Price Bubbles in Asset Market Experiments with a Flat Fundamental Value

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Abstract: This paper describes a laboratory experiment in which traders are given both cash and shares of an asset that pays a randomly determined dividend for a finite number of periods, after which all shares are redeemed for a pre-announced amount. Cash balances earn interest at a known and deterministic rate, which induces discounting of future expected dividends and the redemption payment. According to its no-arbitrage valuation, the fundamental price of the asset is constant over time. In the experiment, trades are determined by a limit-order book that is used to clear submitted bids and asks at a uniform price when the market is called. Strong price bubbles are observed in all sessions in which wealth accumulates from dividend and interest payments. Holding the fundamental value constant, the magnitude of overvaluation is higher in treatments that permit more wealth accumulation, *e.g.*, sessions with higher dividends and interest rates. Bubbles are also more extreme in longer sessions. They are even observed in markets which permit no wealth accumulation from dividend or interest payments), as long as initial cash endowments are high.

I. Introduction

The basic theoretical paradigm of finance is that asset prices are determined by market fundamentals in the long run, and that day-to-day price fluctuations are caused by the random effects of individual traders' portfolio adjustments. In this view, asset markets aggregate disparate information and generate prices based on a fundamental principle: all arbitrage opportunities are exploited in equilibrium. This economic view contrasts with the psychological view of investments presented in Keynes' *General Theory*, where it is argued that investors are less concerned with long-term market fundamentals than with short- or intermediate-term gains. The result is that investors try

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to purchase stocks that others will perceive as "winners," and price cascades can form if price increases attract a frenzy of investors in a self-confirming cycle.

Perhaps the most famous example of an investor frenzy unjustified by market fundamentals is the 17^{th}-century Dutch "tulipmania," described by Charles Mackay:

> Nobles, citizens, farmers, mechanics, seamen, footmen, maid-servants, even chimney-sweeps and old clotheswomen, dabbled in tulips. Houses and lands were offered for sale at ruinously low prices, or assigned in payment of bargains made at the tulip-mart. Foreigners became smitten with the same frenzy, and money poured into Holland from all directions.

Since tulips are inexpensive to produce, it was only a matter of time until some investors tried to sell out before the inevitable decline:

> At last, however, the more prudent began to see that this folly could not last forever. Rich people no longer bought the flowers to keep them in their gardens, but to sell them again at cent per cent profit. It was seen that somebody must lose fearfully in the end. As this conviction spread, prices fell, and never rose again. Confidence was destroyed, and a universal panic seized upon the dealers.

Speculative purchases of an overvalued asset may be rational if a trader believes that it will be possible to sell out quickly when the bubble starts to break, but the problem is that buyers cannot find anything close to previous price levels once the cycle of self-confirming expectations is broken. Sometimes the downturn seems to be instigated by an exogenous shock, such as the effect of the second oil crisis on 1970's housing prices in Houston. In fact, price bubbles can be generated from exogenous shocks in computer simulations of markets composed of a mix of trend-based and fundamentals-based traders. It is even possible to simulate a "negative bubble" from a negative shock (see Steiglitz and Shapiro (1998)), since trend traders try to sell even undervalued assets before the price declines further. The results of these simulations are suggestive, but they raise the issue of whether human investors will actually stick to mechanical, trend-based rules as conditions change. In particular, if trend traders are really just trying to draw inferences about others' information from price fluctuations, then their trading patterns would be volatile.

The complex informational structure of naturally-occurring asset markets complicates the study of price formation, prompting some researchers to use controlled laboratory experiments. The classic study is that of Smith, Suchanek, and Williams (1988), which stripped the away many of the unknown elements of asset markets. An experimental market was constructed using shares of an asset that paid a random dividend according to a pre-announced distribution for a fixed number of periods. After the experimental market ended, all assets were worthless. In the standard setup, the asset paid dividends for 15 periods. This setup makes the calculation of the fundamental expected value a matter of backward induction. If the expected dividend is D and the asset is worth \$0 after the final period, then it is worth D with one period remaining, $2D$ with two periods remaining, and so forth, which is a decreasing, linear series of fundamental values. Traders were endowed with shares and cash at the start of the first period, and shares were bought and sold using a continuous "double auction" in which any trader at any time could make a bid to buy, an ask to sell, or accept another trader's bid or ask to establish a binding contract. Prices in these experimental markets generally crossed the declining fundamental value line from below, and the overvaluation would persist until the final period approached. These bubbles were observed by King et al. (1993) in a variety of settings and under a variety of variations in the trading rules.

