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MARKET EFFICIENCY: EVIDENCE FROM A NO-BUBBLE ASSET MARKET EXPERIMENT

VIVIAN LEI* *University of Wisconsin-Milwaukee and City University of Hong Kong*
FILIP VESELY *University of Wisconsin-Milwaukee*

Abstract. We report the results of an experiment that demonstrates that market experience is not necessary to eliminate bubbles in the type of asset markets studied in Smith *et al.* (1988). We introduce a pre-market phase in which subjects experience a dividend flow themselves by literally observing and receiving dividends for 12 periods. The robust bubble–crash phenomenon never occurs in our experiment. Our results provide strong evidence that so long as a majority of the subjects have full understanding of the structure of the dividend, market efficiency can be ensured.

1. INTRODUCTION

One of the most important implications of the efficient market hypothesis is that prices should fully reflect all available information and, consequently, always be consistent with the fundamentals (Fama 1970). Nonetheless, there has been substantial evidence suggesting the existence of behaviour anomalies and, more importantly, the misalignment of asset prices from the fundamentals.[1] Should we believe that mispricing is indeed a norm in most asset markets and, therefore, reject the efficient market hypothesis?

This is certainly not an easy question to answer due to the following reasons. First, intrinsic values are in general not observable in the field markets. Second, a more problematic issue with the current empirical studies, as Fama (1991) points out, is that anomalies are sensitive to methodology. Any empirical test of market efficiency is in fact a joint test of market efficiency and some model for expected returns. Hence, when the joint hypothesis is rejected, it is unclear whether the rejection is a result of market inefficiency or a bad asset-pricing model. Some economists have tried to use laboratory methodology as an alternative to test the efficient market hypothesis. In a laboratory environment, one can control, for example, the fundamental value of an asset and the information

**Address for correspondence*: Department of Economics, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, U.S.A. E-mail: vlei@uwm.edu. We thank the College of Letters and Science and the Center for Research on International Economics at University of Wisconsin-Milwaukee for financial support. Laboratory support from the Krannert School of Management at Purdue University for the pilot session is gratefully acknowledged. We thank two anonymous referees, Peter Bossaerts, Ken Chan, John Heywood, Charles Noussair, Steven Tucker, Yong Wang, seminar participants at City University of Hong Kong and the University of Wisconsin-Milwaukee, and participants at the 2003 North American Meeting of the Economic Science Association for helpful comments.

[1] See Fama (1991) for a discussion of the debate on the efficient market hypothesis, and Beechey *et al.* (2000) for a survey on related empirical work.

available to market participants. Therefore, the 'bad model' problem or debate regarding measurement issues can be easily avoided.

Yet, evidence from experiments in which long-lived assets are traded has not supported the efficient market hypothesis either. Smith *et al.* (1988) test the efficient market hypothesis in controlled laboratory markets where assets with a life of 15 or 30 periods are traded. The asset pays a random but common dividend to holders of the asset at the end of each period. The dividend structure is announced as public information to all traders. Because the dividend is the only source for the asset's intrinsic value, the asset's fundamental value for each period is well defined. Rather than tracking the fundamental value, prices exhibit a prolonged boom and crash pattern in the majority of markets.

Many studies have followed Smith *et al*. to test the robustness of the prominent bubble–crash phenomenon.[2] The only manipulation that has been shown to consistently eliminate bubbles is subjects' experience. Subjects learn the structure of the asset, the nature of the market, and the behaviour of other participants through participating in at least two sessions of the experiment with the same group of traders. As a result, prices tend to track the fundamental values relatively well.[3]

In the present paper, we focus on another aspect of learning and investigate the impact of changes in experimental protocol on the formation of bubbles. A pre-market phase is introduced to facilitate participants' understanding of the characteristics of the asset. The pre-market phase, which consists of 12 periods, is designed to engage participants' exclusive attention on the dividend structure. The dividend payment in our experiment follows a two-point i.i.d. distribution with an expected value of 30 francs (experimental currency).[4] Subjects observe the complete dividend flow by receiving dividends at the end of each period over the entire time horizon (i.e. periods 1–12).

As we report in detail below, the robust bubble–crash phenomenon observed in previous studies never emerges in the market phase of our experiment. Furthermore, price adjustments fully reflect changes in the fundamental value. Our results indicate that experience from market participation, at least twice, is not necessary to eliminate bubbles.

