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Speculation, money supply and price indeterminacy in financial markets: An experimental study ☆

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ABSTRACT

To explore how speculative trading influences prices in financial markets, we conduct a laboratory market experiment with speculating investors (who do not collect dividends and trade only for capital gains) and dividend-collecting investors. Moreover, we operate markets at two different levels of money supply. We find that in phases with only speculating investors present (i) price deviations from fundamentals are larger; (ii) prices are more volatile; (iii) mispricing increases with the number of transfers until maturity; and (iv) speculative trading pushes prices upward (downward) when the supply of money is high (low). These results suggest that controlling the money supply can help to stabilize asset prices.

1. Introduction

Speculators are short-term traders seeking capital gains. The value of a security to them depends on their future price expectations, which are sensitive to noisy information, higher-order expectations, and even recent price changes. Therefore, in a market populated by speculators, stock prices can be susceptible to excess volatility and bubbles (Keynes 1936; Shiller 2000; Stiglitz 1989). Standard finance theory, however, does not associate these phenomena with speculation. Even short-term speculators are assumed to form rational expectations of future prices; they form iterated expectations from near-to-distant future generations and conduct backward induction to arrive at the present value of the security. In the resulting rational expectation equilibrium (REE) prices are equal to fundamental values (Adam and Marcet 2011; Tirole 1982).

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The REE outcomes depend on the assumption of common knowledge of rational expectations among all generations of investors (Cheung et al., 2014; Smith et al., 1988; Sutan and Willinger 2009): investors form rational expectations themselves, but also believe that the subsequent generations of investors do the same. However, common knowledge of rationality among agents is rarely achieved in practice (Aumann 1995; Geanakoplos 1992). In experimental studies, backward induction often fails due to a lack of common knowledge of rationality in the centipede game (McKelvey and Palfrey 1992), bargaining game (Johnson et al., 2002), and the beauty contest game (Nagel 1995; Camerer 2003). Given this background, the assumption of common knowledge of rational expectations across several generations of investors is unlikely to hold in practice. Without it, short-term speculators should have difficulty in backward induction and prices should no longer be anchored to the fundamental value and may wander away.

In this paper, we examine how speculation and money supply influence price indeterminacy in financial markets. We conduct a laboratory experiment because it is not possible to distinguish capital gains-seeking speculative trading from non-speculative trading in field data. Even if we can identify speculative trading and its effect on price volatility, it is difficult to determine whether it arises from investors' difficulty in forming rational expectations.[1] Furthermore, the fundamental value of the security to serve as a benchmark for measuring mispricing is rarely identifiable in the field.[2] We, therefore, choose the experimental approach where we can control the presence of speculating investors as well as money supply, focus on the feasibility of rational expectations, and define the asset's fundamental value in the laboratory.

Although there have been numerous asset market experiments (for review, see Duxbury 1995; Sunder 1995, Noussair and Tucker 2013, Palan 2013, Powell and Shestakova 2016), the question of whether speculation causes price volatility or bubbles remains unresolved. In a design introduced by Smith et al. (1988), price bubbles are observed frequently and some researchers interpret the bubbles as a consequence of speculative trading based on others' irrationality. However, in their experimental setting, it is difficult to judge whether the bubbles occur due to speculation or confusion about the fundamental value of the security. Indeed, Lei et al. (2001) repeat that experiment but prevent speculation by forbidding re-sales. They still observe bubbles, reinforcing the confusion hypothesis (see also Kirchler et al., 2012).[3]

Hirota and Sunder (2007), Moinas and Pouget (2013), and Janssen et al. (2019) conducted experiments that are directly related to speculation in financial markets. In their bubble game experiment, Moinas and Pouget (2013) present evidence counter to standard finance theory on speculation. They show that subjects often buy the security above its fundamental value even when bubbles are (theoretically) ruled out by backward induction. They also find that the propensity for a subject to buy increases with the number of steps of iterated reasoning needed for backward induction. These results indicate that the lack of common knowledge of rationality might be an important driver of speculation. However, from their experiment, we cannot know whether and how speculative trading affects price formation since the security price is exogenously given by the experimenter. Janssen et al. (2019) find that overpricing is higher in markets composed of traders with a high propensity to speculate than in markets composed of traders with a low propensity to speculate. Instead of using a subject's propensity to speculate as a treatment variable, we develop an experimental design that creates investors engaged in speculative trading for capital gains and examine the effect of speculation on price formation in the laboratory. In Hirota and Sunder (2007) price bubbles emerge in a treatment where investors receive the expected next period price (predicted by a separate set of subjects) as liquidation value at the end of a market session. Their results show that when investors face the *impossibility* of backward induction, their speculation induces security prices to deviate from the fundamental value.

In the present paper, we take the ideas presented in Hirota and Sunder (2007) a step further and examine whether short-term speculation causes price deviation from the securities' fundamental value in a market where REE (through investors' backward induction) is *theoretically feasible* but calls for a controlled number of steps of expectation formation and iterated reasoning. To this end, we build on earlier designs of Hirota and Sunder (2007), Moinas and Pouget (2013), and Janssen et al. (2019) by adding two unique features. First, a single kind of simple securities is traded in the market. Each security pays only one (terminal) non-stochastic common knowledge dividend ($D = 50$) at the end of the final period of the session. Second, the market has an overlapping-generations structure, where only the first generation is endowed with securities (see Fig. 1).[4] All subsequent generations of investors enter endowed with cash but no securities; they buy securities from the (overlapping) "older" generation, and then sell them to the next "younger" generation, before exiting the

[1] Theoretical literature suggests several possible reasons why short-term speculation could cause security prices to deviate from the fundamental values. First, the rational bubble literature shows that when securities with infinite maturity are traded in a market populated by short-term speculators, price bubbles can emerge as the REE (e.g., Blanchard and Watson 1982, Tirole 1985). In a second class of models, speculation induces prices to deviate from fundamentals due to future investors' noisy beliefs or asymmetric information (Abreu and Brunnermeier 2003, Allen et al. 2006, De Long et al. 1990a, 1990b, Dow and Gorton 1994, Froot et al. 1992, Scheinman and Xiong 2003). We should point out that both these classes of models, as well as standard finance theory, utilize the rational expectation hypothesis. Even the second class of models assume that *at least* current investors form rational expectations of future prices by considering how current and future prices are determined by future investors' beliefs.

[2] Xiong and Yu (2011) is a notable exception. They examine the case of a dozen put warrants traded in China that went so deep out of money in 2005–2008 that their fundamental values were practically zero. They show that warrants traded at prices significantly above zero which they characterize as bubbles.

[3] Akiyama et al. (2017) and Cheung et al. (2014) manipulate traders' information regarding the rationality of others in the Smith et al. (1988) setting. They find that uncertainty over the rationality of others is responsible for a substantial part of the mispricing. This result suggests that speculation on other's irrationality is a potential cause of price volatility and bubbles.

[4] Marimon and Sunder (1993) use an overlapping-generations structure for their experiment on money and inflation. Deck et al. (2014) design an overlapping generation structure for the asset market experiment in a Smith et al. (1988) setting. Their experiment focuses on the effect of money injection on prices, accompanied by the entry of new generations. They do not examine the effect of speculative trading.

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Fig. 1. Overlapping generations design *Notes:* D means that the last generation of investors receives terminal dividends (50) at the end of Period 16.

market. Only the investors of the very last generation collect the dividend at the end of the final period, and these are called "*dividend-collecting investors*". All other generations exit the market before receiving any dividend, trading the security only for capital gains; these traders are labeled "*speculating investors*".[5]

This design creates speculating investors (who trade only for capital gains without ever collecting dividends), allowing us to examine the effect of speculative trading on price formation. We compare price deviations from the securities' fundamental value in markets with dividend-collecting investors to markets with only speculating investors. We also vary the number of entering generations (and hence the number of transfers of security among generations of investors) to explore its effect on price formation. Furthermore, our choice of the single non-stochastic common knowledge dividend paid to holders of the security at the end of the final period leaves little room for doubt or confusion in the mind of any subject that the fundamental value of the security is indeed 50.[6]

Standard finance theory predicts that even in a market populated by speculating investors, the market price of this security should be close to the fundamental value of 50 throughout since 50 is the REE price at which each generation of investors arrives through backward induction. However, our experimental results show that with speculating investors in the market, transaction prices deviate substantially from 50. Specifically, we find that (i) in phases with only speculating investors present prices are more likely to depart from fundamentals, compared to prices in phases in which dividend-collecting investors are present; (ii) volatility of prices is higher when only speculating investors are present; (iii) prices are more likely to depart from fundamentals as the securities change hands among speculating investors more often over their 16-period life (i.e., the holding period of speculating investors shrinks and more steps of iterative reasoning are called for). These laboratory results document deviations from price predictions of REE, as well as greater volatility, generated by speculation.

We also explore whether money supply influences the effect of speculative trading on price formation by varying the total amount of money supply in a market by controlling the cash endowment of entering subjects by a factor of five between low- and high-liquidity treatments. We find that (iv) when the supply of money is high (low), speculative trading pushes prices above (below) the fundamental value providing evidence that the direction of price deviations from the fundamentals (positive or negative) is driven mostly by money supply. This result implies that controlling money supply is important for stabilizing asset prices when markets are dominated by speculative trading.

[5] In their models, Allen et al. (2006) call these investors "short-lived investors" and Froot et al. (1992) call them "short-horizon speculators."

[6] Also note that our experimental setting excludes two factors–infinite maturity and heterogeneity of dividend expectations–that are also supposed to cause prices to deviate from fundamentals in theoretical models (Blanchard and Watson 1982, Tirole 1985, Allen et al. 2006, De Long et al. 1990a, 1990b, Dow and Gorton 1994, Froot et al. 1992). By doing so, we examine if the deviation between prices and fundamentals may be rooted in more basic investors' difficulty of forming common knowledge of rational expectations. Still, prices above and below 50 can be considered rational under certain conditions, as we will argue in Section 3.

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Table 1
Overview of treatments with two dimensions: liquidity (high/low) and number of entering generations (1, 2, 4 or 8).

		Liquidity	
		HIGH (C/A-ratio=10)	LOW (C/A-ratio=2)
Number of entering generations	1	T1H	T1L
	2	T2H	T2L
	4	T4H	T4L
	8	T8H	T8L

The paper is organized as follows: Section 2 describes the experimental design and procedures. Section 3 presents theoretical considerations and the hypotheses to be tested in the laboratory. Section 4 reports experimental results and Section 5 discusses the implications and presents concluding remarks.

2. Design of the experiment

2.1. Setup and treatments

In total we run 48 market sessions. Each consists of 16 trading periods of 120 s each. Each session is populated with ten investors (who buy and sell securities), and eight (with the exception of five in T1) predictors (who predict the average transactions price for the period).

We differentiate investors into two classes of five each by implementing an overlapping generations structure shown in Fig. 1. At any time, there are two generations in the market. The security traded has a maturity of 16 periods and pays a single, common knowledge terminal dividend, $D = 50$, at the end of Period 16 only to its holders from the last-to-enter generation, referred to as "*dividend-collecting investors*". All other generations of investors are called "*speculating investors*" who collect no dividend, and who trade the security only for capital gains. Any securities these investors hold at the time of their exit are worthless (and are redistributed to the next entering generation to keep the number of securities in the market fixed).[7]

The experiment has a 4×2 design (see Table 1) in which the first treatment (number of entering generations until maturity of the security) takes four different values and the second treatment (money supply, henceforth also referred to as liquidity) takes two values. By varying the number of entering generations (1, 2, 4, and 8), we manipulate the number of periods with only speculating investors and the level of difficulty (number of iterative steps) for each generation of investors to arrive at REE through backward induction. Fig. 1 illustrates that in Treatment T1 dividend-collecting investors (G1) are present in all 16 periods of the market session. In T2, T4, and T8 periods 1–8, 1–12, and 1–14, respectively, have only speculating investors active in the market; in other periods dividend-collecting investors (the last generation) are present in the market (periods 9–16 in T2, periods 13–16 in T4 and periods 15–16 in T8).