As with the Smith, Suchanek, and Williams (1988) setup, the risky asset used in the experiments reported here has a randomly-determined dividend. We introduce a second, risk-free asset that pays a known interest rate, r, in order to induce discounting of future dividend payments. In particular, a share that pays an expected dividend of D at the end of the present period and at the end of all future periods, would have a present value of D/r, which would be "flat" or unchanging from period to period over an infinite horizon. One easy way to induce a flat present value in an experiment of finite length of T periods is to have the asset be redeemed for an amount, V, at the end of the period T, where $V = D/r$. Thus, the redemption value intuitively represents the discounted expected value of all dividends that would have been received after the final period, if the experiment had lasted indefinitely. To see this, suppose that the asset trades for P_T at the beginning of period T, so that a risk-neutral investor with cash of P_T would be indifferent between holding cash and buying the asset to obtain the dividend and final redemption value if $D + V = (1+r)P_T$. Using the fact that the experimenter sets $V = D/r$, the no-arbitrage condition can be solved for the final period price: $P_T = D/r$. In other words, if it is known that the asset will be redeemed for the present value of an infinite stream of dividends, then its price in the final period must equal this present value. Using backward induction, this logic implies that the asset must sell for $P_t = D/r$ in all periods, $t = 1, \ldots, T$.[1]

In a setup with a flat fundamental value, speculative price bubbles will be observed when prices rise systematically above this value. Such bubbles will be constrained by common knowledge of the final redemption value, as the final period approaches. Therefore, we also consider a setup in which the final redemption value is uncertain, but where each trader obtains a random "signal" that is known to be within a given range of the true final redemption value. Intuition suggests that bubbles may be stronger when the final trading price is not common knowledge, and we will report results for sessions with "common-value trading" to assess this intuition.

The initial setup, with a known final redemption value, will be described in section II, where the main treatments are structured to evaluate an "excess cash effect" on trading prices observed by Caginalp, Porter, and Smith (2001). The data for laboratory markets with known and unknown common redemption values are presented in Sections III and IV respectively. Section V contains implications for future research based on these findings.

II. Procedures

The experimental cohort consisted of undergraduate participants from the University of Virginia. A total of 10 sessions were conducted during June-July 2004 and June-July 2005. In each session, the participants were endowed with identical asset portfolios, consisting of cash and shares of a stock. Trading lasted for a pre-announced number of rounds, in each of which the participants could place bid and ask orders for the stock. The market cleared in each round at the equilibrium implied by the resulting aggregate supply and demand arrays. Any alterations to a participant's portfolio during a

[1]Ball and Holt (1998) consider an alternative market with a flat fundamental value, where the present value of the dividend stream is determined by the probability of asset termination. Noussair, Robin, and Ruffieux (2001) obtain a flat fundamental value by setting the dividend payments so that the expected dividend is zero in every period, in which case the value of the whole dividend stream is zero.

round carried forward to the following round.[2] Participants were paid a \$6.00 participation fee as well as their individual experimental wealths at a \$100:\$1 ratio. Earnings from the asset market ranged from \$3.70 to \$79.35. The asset market experiment always followed an unrelated experiment.

In Sessions 1-7, interest and dividends were paid. These sessions can be conveniently divided into "low return" (Sessions 1-3), "high return" (Sessions 4-6), and "long" (Session 7) markets. Each of these sessions consisted of 12 participants, each of whom were initially endowed with a \$50.00 cash account and 6 shares of stock. At the end of each round (*i.e.*, after the stock market had cleared), each dollar in the cash account paid interest at a pre-announced and fixed rate. This rate was 10% in the low-return and long sessions, and 20% in the high-return sessions. Also at the end of each round, each share of stock paid dividends according to a pre-announced probability distribution. The dividend was either \$0.70 or \$1.00 with probability 0.5 in the low return and long sessions, and either \$1.40 or \$2.00 with probability 0.5 in the high return sessions. After the stock market cleared in the final round, all shares were converted to cash at a pre-announced rate of \$7.00 per share. The low and high return sessions lasted 20 rounds each, and the long session lasted 40 rounds. The $V = D/r$ formula shows that the fundamental value of the stock is flat at \$7.00 for all of these parameterizations.

In Sessions 8-10, interest and dividends were not paid. Before trading began, the terminal value of the stock was determined by a random draw from a uniform [\$40.00, \$60.00] distribution. This value and the distribution from which it was drawn were hidden from the participants. Instead, each participant received a random signal that was known to be centered at the true value, with an error drawn from a uniform [-\$25.00, \$25.00] distribution. The participants were initially endowed with a \$1,500.00 cash account and 6 shares of stock. Each session lasted for 20 rounds. Session 8 consisted of 8 participants, Session 9 of 5 participants, and Session 10 of 11 participants.