[2] For instance, King *et al*. (1993) show that treatments such as allowing short selling or margin buying, imposing a transaction fee, executing limits on price changes, and having corporate executives or stock market dealers rather than college students as subjects do not eliminate bubbles. As opposed to the double auction market mechanism that is broadly used in the published literature, Van Boening *et al*. (1993) adopt the call market mechanism and find that this change in trading mechanism has no significant impact on removing bubbles. Porter and Smith (1995) observe the same price pattern when futures markets are introduced, and the bubble–crash phenomenon continues to emerge in their study when a random dividend is replaced by a fixed dividend payoff. Smith *et al*. (2000) study the effect of dividend timing and find that having a single dividend paid at the end of the trading horizon helps to reduce the incidence of bubbles. Noussair *et al*. (2001) observe bubbles in their markets in which an asset with a constant fundamental value over the entire trading horizon is traded.

[3] See Smith *et al*. (1988), Van Boening *et al*. (1993) and Dufwenberg *et al*. (2005) for the impact of experience on bubbles.

[4] Although the dividend paid in Smith *et al*. 1988) follows a four-point distribution, Lei *et al*. (2001) find that the dividends drawn from either a four-point or a two-point distribution have no significant impact on price formation.

Section 2 describes the experimental design and procedures. We report the results of the experiment in Section 3. Finally, we conclude the paper in Section 4.

2. THE EXPERIMENT

The experiment consisted of five sessions, conducted at the University of Wisconsin-Milwaukee between February and April 2003. There were 37 subjects, all recruited from introductory microeconomics or macroeconomics courses.[5] None of the subjects had any experience with market experiments prior to participating in our experiment.

Each of the five sessions was divided into two phases: the pre-market phase and the market phase. Each phase consisted of 12 periods.[6] In the market phase of the experiment, subjects were free to buy and sell an asset using continuous double auction rules. The asset market was programmed and conducted using the software z-Tree (Fischbacher 2007). Transactions were denominated in an experimental currency, francs, which were converted to US dollars at the end of the experiment at a rate of 170 francs to 1 dollar. Each session lasted approximately 3 h, and subjects earned an average of $US40.84.

2.1. *The pre-market phase*

In the pre-market phase, an artificial asset certificate, called *Asset Certificate 1*, was handed out to each participant at the beginning of period 1. There were 12 dividend coupons on Asset Certificate 1. Subjects were told that the experimenter would redeem 1 dividend coupon at a time for 12 periods, and that a coin flip would be used to determine each period's dividend payment. The dividend was either 20 or 40 francs. In other words, the expected dividend was 30 francs per period.

Starting from period 2, subjects were given one additional asset certificate at the beginning of each period. These certificates were exactly the same as Asset Certificate 1, except that there were $13 - t$ redeemable dividend coupons on each of these period t asset certificates. For example, the certificate received at the beginning of period 2, called *Asset Certificate 2*, had only 11 dividend coupons that could be redeemed at the end of each period for the rest of the pre-market phase. The procedure for redeeming Asset Certificate t's coupons was the same as that for Asset Certificate 1's. Asset Certificate 1 and 2 are shown in Figure 1.

Each period of the pre-market phase was designed to last 3 min to be consistent with that in the market phase. For the first 6 periods, subjects were asked to cut the current period's dividend coupons from the asset certificates and hand them over to the experimenter at the end of each period. After

[5] There were 7 and 6 subjects in sessions 1 and 3, respectively. The rest of the sessions had 8 subjects each.

[6] In addition to 12 trading periods, the market phase also included period 0, which was for practice use only.