The liquidity or money supply treatment varies the initial cash-to-(fundamental) asset value ratio (commonly referred to as C/A-ratio, that is the amount of cash available to trade securities in the economy divided by the sum of the fundamental value of all securities) for H (= 10) and L (= 2).[8] Treatments are denoted as Txy with $x \in \{1, 2, 4, \text{or } 8\}$ indicating the number of entering generations and $y \in$ {H or L} indicating high and low-liquidity treatments. In six independent replicating sessions of each treatment, the market structure (number of investors, number of securities, and cash endowment of an entering generation) remains unchanged over the 16 periods.

To keep the total number of subjects within reasonable limits we recruit 18 subjects for each session.[9] In every period, two five-subject generations (ten subjects in total) are active investors, while the other eight (five in T1) subjects are predictors. When an investor generation exits the market, five subjects are randomly chosen from the pool of eight predictors to form the newly entering generation for the next period, and the exiting generation joins the pool of predictors. Subjects stay in this pool for one or more periods. This rotating mechanism allows each generation of investors to gain experience and an understanding of the environment without significantly interfering with the purpose of the experiment

[7] This dividend structure is far simpler than Smith et al. (1988) where the security pays numerous (period-by-period) stochastic dividends generating a declining fundamental value. We chose this simpler dividend structure in order to minimize the chances of subjects' confusion and to gather data from markets populated only by speculating investors. Smith et al.'s (1988) design makes it difficult to create speculating investors (who do not receive dividends and trade only for capital gains) in the overlapping-generations structure. In addition, our design of the security (a single lump sum common knowledge dividend without uncertainty) differs from previous experimental studies featuring constant fundamental values (Porter and Smith 1995, Smith et al. 2000, Noussair et al. 2001, Kirchler et al. 2012, Stöckl et al. 2015, all of which yield efficient pricing).

[8] A higher C/A-ratio allows investors to take additional risk in trading the security. In H (L) treatments each individual investor initially holds an amount of cash that is twice (0.4 times) the total fundamental value of all securities in the market. While the C/A-ratio is deliberately high in H treatments, a C/A-ratio of 2 in L treatments ensures that investors are able to make transactions at reasonable frequencies. See Kirchler et al. (2012), Noussair and Tucker (2014), and references therein on the effects of cash endowments on mispricing.

[9] In treatment T1, we invited only 15 subjects instead of 18 since no rotation is needed. Ten subjects trade through all 16 periods and the other five act as predictors (to be explained below).

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Table 2
Parameterization of the eight Treatments.

Treatment	T1H	T1L	T2H	T2L	T4H	T4L	T8H	T8L
Market setup								
Number of generations	2	2	3	3	5	5	9	9
Terminal dividend *D*	50	50	50	50	50	50	50	50
Initial no. securities/investor G0	32	32	16	16	8	8	4	4
Initial no. of securities/G1-G8	0	0	0	0	0	0	0	0
Total securities outstanding	160	160	80	80	40	40	20	20
Total value of securities	8000	8000	4000	4000	2000	2000	1000	1000
Initial cash/investor G0	0	0	0	0	0	0	0	0
Initial cash/investor G1-G8	16,000	3200	8000	1600	4000	800	2000	400
Total cash	80,000	16,000	40,000	8000	20,000	4000	10,000	2000
Cash-to-asset value ratio (C/A-ratio)	10	2	10	2	10	2	10	2
Invited subjects ($3n$+3)	15[a]	15[a]	18	18	18	18	18	18
Participating subjects	90	90	108	108	108	108	108	108
Exchange rates (taler/€)								
Generation 0 (G0)	100	100	100	100	100	100	100	100
Transition generations			500	100	500	100	500	100
Last generation	1000	200	1000	200	1000	200	1000	200
Predictors	133	133	133	133	133	133	133	133
Expected payout/subject (€)	16	16	16	16	16	16	16	16

Notes: The following parameters are identical across all treatments: The number of investors/generation (5); the number of active generations (2); active investors (10 investors); period length (120 s.); the total number of periods (16); the number of markets per treatment (6); the number of expected transactions (160).
[a]In treatments T1L and T1H we invited 15 subjects instead of 18 as no subject pool for future generations is needed. Ten subjects were investors, and five served as predictors.

(see Lim et al., 1994, Marimon and Sunder 1993). Since subjects cannot know whether and when they will reenter the market, their current behavior is unlikely to be influenced by their anticipations of any future re-entries into the laboratory economy.

2.2. Security and cash endowments

Only the initial generation of investors (G0) is endowed with units of the security at the beginning of period 1. All other generations (G1 up to G8) are initially endowed with only cash and no securities. They can use their cash to buy securities from the 'older' generation, then sell the securities to the next 'younger' generation and exit the market, just when another generation enters (or the session ends).[10] This design ensures that even in T1, where G0 and G1 are present in all 16 periods each security needs to be traded at least once (from a member of G0 to a member of G1) to realize its dividend.

To equalize the per period trading 'workload' across the four treatments, security and cash endowments are varied; the expected number of transactions for the entire 16-period session is kept fixed at 160, independent of the number of generations (see Table 2 for details on parameter selection in each treatment). To ensure that the total number of securities in the experimental market stays constant throughout the session, any securities in the hands of exiting investors are distributed at zero cost to randomly chosen members of the entering generation in integer numbers (to avoid fractional unit trades). This arrangement ensures that no buyer is forced to buy a security at a price unacceptable to him/her, and the sellers have an incentive to sell their securities before exiting the market.[11]

2.3. Trading mechanism

The trading mechanism used is a continuous double auction with an open order book, opportunity to cancel a bid or ask until it is accepted, single-unit trades, and shorting constraint (no negative holdings of cash or securities allowed at any time). The single-unit trades help homogenize the amount of trading workload per period across treatments. All cash and security balances are carried over to the following period until the investor exits. Investors can buy and sell securities freely

[10] Note, that the cash endowment of an entering generation is ten (two) times the amount needed to buy all securities at their terminal dividend value in H (L) treatments. The amount of cash going out of the market with the exiting subjects will, of course, vary with each generation change and will be equal to the cash endowments of the entering subjects only by chance.

[11] We chose random distribution of forfeited securities in whole units because equal distribution would have resulted in fractional securities being allocated in most instances. For example, if only one security was forfeited in a given period, this would have had to be split equally among the five incoming traders of the "young" generation. To avoid trading of fractional securities, which would complicate the auction mechanism, we chose random allocation. One may argue that the pressure on the exiting generation to sell its securities at the risk of forfeiture may create a downward pressure on market prices. As shown in the results section, prices in the low-liquidity treatments tend to be below the fundamental value, but not in the high-liquidity treatments. Therefore, the downward-pressure hypothesis has some validity, but is not a consistent explanation of all observed data.

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as long as neither their cash nor the security holdings become negative.[12] Each trading period lasts for 120 s with a digital wind-down clock on the trading screen. Earnings accounts are shown on a history screen at the end of each period.

2.4. Investor payoff

The final earnings of each member of the last generation of investors are [number of securities in their hands at the end of Period 16] × [terminal dividend of 50] + [cash holdings at the end of Period 16]. The final earnings of all other generations of investors are equal to their cash holdings at the time of exit with any unsold securities in their hands forfeited.[13] The final earnings of investors are converted to euros at a pre-announced rate and paid out.[14]

2.5. Predictors' task and payoff

Eight (five in T1) subjects assigned the predictor role in each period are required to submit a prediction of the average transaction price at the beginning of the period. The mean of all eight (five T1) individual price predictions is disclosed to the market at the end of the period to avoid predictions influencing investors' trading behavior.[15] Individual predictors earn 140 units of cash for perfect forecasts, and one unit is deducted for each unit of forecast error (subject to zero minimum earnings).[16] The amount earned is later exchanged to euros at a rate of 133:1.

2.6. Implementation

The experiment was conducted at the Innsbruck–EconLab using software written in z-tree (Fischbacher, 2007) in 2013 with a total of 828 University of Innsbruck bachelors and masters students from different fields in 48 sessions (eight treatments of six sessions each). Most subjects had participated in other economics experiments, but none participated in more than one session of the present study. Subjects were recruited using ORSEE by Greiner (2004).

At the beginning of each session, subjects had 15 min to read the common knowledge instructions (with their understanding tested through a written questionnaire to minimize the possibility of misunderstanding and experimenter bias, see Appendix B for details). Any questions from subjects were answered privately. The trading screen was explained, followed by two trial periods to allow subjects to become familiar with the environment, trading and prediction tasks, mapping from experimental actions and events to their payoffs, and to test their comprehension.[17] In both trial periods, all subjects played dual roles of investor and predictor. As an example, instructions for treatment T2L, along with screenshots, are provided in Appendix A. Each session lasted approximately 90 min. Calculations of period as well as cumulative earnings were shown to subjects on the history screen at the end of each period. At the end of a session earnings of each subject were calculated, converted into euros, and paid to them in private.[18]

3. Theory and hypotheses

In this section, we present theoretical considerations raising the possibility that speculating investors may or may not induce price indeterminacy in these laboratory markets. In Section 3.1, we show that prices are equal to the fundamental value (terminal dividend) in a market with dividend-collecting investors. In Section 3.2, we argue that in a standard securities pricing model REE predicts prices equal to the fundamental value even in a market with only speculating investors.

[12] Shorting securities and cash was forbidden as it would have led to the possibility of bankruptcy, and complicated consequences at generation changes – e.g., if a trader of an existing generation had negative securities holdings, the securities of other traders would have had to "evaporate" to keep the number of securities in the market constant.

[13] During 48 sessions, a total of 970 securities were forfeited across 768 periods. This was mostly due to holders being unable to sell at a price acceptable to them. Forfeiture rates markedly increased with the number of generation changes and ranged from 1.1 percent of shares in T1H to 23 percent in T8L. See Appendix F1 for more information.

[14] We use different rates for the first, transition, and last generations and the low/high-liquidity treatments to equalize expected euro payouts. See Table 2 for details.

[15] We deliberately separate predictor's role from investor's role in each period to eliminate the possibility that eliciting price prediction from investors induces some bias in their trading behavior in the same period. Such strategic behavior is unlikely to motivate trades in real-world markets, but might bias our experimental results. Previous literature suggests that eliciting beliefs and forecasts in the laboratory can change the subjects' behavior (see Schotter and Treviono 2014 for a survey). In particular, Bao et al. (2013) provide experimental evidence on a cobweb economy showing that REE is less likely to be attained when subjects are asked to play the forecasting role and make decisions simultaneously. Also, Hanaki et al. (2018) show that eliciting forecasts significantly increases the magnitude of mispricing in Smith et al.'s (1988) asset market experiment when subjects are rewarded for both trading and forecasting performance. See Marimon and Sunder (1993) for further analysis.

[16] We use this linear payoff function (with a zero lower boundary) following Hirota and Sunder (2007). We use this instead of alternatives like a quadratic scoring rule (Bao et al. 2012, Bao et al. 2013, Evans et al. 2019, Hommes et al. 2005) or other non-linear functions (Akiyama et al. 2017, Haruvy and Noussair, 2006) as we wanted to keep the incentives in the predicting task similar to those in the investor task. Moreover, we wanted to keep the payoff function easy and straightforward to understand. Hanaki et al. (2018) report that forecasting performance (the accuracy of price prediction) does not significantly differ between two functional forms in their forecasting-only experiments.

