.1 The spot markets

The time series of transaction prices in the spot market for each session are shown in Figure 2. The horizontal axis indicates the period of the session and the vertical axis shows the average price over all transactions that occur in the period. The straight line is the fundamental value as it evolves over time. The data series are the average transaction prices in each period during each of the four sessions. The figures suggest that prices remain close to fundamental values in the spot markets for most of the life of the asset in each of the four sessions, contrasting sharply with previous studies.

[Figure 2: About Here]

To confirm the impression that the presence of futures markets has an attenuating effect on asset price bubbles, we use several precise measures of the magnitude of bubbles in laboratory markets that previous authors (King et al. 1993; Van Boening et al., 1993; Porter and Smith, 1995) have developed. The measures are useful because they allow comparisons between different studies with regard to the extent of bubble formation. Three of these measures are *Price Amplitude*, *Normalized Absolute Deviation*, and *Turnover*.

The Price Amplitude is defined as the difference between the peak and the trough of mean period prices relative to the fundamental value, normalized by the initial fundamental value. In other words, the price amplitude equals $max_t\{(P_t - f_t)/f_1\} - min_t\{(P_t - f_t)/f_1\}$, where P_t and f_t equal the average transaction price and the fundamental value in period t, respectively (in our markets $f_1 = 360$, and $f_t - f_{t-1} = -24$ for all $t \in \{2,\ldots,15\}$).

The Normalized Absolute Deviation is the sum, over all transactions, of the absolute deviations of prices from the fundamental value, divided by the total number of shares outstanding. It equals $\sum_t \sum_i |P_{it} - f_t|/(100*TSU)$,[5] where P_{it} is the price at which the ith transaction in period t occurs and *TSU* is the total stock of units. *TSU* equals the sum of all traders' inventories of asset. The third measure, *Turnover*, equals the total number of transactions over the life of the asset divided by the total stock of units.

High Price Amplitude indicates large price swings relative to fundamental value, evidence that prices have become decoupled from fundamental values. A high Normalized Absolute Deviation corresponds to a large amount of trading activity at prices removed from fundamental value. A high Turnover means that there is a high volume of trade, suggesting either heterogeneous expectations or biases in decision making prompting trade. The value of the three measures observed in each of the sessions is reported in table 1. The four sessions are identified by the dates on which they were conducted. The table also includes data (averaged across all sessions with inexperienced subjects) from the studies of Smith et al. (1988, SSW), Porter and Smith (1995, PS Baseline treatment), and Van Boening et al. (1993, VWL), in which the asset traded had a life of 15 periods and a declining fundamental value over time, as in our experiment. The

[5] We divide by 100*TSU here while some other studies simply divide by TSU to calculate Normalized Absolute Deviation and Turnover. The purpose is to render our measure comparable to previous studies. Previous studies used an expected dividend equal to 24 cents in each period and calculated the normalized deviation in terms of dollars (units of 100 cents). Here the expected dividend is 24 francs, units of experimental currency, per period. Therefore the appropriate measure for comparison with previous studies would be in units of 100 francs.

data from the studies of Smith et al. (2000, SVW) and Noussair et al. (2001, NRR), in which the asset traded had a fundamental value that was constant over time, are also given in the tables for comparison.

[Table 1: About Here]

As illustrated in the table, each of our four sessions yield bubble measures smaller than the average obtained in any of the previous studies of markets where the asset has a declining fundamental value. This provides strong evidence that the presence of futures markets impedes bubble formation in the spot market. Turnover, the measure of market volume, ranges from .59 to 1.29 in our data, while in previous studies it typically averages between 4 and 6. The normalized deviation ranges from .165 to .296 in the current study, while in the other studies it takes on values between 2 and 6. The drastically lower value reflects lower transaction volume as well as smaller deviations from fundamental value. Amplitude shows a similar pattern, ranging from .161 to .537 in our data, while reaching values between .515 and 4.19 in the previous studies. All previous studies where the asset has a declining fundamental value, and that are therefore the most comparable to our markets, show amplitude greater than 1.24, more than three times the average in our data. Thus, the evidence is clear that spot market bubbles are much smaller in our markets than in previous studies.

Further evidence of the absence of a tendency for bubbles to form in our experiment comes from an investigation of offer patterns. Smith et al. (1988) and subsequent authors have observed that when a bubble occurs, it is typically accompanied by a positive relationship between the change in asset price between periods *t*-1 and *t*, and the difference between the number of offers to buy and offers to sell in period *t*-1. That is, a positive relationship between $Pdiff$ and the variable $B_{t-1} - O_{t-1}$ is associated with an asset price bubble. $Pdiff = P_t - P_{t-1}$ is the difference between the average transaction price in period t and the average price in period $t-1$. B_{t-1} equals the number of offers to buy submitted to the market in period $t-1$. O_{t-1} equals the number of offers to sell submitted in period $t-1$. The variable $B_{t-1} - O_{t-1}$ can be viewed as a measure of capital gains expectations, which can generate a price bubble. To investigate the relationship, Smith et al. (1988) estimated the regression model:

$$Pdiff = a + b\left(B_{t-1} - O_{t-1}\right) \qquad (1)$$

and found that the coefficient b tended to be significantly positive in markets in which a bubble and crash occurred and not significant when they did not occur. The coefficient a was generally not significantly different from the single period change in the fundamental value, $f_t - f_{t-1}$. The estimates of equation (1) for our data are given in Table 2, with the t-statistics of the hypotheses that a = -24 and b = 0 in parentheses.