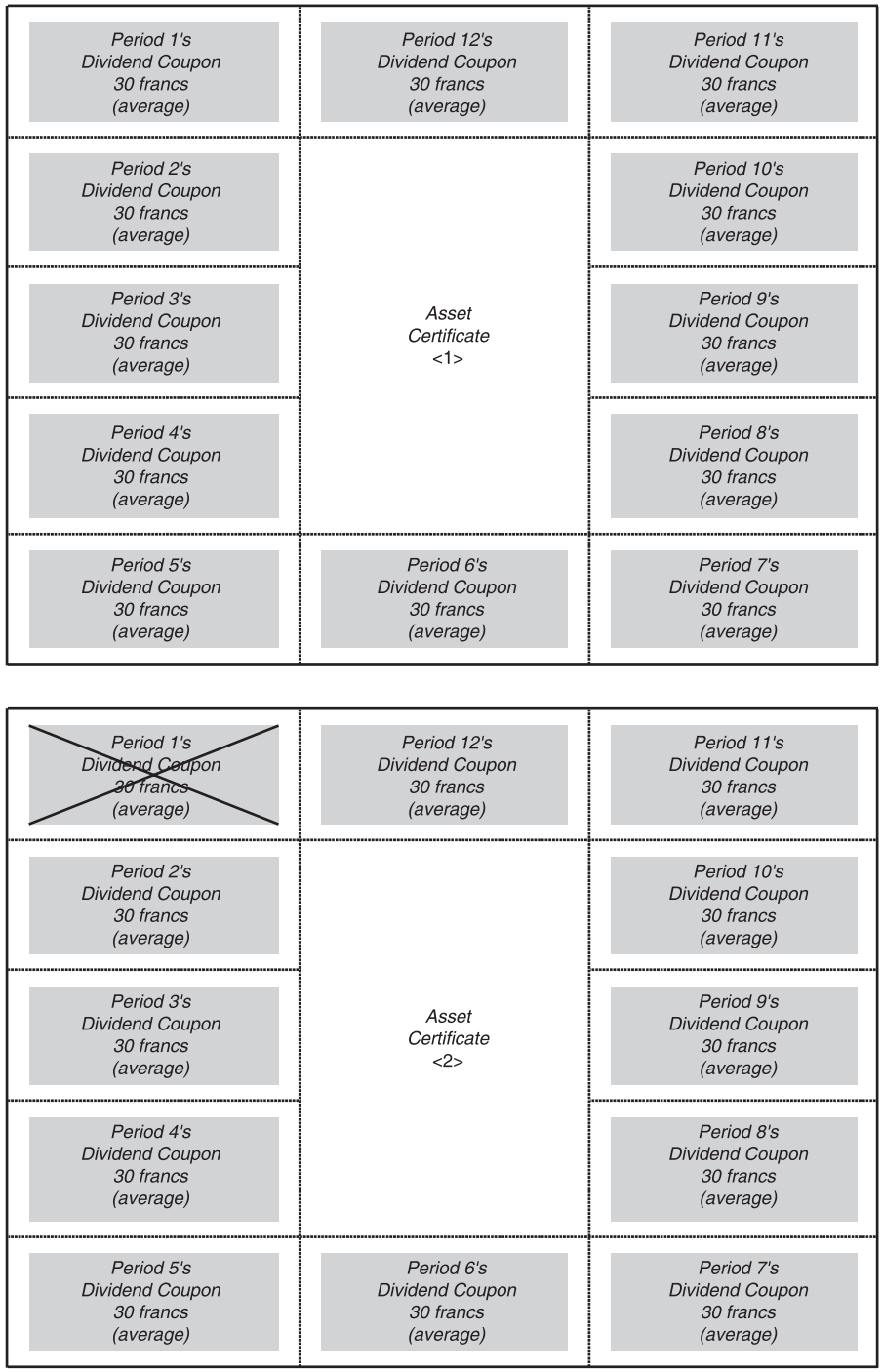

Figure 1. Asset Certificates 1 & 2.

subjects redeemed their coupons and finished recording their dividend earnings, the experiment proceeded to the next period. The experimenter stopped collecting the coupons after period 6. That is, for the last 6 periods of the pre-market phase, all subjects were asked to do was to sit and wait for 3 min each period before a coin was flipped to determine their dividend earnings.[7]

To see if our pre-market phase had helped to induce rational expectations about the value of the asset, a questionnaire was administered right after the completion of the pre-market phase. For each Asset Certificate t, subjects were asked to indicate: (i) the value of the asset certificate; (ii) the minimum price they would be willing to accept (WTA) in order to sell 1 unit of the asset; and (iii) the maximum price they would be willing to pay (WTP) in order to buy 1 unit of such an asset.[8] Dividend earnings in the pre-market phase, which were common to all subjects within a session, were paid in dollars after subjects completed the questionnaire. The questionnaire, the pre-market phase's instructions and the Period Earnings Sheet were all left to subjects for their own reference.

2.2. *The market phase*

The structure of the asset market in our experiment mirrored that studied in Smith *et al.* (1988). Subjects were endowed with 10,000 francs and 10 units of an asset with a life of 12 periods. Excluding the practice period, period 0, there were 12 trading periods in the market phase, and each period lasted 3 min. In each period, there was a market open in which subjects were free to buy and sell the asset. The inventories of the asset and cash balance were carried over from period to period starting from period 1.

