Experimental Asset Markets with An Indefinite Horizon*

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Abstract

We study the pricing and trade of indefinitely lived assets in experimental markets. Our experimental design disentangles several confounding factors in such markets: (1) payoff uncertainty about the asset's dividend payments; (2) horizon uncertainty about the duration of trade in the asset, and (3) the assumption that agents are risk neutral expected utility maximizers. In a baseline treatment with all of these features or assumptions in place, we find that trading prices are on average more than 40% below the risk-neutral fundamental value, and decrease further as traders gain experience. In the two other treatments, we separate trade in the asset from dividend realizations. While there continues to exist uncertainty in the number of dividend payments, coupled with or without the uncertainty in the length of the trading horizon, we find that market prices in the latter two treatments are not significantly different from the asset's risk-neutral fundamental value. We therefore conclude that the low trading prices observed in our baseline, indefinite-horizon market cannot be explained by assuming risk neutral expected utility maximizers. By contrast, an Epstein-Zin recursive preference specification that allows risk preferences to be disentangled from preferences for certainty can account for the low trading prices observed in our baseline treatment. Indeed, a further contribution of our paper is that we propose a method to calculate the risk-adjusted market fundamental value of the asset under expected utility or under Epstein-Zin preferences, respectively.

Key Words: asset market experiments, indefinite horizon, random termination, risk and uncertainty, expected utility, Epstein-Zin preferences.

JEL Codes: C90, D81, G12

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1 Introduction

Many economic models employ an infinite horizon with a discount factor in order to examine agents' behavior under the shadow of future. Such environments are quite natural for studying the pricing of assets, since many assets, e.g., equities, are long-lived and have no definite maturity date.

Nevertheless, experimental economists have typically studied assets in a finite horizon setting where the fundamental value of the asset, as measured by the present value of the dividend flow, is decreasing over time, as in the canonical experimental design of Smith et al. (1988). While it is possible to generate constant values for the fundamental values in finite horizon settings, this is typically done by having some known constant terminal value of the asset as in Smith et al. (2000), possibly also accompanied by a dividend process where the expected dividend payment is 0 as in Noussair et al. (2001).

In this paper, we study what we view as a more natural setting where the asset's expected dividend payments are strictly positive and there is no terminal payoff value for the asset since the horizon over which the asset may generate value is not known in advance. In experimental analyses of such environments, several different approaches to implementing such indefinite horizons have been employed. The most commonly used method is the random termination approach of Roth and Murnighan (1978), which uses a constant probability, δ, that an asset has value and can be traded in a market from one period to the next. If agents are risk neutral, expected utility maximizers, then it is easily shown that repeated market trading periods subject to such random termination are isomorphic to an infinitely repeated horizon with a period discount factor of δ.[1] Methodologically, some recent papers have examined the effect of random termination in experiments using the repeated Prisoner's Dilemma game (Frechette and Yuksel, 2017) and the effects of different payment schemes in indefinite-horizon experimental games (Sherstyuk et al. 2013).

In this study, we propose to examine the effect of random termination in experimental asset markets. We choose to study experimental asset markets with an indefinite horizon using random termination for several reasons. First,heterogeneous risk attitudes, combined with random termination, can create incentives for trade in such assets even in settings where the dividend process is common knowledge such as in Suchanek, Smith, and Williams (1988). Second, the risk induced by random termination may play a larger role in influencing individuals' behavior in *asset market* experiments as

[1] Another method involves subjects playing a fixed number of periods with discounting on the instantaneous payoffs, followed by play of a game that captures the continuation payoff (Cooper and Kühn, 2011).

compared with repeated game settings.

To see the latter, consider an asset holder as playing the following game against nature (or lottery) as shown in Table 1: each state is the event that the game lasts until period t, which occurs with probability $\delta^{t-1}(1-\delta)$, i.e., the asset can be traded in a market and thus yields a dividend d for the first $t-1$ periods and the market ends and the asset ceases to have any value in period t.