[Table 2: About Here]

The coefficient a is not significantly different from the change in fundamental value between one period and the next, -24, in any session at the 5% level. The coefficient b is positive in sign but also insignificant in all sessions. Excess revealed supply and demand was therefore not a strong predictor of future price movements in the spot markets. This suggests that the fundamental value was a powerful attractor and prices were not moved away from it by inflows of purchase and sell orders. It also indicates that any capital gains expectations that did exist were not borne out by subsequent price movements.

3.2 Futures Markets

Tables three and four illustrate the prices in the futures market in comparison to the rational expectations equilibrium prices. The values in the tables are calculated by averaging the transaction prices in each market during each period within each session, and then computing an overall market average for the period that weights each session equally. The values in parentheses are the volumes of trade in the market for the period, averaged across sessions. If no value is indicated in a cell, no trades occurred in the particular market during the specified period in any session. Table 3 displays the data for each of the 15 spot market periods. Table 4 contains the data from the time interval before the spot market opens. We will refer to the periods in this interval as periods –15 to –1, where –*t* denotes the three-minute period immediately following the open of futures market *t*.

[Tables 3 and 4: About Here]

Table 3 reveals a strong tendency for current prices in futures markets to be lower than the current fundamental value. Only 6.7% of futures market transaction prices during period *t* exceeded f_t. This indicates that at no time were there expectations of future prices higher than current prices. However, most prices were higher than the rational expectations equilibrium (REE) prices, which for each market equal the fundamental value of the asset in the period of maturity (that is, equal to 24*(16 – *s*) for FMKT*s*). This pattern is consistent with expectations of prices greater than fundamental values in future periods.

However, the tables also suggest that the futures markets exhibit different behavior in the periods just prior to their maturity than in earlier periods. Just before their maturity, the futures markets track their REE prices fairly closely. However, in periods that are relatively long before their maturity, futures market prices are often quite different from the rational expectations equilibrium prices. Consider the variable $\left|FP_t^s - f_s\right|$, the absolute difference between the average price in futures market *s* during period *t* from the REE level. We average over all transaction prices in futures market *s* during spot period *t* during an individual session to calculate the value of FP_t^s in market *s* for period *t* for each individual session. Overall, for period $s-1$, the period before the maturity of a futures market, the average absolute difference from the rational expectations equilibrium price over all markets, periods, and sessions, equals 34.8 francs. In period $s-2$, the average is 49.8, and over periods $s-3$ and earlier it is 75.2. Thus, while for much of the time horizon futures market prices deviate considerably from REE prices, the deviations are smaller in the two periods immediately preceding maturity.

Indeed, some of the futures markets exhibit properties that are reminiscent of the bubbles observed in spot markets in previous studies. In particular, the markets that are the last to mature seem to exhibit the strongest tendency to become decoupled from rational expectations equilibrium prices. We can calculate the Normalized Absolute Deviation and the Amplitude of price bubbles in the futures markets.[6] The values of these measures for each of the fifteen futures markets, averaged over all sessions, are given in Table 5. For the futures markets, in the calculation of the measures, the rational expectations equilibrium price is considered as the fundamental value. Futures market 15 attains the highest value of both measures of any of the markets. In general, there is a tendency for the values of the two measures to be lower in the markets that mature earlier.

[Table 5: About Here]

The high values of the bubble measures for the relatively late maturing futures markets take the form of trade at prices higher than REE prices in periods well in advance of the period of maturity of the particular futures market. In contrast, prices in the futures markets that mature earlier tend to be somewhat below fundamental values. The pattern that emerges is one of futures prices below current fundamental values and the current spot price, but of less cross-sectional variation across futures market prices during a given spot period than under rational expectations.

To make this last notion more precise, we calculate a measure of the variance of current futures market prices during each spot period. We find

$Var\left(FP_t^s\right)=\sum_s\left(FP_t^s-\left(\sum_s FP_t^s \Big/ (15-t-1)\right)\right)^2$ and compare it to the value of the measure under rational expectations, $Var_{RE}\left(FP_t^s\right)$. The number $(15-t-1)$ is used in the denominator because it equals the number of futures markets in operation in period t - 1. The lower the value of $Var\left(FP_t^s\right)$, the less cross-sectional variation in futures market prices during spot period t. Table 6 reports the value of the variable $Vratio=Var\left(FP_t^s\right)\big/Var_{RE}\left(FP_t^s\right)$ in each period, averaged across the four sessions. The ratios are less than one in the early periods, which confirms that there is a clustering of

[6] Turnover is a misleading measure of bubble magnitude here because of the large number of interdependent futures markets and a total stock of units of only 120 to be traded in all of them. It is thus inevitable that turnover will be much lower than the values typically obtained.

futures market prices. Between periods –13 and +3, all but one of the ratios is below 1. In the remaining periods, the ratio exceeds 1 in six of the ten periods for which the ratio is defined. This suggests no consistent clustering near the end of the sessions, when subjects have acquired more experience in the decision environment and the time to maturity in the remaining futures markets is relatively short.

[Table 6: About Here]

Investigation of individual transactions in the futures markets reveals two types of individual behavior that appear to be important in generating the clustering pattern of futures prices. These behaviors are *myopic trading* and *liquidity trading*. Myopic trading is speculation between futures markets that ignores the actual time in the future at which the trade contracted in the market is to be carried out. In essence, a myopic trader acts as if he treats the good trading in each market as identical, in the sense that he assigns equal value to the goods trading in futures markets s and $r \neq s$. He ignores the fact that the value of the good, and thus the rational expectations equilibrium price for the good, differs because of the different future expected dividend streams beginning in period s and in period r. He therefore makes purchases in a futures market at a low price in order to resell in another futures market or in the spot market where the price is higher.