As in the pre-market phase, each unit of the asset held in inventory paid a dividend of either 20 or 40 francs. A coin flip was used to determine the actual dividend payment. Because the expected dividend was 30 francs per period, the asset's fundamental value in each period t for a risk-neutral participant equalled $30(13 - t)$, where $13 - t$ is the number of periods remaining for the rest of the market phase.

In sum, the timing of activity within a session was as follows.

1 Upon their arrival, subjects were given approximately 20 min of instruction on how to use the z-Tree software to trade in a continuous double auction environment.
2 The instructions for the pre-market phase were read aloud for subjects, while they followed along with their own copy of the text. Subjects were allowed to ask questions at any time.

[7] We could have made subjects just sit through the entire pre-market phase, but we were afraid that receiving 'earnings' without performing any task would confuse subjects, especially at the beginning of the experiment. The rather trivial task we came up with, meaning cutting coupons and turning them in, was aimed to reduce such confusion.

[8] The last two questions were similar to the questions adopted in Knez *et al.* (1985). As in the present paper, the WTA–WTP instrument was implemented before the opening of the first trading period in Knez *et al.*

3 Periods 1–12 of the pre-market phase proceeded.
4 A questionnaire was administered after period 12. Subjects received the total dividend earnings for the pre-market phase as soon as they finished the questionnaire.
5 The instructions for the market phase were handed out and read aloud.[9]
6 The market was open for period 0, the practice period, for 3 min. Earnings in period 0 did not count toward subjects' final earnings.
7 Inventories of the asset and the cash balance were reinitialized to 10 units and 10,000 francs, respectively, at the beginning of period 1.
8 Periods 1–12 of the market phase proceeded. Subjects' earnings for the market phase, including dividend payments and capital gains, were paid at the end of period 12.

3. RESULTS

We first discuss the results from the pre-market phase. Note that no interaction among subjects was allowed in the pre-market phase. The pre-market phase was designed to have subjects focus on the dividend flow and, therefore, gain better understanding of the decision environment. We purposely excluded the possibility of subjects interacting so that the influence of expectations about other participants' behaviour on the task of asset valuation could be reduced to the minimum.

RESULT 1: *The presence of the pre-market phase in our experiment induces rational expectations regarding the value of the asset. Furthermore, the WTA–WTP equilibrium price closely tracks the fundamental value*.

SUPPORT FOR RESULT 1: To see if the pre-market phase improved subjects' understanding and helped them relate the expected total dividend payment with the asset's fundamental value, we first investigate the data from subjects' responses to the following question in the questionnaire: 'In terms of francs, how much would you value an Asset Certificate t, which would pay you on average 30 francs at the end of each period for $13 - t$ periods?' Combining all five sessions and 12 periods together, 51% of the responses valued the asset right at the expected future dividends, 17% valued the asset between the expected future dividends and the maximum possible realization of dividends, and 27% attached values that were between the expected future dividends and the minimum possible realization of dividends. In other words, only 5% of the responses were irrational in the sense that they were outside the range of

[9] Unlike previous studies, the Average Holding Value Table, which usually laid out not only the average total dividend but also the maximum and minimum total dividends for the remainder of the experiment, was not included in the instructions for the market phase. The reason that we did not provide the Average Holding Value Table was because the Period Earnings Sheet in our pre-market phase served exactly the same function as the Average Holding Value Table. Because subjects had spent the entire 12 periods in the pre-market phase completing the Period Earnings Sheet, we believed it was not necessary to provide them the Average Holding Value Table for the market phase.