Market Duration	1	2	3	...	t	...
Probability	$1-\delta$	$\delta(1-\delta)$	$\delta^2(1-\delta)$	...	$\delta^{t-1}(1-\delta)$	...
Payoff from holding an asset	d	$2d$	$3d$	...	td	...

Table 1: The Lottery Faced by an Asset Holder in an Indefinite Horizon

If the asset lives for t periods, then each share yields a payoff of td. In repeated games, individuals' action choices may affect the payoffs under each state, i.e., the accumulated payoffs until period t. However, in repeated games, subjects have *no choice* but to participate in the game. Differently, in asset market experiments with an indefinite horizon, subjects can choose whether to participate in the lottery or not. Specifically, in asset pricing experiments, subjects can immediately (i.e., in the very first period) sell off all of their asset holdings and receive a certain monetary payoff rather than continue to participate in the lottery. Alternatively, subjects can buy all the assets they want in the first period and hold that asset position for the duration of the trading horizon. In the first case, subjects who sell off their assets immediately face neither payoff uncertainty nor horizon uncertainty; they sell their assets for a known amount and are not engaged in any further trading for the duration of the asset market. In the second case of the subject employing a buy-and-hold strategy, the subject continues to face payoff uncertainty, e.g., as to the sum of dividends each of his assets yields over the indefinite horizon, but because this subjects ceases to engage in further trading s/he no longer faces any trading horizon uncertainty. There is, of course, a third case where a subject trades in each period so that his asset position is constantly changing, in which case the subject faces both payoff and trading horizon uncertainty. Our experimental design seeks to distinguish between the roles of payoff and horizon uncertainty as well as to disentangle risk preferences from preferences for certain payoffs. To the best of our knowledge, there is no study that tries to distinguish or qualitatively measure the effect of these two types of uncertainty associated with random termination. Third, the general use of the risk-neutral FV of the asset as a benchmark for analysis in finite horizon studies, as well as various miss-pricing measures based on that FV are problematic in calculating the extent of miss-pricing in the indefinite horizon case. Our experiment enables us to disentangle the effect of the uncertain fundamental value (FV) associated with the indefinite horizon and the effect of an uncertain trading horizon itself. Finally, we propose a procedure to calculate the FV that incorporates traders' risk attitudes, and we use this FV to evaluate the extent to which prices depart from risk-adjusted fundamental values.

There is a large literature involving experimental asset markets with known, finite horizons beginning with Smith et al. (1988). Surveys of this literature are found in Palan (2009) and Noussair and Tucker (2013). In this set-up, the asset traded yields dividends up to some known terminal date, beyond which the asset pays no further dividends (is worth zero or pays some final continuation value). By comparison, there are relatively fewer experimental studies of asset markets with indefinite horizons. The studies we are aware of include Camerer and Weigelt (1993), Ball and Holt (1998), Hens and Steude (2009), Kose (2013), Fenig, Mileva and Peterson (2014), Asparouhova, Bossaerts, Roy and Zame (2016), Crockett, Duffy and Izhakian (2017) and Weber, Duffy and Schram (2017). Camerer and Weigelt (1993), Ball and Holt (1998) Kose (2013) and Weber et al. (2017) study environments where subjects only engage in asset-trading activities. Hens and Steude (2009), Fenig et al. (2014) Asparouhova et al. (2016) and Crockett et al. (2017) consider experimental economies where subjects also participate in other activities such as consumption, employment or production decisions. However, none of these studies provides a rigorous comparison between indefinite-horizon and definite-horizon asset markets and also considers as the relevant benchmark, the FV that incorporates traders' elicited risk attitudes. Therefore, our study also provides methodological contribution to experimental research on asset pricing in indefinite horizons.