[17] We implemented this procedure to minimize mispricing due to subjects' confusion or misunderstanding.

[18] There was no fixed payment for the subjects. The average and standard deviation of actual earnings of the subjects across treatments are shown in Appendix C.

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In Section 3.3, we examine the validity of REE assumptions and provide arguments for potential price deviations from the fundamental value in our laboratory markets. In Section 3.4, we derive a set of hypotheses to be evaluated with the data generated in the experiment.

3.1. Pricing in a market with dividend-collecting investors

We start by examining price formation in periods with dividend-collecting investors in our laboratory sessions, using market T4 (see Fig. 1) for illustration (similar reasoning applies to treatments T1, T2, and T8). To simplify, divide the 16 periods of T4 into four subsets: Subset 1 (periods 1–4) in which subjects from G0 and G1 trade, Subset 2 (periods 5–8) in which subjects of G1 and G2 trade, Subset 3 (periods 9–12) in which subjects of G2 and G3 trade, and Subset 4 (periods 13–16) in which subjects of G3 and G4 trade. Only G4 traders collect dividends; traders of G0 to G3 are speculating investors who exit the market before the security pays its dividend D at the end of period 16.

In Subset 4 where dividend-collecting investors (G4) are present, the equilibrium price P_4 of the security is equal to the terminal dividend D due to the G4's arbitrage transactions (assuming perfect competition among G4 traders in a frictionless market):

$$P_4 = D = 50. \tag{1}$$

The prediction that the price is equal to the security's fundamental value holds whenever dividend-collecting investors are present (periods 1–16 in T1, period 9–16 in T2, and periods 15–16 in T8).[19]

3.2. Rational expectation equilibrium (REE) in a market with only speculating investors

Next, we examine price formation in a market with only speculating investors. The REE in the standard security pricing model predicts prices to be equal to the fundamental value. To see this, we consider Subset 3 (periods 9–12) where G2 and G3 are present. In this situation the price of the security, P_3, depends on G3's expectation of the price in Subset 4 (assuming perfect competition among G3 traders in a frictionless market):

$$P_3 = E_3(P_4). \tag{2}$$

Standard security pricing models claim that speculating investors form rational expectations of future prices through backward induction: G3 rationally expect P_4 to be given by (1):

$$E_3(P_4) = 50. \tag{3}$$

Therefore,

$$P_3 = 50. \tag{4}$$

In Subset 2 (periods 5–8) where G1 and G2 are present, the price of the security, P_2, depends on G2's expectation of the price in Subset 3 (assuming perfect competition among G2 in a frictionless market):

$$P_2 = E_2(P_3). \tag{5}$$

G2 rationally expect P_3 using (4),

$$E_2(P_3) = 50. \tag{6}$$

Thus, $P_2 = 50$ holds. Repeating this process one more stage, we get $P_1 = 50$.

This step completes the derivation of the REE yielding $P_1 = P_2 = P_3 = P_4 = 50$. Under the stated assumptions, prices in markets with only speculating investors (P_1, P_2, and P_3) are equal to those in a market with dividend-collecting investors (P_4). This argument also applies to other treatments (T2 and T8), predicting price is 50, irrespective of the presence or absence of speculating and dividend-collecting investors in the market. Therefore, the standard security pricing model predicts that, even in a market populated by speculating investors, the price of the security with fixed maturity is determined through investors iteratively forming common knowledge rational expectations through backward induction, and prices are equal to the security's fundamental value.

[19] One may argue that the theoretical equilibrium price is not necessarily equal to 50 in the market with dividend-collecting investors. The argument would be as follows: dividend-collecting investors (e.g., G4 in T4) would buy the security if the price is below 50 and non-dividend-collecting investors (e.g., G3 in T4) would sell the security if the price is above 0 (because they cannot receive the dividend). Hence the equilibrium price lies in the range of [0, 50]. This argument, however, is not theoretically valid under perfect competition. In our experimental design, the total number of the securities outstanding is limited (e.g., 40 in T4) and total cash held by investors is twice (4000 in T4L) or ten times (20,000 in T4H) as much as total fundamental value of the securities outstanding ($40 \times 50 = 2000$ in T4). The demand function being horizontal at $P = 50$ for values of Q (number of securities) from 0 to 80 and the supply function being vertical at $Q = 40$, their intersection at $P = 50$, $Q = 40$ is the competitive equilibrium in presence of dividend-collecting investors.

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3.3. Feasibility of REE

The result of the standard security pricing model presented above critically depends on two assumptions. First, it is common knowledge among all generations of investors that speculating investors form rational expectations. This assumption (common knowledge of rational expectations) implies that speculating investors must not only form rational expectations themselves, but also believe that all subsequent generations of speculating investors also do the same.[20] In the example above, traders of G2 form rational expectations of P_3 (Eq. (6)) by believing that traders of G3 also form rational expectations of P_4 (Eq. (3)). Furthermore, traders of G1 form rational expectations of P_2, not only believing that traders of G2 also form rational expectations of P_3, but also believing that traders of G2 believe that traders of G3 form rational expectations of P_4. This common knowledge assumption of rational expectations among speculating investors, however, may not hold in practice. For example, traders of G2 may believe that some traders of G3 do not form rational expectations ($E_3\ (P_4) = 50$) and that they form the expectation, $E_3\ (P_4) > 50$. In high-liquidity markets where each investor has plenty of cash to buy a large number of securities (each investor's cash holding is twice the total fundamental value of all securities), this G3's expectation could cause P_3 to rise above 50 in Subset 3. Anticipating this, traders of G2 buy the security at $P_2 > 50$ in Subset 2 by backward induction. Further, if traders of G1 expect these price realizations, we would observe $P_1 > 50$ in Subset 1 as well.

Second, REE assumes that it is common knowledge among all generations of investors that investors conduct perfect arbitrage. This assumption (common knowledge of perfect arbitrage) implies that speculating investors must not only exhaust arbitrage opportunities in a competitive, frictionless market, but also believe that all subsequent investors do the same. In T4, traders of G3 form rational expectations of P_4 (Eq. (3)) believing that traders of G4 conduct perfect arbitrage to realize $P_4 = 50$ (Eq. (1)). It is not clear that this assumption holds in practice. Some traders of G3 may expect that in Subset 4 some G4 traders are not rational and buy the security at $P_4 > 50$. Such G3 traders may buy the security in Subset 3 even if $P_3 > 50$, hoping to resell it at even higher prices in Subset 4. In high-liquidity markets with plenty of cash on their hands, strong demand from these "bullish G3 traders" may push Subset 3 price P_3 above 50, and create deviations from predictions of REE. At the same time, another G3 trader may expect that in Subset 4 G4 traders may be unwilling to buy the security at P_4 slightly below 50 because a small profit is not worth the extra effort. Such G3's may not be willing to buy the security in Subset 3 even if $P_3 < 50$ if they are not confident of having the opportunity to resell it at a higher price in Subset 4.[21] In low-liquidity treatments with less cash on their hands (each investor's cash holding is 0.4 times the total fundamental value of all securities), the buy orders of the other G3 traders may not be sufficient for prices to rise to 50 in Subset 3. $P_3 < 50$ can arise due to insufficient cash of the willing buyers if some potential buyers are, for whatever reason, do not buy.

Therefore, the two abovementioned assumptions needed for REE may not hold in practice; even if traders could form rational expectations, they might expect that subsequent traders will not form rational expectations or they will not conduct perfect arbitrage. Consequently, P_1, P_2, and P_3 may not be formed in line with REE predictions (50) and get unhinged from the fundamental value in T4. This pricing pattern may also occur in a market with only speculating investors in other treatments (periods 1–8 in T2 and period 1–14 in T8). This argument opens the possibility that price formation is different in markets with only speculating investors compared to markets with dividend-collecting investors present. Furthermore, if REE is not realized in markets with only speculating investors, the algebraic sign of pricing error may depend on the amount of money supply (liquidity). In high-liquidity markets, positive price deviations from the fundamental value are more likely to occur because each speculating investor expecting high future prices (bullish traders) could make a large number of buy orders. In contrast, in low-liquidity markets, negative price deviations are more likely because buy orders of the generation may not be sufficient to push prices to 50.

3.4. Hypotheses

As discussed in Sections 3.1 and 3.2, in standard security pricing models the nature of investors (dividend-collecting vs. speculating) does not affect security prices; actions of arbitraging and competitive dividend-collectors as well as of rational expectations through backward-inducting speculators both push the prices towards the fundamental value given by the terminal dividend (50). In laboratory security markets, precise correspondence between transaction prices and fundamental values is rare.[22] The observed deviations are often attributed to noise trading arising from subjects' gradual and imperfect learning, confusion, and irrationality.[23] While some noise in transaction prices is to be expected in all treatments of our

[20] In fact, the first generation (G0) need not form rational expectations because they should be willing to sell the security to G1 at all positive prices before they exit.

[21] We can also interpret this behavior to reflect G3's ambiguity aversion for future sales prices. That is, G3 does not have sufficient information to form beliefs on the probability distribution of P_4 and require a premium for this ambiguous situation. Easley and O'Hara (2010) show that ambiguity may induce an increase in the equilibrium risk premium (implying a decrease in the equilibrium price). See Guidolin and Rinaldi (2013) for a survey article on the effect of ambiguity on asset pricing. However, this theoretical work remains to be supported by methods of estimating ambiguity and risk aversion that exhibit empirical out-of-sample predictive power.

[22] See e.g. Plott and Sunder (1982, 1988), and Smith et al. (1988) and the large follow-up literature reviewed in Palan (2013).

[23] This is true even when the security traded has a simple dividend structure, e.g., in Smith et al. (2000), Lei et al. (2001), and Kirchler et al. (2012). However, none of these papers features overlapping generations of investors.

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experiment, our purpose is to examine whether or not speculation and money supply affect price deviations. We pose the following null hypothesis based on REE:

Hypothesis I_0: Deviations of prices from the fundamental value are the same during periods when only speculating investors are present compared to periods when dividend-collecting investors are also present in the market.

In contrast, in Section 3.3, we also considered the possibility that prices in a market with only speculating investors may become unhinged from REE. Speculating investors may not form rational expectations of future prices due to the lack of common knowledge of rational expectations and/or perfect arbitrage. In that case, prices are more likely to depart from the fundamental value in a market with only speculating investors leading us to the formulation of the alternative hypothesis:

Hypothesis I_A: Deviations of prices from the fundamental value are larger during periods when only speculating investors are present compared to periods when dividend-collecting investors are also present in the market.

Next, we investigate whether, for a security of a given maturity, the number of security transfers across generations (and hence the length of investors' maximum holding period) influences the security's pricing. In the four treatments of our experiment, the security always has the same time to maturity (16 periods) and pays the same terminal dividend, but the number of security transfers across generations until maturity of the security differs (one in T1, two in T2, four in T4, and eight in T8).[24] According to standard security pricing models (REE), price paths should not differ across the four treatments; investors of each generation should form rational expectations through backward induction and prices at all times should be equal to the fundamental value. However, we argue that the formation of speculating investors' rational expectations may be difficult due to a lack of common knowledge of rational expectations. In particular, as the number of generations until maturity increases, the number of periods with only speculating investors increases, and failure to form common knowledge rational expectations and departure of prices from the fundamentals become more likely. This leads to the following null and alternative hypotheses:

Hypothesis II_0: For a security of a given maturity, the magnitude of deviation of prices from the fundamental value is not affected by the number of security transfers across generations.