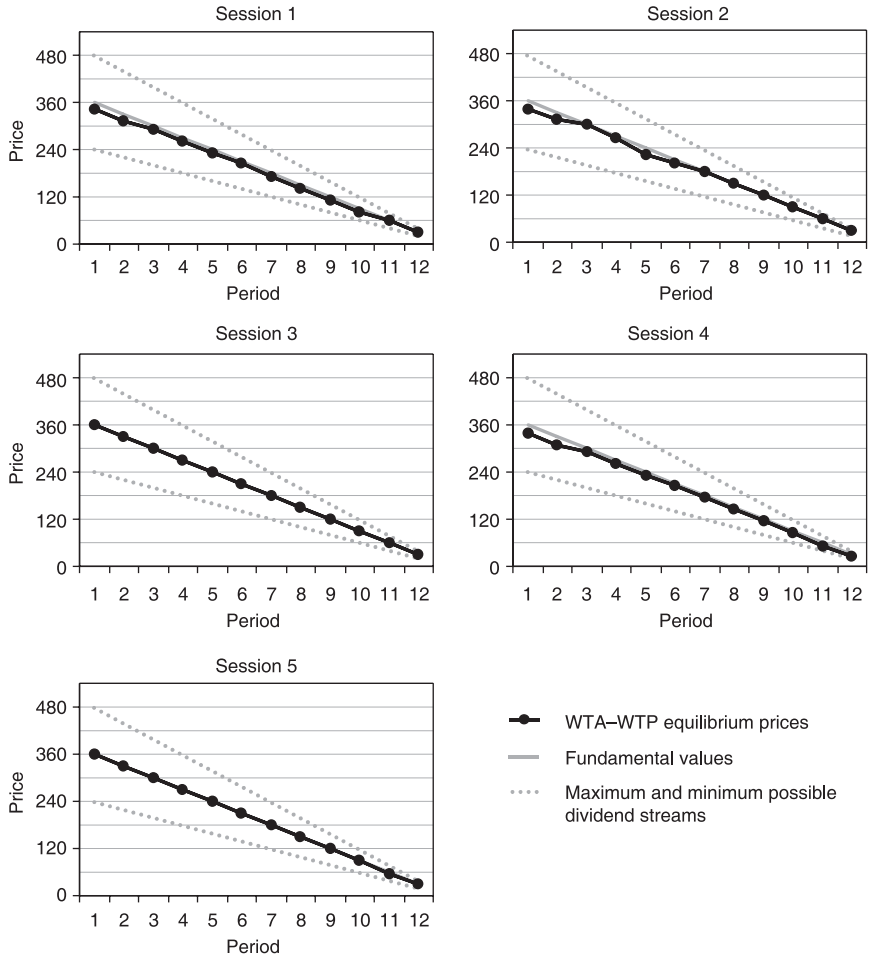

Figure 2. Time series of willing to accept–willing to pay (WTA–WTP) equilibrium prices.

maximum and minimum possible realization of future dividends. Along with the tally that there were 33 out of 37 subjects who never responded irrationally when asked to value asset certificates 1–12, we are certain that, after experiencing the dividend flow for 12 periods in the pre-market phase, the majority of our subjects fully comprehended the dynamic feature of the asset and valued the asset rationally conditional on its dividend payment.

Another piece of evidence that suggests the existence of rationality comes from subjects' WTA and WTP responses solicited at the end of the pre-market phase. Figure 2 presents the time series of the WTA–WTP equilibrium price for each of the five sessions. To generate the WTA–WTP equilibrium price,

we construct a demand curve by ordering the WTP responses from highest to lowest, and a supply curve by ordering the WTA responses from lowest to highest. The WTP–WTA equilibrium price is the price at which demand equals supply. Figure 2 shows that the WTA–WTP equilibrium price tracks the fundamental value remarkably well. It perfectly follows the fundamental value for each of the 12 periods in session 3. A similar pattern can be observed in session 5, except that the equilibrium price is 4.5 francs lower than the fundamental in period 11. The WTA–WTP equilibrium price tends to be somewhat lower than the fundamental value for most of the periods in sessions 1, 2 and 4. Nonetheless, the deviations never exceed 30 francs.

It is possible that Result 1 is caused by the fact that subjects were not told they could resell the asset and, therefore, were unaware of the possibility of speculation when answering the questionnaire.[10] If this is the case, it would be interesting to see if the same price pattern would prevail during the market phase in which buying for resale is allowed. Figure 3 provides the time series of median transaction prices in the market phase for all five sessions. With the exception of session 2, the general pattern is that the median price tends to start from somewhere very close to the fundamental value, and then, with a descending pattern over time, stays mostly between the fundamental value and the minimum possible realization of future dividends. This is particularly true for sessions 1 and 4. In session 3, the median price for the first half of the session stays within the range of the fundamental value and the minimum possible realization of the dividends, although it goes somewhat below the minimum for the last six periods. The median price in session 5 is slightly higher than the fundamental value from period 3 to period 5, but it stays fairly close to the fundamental value for the remaining 7 periods. In sum, a prolonged boom followed by a sudden crash in the median transaction price never occurs in the market phase of our experiment.