2 Experimental Design

Our experimental design consists of three treatments having the following features in common. In each treatment, subjects participate in an experimental asset market involving trading an asset with a constant, risk-neutral FV that is always equal to 50 EM (experimental money). Each session of a treatment consists of three consecutive markets and 10 participants with no prior experience in our experiment. At the beginning of each of the tree markets, one-half of the participants are endowed with 20 shares of the asset and 3,000 EM cash, while the other half are endowed with 60 shares of the asset and 1,000 EM cash; at the FV of 50 EM, these endowments are identical. In each session, the same set of traders participate in all market activities on a trading interface using a double auction mechanism programmed in z-Tree (Fischbacher, 2007).[2]

Kirchler et al. (2012) have shown that the pattern of the FV process (constant, increasing, or decreasing over periods) has a large impact on the formation of non-rational asset price bubbles (sustained departure from fundamental values). In addition, Caginalp et al. (1998, 2001), Haruvy and Noussair (2006) and Kirchler et al. (2012) report that high initial or increasing cash-to-asset (C/A) ratios can drive bubble formation in experimental asset markets. In our asset market experiments, the supply of assets and the dividends that each asset share yields is held constant so that we always have the same, constant risk-neutral FV prediction for the price of the asset. While the traded asset pays dividends, we keep the C/A constant as well (as explained below) so as to minimize the effects of variations in that ratio on market outcomes. Smith et al. (1988) and some follow-up studies have consistently found that when the *same group* of traders interact in consecutive fixed-horizon asset markets, prices converge toward the intrinsic risk-neutral FV by the third market having the *identical* market structure. The experience of Smith et al. accounts for our design of having three consecutive repeated identical markets to allow for subject learning and to examine the possibility of price convergence in indefinite-horizon markets.

2.1 The Three Treatments

The main purpose of our experiment is to understand how subjects price assets in an indefinite horizon setting as implemented by random termination and to disentangle the effect of an uncertain trading horizon from the effect of an uncertain FV on pricing behavior. Toward that goal, we use three different experimental treatments.

Our baseline treatment A (Block Random Termination, BRT hereafter), implements the three indefinite horizon asset markets using the block random termination scheme proposed by Frechette and Yuksel (2017) (as discussed in further detail below). Following the completion of each trading period, one dividend of $d = 5EM$ is realized for each share of the asset that a trader possesses at the end of that period. This dividend payment is placed in a separate account that the subject cannot use as income for asset purchases in later periods of the market. This restriction prevents the dividend payments from increasing the cash-to-asset ratio and so the dividend payment can be regarded as current consumption. After dividends are paid out, a random number is drawn to determine whether or not the market will continue to the next period. If the market continues, then each trader's asset position carries over to that next period and if it does not continue then each trader's asset position is set to 0. This process is

[2] The z-Tree program was modified from the program published by Kirchler et al. (2012).

Table 2: Summary of Treatments

Treatment	Trading Horizon	Uncertain FV_t?	Dividends Realized after Trading Phase?
A (BRT)	Random	Yes	No
B (D-R)	Definite	Yes	Yes
C (BRT-R)	Random	Yes	Yes

Notes: Dividend $d = 5$ and risk-neutral FV=50 in all treatments.

repeated three times, so that we have three indefinite horizon markets for each session of treatment A.

In treatment B (Definite-Random, D-R hereafter) each of the three asset markets is divided up in to two phases. In the first phase, trade in the asset takes place in a market with a known, fixed duration of T trading periods (as in much of the experimental asset pricing literature beginning with Smith et al. (1988). During these T trading periods, there are no dividend realizations for asset holdings; subjects can choose to buy or sell assets as they wish subject to budget constraints. Following the final trading period T, all asset positions are final and subjects move on to the second phase of the market where they experience a random sequence of dividend payments that is identical to that of treatment A. Thus, subjects' final asset position at the end of period T and the random sequence of dividends that follows the same realization as in Treatment A determine each subject's earnings for the market. Again, this process is repeated three times so that we have three markets for each session of Treatment B. The purpose of Treatment B vs. treatment A is to examine the effect of a finite trading horizon vs. an indefinite trading horizon that is isolated from the effect of an indefinite number of dividend realizations.

Finally, considering that the different timing of dividend realizations between treatment A and treatment B may result in changes in traders' behavior, in treatment C (Block Random Termination-Random, BRT-R hereafter) we implement asset markets with an indefinite-horizon trading phase, which is then followed by an indefinite-horizon dividend realization phase, while keeping other treatment variables identical to those in the baseline treatment A. Again, for each session of treatment C, we have results from three asset markets with this timing.