III. Results with a Known Final Redemption Value

Figure 1 provides a time series of the equilibrium prices from Session 1. The horizontal line at \$7.00 represents the flat fundamental value (D/r), and the vertical lines

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[2]The sessions were conducted using the *Veconlab* Internet-based experiment platform. Additional information about this particular experiment can be found under "Limit Order Asset Market" on the Finance section of the *Veconlab* experimenter's page: http://veconlab.econ.virginia.edu/admin.htm

delineate individual trading periods. The distance between successive vertical lines is proportional to the number of shares exchanged in that period. The bold dotted line represents the market-clearing price, and the lighter dotted lines represent the prices of individual bid and ask orders which cleared. (Bids and asks for orders that did not trade are not shown.) In this session, the price started at $10.00 (43% overvaluation), peaked at $12.03 (72% overvaluation) in period 13, and gradually declined to the fundamental value by the final round. This "bubble-and-crash" pattern is a common dynamic observed in the experimental asset market literature.

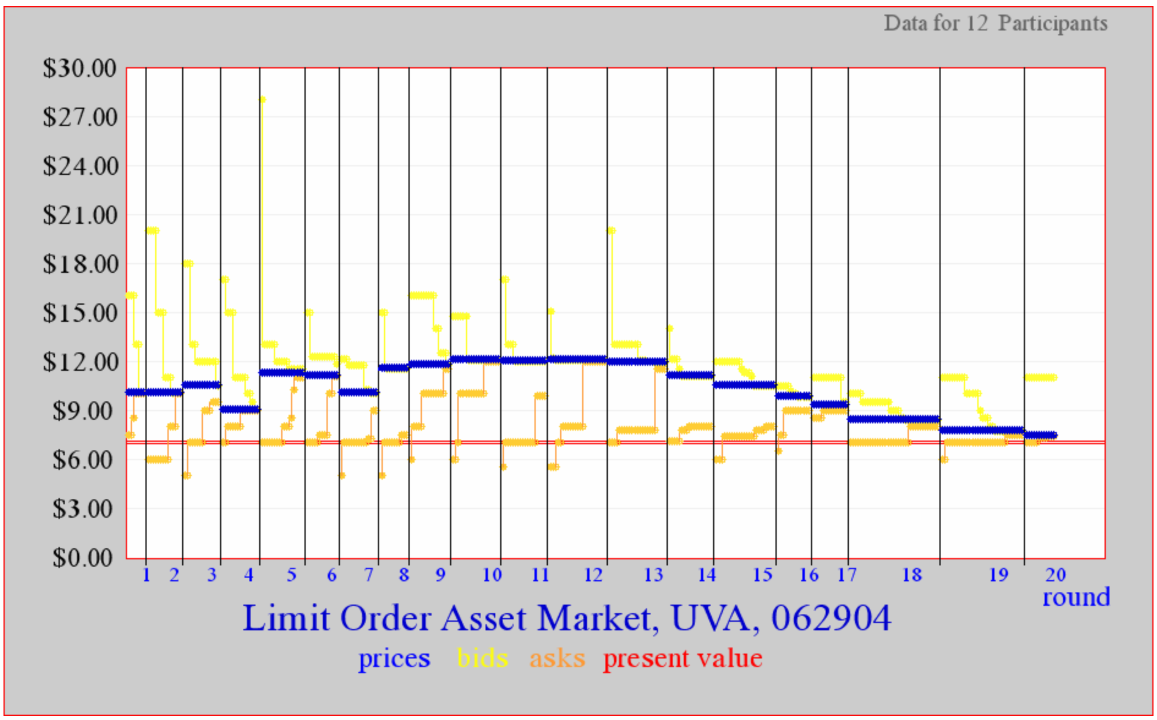

Figure 1. Price series for Session 1, with low returns.

Figure 2 presents the equilibrium prices in all three "low return" markets. Recall that these 20-period sessions involved an interest rate of 10% and dividends of either $0.40 or $1.00 with equal probability. The most subdued bubble is that of Session 1 discussed previously; the bubbles in Sessions 2 and 3 are much more pronounced. The Session 2 price peaks at $28.00 (300% overvaluation) in round 19, and the Session 3 price peaks at $29.00 (314% overvaluation). The "missing" elements in these latter series indicate that the participants could not agree upon a price in that round, *i.e.*, there was no bid price that was at least as great as any ask price.