Result 2: *The bubble–crash phenomenon is not observed in our experiment. The median prices tend to stay within the range of the fundamental value and the minimum possible realization of future dividends, with a declining pattern that reflects the change in the fundamental value over time.*

Support for Result 2: In addition to the price pattern described above, we compare the magnitude of price deviations from our data with those in previous studies. Two measures typically used to determine the size of bubbles are *price amplitude* and *normalized deviation*. The price amplitude is defined as the difference between the largest and the smallest price deviation from the fundamental value, adjusted by period 1's fundamental value: $\max_t\{(P_t - f_t)/360\} - \min_t\{(P_t - f_t)/360\}$, where P_t and f_t are the median transaction price and the fundamental value in period t, respectively. The normalized deviation is the sum of all price deviations from the fundamental values, adjusted by the

[10] We thank one of the referees for pointing this out.

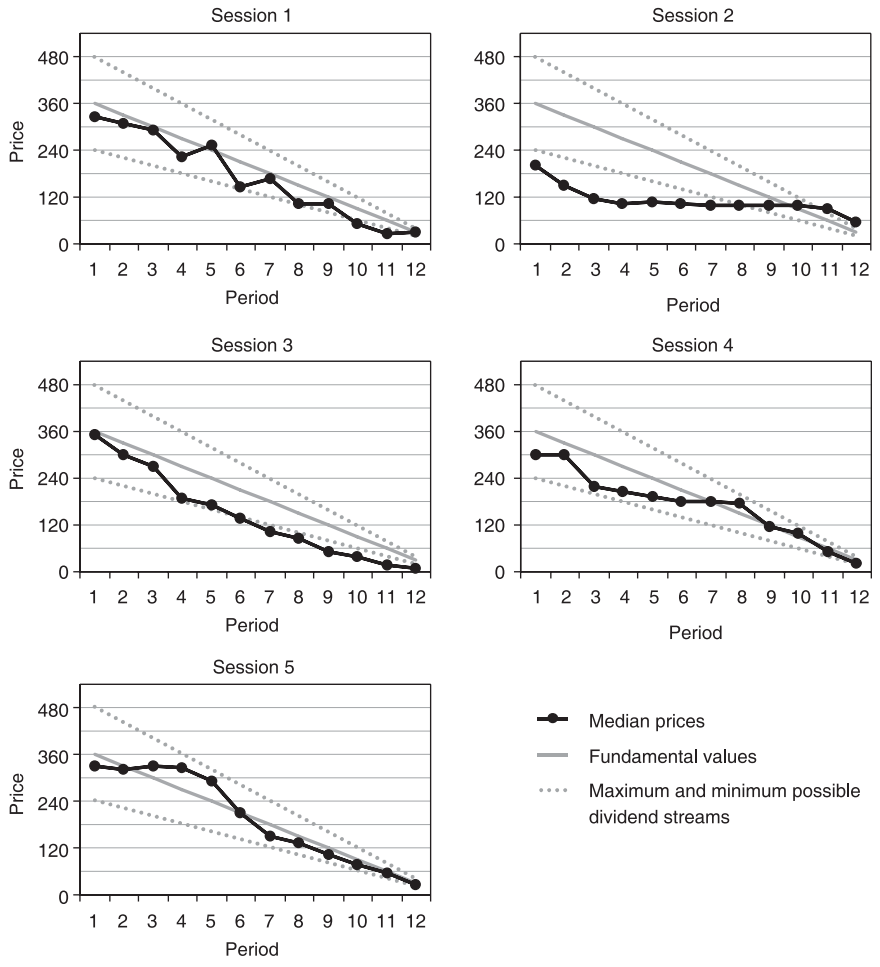

Figure 3. Time series of median transaction prices.

total stock of units: $\Sigma_t\Sigma_i | p_{it} - f_t | /(TSU * 100)$, where p_{it} denotes each individual transaction price in period t, and TSU stands for the total stock of units. Table 1 reports the statistics of these two measures for each of the five sessions. The price amplitude in our experiment ranges from 0.20 to 0.30, with the exception of session 2, in which the amplitude is 0.60. The normalized deviation, ranging from 0.29 to 2.83, has an average of 1.28. These measures are much smaller than those found previously.[11]

[11] According to Noussair and Tucker's (2006) summary, the price amplitude ranges from 0.52 to 4.19, and the normalized deviation varies between 2.24 and 5.68 in previous studies. For more examples, see King *et al.* (1993), Van Boening *et al.* (1993), Porter and Smith (1995), Noussair *et al.* (2001) and Lei *et al.* (2003).