Table 2.1 summarizes the main features of the three treatments described above. Further details of each treatment are discussed below.

Treatment A (BRT) employs random termination to generate markets of an indefinite horizon, similar to Camerer and Weigelt (1993) and treatment T2 in Kose (2013). In each market, the asset lasts for an indefinite number of periods. In particular, at the end of each period, the market continues with probability $\delta = 0.9$ and ends with probability $(1-\delta) = 0.1$, which yields an average length of $T_0 = 1/(1-\delta) = 10$ periods from the start of the market or from any period reached. Under the random stopping rule, the realized life span of the asset can be any number of periods between 1 to ∞. The indefinite horizon introduces two types of uncertainty: 1) uncertainty about the duration of the trading horizon and 2) uncertainty about the FV of the asset. If a trader buys a share of the asset in any period and holds it until the end of the market, it is similar to buying a lottery as in Table 1. The risk-neutral FV of the asset, denoted by V_0, is constant in all periods at

$$V_0 = d\sum_{\tau=t}^{\infty} \delta^{\tau-t} = \frac{d}{1-\delta} = 50.$$

One consensus from the experimental asset market literature is that it takes time for sustained departures from fundamental values, or "bubbles" to occur (if one occurs at all). In order to obtain data on traders' behavior in a market with sufficient duration (number of trading periods), in treatment A we implement the indefinite horizon by using a modified version of the "Block Random Termination" (BRT) design proposed by Frechétte and Yuksel (2017). At the end of each trading period, a random number is drawn to determine whether or not the market continues into the next period. In the first 10 periods, however, subjects get no feedback on the random draws and are asked to consider making trades in all 10 periods. At the end of period 10, subjects are told whether or not the market has ended and, if so, in which period this occurred within the block of 10 periods. If the market did not end within the 10 period block, then subjects will continue to participate in the market as in regular indefinite-horizon markets with random termination, that is, at the end of each period the realization of the random draw will be revealed. If the market ends within the first 10 periods, then all trading activities in the subsequent periods after the market has actually ended are void. Subjects are paid for periods only up to the end of a market. Under the BRT design, subjects play for the first 10 periods without interruption (although being aware that the market may actually end in one of these 10 periods and if so, trading from that period on will be rewound). The BRT allows us to obtain, at a minimum, a 10-period data series to analyze bubble formation; without it, we may have sessions where all markets are too short to have any meaningful discussion of asset miss-pricing within an indefinite horizon.

Treatment B (D-R) has two separate phases: a definite-horizon trading phase and an indefinite-horizon dividend realization phase. The trading phase lasts for $T_0 = 10$

periods, during which subjects can trade the asset but no dividends are paid during the trading phase. Asset positions at the end of period T_0 are final. Then, the market moves to the dividend realization phase. Trading is not allowed during the dividend realization phase; traders only observe how dividends accrue for the shares they possess as of the end of the trading phase. Each share yields at least one dividend for certain. After each dividend realization, a random number between 1 and 100 is drawn to determine whether or not there is another dividend realization. If the random number is greater than 90, the dividend realization phase ends; this process implements the termination probability of $(1-\delta) = 0.1$. Otherwise, each share yields another dividend payment, d followed by another independent random draw. Using this procedure, with the same continuation probability of $\delta = 0.9$ and $d = 5EM$ as in treatment A, the asset in this treatment not only has the same risk-neutral FV as in treatment A, but its value can also be represented by the same lottery as in treatment A if the trader holds the share to the end of the market.

Treatment C (BRT-R) again has two separate phases: an indefinite-horizon trading phase and an indefinite-horizon dividend realization phase. Similar to treatment B, no dividends are realized during the trading phase and no trading is allowed during the dividend realization phase. The only difference between treatment C and treatment A is the timing of dividend realizations. Therefore, treatment C keeps both the uncertainty of the trading horizon and the uncertainty of FV as in treatment A, but presents them in two independent phases. Meanwhile, the only difference between treatment C and treatment B is the indefinite-horizon trading phase of treatment C vs. the fixed-horizon trading phase of treatment B. Thus, the existence of treatment C helps us to identify any confounding effect between the indefinite trading horizon and whether or not dividends are realized in each trading period or only after the entire trading phase. Following the design in treatment A, we employ block random termination in the trading phase of treatment C as well. Importantly, in this treatment the realizations of the random variable that determine the trading duration and the dividend realizations are independently drawn, although under the same continuation probability of $\delta = 0.9$. Therefore, traders have no way to infer the number of dividends they may collect later in the dividend realization phase from the indefinite lengths of the three asset markets they have participated in.