For example, a myopic trader might make a purchase in FMKT10 at a price of 100 as well as a sale at a price of 110 in FMKT9, believing it to be profitable, because the sale price exceeds the purchase price, but neglecting to take account of the fact that the fundamental value is 24 francs lower in spot period 10 than in period 9. If a sufficient percentage of traders behave in this manner, the prices in futures markets with different terminal periods will be moved closer together than under rational expectations, as they are in our data. If all traders were completely myopic, all futures market prices, regardless of period of maturity, would be equal. The observed values of *Vratio* less than one early in the sessions appear to result mainly from the fact that some myopic trading is taking place.

Liquidity trading is the use of futures markets as a means to overcome cash and short-selling constraints. Binding cash constraints can generate additional supply of units in futures markets. Agents who would like to make purchases in the spot market or in a futures market but have insufficient cash to do so sell units in another futures market to give themselves more available cash to make the desired purchases. Similarly, short-selling constraints generate demand for units in futures markets. Agents who would like to sell more units than they have available in spot or futures markets can make contracts to purchase in the futures markets and increase their current selling capacity in the spot or other futures markets. It appears that liquidity trading accounts for some of the demand and supply of units of asset at prices that differ from rational expectations levels.

Tables 3 and 4 show that the volume of futures market trade is concentrated in particular markets at certain times. The volumes, averaged over the four sessions, for each period and each market are indicated in parentheses. Table 4 shows that volumes are relatively high in a given futures market in the two periods after it opens, and especially in the first period in which it is in operation. In every period from –15 to –1, the most recently opened futures market has the greatest number of transactions of any of the futures markets. Some of this activity appears to be due to liquidity trading. To relax a binding cash constraint, a liquidity trader can acquire more cash by selling in a futures market. The trader has a preference for selling in the markets with the highest prices, and these are typically those closest to maturity. This trading has the effect of moving prices in these markets downward. Furthermore, the most recently opened markets are also those in which the heterogeneity of expectations among traders, which would promote trade, can be presumed to be most widespread.

Both tables reveal a concentration of trade in FMKT15 throughout the entire time horizon of the sessions. In periods 1-14, FMKT15 has the greatest quantity traded of any of the futures markets. This also appears in part to be due the activity of liquidity traders. Consider a trader who would like to have the option to sell a unit but has none remaining in his inventory. This constraint is relaxed most cheaply by making a futures market purchase at the lowest possible price. The lowest prices are often found in FMKT15, which has the lowest overall average price during the period the spot market is in operation.

4. Discussion

The pervasiveness of price bubbles and crashes in laboratory asset markets populated with inexperienced subjects has proven resilient to many institutional changes. However, these changes have not directly attacked what we believe are the sources of the bubble phenomenon. These sources lie in speculative behavior and in decision errors. Speculation occurs because there is a lack of agreement among traders about anticipated prices in future periods, which in the presence of decision errors becomes more severe. The sources of the decision errors appear to be twofold. The first is the difficulty of valuing a multi-period but finitely-lived asset, which is simple if the backward induction principle is applied but difficult if it is not. The second source of errors is a tendency for agents to make transactions before they understand the decision environment, because of the absence of alternative activities to the spot market (see Lei et al., 2001, for a discussion). The introduction of short-selling, margin buying, fees on transactions, capital gains taxes, call markets, and the other institutional features that have been previously examined in the laboratory are powerless to aid backward induction. Neither do they introduce alternative activities to mitigate the bias toward active participation in the market. Other than in the case of transaction fees, there is also no obvious reason to suppose that these instruments might reduce speculation.

Futures markets have the potential to address these causes of bubble formation. The presence of 15 futures markets operating simultaneously in conjunction with the spot market and the fact that the futures markets were open for a considerable period of time before the spot market began operation seems to have reduced the bias toward active participation in the spot market. In the experiment we report here, the existence of a futures price for every period also appears to reduce speculation in the spot market, presumably because it reduces the level of heterogeneity in expectations about spot prices in future periods. The relatively low volumes of trade in the spot market are consistent with both a reduction in the amount of speculation and a reduction in the bias in favor of active trading.

In principle, when futures markets exist that mature in the final periods of the life of the asset, they should encourage correct backward induction beginning from period 15.

However, this does not seem to have occurred in our experiment. Rather, the prices are consistent with backward induction only for a small number of periods before maturity in the futures markets, while the spot market tracks its fundamental value for essentially the entire market horizon.

This rather paradoxical behavior is challenging to explain. Our rationale for the use of futures markets was that the existence of the markets would facilitate backward induction. This would cause prices in the futures markets to track rational expectations equilibrium prices, and thus make it common knowledge that spot prices will track fundamentals. Any bias toward active participation would not greatly distort spot prices because any resulting trade would be spread over all 16 markets, in particular the futures markets that are the first to open. However, the mechanism whereby the futures markets induce spot prices to track fundamentals may be the following. The existence of many markets reduces the volume in the spot market resulting from any active participation bias, and channels most of this activity into the futures markets. This causes the spot market to operate at prices close to fundamentals. The futures markets converge to rational expectations equilibrium prices shortly before maturity, because of arbitrage on the part of rational traders between those markets and the spot market. Thus, it may be the spot market, freed of active participation considerations, which pulls the futures markets to their theoretical values, rather than the other way around.

It appears that the futures market that Porter and Smith (1995) studied did not greatly affect bubble formation because there was only one futures market in their design, an insufficient number to create the appropriate dynamic. Our full compliment of futures markets, one for each period, essentially eradicated the bubble and crash phenomenon in the spot market. The spot market data is consistent with rational expectations on the part of traders.