Table 1. Amplitude, normalized deviation and turnover rate

	Session 1	Session 2	Session 3	Session 4	Session 5	Average
Amplitude	0.22	0.60	0.20	0.29	0.24	0.31
Normalized deviation	0.85	2.83	1.76	0.67	0.29	1.28
Turnover	2.04	2.75	3.11	1.81	1.18	2.18

Table 2. Estimated values for α and β

	Session 1	Session 2	Session 3	Session 4	Session 5
$\hat{\alpha}$	–23.84 (7.73)	–6.97* (4.67)	–21.38 (6.89)	–24.42 (6.51)	–27.40 (20.30)
$\hat{\beta}$	0.53 (0.55)	0.50 (0.37)	1.09 (0.57)	0.46 (0.52)	0.03 (1.21)
N	11	11	11	11	11

*Significant at the 1% level (different from –30 for α and from 0 for β).
The numbers in parentheses are the first-order autocorrelation consistent Newey–West standard errors.

The following regression model, first adopted by Smith *et al.*, is used to determine whether the dynamics of the median price are consistent with declining fundamental values:

$$P_t - P_{t-1} = \alpha + \beta(B_{t-1} - O_{t-1}) + \varepsilon_t, \quad (1)$$

where P_t denotes the median price in period t, and B_{t-1} and O_{t-1} are the numbers of bids and asks in period $t-1$, respectively. The excess bids, $B_{t-1} - O_{t-1}$, are used to proxy excess demand resulting from expectations of capital gains. Smith *et al.* and several subsequent studies have found that in markets where bubbles and crashes are most prominent, the price movement between period t and $t-1$ is significantly and positively related to period $t-1$'s excess bids (see, for example, King *et al.* (1993), Porter and Smith (1995) and Lei *et al.* (2001)). Therefore, to show that the bubble–crash pattern did not arise in our data and that the price movement mainly reflects changes in the fundamental value, we need to show that α is not significantly different from –30 and that β is not significantly different from zero. Table 2 provides the ordinary least squares estimates of α and β for each of the five sessions.

We cannot reject the null hypothesis $\alpha = -30$ at the 1% level for sessions 1, 3, 4 and 5. Furthermore, $\hat{\beta}$ is not significantly different from 0 in all five sessions of the experiment. In sum, the data from our market phase show that capital gains expectations, proxied by the excess bids in the market, have no significant influence on price formation.[12] More importantly, the dynamics of the median transaction price can be explained by the change in the fundamental value.

[12] One of the referees suggests that demand and supply must be rather elastic around the fundamental value to cause price irresponsiveness to excess bids. This suggestion, in our opinion, is consistent with the observation that subjects tended to use the discounted future dividends as reservation prices when placing offers in our experiment.

One might suspect that the lack of bubbles and crashes is associated with a lack of trading activities in our experiment. The turnover rate, defined as the total trading volume divided by the total stock of outstanding units, is provided in Table 1 along with the amplitude and the normalized deviation. The turnover rate, ranging from 1.18 to 3.12, has an average of 2.18. Although these turnover rates appear to be smaller than those observed in previous studies, they are certainly not negligible.[13]

Contrary to the finding by Knez *et al.* (1985) that the WTA–WTP equilibrium prices do much better in predicting the mean market trading prices than the fundamental values, we find that both the WTA–WTP equilibrium prices and the average trading prices are closely in line with the asset's fundamental values. This suggests that individual rationality induced in the pre-market phase was so profound that uncertainty about the behaviour of others, which might have existed, never became strong enough to divert market prices away from the fundamental values.

The individual trading behaviour summarized below is used to further support our argument that the discounted future dividends were the reservation prices participants used most of the time to trade with others in our markets.

Result 3: *Rational trading behaviour is widely observed during the market phase of the experiment. Subjects tend to behave equally rationally when submitting offers and when consummating deals.*

Support for Result 3: Let us first investigate the prices that subjects submitted to the market. Taking subjects' risk attitudes into consideration, we consider a bid submitted by trader i to be rational if its price is lower than or equal to the maximum possible realization of future dividends. Similarly, we consider an ask submitted by trader i to be rational if its price is higher than or equal to the minimum possible realization of future dividends. The percentage of total submitted bids and asks that are rational for each of the 37 subjects is represented as a black column in Figure 4. On average, 99% of the offers submitted by a market participant are rational in session 1. The analogous numbers for sessions 2, 3, 4 and 5 are 65, 76, 100 and 100%, respectively. That is, the vast majority of the time, our subjects did use the discounted future dividends as reservation prices when placing offers in the market.