Hypothesis II_A: For a security of a given maturity, the magnitude of deviation of prices from the fundamental value increases with the number of security transfers across generations (as the length of investors' holding periods becomes shorter).

Prior experimental evidence suggests that higher liquidity tends to raise security prices.[25] Therefore, we additionally examine whether liquidity influences speculative trading and thus may have an effect on prices. In standard finance theory (REE), neither speculation not liquidity cause prices to deviate from the fundamental value. However, in Section 3.3, we argued that if REE does not apply, speculation may give rise to positive (negative) price deviations when liquidity is high (low). We set up the following null and alternative hypotheses:

Hypothesis III_0: Prices are the same during periods when only speculating investors are present compared to periods when dividend-collecting investors are present, irrespective of liquidity (i.e. the C/A-ratio in the market).

Hypothesis $III_{A\text{-}1}$: In high-liquidity sessions (the C/A-ratio = 10), prices are higher during periods when only speculating investors are present compared to periods when dividend-collecting investors are present.

Hypothesis $III_{A\text{-}2}$: In low-liquidity sessions (the C/A-ratio = 2), prices are lower during periods when only speculating investors are present compared to periods when dividend-collecting investors are present.

Experimental asset market prices tend to exhibit significant within-period variation. However, we do not know if the volatility of price changes will be the same when only speculating investors are present, or when dividend-collecting investors are also present. In our experiment, since the fundamental value is constant (50), REE predicts no effect on the kinds of traders present in the market on price variations and volatility. However, when REE assumptions do not hold, speculating investors may engage in short-term trading on the expectation of the future price changes even within a period, and prices become more volatile during periods with only speculating investors compared to periods with dividend-collecting investors. This leads to the following null and alternative hypotheses:

Hypothesis IV_0: Volatility of price changes is the same during periods when only speculating investors are present compared to periods when dividend-collecting investors are also present in the market.

Hypothesis IV_A: Volatility of price changes is higher during periods when only speculating investors are present compared to periods when dividend-collecting investors are also present in the market.

[24] The maximum holding periods of the security for each generation are different among the four treatments. For example, the maximum holding periods for G1 are 16 in T1 and T2, eight in T4, and four in T8. Note that these are only the maximum and not the actual holding periods, because an investor of generation G1 in T4, for example, may choose to wait until period 3 to buy a security and sell it in period 5 and thus hold it only for two periods. Henceforth, we refer to the maximum holding periods simply as "holding periods".

[25] See, e.g., Ackert et al. (2006), Breaban and Noussair (2014), Caginalp et al. (1998), Caginalp et al. (2001), Caginalp and Ilieva (2008), Deck et al. (2014), Haruvy and Noussair (2006), King et al. (1993), Kirchler et al. (2012), Noussair et al. (2012), and Porter and Smith (1995).

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4. Results[26]

4.1. Evolution of prices

Figs. 2 and 3 illustrate the dynamic evolution of transaction prices in our experiment for each of the six independent sessions (mean transaction prices by period in thin gray lines) and the fundamental value (red bold line) for high-liquidity treatments (T1H, T2H, T4H, and T8H) and low-liquidity treatments (T1L, T2L, T4L, and T8L), respectively.[27] Note that the fundamental value – the terminal dividend of 50 – is constant across all periods throughout our experiment. The thick blue line with hollow circular markers is the average of six sessions in each panel.

Fig. 2 for high-liquidity sessions shows that in T1H markets (the upper left panel where the dividend-collecting generation G1 is present in all 16 periods) prices are near or above the fundamentals (50). While prices are relatively high in period 1, they tend towards fundamentals with time (except in one session), and they converge close to the fundamental value in the last period (Period 16) in four of the six replications.[28] Earlier experimental studies with constant fundamental values also report that prices tend to converge to fundamentals (Porter and Smith 1995; Smith et al., 2000; Noussair et al., 2001; Kirchler et al., 2012; Stöckl et al., 2015). In contrast, in treatments T2H, T4H, T8H, where many periods with only speculating generations exist, positive deviations of prices from fundamentals are larger and more persistent.[29] In these high-liquidity treatments, prices usually converge towards fundamentals only once the dividend-collecting investors (of the last generation) enter the market. The low-liquidity sessions (Fig. 3) also exhibit a similar tendency of larger deviations from fundamental prices in periods with only speculating investors, and these deviations are mostly negative.

Figs. 2 and 3 point to inconsistencies with the REE predictions because (i) the absence of dividend-collecting investors influences prices, and (ii) the securities with identical dividend and maturity are priced differently in the four treatments. These data appear to reject hypotheses I_0 and II_0 in favor of I_A and II_A for high as well as low-liquidity treatments. In addition, in periods with only speculating investors, generally positive price deviations from the fundamental value in the high-liquidity treatment (Fig. 2) and generally negative deviations in the low-liquidity treatment (Fig. 3) favor rejecting null hypothesis III_0 in favor of alternatives $III_{A\text{-}1}$ and $III_{A\text{-}2}$.

4.2. Analyses of price deviations from the fundamental value

To examine hypotheses I and II econometrically, we calculate deviations of prices from the fundamental value applying a measure of mispricing per period. In the experimental security market literature, the degree of mispricing is often measured by Relative Absolute Deviation (*RAD*) proposed by Stöckl et al. (2010):

$$RAD = \frac{1}{N}\sum_{t=1}^{N} |P_t - F_t| / \left|\overline{F}\right| \tag{7}$$

where $|P_t - F_t|$ is the deviation of the mean price from the fundamental value in period t, $|\bar{F}|$ is the absolute average fundamental value in the session, t is period number, and N stands for the total number of periods. *RAD* measures the average level of mispricing across all periods of the session. As we wish to compare price deviations among dividend collecting and other periods within a session, we propose *Period-RAD*, a measure of mispricing per period.

$$Period\text{-}RAD = |P_t - F_t| / F_t \tag{8}$$

Since $F_t = 50$ throughout all sessions of the experiment *Period-RAD* is

$$Period\text{-}RAD = |P_t - 50| / 50. \tag{9}$$

[26] In this section, we only present analyses directly related to the hypotheses formulated in Section 3.4 and the formation of price expectations. In the Appendices D, E, and F we provide additional analyses on the accuracy of price predictions (Appendix D) and regression results (Appendix E; results shown in Table E1 are robust to different variations of OLS and panel regressions; details are available on request). In Appendix F, we present additional analyses on trading patterns observed in our markets (Appendix F1: Forfeiture rates of securities; Appendix F2: Concentration of security holdings among traders; Appendix F3: Trading activity between different combination of two investor types; Appendix F4: Do the last generations behave like fundamental traders?; Appendix F5: Cash constraint investors; Appendix F6: Ratio of buy transaction value to fundamental transaction value).

[27] We dropped two transactions that occurred at prices above 800 from the analyses; one was at 999 in period 9 of a T2H market (one of 64 transactions in that period; it was probably a keyboard error made under pressure of heavy/fast trading); the second observation was a price of 900 in period 16 of a T2H market, and it was the only transaction in that period; it was probably caused by boredom because there had been no transactions in period 15. We repeated the analyses without dropping these two outliers and confirm that the results remain qualitatively unchanged. Note that no session ended before period 16. The two sessions appearing to have ended early did not see any transactions in spite of several bids and asks in the final periods.

[28] Noisy convergence suggests far-from-perfect arbitrage even in the final period. In a few sessions in Figs. 2 and 3, the mean prices (thin grey lines) are above 50 in Period 16 indicating that some traders bought the security at prices above 50 even in the final period. Either these traders hoped to resell the security to others at even higher prices within the 120 s of the last period, or they did not fully understand the rules of the market. In Appendix F4 we provide further data on whether the last generation behaves like fundamental traders.

[29] In the transition periods when a new cohort/generation of traders enters the market, we frequently see "price jumps" that appear to be similar to the "restart effect" often observed in public good games. This is likely driven by (i) new and inexperienced traders entering the market and (ii) their initially available cash balances.

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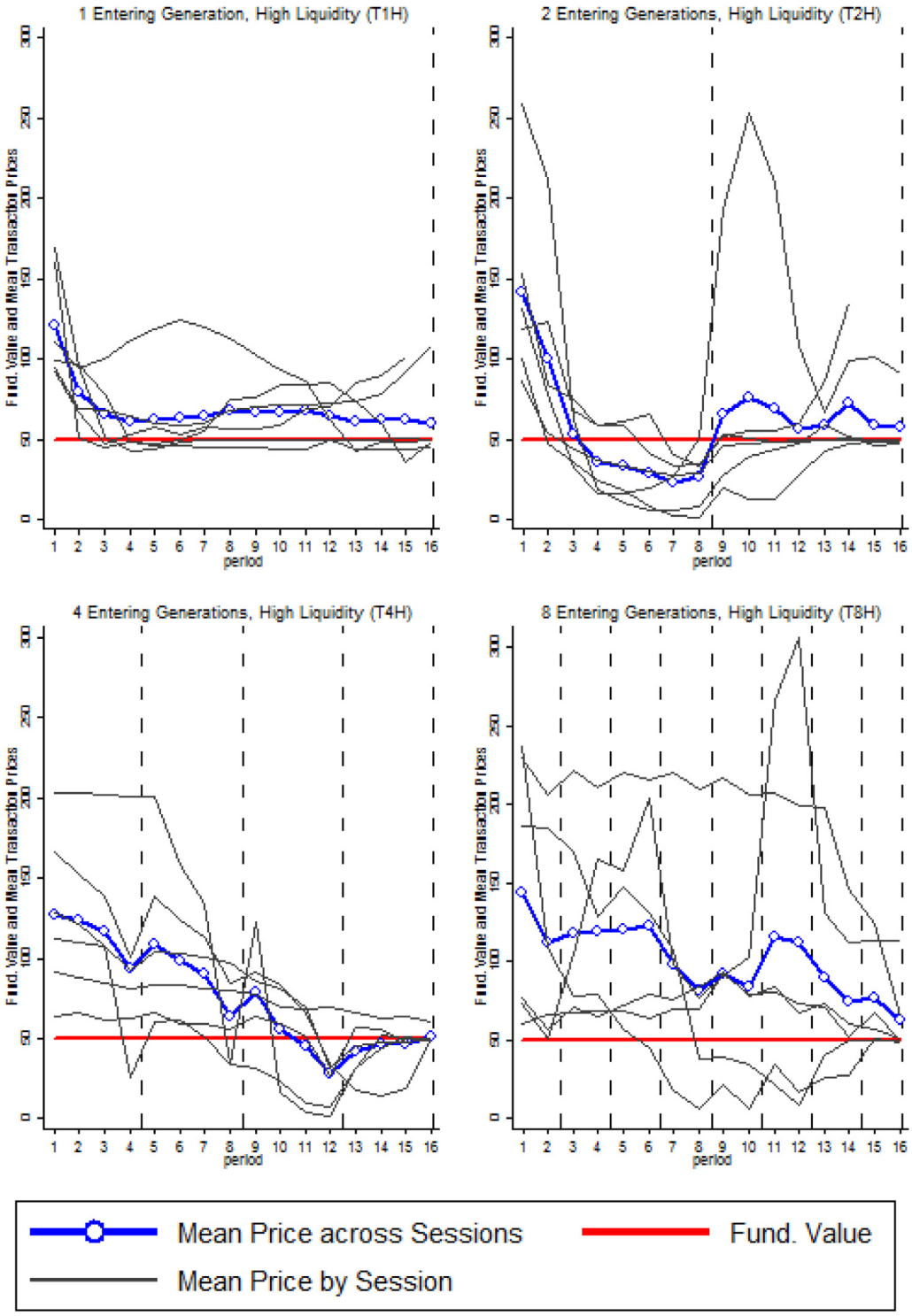