Each market may take 20-40 minutes to complete, depending on the treatment and the realized market length. In each trading period, the trading interface (market) is open for 2 minutes. Since an indefinite horizon can result in large variance in the lengths of asset markets, in our experiment we employ the same three sequences of random numbers for dividend payments and/or trading market horizons in all three sessions.[3] These sequences of random numbers produce 6, 20, and 9 dividends for the three markets of all three treatments; that is the sequence of dividend realizations is constant across all treatments. For treatment A (BRT), these three sequence lengths determine the length of the three markets as well, although each market is open for at least a block of 10 periods. For treatment C (BRT-R), we independently draw another three sequences of random numbers with the same continuation probability $\delta = 0.9$, which determine that the actual length of the three trading phases in treatment C which are 11, 5 and 16 periods; the number of dividend realizations remains 6, 20 and 9 for the three markets of treatment C. For treatment B (D-2), the trading horizon for each market is fixed at 10 rounds.

2.2 Hypotheses

The asset value in all the three treatments can be represented by the lottery shown in Table 1 under the assumption of expected utility, by which the timing of dividend payments does not affect agents' preferences. Therefore, the comparison between treatments A and C identifies the effect of the timing of dividend payments (and to a certain extent, whether subjects have an expected utility or non-expected utility specification). The comparison between B and C captures the effect of uncertain trading durations, which may affect subjects' ability to engage in speculative transactions.

Based on our experimental design, we derive the following null hypotheses.

Hypothesis 1: Market outcomes, i.e., prices, quantities, are not significantly different between treatments A, B and C.

- Alternative hypothesis: Differences between treatment A and C indicate non-expected utility specifications; Differences between treatment B and C indicates that uncertainty about the trading horizon matters.

Based on previous experimental findings that most agents are risk averse (Holt and Laury, 2002), we conjecture

Hypothesis 2: Market price in all treatments are significantly lower than the risk-neutral FV.

In this paper, we also propose two methods to calculate the fundamental value of the asset that incorporates the risk preference of traders, which will be explained in more

[3]The first two sequences of random numbers were obtained from a pilot session that consisted of just two asset markets and the last sequence of random numbers was produced using a random number generator.

detail in the next section. We conjecture that the market price will not be significantly different from the estimated risk-adjusted FV.

Hypothesis 3: Market price in all treatments is not significantly different from the risk-adjusted FV.

2.3 Experimental Procedure

All sessions began with subjects completing a Holt and Laury (2002) individual risk preference elicitation task - details are provided in Appendix A. Subjects were instructed to make choices between a series of 10 paired lotteries and were paid based on their choice for one, randomly chosen lottery from the list of 10 pairs. This procedure enables us to obtain a measure of each subject's risk aversion, which we use later in assessing how we might adjust the fundamental value of the asset for subjects' risk preferences. After subjects completed this individual decision-making task which took about 10 minutes, the session then proceeded with the three indefinitely repeated asset markets. The instructions for the asset markets were only distributed after the Holt-Laury risk elicitation procedure was completed (payments from this task were made only at the end of the experiment). After the experimenter read aloud the instructions for the asset market experiment, subjects were asked to answer a set of quiz questions. After reviewing the answers to these questions with the experimenter, subjects practiced using the trading interface before the formal asset market was officially opened.

The experimental money used in the asset market was converted into Canadian dollars at the fixed and known exchange rate of 500 EM = CAD$1 at the end of the experiment.[4] Given that there are 6, 20, and 9 dividend payments in markets one, two, and three, respectively, the average earnings from the asset markets was CAD$26.