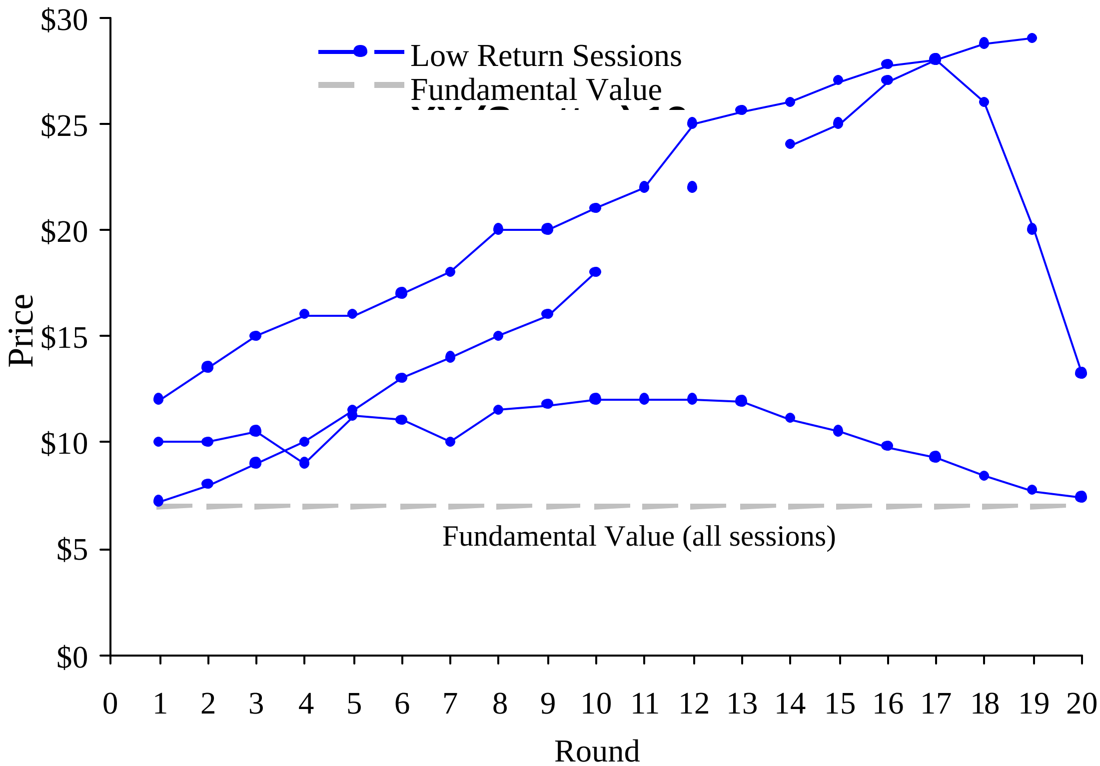

Figure 2. Price series for Sessions 1-3 (“low return” markets).

Figure 3 contrasts the “low return” results with the corresponding results for Sessions 4-6, the “high return” markets in which the interest rate and the dividend payments were doubled. Even though the fundamental value is unchanged at $7, the bubble is stronger than in the “low return” markets. In particular, the price peaks are at $35.70 for Session 4 (407% overvaluation), $55.00 for Session 5 (686% overvaluation), and $75.00 for Session 6 (907% overvaluation). Note that higher price peaks are associated with bubbles that burst later.