Fig. 2. Period-wise average transaction prices in high-liquidity treatments. *Notes:* Volume-weighted mean prices from six individual sessions (thin gray lines), mean prices across the six individual sessions (blue bold line with hollow circles), and Fundamental Value (red bold straight line) by period. Broken vertical lines mark the entry/exit points of overlapping generations of investors. Each panel shows data for one of the four treatments: T1H, T2H, T4H, and T8H. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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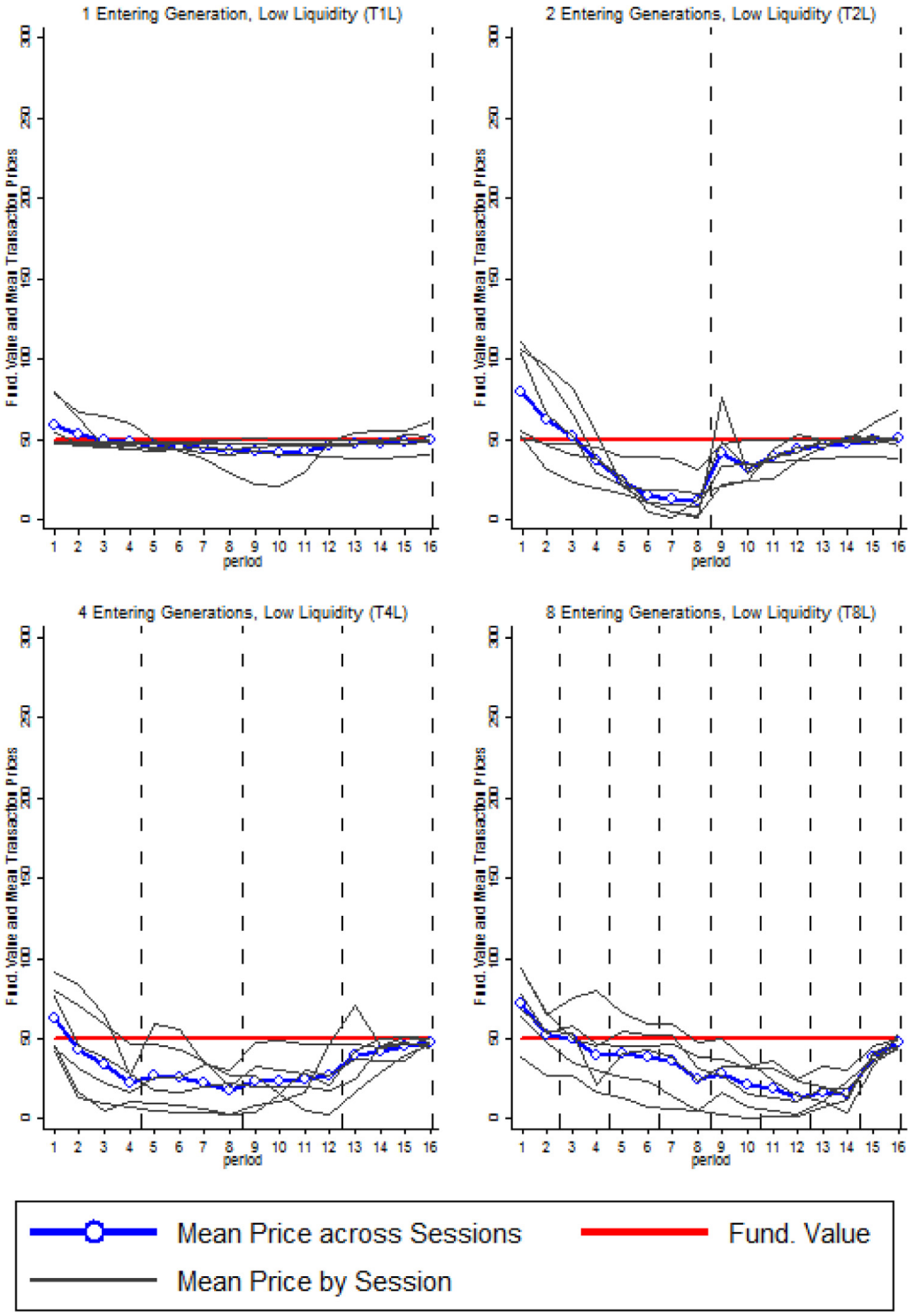

Fig. 3. Period-wise average transaction prices in low-liquidity treatments. *Notes:* Mean prices from six individual sessions (thin gray lines), mean prices across the six individual sessions (blue bold line with hollow circles), and Fundamental Value (red bold straight line) by period. Broken vertical lines mark the entry/exit points of overlapping generations of investors. Each panel shows data for one of the four treatments: T1L, T2L, T4L, and T8L. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Average *Period-RAD* by treatment and period.

Panel A: High-liquidity Sessions

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1	1.423	0.582	0.354	0.293	0.329	0.301	0.321	0.390	0.374	0.382	0.396	0.303	0.323	0.286	0.387	0.259
T2	1.825	1.016	0.310	0.406	0.467	0.536	0.541	0.477	0.676	0.865	0.705	0.313	0.232	0.468	0.232	0.179
T4	1.552	1.471	1.342	1.038	1.182	0.960	0.798	0.499	0.697	0.509	0.470	0.559	0.325	0.210	0.167	0.040
T8	1.879	1.249	1.373	1.392	1.409	1.498	1.177	0.991	1.108	1.082	1.607	1.733	1.019	0.647	0.550	0.273

Panel B: Low-liquidity Sessions

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1	0.226	0.139	0.106	0.098	0.077	0.101	0.103	0.138	0.152	0.158	0.147	0.070	0.084	0.083	0.085	0.085
T2	0.596	0.425	0.299	0.278	0.503	0.685	0.743	0.760	0.342	0.352	0.222	0.146	0.071	0.053	0.085	0.115
T4	0.385	0.489	0.495	0.543	0.517	0.527	0.556	0.653	0.535	0.530	0.511	0.459	0.341	0.163	0.110	0.052
T8	0.527	0.214	0.249	0.398	0.315	0.313	0.355	0.499	0.446	0.584	0.628	0.741	0.663	0.679	0.230	0.066

Notes: RAD stands for "relative absolute deviation", see Stöckl et al. (2010).
Cells shaded gray are periods where the last, dividend-collecting generation of investors is present. In the other periods (no shading) only speculating investors are present. Subsets of periods in which the same two generations trade have a bold border.

Table 4
Comparison of average *Period-RAD* between periods with dividend-collecting investors and periods with only speculating investors.

	Periods with dividend-collecting investors present	Periods with only speculating investors	Difference (2)-(1)
High-liquidity Session (Treatment H)	0.401 (177)	1.024 (204)	0.623*** [−7.10]
Low-liquidity Session (Treatment L)	0.140 (178)	0.502 (203)	0.362*** [−14.42]

Notes: The sample size is in parentheses. *t*-stats are in brackets. *** indicates that the difference is statistically significant at the 1% level determined by a two-sided *t*-test.

We calculated *Period-RAD* for each of 16 periods in 24 high-liquidity sessions (six sessions × four treatments) and 24 low-liquidity sessions.[30]

The two panels of Table 3 show the six-session average of *Period-RAD* for each period of the high and low-liquidity treatments. Periods with dividend-collecting investors (the last generation) present are shaded in gray and those with only speculating investors present are white. Subsets of periods in which the same two generations trade have a bold border. In both Panels A (high-liquidity session) and B (low-liquidity session), we find that (for a given period sequence number) *Period-RAD* is almost always larger when only speculating investors are present (white cells) than in presence of dividend-collecting investors (gray cells).

Table 4 summarizes these observations. It compares the average *Period-RADs* across all periods with dividend-collecting investors (0.401 in *H* and 0.140 in *L*) with periods populated only by speculating investors (1.024 in *H* and 0.502 in *L*). The respective differences (0.623 in *H* and 0.362 in *L*) are large in absolute terms and statistically significant at the 1% level for each liquidity treatment (two-sided *t*-test).[31] The Null hypothesis I_0 (that the presence of dividend-collecting investors

[30] We excluded three periods from the sample of high-liquidity sessions: period 16 in Market 5 of T1H and period 15 in Market 5 of T2H had no transactions and period 16 in Market 5 of T2H had only the outlier transaction price of 900. We also deleted three periods for the low-liquidity sample (periods 11 and 13 in Market 3 in T1L and period 14 in Market 3 of T8L since they had no transactions). These deletions reduced the sample size for each liquidity treatment to 381. The resulting average of *Period-RAD* is 0.735 (with a standard deviation of 0.908) across all high-liquidity sessions and 0.333 (with a standard deviation of 0.304) for the low-liquidity sessions.

[31] Note that *Period-RAD*s are not independent across periods within a session. We dealt with this dependence by regressing *Period-RAD* on the dummy variable which takes a value of one for periods with only speculating investors and checking whether the coefficient of the dummy is statistically significant using standard error adjusted for clusters (sessions). The coefficients are significant for both H and L treatments. As an additional robustness check, we added the period number (1–16) to the above regression to control for the learning effect of the subjects within a session. We also confirmed that the dummy for periods with only speculating investors is significant for both H and L treatments.

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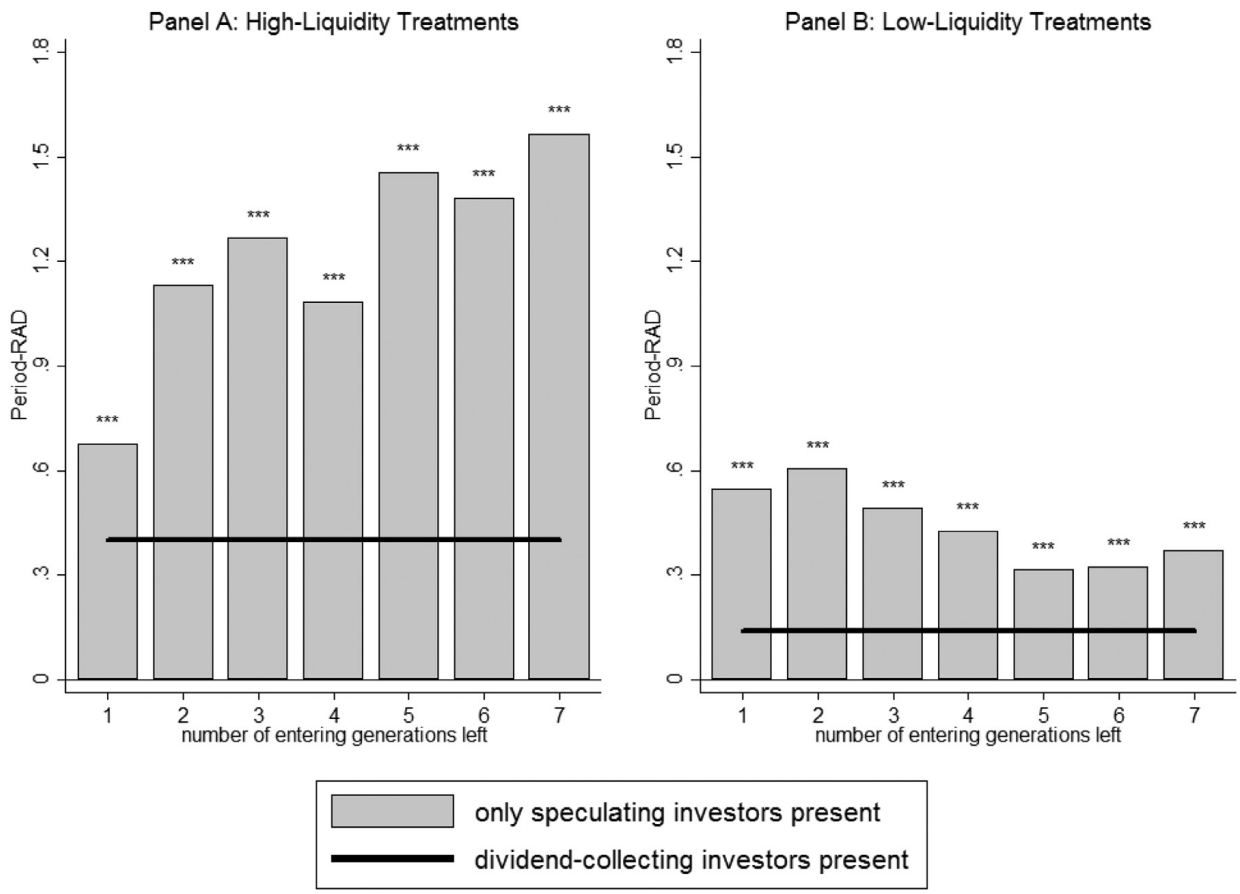