The system of futures markets we have constructed here is effective in aiding price discovery, in the sense that it improves the likelihood that the spot market will reflect the fundamental value of the asset. However, our institution is complex, consisting of many markets that begin operation in a particular sequence. It may be the case that the system is more complex than would be required. Future research might focus on possible simplifications of the system. There are at least three obvious directions in which to proceed. The first would be to open all of the futures markets simultaneously. However, this may have the effect of reducing the system's effectiveness in assisting agents to apply backward induction to the asset valuation task. Another possibility is the presence of fewer futures markets. It may be sufficient to have markets to mature at intervals, for example every five periods, so that futures markets 5, 10, and 15 would be sufficient to cause convergence of spot prices to fundamentals. A third possibility is that the futures markets need only be open for a short period of time prior to their maturity, so that fewer markets operate at one time. The futures market for period t could be opened in t-3, so that it would only be in operation for three periods. Since futures market prices are only close to rational expectations equilibrium prices in the last few periods before maturity, shortening the time interval during which the market is in operation may not reduce the informational content of the futures market activity. [7]

References

Camerer, C., and Weigelt (1991), "Information Mirages in Experimental Asset Markets", *Journal of Business*, 64(4), 463-493.

Fisher, E., and F. Kelly (2000), "Experimental Foreign Exchange Markets", *Pacific Economic Review*, 5(3), 365-387.

Forsythe, R., T. Palfrey, and C. Plott (1984), "Futures Markets and Informational Efficiency: A Laboratory Examination", *Journal of Finance*, 39(4), p. 955-981.

Friedman, D., G. Harrison, and J. Salmon (1984) "The Informational Efficiency of Experimental Asset Prices", *Journal of Political Economy*, 92, p. 349-408.

Hirota, S. and S. Sunder (2003), "Stock Market as a Beauty Contest: Investor Beliefs and Price Bubbles sans Dividend Anchors", working paper, Yale University.

King R., V. Smith, A. Williams, and M. Van Boening (1993), "The Robustness of Bubbles and Crashes in Experimental Stock Markets," in *Nonlinear Dynamics and Evolutionary Economics*, I Prigogine, R. Day and P. Chen eds. Oxford University Press.

[7] There may exist effective alternatives to the use of futures markets that also have the effect of reducing the incidence and magnitude of price bubbles and crashes in experimental markets with inexperienced subjects. For example, Hirota and Sunder (2003) show that in simple asset markets with a single terminal dividend, training procedures can affect the likelihood that a bubble forms. However, we believe that focusing on economic institutions rather than on procedural aspects yields more straightforward policy recommendations, and results that are more robust to the use of different subject pools and experimenters.

Lei, V., C. Noussair and C. Plott (2001), "Non-Speculative Bubbles in Experimental Asset Markets: Lack of Common Knowledge of Rationality vs. Actual Irrationality", *Econometrica*, forthcoming.

Lei, V., C. Noussair and C. Plott (2003), "Bubbles in Experimental Asset Markets: The Use of Capital Gains Taxes to Separate Theories of Bubble Formation", working paper, Emory University.

Noussair, C., S. Robin and B. Ruffieux (2001), "Price Bubbles in Laboratory Asset Markets with Constant Fundamental Values", *Experimental Economics*, 4(1), 87-105.

Plott C., and P. Gray (1990), "The Multiple Unit Double Auction," *Journal of Economic Behavior and Organization,* 13(2), 245-258.

Porter, D., and V. Smith (1995), "Futures Contracting and Dividend Uncertainty in Experimental Asset Markets," *Journal of Business*, 68(4), 509-541.

Smith, V. (1962), "An Experimental Study of Competitive Market Behavior", *Journal of Political Economy*, 70, 111-137.

Smith V. (1994), "Economics in the Laboratory," *Journal of Economic Perspectives*, 8(1), 113-131.

Smith V., G. Suchanek, and A. Williams (1988), "Bubbles, Crashes and Endogenous Expectations in Experimental Spot Asset Markets," *Econometrica*, 56, 1119-1151.

Smith, V, M. Van Boening, and C. Wellford (2000), "Dividend Timing and Behavior in Laboratory Asset Markets", *Economic Theory*, 16, 511-528.

Sunder S. (1995), "Experimental Asset Markets: A Survey", in The Handbook of Experimental Economics, J. Kagel and A. Roth, eds, Princeton University Press.

Van Boening, M., A. Williams, and S. LaMaster (1993), "Price Bubbles and Crashes in Experimental Call Markets", *Economics Letters*, Vol. 41, 179-185.

Willer, D., L. Rutstrom, L. Karr, M. Corra and D. Girard (2002) "A Web-Lab to enhance Social Science Infrastructure: Experiments, Simulations and Archiving", http://weblab.moore.sc.edu

Appendix: Instructions for Experiment

1. General Instructions

This is an experiment in the economics of market decision-making. The instructions are simple and if you follow them carefully and make good decisions, you might earn a considerable amount of money, which will be paid to you in cash at the end of the experiment. The experiment will consist of *fifteen* trading periods in which you will have the opportunity to buy and sell in a market. The currency used in the market is francs. All trading and earnings will be in terms of francs. Each franc is worth ____ dollars. (_____ francs = 1 US dollar). At the end of the experiment, your francs will be converted to dollars at this rate, and you will be paid in dollars. The more francs you earn, the more dollars you earn.