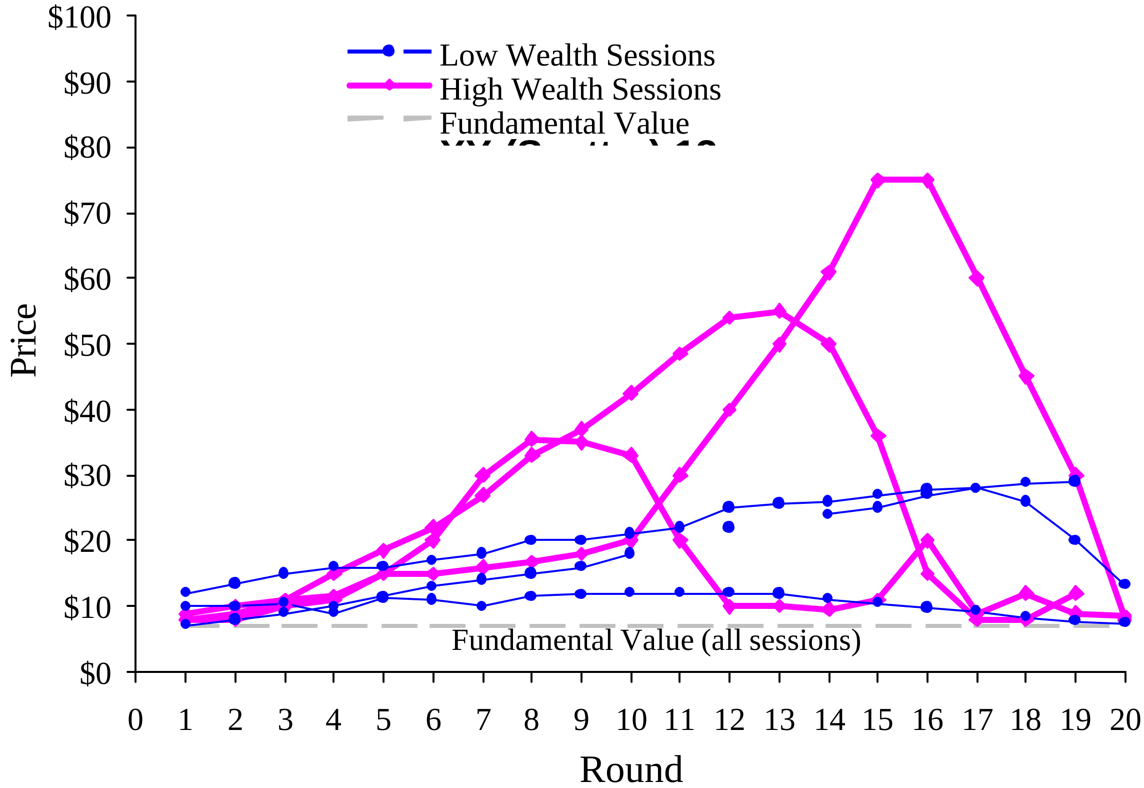

Figure 3. Price series for Sessions 1-3 ("low return" markets; dotted series) and Sessions 4-6 ("high return" markets; diamond series).

Finally, the price series of the "long" market, Session 7, is presented in Figure 4. This session involved extending the "low return" setup by an additional 20 periods. This session evinces the strongest bubble yet; the market peaks at $257.50 (3,579% overvaluation) in round 31! Even though the returns were set at the low level (10% interest and an expected dividend of $0.70), the longer session permitted a very high wealth accumulation as interest compounded, and the total earnings for this session were the highest of all sessions. We conjecture that this high wealth accumulation was responsible for the dramatic price bubble observed.

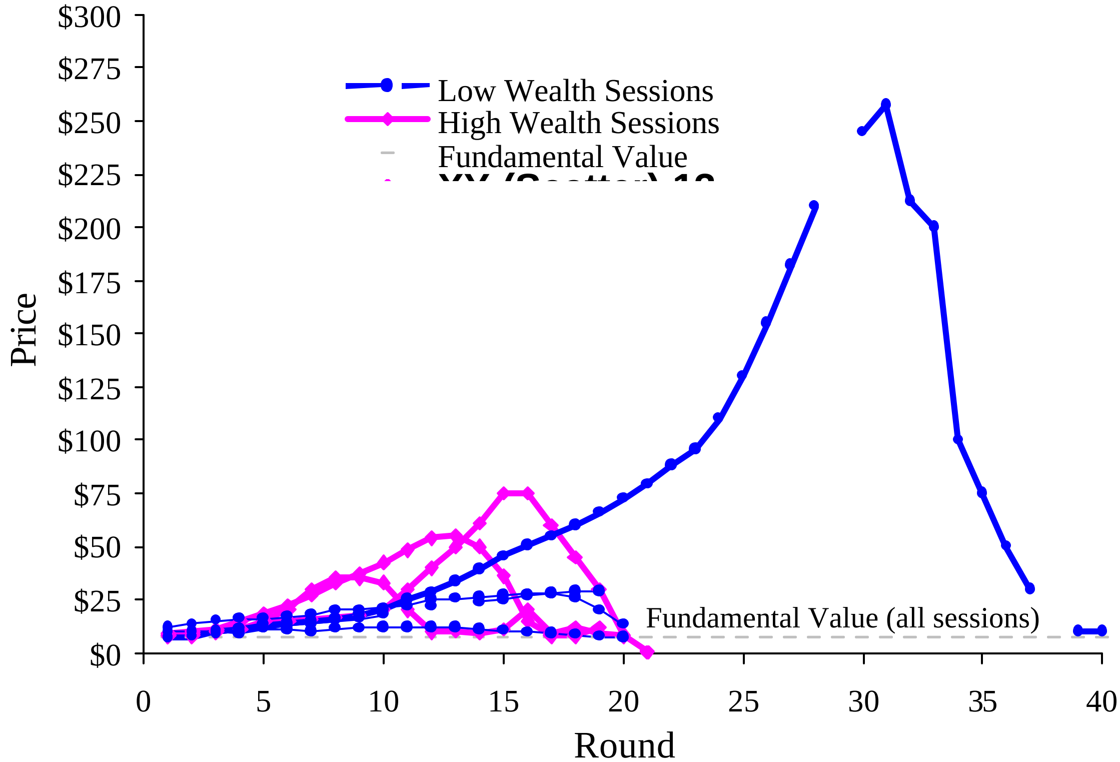

Figure 4. Price series for Session 7 (“long” market; single dotted series).