The experiment was conducted at the Bell economics lab at CIRANO in Montreal. All sessions took less than 2.5 hours, including 45 minutes for instructions and practice on the trading interface. Subjects were recruited for the experiment using ORSEE (Greiner, 2004). Subjects were students from McGill university and Concordia University in Montreal. All subjects participated in one session only. Participants were paid in cash, privately, at the end of the session, Their earnings were the sum of their earnings in the three asset markets which averaged CAD$26, their earnings from the Holt-Laury procedure which averaged CAD$4 and a CAD $5 show-up fee.

[4] In session B1 and C1, the exchange rate is 400 EM = CAD$1, which results in a higher payment in the asset markets as shown later in Table 3.

Table 3: Summary of the Sessions

Session	Duration	No. of Subjects	Avg. Payment
A1	2.5 hr	10	\$34.98
A2	2.5 hr	10	\$35.87
A3	2.5 hr	10	\$35.34
A4	2.5 hr	9	\$34.17
A5	2.5 hr	10	\$34.45
B1	2 hr	10	\$42.29
B2	2 hr	10	\$35.26
B3	2 hr	10	\$36.00
B4	2 hr	10	\$35.64
B5	2 hr	10	\$34.58
C1	2.5 hr	10	\$41.99
C2	2.5 hr	8	\$35.83
C3	2.5 hr	10	\$35.86
C4	2.5 hr	10	\$36.61
C5	2.5 hr	10	\$35.12

3 Experimental Results

We conducted 5 sessions for each of the three treatments. Table 3 presents information on these sessions. All sessions except two involved 10 subjects. The sessions in treatment B took half an hour less than the sessions in treatment A and C but all sessions finished within two and half hours. The average total payment is close to \$35 (\$26 from the asset market, plus \$4 from the Holt-Laury procedure, plus \$5 show-up fee).

Figure 1 shows the average price over periods in each treatment. The average price in the first market starts at about 50 (the risk-neutral FV) in treatments A and C and at about 60 in treatment B, which does not appear to be a significant difference. However, the average price in treatment A in the second and third markets steadily declines falling as low as 20 when the market ends, while the price in treatments B and C remains at or above 50 in the last two markets. This pattern holds at the session level as well, which is shown in Figure 4 in Appendix B.[5]

Table 4 lists the average price and the trading volume in each market of each session. The session-level data is consistent with Figure 1. Formally, we conducted two-tailed Mann-Whitney tests and present the p-values in Table 5. In market 1 the average trading price is not significantly different between any two treatments. However, the

[5]Given that the price pattern in different treatments is quite clear, we choose not to report the bubble (miss-pricing) measures as in most of experimental papers on asset markets. The statistical tests on bubbles measures, RAD and RD developed in Stöckl et al (2010), are consistent with the test results on prices.