Fig. 4. Average *Period-RAD* conditional on the number of future entering generations *Notes:* Gray shaded bars represent values based on periods where only speculating investors were present. The black bold line represents periods where dividend-collecting investors were present. ***, **, or * indicates that the average Period-RAD across periods where only speculating investors were present is significantly different at 1%, 5%, or 10% level, respectively, from the average Period-RAD across periods with dividend-collecting investors (two-sided *t*-test).

makes no difference) can be rejected in favor of the alternative I_A. The REE hypothesis does not hold in our laboratory markets, although theoretically, the REE would seem to be an obvious outcome in this simple market environment.

When the number of future generations who will enter the market until the security matures is higher, speculating investors would need to perform the more difficult task of backward inducting over expectations of more generations to arrive at REE, causing greater mispricing.[32] To examine this proposition, we calculated averages of *Period-RAD* across periods with only speculating investors, conditional on the number of yet-to-enter generations until maturity (for example, one in periods 1–8 in T2, periods 9–12 in T4, and periods 13–14 in T8; two in periods 5–8 in T4 and periods 11–12 in T8).

The average *Period-RADs* are presented in Fig. 4, which shows that the averages of *Period-RAD* are high even when the number of remaining security transfers across generations is one (0.677 in H and 0.546 in L liquidity sessions), and both are significantly different from 0.401 (in H) and 0.140 (in L) in the presence of dividend-collecting investors. This finding suggests that speculating investors have some difficulty in forming rational expectations even when only one future generation is left. This difficulty may arise from investors' limited cognitive ability, lack of common knowledge of rationality, or doubts about perfect arbitrage in the future. Taken together, these observations suggest that the assumption of rational expectations used in standard finance theory to derive REE may not hold even in this simple laboratory market.

To evaluate Hypothesis II, we use the data presented in Table 5. We see that the number of security transfers across generations until the maturity of the security (inverse of the length of investors' holding periods) affects mispricing. We calculated the average of *Period-RAD* for T1, T2, T4, and T8, respectively, and compared them across these four treatments. Average *Period-RAD* in the high-liquidity treatments is the smallest (0.421) in T1, 0.586 in T2, 0.739 in T4, and the largest (1.187) in T8 (Panel A of Table 5), which are mostly statistically different from each other (see panel B in Table 5 which provides the difference in Average *Period-RAD* across treatments). The pattern is similar in the low-liquidity treatments, though with smaller numbers. We conclude that given the maturity of the security, the higher the number of future security transfers across generations of investors, the greater the deviation of prices from fundamentals. This result rejects Hypothesis II_0 in favor of the alternative hypothesis II_A.

[32] Moinas and Pouget's (2013) experiment shows that subjects are more likely to buy the security at higher prices than fundamentals as the number of steps of iterated reasoning needed for backward induction increased.

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Table 5
Comparison of average *Period-RAD* between treatments with high and low liquidity.

Panel A: Average *Period-RAD* by Treatments				
Treatment	T1	T2	T4	T8
High-liquidity session (H)	0.421 (95)	0.586 (94)	0.739 (96)	1.187 (96)
Low-liquidity session (L)	0.116 (94)	0.355 (96)	0.429 (96)	0.429 (95)
Panel B: Differences between Average *Period-RAD* across Treatments				
High-liquidity Session (H)				
	T2	T4	T8	
T1	0.165* [−1.68]	0.318*** [−3.46]	0.766*** [−5.67]	
T2		0.153 [−1.33]	0.601*** [−3.96]	
T4			0.448*** [−3.05]	
Low-liquidity Session (L)				
	T2	T4	T8	
T1	0.239*** [−6.60]	0.313*** [−9.31]	0.313*** [−9.29]	
T2		0.075 [−1.64]	0.074 [−1.64]	
T4			0.000 [0.00]	

Notes: The sample size is in parentheses. t-stats are in brackets. Two-sided *t*-test significance levels * (10%), ** (5%) and *** (1%).

Table 6
Comparison of average *Period-RD* between periods with dividend-collecting investors and periods with only speculating investors.

	Periods with dividend-collecting investors present	Periods with only speculating investors	Difference (2)-(1)
High-liquidity session (Treatment H)	0.295 (177)	0.741 (204)	0.446*** [−4.27]
Low-liquidity session (Treatment L)	−0.087 (178)	−0.340 (203)	−0.253*** [6.63]

Notes: The sample size is in parentheses. *t*-stats are in brackets. *** indicates that the difference is statistically significant at 1% level determined by a two-sided *t*-test.

4.3. Liquidity supply and mispricing

With Hypothesis III, we explore whether liquidity supply in the market affects overall mispricing and the price level. Visual inspection of Figs. 2 and 3 already gives a tentative answer, as prices tend to be above the fundamental value in periods with only speculating investors in the high-liquidity sessions, but below the fundamental value in those periods in the low-liquidity sessions. To assess the direction of price deviations from fundamentals, we replace the relative absolute deviation measure (*Period-RAD*) used in the preceding subsection by the relative deviation measure (*Period-RD*):

$$Period\text{-}RD = (P_t - 50)/50 \tag{10}$$

where P_t is the mean price in period t.[33] The average of Period-RD across all high liquidity markets is positive (0.534 or 53.4% above the fundamental value), but negative (−0.222, or 22.2% below the fundamental value) across all low-liquidity sessions; the difference (0.756) is statistically significant at the 1% level (two-sided *t*-test).[34]

To test Hypotheses III, we first examine whether positive mispricing in high liquidity markets is larger when only speculating investors are present in the market. Table 6 compares average *Period-RD* in periods with dividend-collecting investors present to those with only speculating investors. In high-liquidity sessions, the average *Period-RD* across periods with dividend-collecting investors is 0.295 (significantly different from zero at the 1% level, two-sided *t*-test), which indicates that prices are on average 29.5% higher than the fundamental value. On the other hand, the average *Period-RD* across periods with only speculating investors is much higher (0.741) and the difference (0.446) is statistically significant at the 1% level (two-sided *t*-test). This result rejects Hypothesis III_0 in favor of the alternative $III_{A\text{-}1}$; with high liquidity, speculating investors amplify the magnitude of overpricing. As seen in Section 3.3, if speculating investors have difficulty in forming rational expectations of future prices, they (e.g., traders of G2) may buy the security at prices over 50 if they think that some future buyers (e.g., traders of G3) may purchase the securities at even higher prices with the hope of subsequent price increases. This "hot potato" game is more likely to occur when more cash is on hand in the high-liquidity (H)

[33] *Period-RD* is an analog of *RD* (Relative Deviation), proposed by Stöckl et al. (2010) which measures the average level of gross (not absolute) price deviations from fundamental values across all periods throughout the session.

[34] This overpricing is consistent with the findings of the previous literature on security market experiments: in a market with investors who can receive dividends (corresponding to dividend-collecting investors in our experiment), a larger C/A-ratio is associated with greater positive mispricing (see Palan (2013) for a survey).

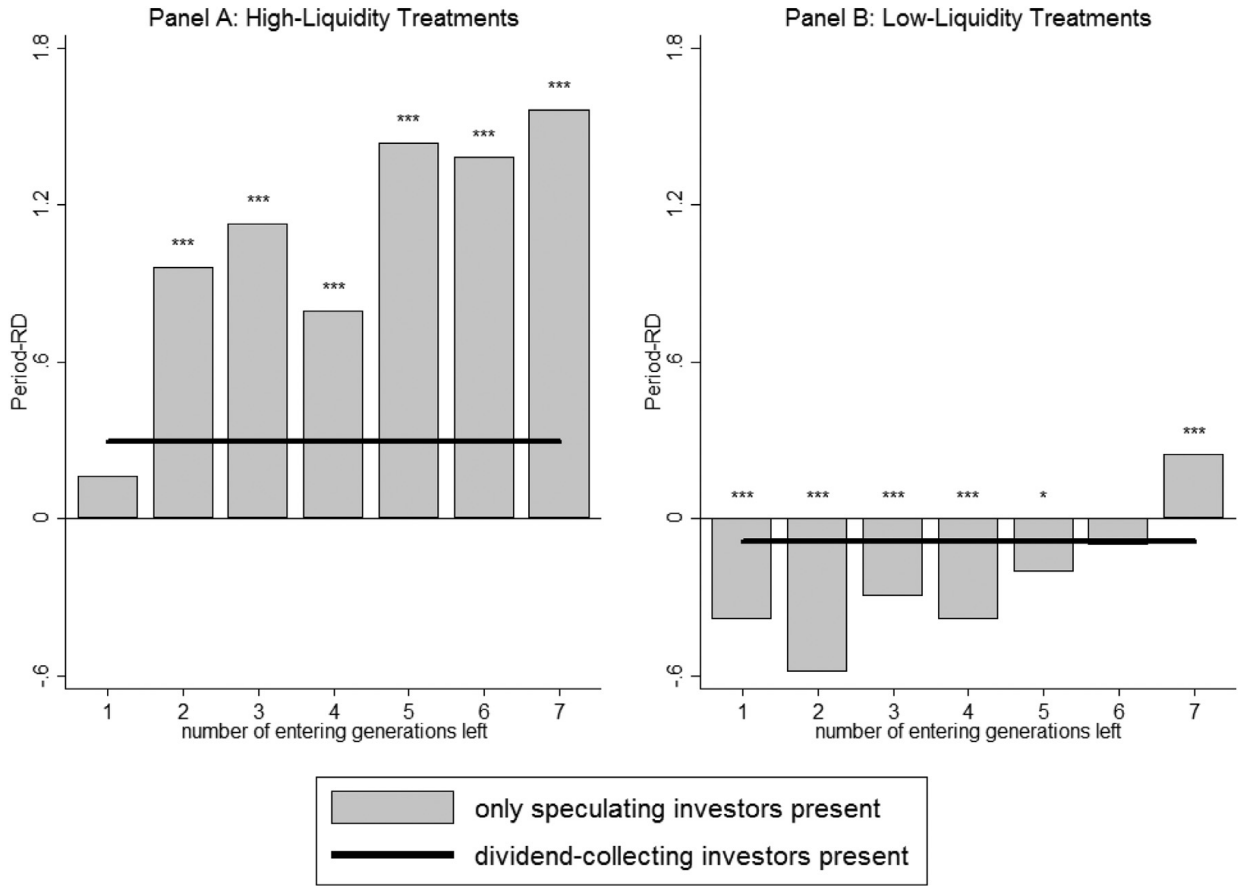

Fig. 5. Average *Period-RD* conditional on the number of entering generations *Notes:* Gray shaded bars represent values based on periods where only speculating investors were present. The black bold line represents periods where dividend-collecting investors were present. ***, **, or * indicates that the average *Period-RD* across periods where only speculating investors were present is significantly different at 1%, 5%, or 10% level, respectively, from the average *Period-RD* across periods with dividend-collecting investors (two-sided *t*-test).