IV. Results with an Unknown (Common) Final Redemption Value

The final series of markets involved no wealth accumulation during the experiment, *i.e.*, dividends and interest were set at zero. To make these markets interesting, a random final redemption value was generated, and each person received a “signal” that was known to be uniformly distributed on a range of $25.00 above or below the unknown true value. Subjects were not given prior information about the true redemption value, and the parameters were set so that the signal would be at least $25.00, to avoid truncation inference problems with low signals. Thus a person with a signal of S perceives the final redemption value to be distributed uniformly on $[S - 25, S + 25]$. This setup corresponds is analogous, for example, to a situation in which traders with private information trade shares of a pharmaceutical company that is developing a new drug with a market value that will be determined on the basis of future clinical trials. The asset possesses a common value which is worth the same for all traders, but the traders’ signals of this value differ randomly. We will refer to the setup as a “common-value asset market.”

In this common-value setup, the set of traders' signals determines the knowledge of the market as a whole, or what a trader would infer if all signals were made public. For example, suppose that one trader has a signal of \$45.00 and the other has a signal of \$75.00. Then the first person knows that the redemption value cannot be above \$70.00, and the second person knows that the price cannot below \$50.00, so the set of traders' signals restrict the redemption value to be between \$50.00 and \$70.00, with each value in this range being equally likely. With more than two traders, the lowest of the signals establishes the upper bound on the range of redemption values, and the highest of the signals establishes the lower bound on this range. Therefore, the range will tend to be narrower in markets with more traders.

The three sessions involving a common-value asset market were initialized by endowing each trader with 6 shares and a cash account of \$1,500.00, enough to buy 30 shares at \$50.00 per share, which was the center of the range of true redemption values. (Recall that this range was not revealed to the subjects). The motivation for this setup was to provide each trader with enough cash to purchase a large proportion of the shares in the market. Therefore, even though cash and dividends were not accumulating during the course of trading in these sessions, initial wealth positions were high.

Figure 5 shows the transaction prices for Session 8, a session with 8 participants and an unknown common value of \$59.22. The traders' signals restricted the range of possible common value to be between \$49.27 and \$62.57. This range is indicated by the upper and lower horizontal light lines in Figure 5, and the true common value is indicated by the dark line near the top of this range. Of course, no individual trader had anywhere near the same amount of information as the market; recall that each trader's range of possible values was \$50.00 wide. The transaction prices for this session reveal the true common value for the asset. Note that there are three periods in which prices rise slightly above range implied by all signals.