In each period, you may buy and sell units of a good called X in the *Spot Market*. X can be considered an asset with a life of 15 periods, and your inventory of X carries over from one trading period to the next. Each unit of X in your inventory at the end of *each* trading period pays a dividend to you. The dividend paid on each unit is the same for every participant.

You will not know the exact value of the dividend per unit until the end of each trading period. The dividend is determined by chance at the end of each period by a random number generator. The dividend in each period can be either 0, 8, 28, or 60, and each of the four values are equally likely. The information is provided in the table below.

Dividend	→	0	8	28	60
Likelihood	→	25%	25%	25%	25%

The average dividend per period for each unit of X is 24 francs.

The dividend draws in each period are independent. That means that the likelihood of a particular dividend in a period is not affected by the dividend in previous periods.

2. Your Earnings

At the beginning of the experiment, you will be given 10,000 francs in your Actual Cash inventory. Your earnings for the entire experiment are equal to your Actual Cash inventory at the end of period 15.

All dividends you receive are added to your Actual Cash inventory.

All money spent on purchases is subtracted from your Actual Cash inventory.

All money received from sales is added to your Actual Cash inventory.

Example of earnings from dividends: if you have 6 units of X at the end of period 3 and the dividend draw is 8 francs (which has a 25% chance of occurring), then your dividend earnings for period 3 are equal to 6 units x 8 francs = 48 francs.

3. Average Value Holding Table

You can use your **AVERAGE HOLDING VALUE TABLE** to help you make decisions. There are 5 columns in the table. The first column, labeled **Ending Period**, indicates the last trading period of the experiment. The second column, labeled **Current Period**, indicates the period during which the average holding value is being calculated. The third column gives the number of holding periods from the period in the second column until the end of the experiment. The fourth column, labeled **Average Dividend per Period**, gives the average amount that the dividend will be in each period for each unit held in your Actual Asset inventory for the rest of the experiment. The fifth column, labeled **Average Holding Value Per Unit of Inventory**, gives the average total dividend for the remainder of the experiment for each unit held in your Actual Asset inventory for the rest of the experiment. That is, for each unit you hold in your Actual Asset inventory for the remainder of the experiment, you receive on average the amount listed in column 5. The number in column 5 is calculated by multiplying the numbers in columns 3 and 4.

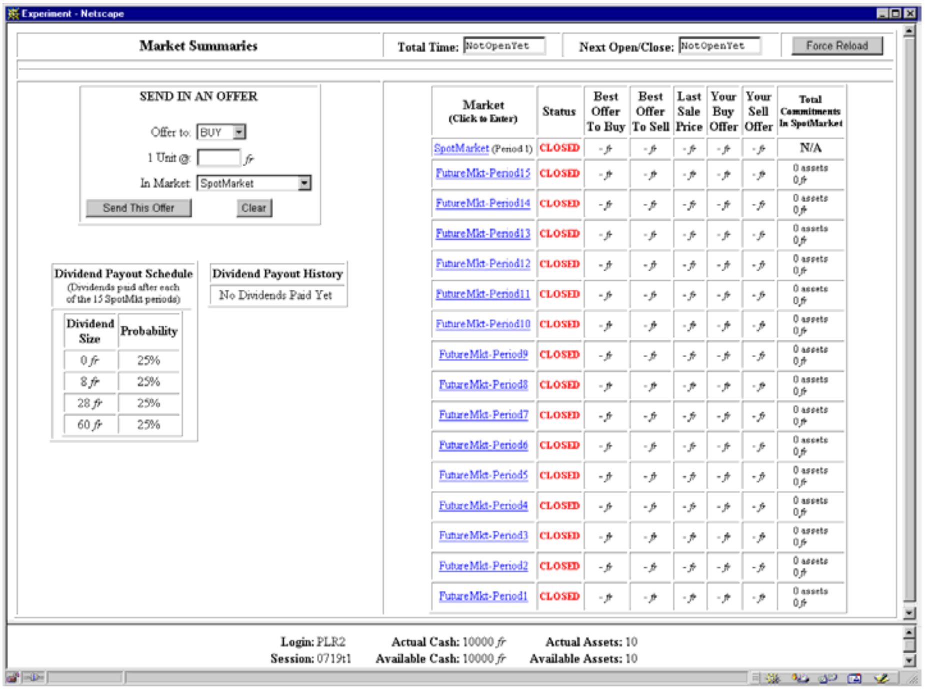
Suppose for example that there are 7 periods remaining. Since the dividend paid on a unit of X has a 25% chance of being 0, a 25% chance of being 8, a 25% chance of being 28, and a 25% chance of being 60 in any period, the dividend is on average 24 per period for each unit of X. If you hold a unit of X for 7 periods, the total dividend paid on the unit over the 7 periods is on average 7*24 = 168.

4. Futures Markets

Before the Spot Market opens for the fifteen periods of trading, a Futures Market for each of the 15 periods will be opened. In each of the Futures Markets, participants may make contracts to buy or sell units of X in future periods. By making a contract to buy (sell) a unit of X in a Futures Market, you are committing to buy (sell) a unit of X at the agreed upon price at the beginning of the corresponding market period. The actual trade will not take place until that time. For example if you make a contract to buy a unit of X for 10 francs in Futures Market-Period 15, then at the beginning of period 15 your Actual Inventory of X will increase by one unit and your Actual Cash will decrease by 10 francs. If you have committed to sell a unit of asset in a future period, you continue to receive the dividends that it pays out until the trade actually takes place in the corresponding period.