We also compute the percentage of offers accepted by trader i that are rational. This is represented by each of the gray columns in Figure 4. Subjects appeared to behave equally rational when it came to the moment to consummate a deal proposed by someone from the other side of the market. The percentages of rational offers out of all offers accepted by a participant are, on average, 95, 73, 70, 99 and 100% in sessions 1, 2, 3, 4 and 5, respectively. Finally, taking each trader as an observation, a Wilcoxon signed-rank test indicates that we

[13] Noussair and Tucker (2006) summarize the turnover rates from previous studies. They show that the turnover rate in general is between 4.00 and 5.50.

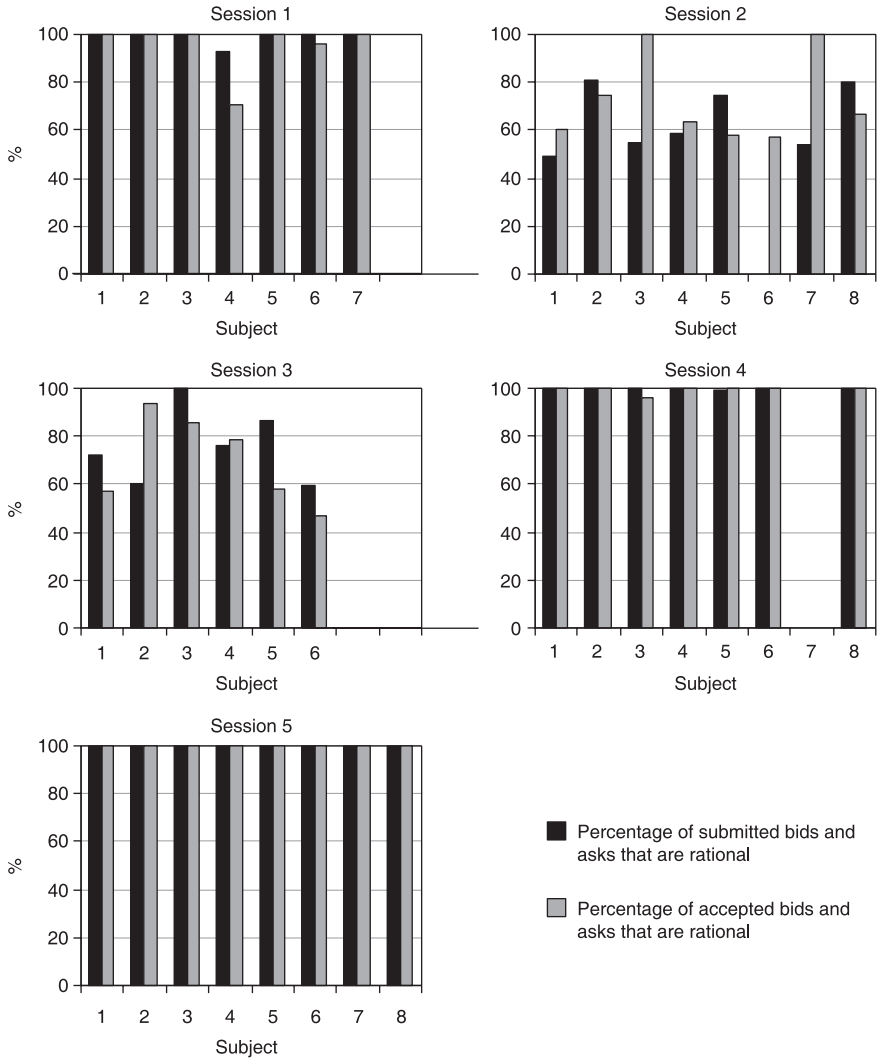

Figure 4. Percentage of bids and asks that are rational (note: subject number 6 in session 2 and number 7 in session 4 did not submit any offers and, therefore, no columns are shown for these two subjects).

cannot reject the hypothesis that the percentage of rational offers submitted and the percentage of rational offers accepted are equal (P-value = 0.474).

4. CONCLUSION

In this study, we show how changes in the experimental protocol can dramatically alter the outcome of experiments of this nature. We adopted the same asset characteristics and market environment as in Smith *et al*. (1988), but changed

how the dividend structure was being *presented*. Rather than presenting the Average Holding Value Table that shows the expected future dividends, the maximum and the minimum possible realization of total dividends for the remainder of the experiment, we had subjects experience the dividend flow themselves by literally observing and receiving dividends for 12 periods in our pre-market phase. The robust bubble–crash phenomenon never occurs in our experiment. Our results suggest that experience from market participation is not necessary to eliminate bubbles. Proper instructions that emphasize the structure of dividends can provide a great substitute for prior experience.

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