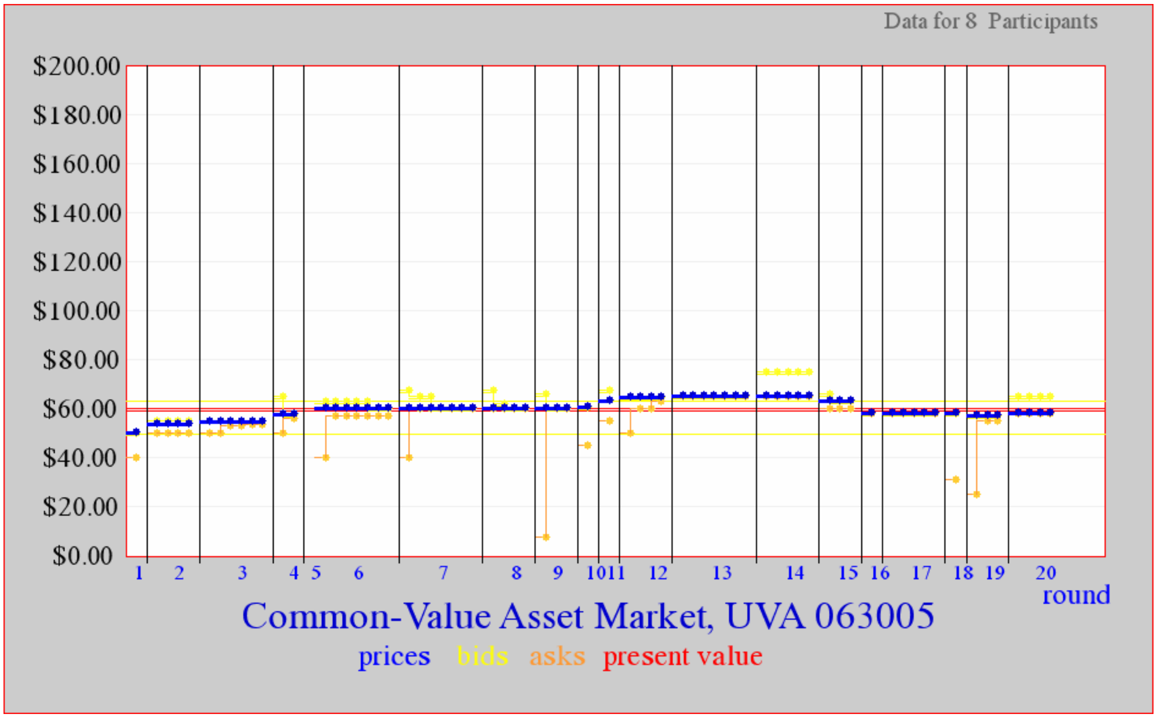

Figure 5. Price series for a common-value asset market.

A stronger bubble-like deviation was observed Session 9, shown in Figure 6. This session only had 5 participants, which explains the wider range of values implied by the price signals, and the somewhat more erratic price pattern.

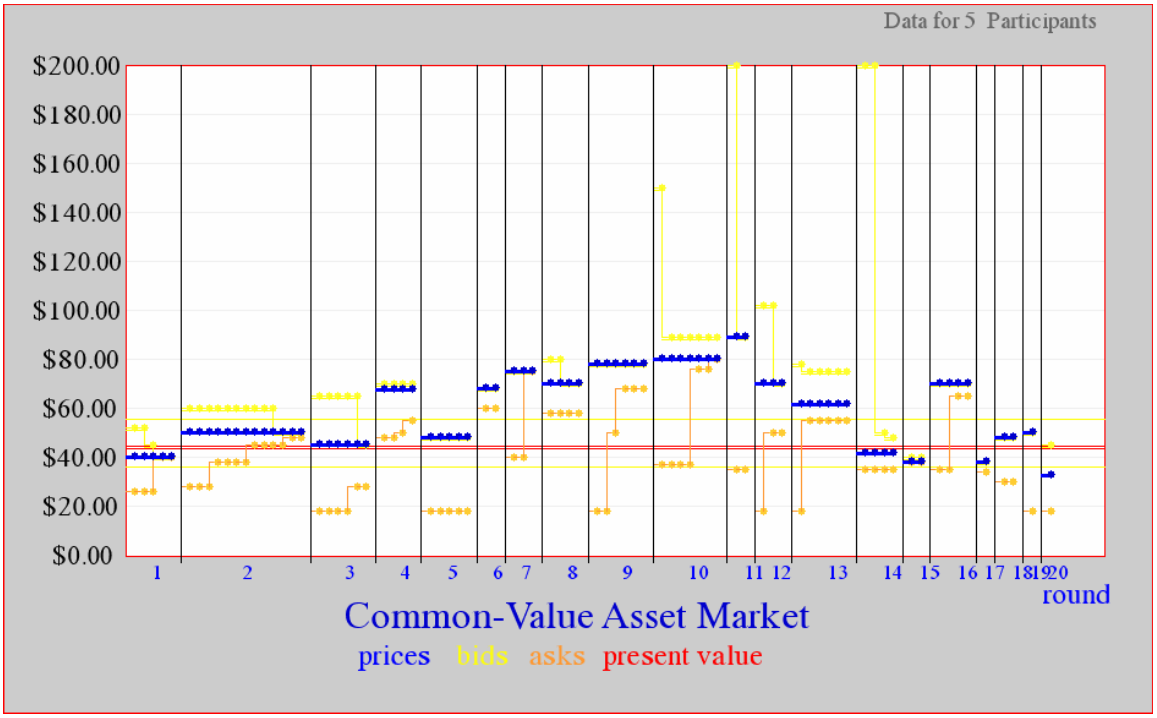

Figure 6. Price series for a common-value asset market with a moderate bubble.

Finally, Session 10, shown in Figure 7, was conducted with 11 traders, and it shows the sharpest bubble for this setup, with prices peaking at $180.00 in period 11. Interestingly, the price started off at $100.00 in period 1, and these purchases were made by a person with a signal of $65.83, so this person knew with certainty that the true value could not be above $90.83. Nevertheless, an investment at $100.00 would have yielded a positive return if it was successfully resold in the middle periods of this market. Other traders also purchased at prices above their upper limits. For example, a person with signal of $29.48 began bidding in the $90.00-$100.00 range, and successfully sold shares later at $105.00 and at $160.00. Clearly, there was a lot of speculation in this session, and the earnings range from $10.05 to $34.53 (after applying the $100:$1 conversion factor).