The Futures Markets will open in sequence with the futures market for period 15 opening first. Futures Markets will open every 3 minutes and remain open until the corresponding Spot Market period opens. For example, the Futures Market for period 15 will remain open until the beginning of Spot Market period 15. Three minutes after Futures Market-Period 15 opens, Futures Market-Period 14 will open and this market will remain open until the beginning of Spot Market period 14. Every three minutes one more futures market will be opened, until all 15 are open. After all of the Futures Markets have been open for three minutes, the Spot Market will be opened and the actual 15 periods during which the asset pays dividends will begin. Each period will last three minutes.

5. Market Summaries Screen



Above is the Market Summaries Screen that you will see in the experiment and it provides you with a summary of information over the course of the experiment. Let us now discuss each of the fields in detail. In the top row, the box labeled **Total Time** tells you the total amount of time that has expired since the beginning of the experiment. The box labeled **Next Open/Close** tells you the amount of time before the next Futures Market opens or the time left in a particular Spot Market period before it closes. The computer will automatically update your screen information every few seconds. However, you may force the computer to update the information at any time by clicking the **Force Reload** button in the top right hand corner.

In the row at the bottom of the screen, the **Login** is your ID. **Session** is the game name. The **Actual Cash** is the actual amount of cash you have in your inventory. The **Available Cash** is the amount of cash you have available to buy units of X. The **Actual Assets** is the actual amount of assets you have in your inventory. The **Available Assets** is the number of assets that you have available to sell. The reason that your Actual and Available cash and assets might differ is because if you have made a commitment to sell units of the asset in the Futures Markets, they are not available to sell, though they will remain in your inventory until the trade actually takes place at the beginning of the corresponding Spot Market period. If you have made a commitment to purchase units in the Futures Markets, the cash you have committed is not available for other purchases.

The large box on the right-hand side of the screen provides a summary of each of the markets in the experiment. The column labeled **Market** lists each of the different markets in the experiment, i.e. the Spot Market and a Futures Market for each period of the Spot Market. To view a particular market screen, click on the name of the market. The second column labeled **Status** will either display "Open" or "Closed" to let you know whether that particular market is open or closed for transactions. The third and fourth columns labeled **Best Offer To Buy** and **Best Offer To Sell** presents the highest current offer to buy and lowest current offer to sell respectively in each market. The column labeled **Last Sale Price** lists the price of the last transaction that occurred in each market. The fifth and sixth columns labeled **Your Buy Offer** and **Your Sell Offer** presents that last price that you offered to buy or sell respectively in each market. The final column labeled **Total Commitments in Spot Market** lists the total number of assets that you committed to buy or sell in each of the futures markets and the amount of francs associated with those committed transactions.

The **Dividend Payout History** box lists the random dividend draws by the computer for each spot market period. The **Dividend Payout Schedule** presents the dividend distribution.

The box in the upper left hand corner of the Market Summaries Screen allows you to make offers to buy or sell in each of the open markets. To make an offer to buy (sell), select **BUY (SELL)** in the "Offer to:" field, enter the price that you are willing to buy (sell) one unit of X in the "1 Unit @" field, and select the market that you want to place the offer in from the pull-down field labeled "In Market:" When placing an offer to buy (sell) in a market with a current standing offer listed in the columns **Best Offer To Buy (Best Offer To Sell)**, your offer must be above (below) the current standing offer for your offer to be valid.

6. Specific Market Screen

Above is a Market screen that can be viewed by clicking on one of the listed markets in the Market column of the Market Summaries screen. The specific market represented by the screen is listed in the top left corner. This screen allows you to place an offer to buy (sell) in a specific market by entering the price that you are willing to buy (sell) one unit of the asset in the price field of the **Submit A New Offer to Buy (Sell)** box. Remember, in order for your offer to buy (sell) to be valid, it must be above (below) the current standing offer listed in the box labeled **Offers to Buy (Offers to Sell)**. The box labeled **Transaction History** lists the prices at which units have been sold in this market.

7. Quiz

Question 1: Suppose that you purchase a unit of X in Spot Market period 5.

- **a.** What is the average dividend payment on the unit of X for Spot Market period 5? _____
- **b.** If you hold that unit of X till the end of the experiment (11 periods including the current period), what is the average total dividend paid on the unit of X? _____
- **c.** What is the maximum possible dividend paid on the unit of X till the end of the experiment (11 periods including the current period)? _____
- **d.** What is the minimum possible dividend paid on the unit of X till the end of the experiment (11 periods including the current period)? _____

Question 2: Suppose that you make a commitment to buy a unit of X in Futures Market period 5.

- **a.** In what period will this unit of X enter your Actual Inventory? _________________
- **b.** In what period will you receive your first dividend payment on this unit of X? ____________
- **c.** What on average is the dividend payment that you will receive in that period for that unit of X? _____
- **d.** What on average is the total dividend payment for that unit of X if you were to hold it in your inventory till the end of the experiment? _____

Question 3: Suppose that you have 10 units of X in your Actual and Available Inventories at the beginning of Futures Market period 10, and you make a commitment to sell a unit of X in Futures Market period 10.