treatments.'[35] [36] We conjecture that this game among speculating investors causes positive price deviations from fundamentals to persist over time in H liquidity treatments.'[37] [38]

In the low-liquidity sessions, the average of *Period-RD* when dividend-collecting investors are present is −0.087, which is small but significantly different from zero at the 1% level (two-sided *t*-test), indicating the imperfect arbitrage by dividend-collecting investors. The average *Period-RD* when only speculating investors are present is −0.340, significantly different from −0.087 at the 1% level (two-sided *t*-test). This result rejects Hypothesis III_0 in favor of $III_{A\text{-}2}$ and indicates that with low liquidity, investors' short-term speculation magnifies the undervaluation.[39] We conjecture that this result might be caused by speculating investors being unsure that future generations conduct perfect arbitrage to move prices to the fundamental value. As reasoned in Section 3.3, some speculating investors (e.g., from G3) may not buy the security at prices below 50 if they fear being forced to resell at even lower prices (or not having the opportunity to resell) in the future due to imperfect

[35] In H treatments, each trader (e.g., with 4000 of cash in T4H) could buy up all the securities (e.g., 40 in T4H) even at a price of 100. In Table F7 of Appendix F5, we report the fraction of cash-constrained traders according to three definitions. The numbers reveal that the fraction of traders satisfying these definitions is markedly higher in the low liquidity sessions.

[36] Additional evidence in this regard is provided in Appendix F2 in which we report that the concentration of securities (SC) is significantly higher in H treatments than in L treatments in T1, T2, and T8. In addition, this concentration increases over the course of the experiment. Crockett et al. (2019) also show the experimental evidence that a small number of subjects accumulate most of the securities.

[37] This hot potato game among traders is often reported in theoretical literature on bubbles (Abreu and Brunnermeier 2003, Allen et al. 2006, De Long et al. 1990a, 1990b, Dow and Gorton 1994, Froot et al. 1992, Scheinman and Xiong 2003) and related to the "greater fool theory" (Kindleberger 2000). In addition, this hot potato interpretation is consistent with DeMarino et al. (2013) who report that subjects with high theory of mind have an increased propensity to ride bubbles.

[38] We could also argue that even dividend-collecting investors (the last generation) may participate in the hot potato game as well, which causes positive price deviations in their presence in H treatments (see positive price deviations in the upper-left cell in Table 6 and the upper-left panel (T1H) in Fig. 2).

[39] For robustness checks on the results of Table 6, we regressed *Period-RD* on the dummy variable which takes a value of one for periods with only speculating investors and confirmed that the coefficient of the dummy is statistically significant using standard error adjusted for clusters (sessions) for both H and L treatments. We also add the period number (1–16) to the above regression to control for the learning effect of the subjects. The result shows that while the dummy for periods with only speculating investors become insignificant for H treatments, it is still significant for L treatments.

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Table 7
Comparison of average *Period-VOLA* between periods with dividend-collecting investors and periods with only speculating investors.

	(1) Periods with dividend-collecting investors present	(2) Periods with only speculating investors	Difference(2)-(1)
High-liquidity session (Treatment H)	0.135 (172)	0.222 (203)	0.087*** [−3.18]
Low-liquidity session (Treatment L)	0.091 (176)	0.266 (201)	0.175*** [−7.58]

Notes: The sample size is in parentheses. t-stats are in brackets. *** indicates that the difference is statistically significant at 1% level determined by a two-sided *t*-test.

arbitrage of the dividend-collecting investors (e.g., from G4).[40] The buy order of the other speculating investors may not be sufficient for prices to rise to 50. This is more likely to occur in low liquidity treatment when each trader does not have enough cash to buy a large number of securities.[41]

Fig. 5 presents *Period-RD* classified by the number of subsequent generations yet to enter the market. In the high-liquidity treatments (Panel A), when this number is two or more, *Period-RD*s are significantly different from periods with dividend-collecting investors, indicating that prices are higher than in the periods with dividend-collecting investors. This observation seems to suggest that in high-liquidity treatments, speculating investors participate in a "hot potato" game when at least two future generations enter the market (i.e., when at least one entering generation of speculating investors is left).[42] Moreover, we find that *Period-RD* tends to increase with the number of generations left, indicating that the hot potato game is more likely to occur when traders are further away from the terminal generation. In low-liquidity treatments (Panel B), five out of seven values of the *Period-RD*s are significantly smaller (more negative) than the *Period-RD* in the periods with dividend-collecting investors. Note that the difference is statistically significant even when the number of entering generations is one (i.e., when the following generation is the generation of dividend-collecting investors). This supports the conjecture that speculating investors are not confident of dividend-collecting investors exhausting arbitrage opportunities and they fear price declines (or being unable to resell) in the future. From these observations, it appears that overpricing in high-liquidity treatments occurs due to investors' "buy low and sell high" strategy; undervaluation in low-liquidity treatments occurs due to their anticipation of low prices in the future. These strategies arise not from REE but from the difficulty of forming rational expectations.

4.4. Volatility of prices

To estimate the within-period price volatility, we calculate for each period the standard deviation of log-returns (*Period-VOLA*) using (11). Here, i indexes transactions in period p; I is number of transactions in period; P_i is the price of transaction i; log returns are calculated as $RET_i = \ln(P_i/P_{i-1})$; $\overline{RET}$: mean of log returns in period p.

$$Period\text{-}VOLA = \sqrt{\frac{1}{I}\sum_{i=1}^{I}\left(RET_i - \overline{RET}\right)^2} \tag{11}$$

Table 7 compares average *Period-VOLA* across all periods with dividend-collecting investors (0.135 in H and 0.091 in L) with periods populated only by speculating investors (0.222 in H and 0.266 in L). The differences (0.086 in H and 0.175 in L) are large in absolute terms and statistically significant at the 1% level for each of the two treatments (two-sided *t*-tests). These results indicate that speculating investors introduce a higher level of price volatility in the market even within a period. When dividend-collecting investors are present, volatility is significantly lower. The null hypothesis IV_0 (that the presence of speculating investors does not impact price volatility) is rejected in favor of the alternative IV_A.

4.5. Formation of expectations

Finally, we examine if the formation of price expectations differs between markets with dividend-collecting investors and markets with only speculating investors. Since the dividend-collecting investors would focus on the known fundamental

[40] This conjecture is supported by theoretical analyses of financial liquidity crises by Bernardo and Welch (2004) and Morris and Shin (2004). They point to speculating investors selling securities expecting future market declines and causing price drops. It is also consistent with an empirical study by Cella et al. (2013) who find that during episodes of market turmoil, short-term investors sell more than long-term investors do, and stocks held mostly by short-term investors experience larger price drops than stocks held mostly by long-term investors. In addition, Morris and Shin's (2004) model predicts a V-shaped pattern in prices around the liquidity crises; after the crisis, prices go back to fundamentals through the long-term investors' arbitrage transactions. Cella et al. (2013) also report that stocks held mostly by short-term investors experienced large price reversals after the turmoil. These V-shaped price paths from theoretical and empirical studies are also observed in our low-liquidity sessions. In Fig. 3, in T2L, T4L, and T8L markets, prices tend to decline when there exist only speculating investors, but they generally recover and converge to fundamentals once dividend-collecting investors (the last generation) enter the market.

[41] In L treatments, each trader (e.g., with 800 of cash in T4L) could not buy all the securities (e.g., 40 in T4L) at prices above 20.

[42] Note that the when the remaining number of entering generations is two, the number of entering generation of speculating investors left is only one, since the final generation consists of dividend-collecting investors.

value, their presence in the markets should tend to bring the investor expectations towards this value. In contrast, in markets with only speculating investors, investors may have to seek alternative mechanisms for forming expectations if they have difficulties in forming rational expectations of future prices through backward induction from the terminal dividend, We use the price prediction data to try to address this question.

We postulate two simple models of the price expectation formation; a fundamental model and a trend model (Hirota and Sunder 2007). In the former, investors form expectations of future prices based on backward induction from the deviation of prices from the fundamental value of the security.

$$E_t(P_{t+1}) = P_t + \alpha(F_t - P_t) \tag{12}$$

where P_t is the price of the security at time t, F_t is the fundamental value, E_t (P_{t+1}) is investor's expectation at time t of the price at time $t + 1$, and α (> 0) is the adjustment coefficient. Investors expect future price appreciation (depreciation) if F_t is higher (lower) than P_t. In this model any $\alpha > 0$ is consistent with the fundamental model, with $\alpha = 1$ corresponding to perfect and instantaneous rational expectation formation supposed by the standard security pricing models: $E_t(P_{t+1}) = F_t$ in any period t.

The trend model assumes that investors form their expectations about future prices through forward induction or extrapolation based on recently observed price changes (it captures momentum).

$$E_t(P_{t+1}) = P_t + \beta(P_t - P_{t-1}), \tag{13}$$

where $P_{t\text{-}1}$ is the price at t-1. If $\beta > 0$, recent price increases (decreases) cause investors to expect further price increases (decreases) in the future; if $\beta < 0$, the reverse holds. With this model, investors' expectations of the future prices are based on recent price movements; fundamentals do not influence the formation of price expectation.

We can combine (12) and (13) into a more general specification of expectation formation:

$$E_t(P_{t+1}) = P_t + \alpha(F_t - P_t) + \beta(P_t - P_{t-1}). \tag{14}$$

This combined model allows for the possibility that investors use some combinations of backward induction from fundamentals and forward induction from the recent past.

Rearranging terms, (12), (13) and (14) become

$$E_t(P_{t+1}) - P_t = \alpha(F_t - P_t), \tag{15}$$

$$E_t(P_{t+1}) - P_t = \beta(P_t - P_{t-1}), \text{ and} \tag{16}$$

$$E_t(P_{t+1}) - P_t = \alpha(F_t - P_t) + \beta(P_t - P_{t-1}), \tag{17}$$

where $F_t = 50$ (the terminal dividend) throughout all periods in all sessions in the experiment.[43]

The cross-sectional average of the predictors' price expectations (for the following period) is used for $E_t(P_{t+1})$, and the average price of the previous period and the one before that are used as P_t and P_{t-1}, respectively.[44] We estimated Eqs. (15), (16) and (17) using the data from 360 periods (24 sessions in four treatments x 15 periods) for each of high and low-liquidity treatments.[45] We divided the sample into the periods with dividend-collecting investors and the periods with only speculating investors. We conducted the estimation using ordinary least squares regression with constant terms, treatment (T2, T4, T8) dummies and period dummies (Period 3–Period 16). Table 8 shows the estimation results.