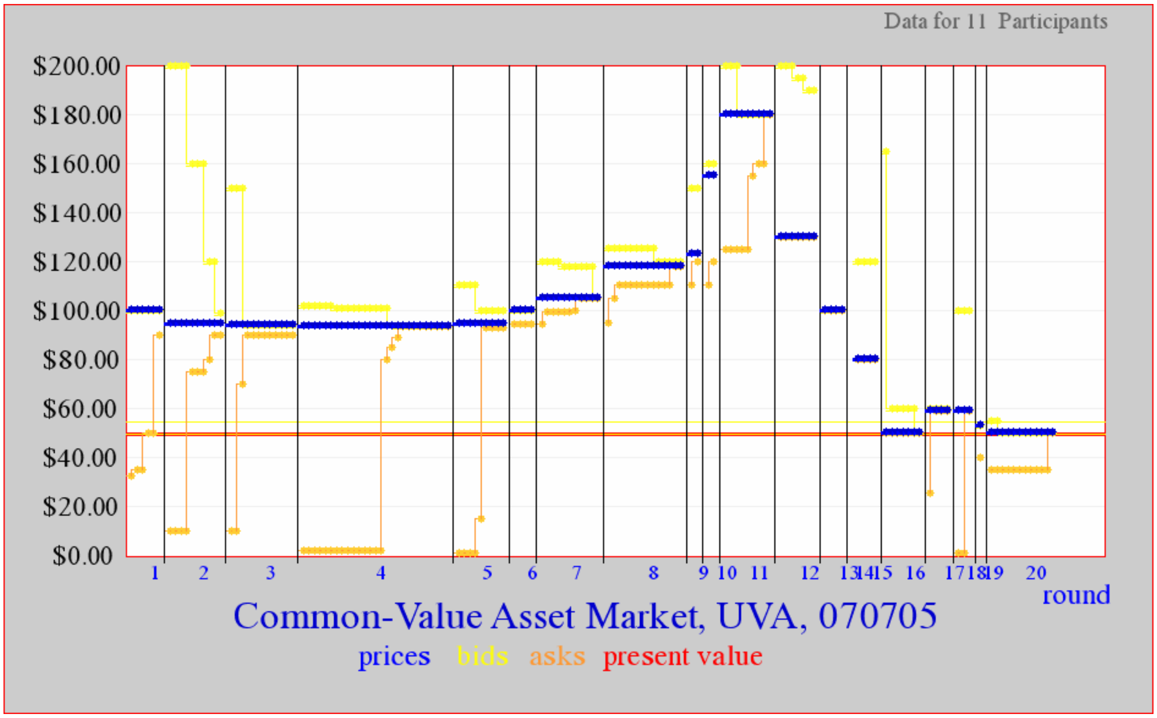

Figure 7. Price series for a session with common value trading and a strong price spike.

V. Conclusion

This paper provides a novel experimental asset market setup with a flat fundamental value. This market involves two assets: cash bearing interest at rate *r*, and stock paying an expected dividend of *D*. The fundamental value is given by the well-known present discounted value formula *D*/*r*. In all sessions using this setup, *D*/*r* remained the same, but the magnitudes of *D* and *r* and the number of periods varied. Stronger bubbles were observed in sessions with the higher *D* and *r*, and a very strong bubble was observed in the session with more periods. The fact that more cash accrues in these latter sessions could support the idea that the accumulation of cash fuels pricing bubbles.

We also provided a setup in which the participants possessed only a random signal of the true fundamental value, and no interest or dividends were paid. At the market level, the signals significantly narrow the range of possible fundamental values for the asset. To allow for the possibility of cash-based speculation, the traders were endowed with large cash accounts. Bubbles were indeed observed in some sessions. Thus, it appears that the total available cash, and not only the ability to accumulate cash, is a factor driving a pricing bubble.

Bubble behavior is difficult to explain by standard theories of financial economics. When one enters the jungle of speculation in these models (a jungle in which arbitrage opportunities exist), it is simply too easy to get lost amongst the numerous factors which might form the speculative beliefs. But, pricing predictions are impossible without some measure of these beliefs. The experimental data presented here suggest a salient feature of asset pricing bubbles: the availability of cash with which to speculate. In particular, we observe that an increase in cash wealth is used to chase after a fixed number of shares for speculative purposes, the result being higher prices. Future research will be directed at modeling the choice of how much wealth to allocate between stock and cash, using the cash on hand as a determinant of the investor's beliefs about possible non-fundamental returns.

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