- **a.** How many units do you have in your Actual Inventory at the end of Futures Market period 10? _____
- **b.** How many units do you have in your Available Inventory at the end of Futures Market period 10? _____
- **c.** What is the last period that you will receive a dividend payment on this unit of X? ______
- **d.** What on average is the dividend payment for this unit of X in that period? _____
- **e.** What on average is the total dividend payment for that unit of X that the Trader who purchased the unit of X will receive if he holds it till the end of the experiment? _____

AVERAGE HOLDING VALUE TABLE

Ending Period	Current period	Number of Holding Periods	*	Average Dividend Value Per Period	=	Average Holding Value Per Unit of Inventory
15	1	15	*	24	=	360
15	2	14	*	24	=	336
15	3	13	*	24	=	312
15	4	12	*	24	=	288
15	5	11	*	24	=	264
15	6	10	*	24	=	240
15	7	9	*	24	=	216
15	8	8	*	24	=	192
15	9	7	*	24	=	168
15	10	6	*	24	=	144
15	11	5	*	24	=	120
15	12	4	*	24	=	96
15	13	3	*	24	=	72
15	14	2	*	24	=	48
15	15	1	*	24	=	24

Table 1: Spot Market Bubble Measures

Session	Turnover	Amplitude	Normalized Deviation
41503	1.16	0.161	0.165
40903	0.59	0.537	0.254
40403	0.9	0.452	0.296
100802	1.29	0.175	0.241
NRR (2001)	4.19	0.515	2.24
SSW (1988)	4.55	1.24	5.68
PS (1995) Baseline	5.49	1.53	N/A
VWL (1993)	5.05	4.19	5.12
SVW (2000)	4.35	1.39	5.5

Table 2: Estimated Relationship Between Number of Offers and Subsequent Price Changes

$$Pdiff = a + b\left(B_{t-1} - O_{t-1}\right)$$

Session	Coefficient of a	Coefficient of b
41503	-23.201 (0.505)	0.328 (0.379)
40903	-23.823 (0.015)	3.113 (1.013)
40403	-12.249 (1.197)***	1.394 (1.513)
100802	-20.380 (0.164)	0.291 (0.593)

*** Significant at the 1% level**
**** Significant at the 5% level**
***** Significant at the 10% level**

Table 3: Average Futures Market Prices during a Given Spot Market Period

REE Price		Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Period 13	Period 14
336	FMKT2	290 (0.75)													
312	FMKT3	N/A	260 (1.50)												
288	FMKT4	300 (0.25)	200 (0.25)	262 (2.50)											
264	FMKT5	400 (0.25)	260 (0.50)	170 (0.25)	206 (0.25)										
240	FMKT6	N/A	N/A	N/A	158 (1.00)	131 (0.50)									
216	FMKT7	N/A	240 (0.25)	218 (0.50)	230 (0.25)	200 (1.00)	N/A								
192	FMKT8	250 (0.25)	200 (0.25)	215 (0.50)	150 (0.25)	N/A	289 (1.00)	206 (1.25)							
168	FMKT9	N/A	190 (0.25)	N/A	390 (0.25)	218 (0.75)	200 (0.25)	161 (1.00)	187 (1.00)						
144	FMKT10	N/A	N/A	350 (0.25)	N/A	350 (0.25)	N/A	180 (0.25)	N/A	157 (1.00)					
120	FMKT11	190 (0.25)	200 (0.25)	N/A	70 (0.25)	N/A	N/A	150 (0.25)	260 (0.50)	135 (0.50)	107 (1.00)				
96	FMKT12	200 (0.50)	200 (0.50)	158 (0.50)	240 (0.75)	240 (0.25)	60 (0.25)	180 (0.25)	400 (0.25)	78 (0.75)	121 (0.75)	103 (1.00)			
72	FMKT13	180 (0.25)	195 (0.75)	133 (0.75)	N/A	N/A	60 (0.25)	135 (0.25)	N/A	180 (0.25)	157 (1.50)	172 (0.25)	79 (2.00)		
48	FMKT14	N/A	155 (2.00)	221 (1.75)	202 (1.00)	110 (0.50)	95 (0.50)	220 (0.25)	70 (0.25)	N/A	162 (1.50)	163 (0.75)	75 (0.75)	100 (0.25)	
24	FMKT15	246 (1.25)	160 (2.75)	166 (3.50)	165 (2.25)	131 (2.00)	147 (2.75)	92 (2.75)	131 (3.25)	76 (2.25)	198 (2.00)	92 (2.50)	47 (3.00)	29 (1.50)	29 (1.50)

Table 4: Average Futures Market Prices during Each 3 Minute Segment Prior to Spot Market Open

REE Price		Period -15	Period -14	Period -13	Period -12	Period -11	Period -10	Period -9	Period -8	Period -7	Period -6	Period -5	Period -4	Period -3	Period -2	Period -1
360	FMKT1															289 (10.00)
336	FMKT2														260 (8.00)	285 (3.00)
312	FMKT3													233 (10.00)	291 (2.50)	305 (0.50)
288	FMKT4												202 (9.50)	239 (2.00)	265 (1.50)	298 (0.50)
264	FMKT5											192 (8.50)	191 (2.25)	213 (1.00)	266 (1.25)	235 (0.50)
240	FMKT6										170 (10.75)	270 (1.25)	172 (0.75)	225 (0.50)	N/A	253 (0.75)
216	FMKT7									184 (7.75)	184 (1.25)	176 (1.25)	100 (0.25)	228 (0.50)	100 (0.25)	240 (0.25)
192	FMKT8								159 (6.75)	145 (4.25)	189 (0.75)	149 (1.25)	175 (1.00)	180 (0.50)	N/A	165 (0.25)
168	FMKT9							147 (8.75)	151 (2.00)	130 (1.50)	166 (1.00)	170 (0.25)	N/A	138 (1.25)	300 (0.50)	N/A
144	FMKT10						142 (9.25)	144 (3.50)	128 (0.50)	230 (0.75)	N/A	120 (0.50)	N/A	115 (0.50)	N/A	N/A
120	FMKT11					158 (8.50)	134 (1.75)	125 (0.25)	122 (1.00)	110 (0.25)	100 (1.25)	140 (0.25)	135 (0.25)	180 (0.25)	N/A	N/A
96	FMKT12				113 (9.50)	104 (3.00)	143 (1.25)	172 (1.25)	159 (1.50)	100 (0.25)	299 (0.25)	85 (0.50)	140 (0.50)	135 (0.50)	210 (0.75)	260 (1.25)
72	FMKT13			104 (8.50)	80 (1.50)	122 (0.75)	80 (0.75)	N/A	93 (1.00)	100 (0.25)	123 (0.50)	140 (0.50)	100 (0.25)	148 (0.75)	130 (0.25)	157 (1.50)
48	FMKT14		117 (8.25)	120 (2.50)	90 (0.25)	65 (0.25)	65 (0.25)	63 (1.25)	79 (1.25)	122 (1.50)	147 (1.25)	121 (1.25)	133 (1.50)	210 (0.75)	111 (1.25)	172 (1.50)
24	FMKT15	138 (14.50)	74 (3.00)	76 (2.50)	89 (3.50)	46 (2.25)	75 (3.00)	72 (1.75)	68 (3.25)	65 (5.25)	75 (5.75)	118 (4.25)	147 (3.00)	194 (3.00)	210 (2.50)	159 (2.00)