Overall, the coefficient of $(F_t - P_t)$ in the combined (COMBINED) model ranges from 0.051 to 0.374, which is significantly less than one (at 1% level). Even when dividend-collecting investors are present, adjustment to REE is gradual, not instantaneous.[46]

Although the data reject the instantaneous rational expectation formation, it reveals that the fundamental value of the security helps anchor the expectation of future price in markets with dividend-collecting investors. In periods with dividend-collecting investors (left half of Table 8), backward induction from fundamental values fits the data better than the forward induction from past prices. In high-liquidity sessions (upper left of Table 8), the coefficient of $(F_t - P_t)$ is significantly positive (0.189) in the fund (FUND) model, but the coefficient of $(P_t - P_{t\text{-}1})$ is not significant in the trend (TREND) model. In the

[43] Hommes et al. (2005) investigate the price expectation formation in asset market experiments. They report that about half of participants follow the linear autoregressive predictions with two lags – AR (2) – which can be interpreted as a trend following strategy (trend extrapolators or contrarians). Using our notation, AR(2) prediction is expressed as E_t $(P_{t+1}) = \gamma + \beta_1 P_t + \beta_2 P_{t\text{-}1}$ and it becomes our trend model (Eq. (9)) when $\gamma = 0$, $\beta_1 + \beta_2 = 1$, and $\beta_2 = -\beta$.

[44] In the experiment, we asked the predictor to forecast the price only for the following period. In this sense, we elicit only "short-run" price expectation. Some asset market experimental studies (e.g., Evans et al. 2019, Hanaki et al. 2018, Haruvy and Noussair 2006) elicit not only short-run but also long run price expectations (asking subjects to forecast prices over multiple periods).

[45] Note that the actual number of observations is below 360 due to periods with no transactions and the fact that we do not have data for Period 1 in TREND and COMBINED, because, while we have the data of the average price expectation $(E_t(P_{t+1}))$ we do not have the data of the average price of the previous period (P_t).

[46] This result is consistent with the empirical results reported by Greenwood and Shleifer (2014). They show that expectations of investors captured by the surveys are not at all the expectations obtained from REE models.

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Table 8
Price expectations model estimates.

High-liquidity Session	Periods with dividend-collecting investors			Periods with only speculating investors		
	FUND	TREND	COMBINED	FUND	TREND	COMBINED
$(F_t - P_t)$	0.189***		0.202***	0.121*		0.100
	(0.048)		(0.055)	(0.065)		(0.062)
$(P_t - P_{t-1})$		0.030	0.104**		−0.285***	−0.250***
		(0.032)	(0.044)		(0.045)	(0.039)
N	173	167	167	186	168	168
R-squared	0.47	0.18	0.49	0.34	0.44	0.52

Low-liquidity Session	Periods with dividend-collecting investors			Periods with only speculating investors		
	FUND	TREND	COMBINED	FUND	TREND	COMBINED
$(F_t - P_t)$	0.358***		0.374***	0.067***		0.051**
	(0.079)		(0.088)	(0.021)		(0.019)
$(P_t - P_{t-1})$		−0.112	0.029		−0.187***	−0.172**
		(0.066)	(0.047)		(0.064)	(0.062)
N	171	162	162	186	168	168
R-squared	0.59	0.41	0.59	0.34	0.40	0.42

Notes: Constant terms, treatment dummies (T2, T4, T8), and period dummies (Period 3 to Period 16) are included in all regressions but not reported. Robust standard errors clustered by session in parenthesis. Significance levels: * (10%), ** (5%) and *** (1%).

combined (COMBINED) model, while both the fundamental factor $(F_t - P_t)$ and the trend factor $(P_t - P_{t-1})$ are statistically significant, the former effect (0.202) is significantly larger than the latter (0.104).[47] In low-liquidity sessions (lower-left of Table 8), the coefficient of $(F_t - P_t)$ is significantly positive in both the fundamental (FUND; 0.358) and the combined (COMBINED; 0.374) models; the coefficient of $(P_t - P_{t-1})$ is not significant in either trend (TREND) and combined (COMBINED) models. These results suggest that in the presence of dividend-collecting investors, the fundamental value of the security helps form expectations and determines transaction prices. Arbitrage transactions of dividend-collecting investors enable market participants to expect that future prices will converge to the fundamental value.

In contrast, the results in periods with only speculating investors (right half of Table 8) support the trend model better than the fundamental model. In high liquidity sessions (upper right of Table 8), the coefficient of $(F_t - P_t)$ in the fundamental (FUND) model (0.121) is marginally significant, but it becomes insignificant in the combined (COMBINED) model. The coefficient of $(P_t - P_{t-1})$ is −0.285 and −0.250 in the trend (TREND) model and the combined (COMBINED) model, respectively, and both are statistically significant at the 1% level. In low liquidity sessions (lower right of Table 8), the coefficient of $(P_t - P_{t-1})$ is significantly negative in both trend (TREND; −0.187) and combined (COMBINED; −0.172) models.[48] These results suggest that in a market with only speculating investors, investors tend to form their expectations based on recently observed prices through forward induction, and not backward induction from fundamental values. In addition, the negative coefficient of $(P_t - P_{t-1})$ shows that market participants expect price reversals; a price rise of 1 from the previous period lowers the expectation of the next period price by about 0.17–0.29.[49]

Overall, the results shown in Table 8 indicate that the expectations about future prices are formed based on the fundamentals (through backward induction) in a market with dividend-collecting investors, and are based on recent price changes (through forward induction) in a market with only speculating investors.[50]

5. Discussion and concluding remarks

This paper proposes, and empirically tests in the laboratory, the idea that security prices tend to deviate from fundamental values when markets are populated by speculating investors. In such markets, investors' expectations about the future cash flows beyond their holding periods are not relevant and therefore frequently ignored; they are replaced in trading decisions by expectations about future prices. Standard finance theory, however, assumes that even in such markets speculators form iterated rational expectations of future prices through backward induction and prices tend toward the fundamental

[47] The difference in two coefficients is significant at 5.6 % level (two-sided test).

[48] $(F_t - P_t)$ is also significant in the fundamental and combined models, albeit with much smaller estimated coefficients (0.067 and 0.051) as compared to the periods with dividend-collecting investors (0.358 and 0.374). We can infer that the trend model is better supported over the fundamental model in periods with only speculating investors for low as well as high-liquidity sessions.

[49] While this pattern of reversal in expectations has been observed in some experimental markets (Bao et al. 2012, 2013), it is in a sharp contrast to the momentum (extrapolative) expectations reported in other experimental markets (Haruvy et al. 2007; Hirota and Sunder 2007; Hommes et al. 2005).

[50] We also considered session-specific fixed effects estimating session-specific fixed effect models (adding period dummies). The results are very similar to the ones in Table 8. In periods with dividend-collecting investors, all coefficients of $(F_t - P_t)$ are significantly positive but two of the coefficients of $(P_t - P_{t-1})$ are not significant; in periods with only speculating investors, all coefficients of $(P_t - P_{t-1})$ are significantly negative. These numbers support our arguments.

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value constituting the rational expectations equilibrium (REE). We conjecture that this assumption cannot be met in practice, causing prices to deviate from fundamentals and become indeterminate in financial markets populated by speculating investors.

We conduct an asset market experiment with an overlapping-generations structure where all investors have identical common knowledge beliefs about the fundamental value of the security. Our laboratory results show that (i) in periods with only speculating investors present prices are more likely to depart from fundamentals compared to prices in periods in which dividend-collecting investors are present; (ii) volatility of prices is higher when only speculating investors are present; (iii) prices are more likely to depart from fundamentals when the securities changed hands among speculating investors more often over their 16-period life (i.e., the holding period of speculating investors shrank); and (iv) speculative trading pushes prices upward (downward) when money supply is high (low). These laboratory results do not support the REE prediction made by standard finance theory for this environment; instead, they suggest that speculation leads to price indeterminacy or bubbles (positive as well as negative with the sign driven mostly by liquidity).

Given these results, it is reasonable to think that price indeterminacies and bubbles in field markets may arise in the presence of speculating investors. The mechanism for these price bubbles observed in the laboratory is unlike the mechanisms suggested in the extant theoretical literature – rational bubbles models (e.g. Blanchard and Watson 1982, Tirole 1985) and heterogeneous belief models (e.g. Abreu and Brunnermeier 2003, Allen et al., 2006, Amershi and Sunder 1987, DeLong et al., 1990a, 1990b, Dow and Gorton 1994, Froot et al., 1992, Scheinkman and Xiong 2003). Even in these simple laboratory markets (the security pays a single non-stochastic common knowledge terminal dividend at the end of its 16-period life), it is difficult for speculating investors to form common knowledge rational expectations of future prices. Since securities traded in real financial markets have more complex features (such as uncertainty, information asymmetries, and heterogeneous beliefs regarding future cash flows), we conjecture that common knowledge of rationality among investors is even less likely to hold in the field and investors face even greater challenges in forming rational expectations, and making such expectations common knowledge. Building theories by relaxing the assumption underlying rational expectations is a promising way to explain the price volatility and indeterminacy in financial markets (see, e.g., Adam and Marcet 2011).

In some earlier experiments, financial markets converged to the static REE (Plott and Sunder 1982, 1988) in which traders can infer the current state of the world from the observed market phenomena. In contrast, the REE examined in our markets is *dynamic* and inter-generational; investors' expectations of future prices must be formed by iterated expectations and backward induction over generations. Arriving at this dynamic REE is implausibly difficult since it requires investors to have not only extraordinary cognitive abilities but also common knowledge to be established within and across generations of investors.

Several implications emerge from this study. First, greater inefficiency, pricing anomalies, and so-called "behavioral" phenomena, which cause security prices to depart from fundamentals, are more likely to be observed when markets are populated with mostly speculating investors. Second, the excess price volatility in real stock markets reported by previous empirical studies (e.g., LeRoy and Porter 1981, Shiller 1981) may be caused by the existence of speculative investors. This observation raises the empirical question of whether stock price volatility is larger in periods and markets with more speculative investors.

Third, securities with longer maturities are more prone to price indeterminacy. Given investors' holding periods, as the maturity becomes longer, the number of trading generations that exchange and hold the security between the present and the maturity date increases, and it becomes more difficult for investors to form rational expectations by backward inducting through multiple iterations, magnifying the impact of backward induction errors on prices. This suggests that common stocks are more susceptible to (positive or negative) price bubbles compared to other securities, because the stock typically has longer maturity than others.[51]

Fourth, the securities with longer durations are more likely to deviate from fundamentals.[52] As the duration of a security increases, investors receive a smaller portion of its value from cash flow within their holding periods and a larger fraction of their valuation depends on more-difficult-to-anticipate capital gains (future prices). This explains the informal observation that bubbles are more likely to occur for high-growth stocks with long durations.

Fifth, prudent monetary policy would matter for the stabilization of security prices. Our laboratory data show that in markets with speculating investors, the high level of money supply enlarges positive price bubbles from fundamentals, whereas the low level of money supply causes negative price bubbles. This finding implies that controlling the supply of money and credit is important for stabilizing not only the real economy but also security prices when markets are dominated by speculating investors.[53] Sixth, to the extent security prices are destabilized by speculating investors, it is possible to develop an argument to support higher tax rates on short-term capital gains. However, the effectiveness of policies for suppressing price bubbles and indeterminacy is a subject for future exploration.

[51] Common stocks would not expire without bankruptcy, liquidation, or acquisition.

[52] Duration is the weighted average time of a security's cash flows.

[53] Some recent laboratory experiments explore the effectiveness of monetary policy in reducing asset market bubbles (Fischbacher et al. 2013, Giusti et al. 2016, Fenig et al. 2018, Hennequin and Hommes 2018, Bao and Zong 2019). These experiments focus on whether interest rate policy (controlling interest rates) deflates asset market bubbles. In contrast, our laboratory result has an implication on monetary policy by suggesting that controlling money supply would be effective in reducing (both positive and negative) bubbles.

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Supplementary materials

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