Table 5: Observed Measures of Bubble Magnitude in the Futures Markets

	Amplitude	Normalized Deviation
FMKT1	N/A	0.061
FMKT2	0.100	0.079
FMKT3	0.224	0.089
FMKT4	0.257	0.109
FMKT5	0.323	0.100
FMKT6	0.335	0.098
FMKT7	0.469	0.071
FMKT8	0.519	0.095
FMKT9	0.637	0.100
FMKT10	0.374	0.073
FMKT11	0.741	0.095
FMKT12	1.474	0.141
FMKT13	1.421	0.111
FMKT14	2.651	0.215
FMKT15	5.888	0.673

Table 6: Ratio of Observed to REE Price Variance Across Futures Markets

	Average Variance	REE Variance	Ratio
Period -15	N/A	N/A	N/A
Period -14	2471.78	288	8.583
Period -13	353.16	576	0.613
Period -12	293.91	960	0.306
Period -11	2819.59	1440	1.958
Period -10	1597.22	2016	0.792
Period -9	789.19	2688	0.294
Period -8	547.33	3456	0.158
Period -7	1987.54	4320	0.460
Period -6	1246.05	5280	0.236
Period -5	2775.27	6336	0.438
Period -4	1954.18	7488	0.261
Period -3	2536.04	8736	0.290
Period -2	5702.75	10080	0.566
Period -1	3999.91	11520	0.347
Period 1	3959.56	11520	0.344
Period 2	2644.27	10080	0.262
Period 3	6057.69	8736	0.693
Period 4	9433.49	7488	1.260
Period 5	11651.67	6336	1.839
Period 6	15706.77	5280	2.975
Period 7	1929.16	4320	0.447
Period 8	8907.04	3456	2.577
Period 9	1730.30	2688	0.644
Period 10	1357.16	2016	0.673
Period 11	1505.16	1440	1.045
Period 12	605.89	960	0.631
Period 13	2938.89	576	5.102
Period 14	N/A	N/A	N/A
Period 15	N/A	N/A	N/A

Figure 1: Timeline of Events During Each Session

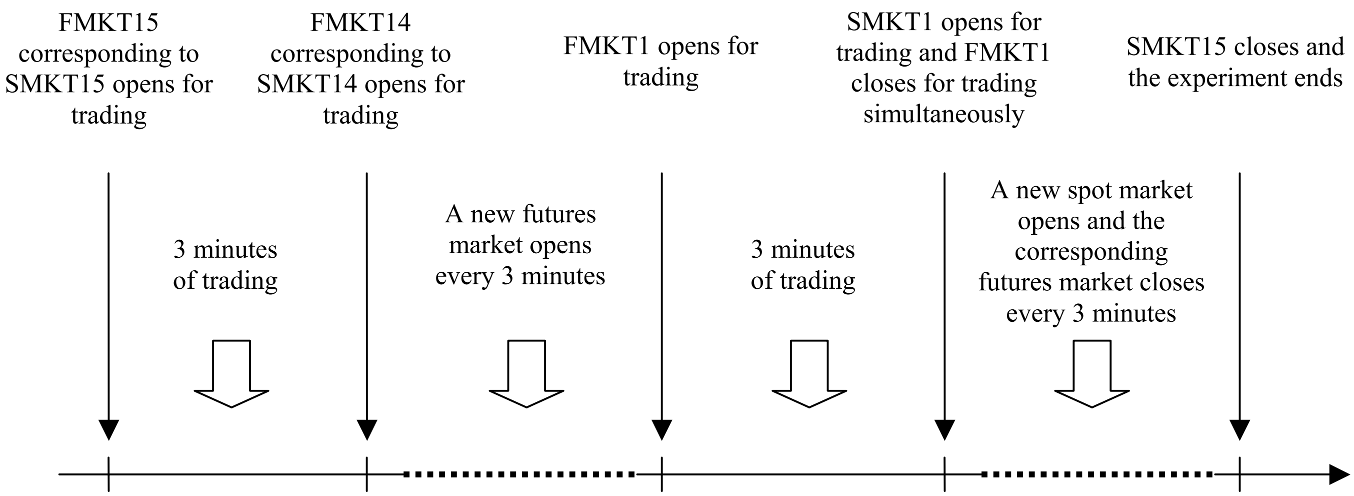


Figure 2: Average Spot Prices by Period, All Sessions