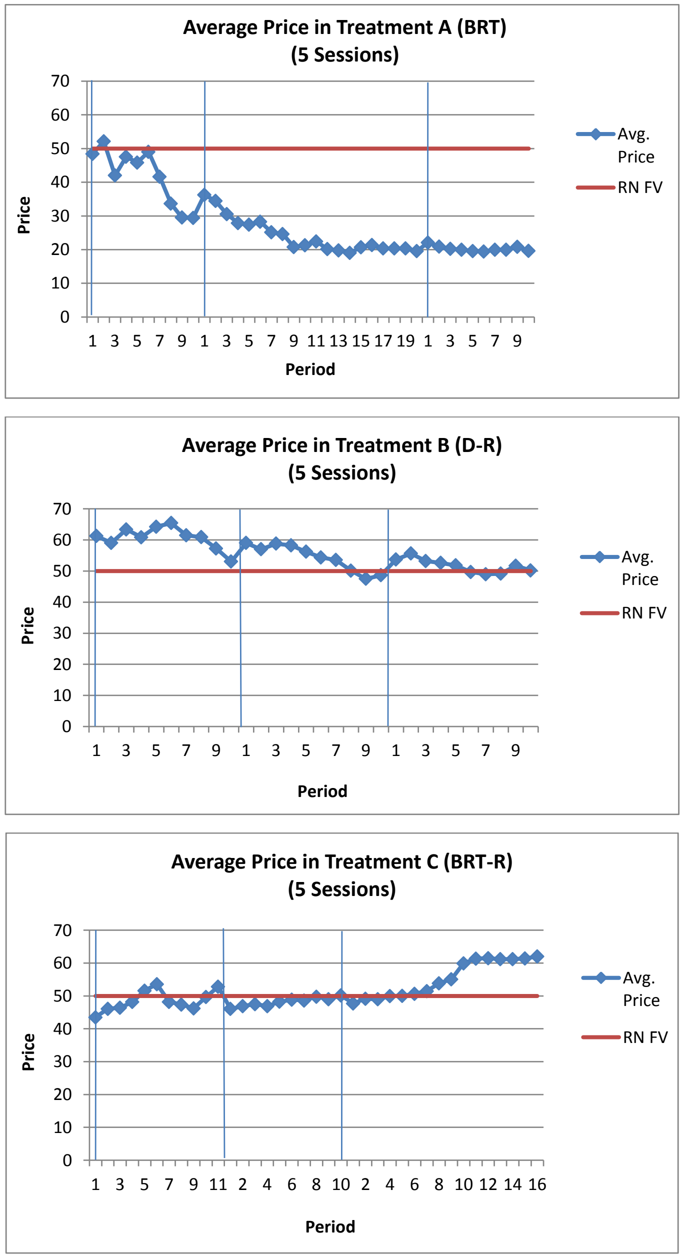


Figure 1: Average Prices over Periods in Each Treatment

average price in market 2 and 3 is significantly lower in treatment A than in treatment B and C ($p < 0.01$ and $p < 0.02$, respectively). Between treatments B and C, the average price is marginally different in market 2 ($p < 0.1$) but the difference disappears when subjects gained more experience in market 3 ($p > 0.4$). There is no significant difference in the average trading volume across the three treatments except in market 3 between treatment A and C, where trading volume in treatment A is significantly

Table 4: Average Trading Price and Volume by Session and Market

Session	Average Price			Average Volume		
	Mkt1	Mkt2	Mkt3	Mkt1	Mkt2	Mkt3
A1	30.87	18.94	17.89	60.70	45.20	67.30
A2	34.26	24.00	11.52	54.30	64.70	62.60
A3	84.87	40.94	33.34	58.70	58.45	64.30
A4	18.33	15.69	16.54	52.50	72.65	101.00
A5	41.29	20.60	22.08	122.80	146.90	221.60
B1	77.93	52.79	45.02	32.00	22.70	10.80
B2	73.56	70.93	67.67	71.10	85.30	67.90
B3	39.49	48.77	49.50	65.20	64.60	66.40
B4	52.69	50.27	50.21	57.40	48.90	48.50
B5	59.81	48.97	45.28	125.30	90.20	65.80
C1	49.11	45.57	47.74	37.18	40.70	24.63
C2	42.65	46.48	46.77	54.82	52.50	75.50
C3	58.64	60.57	62.07	32.45	43.60	29.56
C4	55.61	48.42	49.54	55.91	54.10	22.94
C5	36.56	39.95	70.61	84.36	88.30	60.44

Notes: Average Price is the mean of the period price over all trading periods in a market. For treatments A and C, it includes 10 periods if the market ends within the block. The period price is the volume-weighted average price in the period. Average Volume is the mean of trading volume (number of assets traded) over all trading periods in a market.

Table 5: p-value of Mann-Whitney Tests

Treatments	Average Price			Trading Volume		
	Mkt1	Mkt2	Mkt3	Mkt1	Mkt2	Mkt3
A vs. B	0.175	0.009	0.009	0.602	0.754	0.251
A vs. C	0.175	0.016	0.009	0.347	0.175	0.047
B vs. C	0.175	0.076	0.465	0.347	0.602	0.602
No. of Obs.	10	10	10	10	10	10

greater than in treatment C ($p < 0.05$). Based on these statistical results, we reject Hypothesis 1, as market outcomes in treatment A, particularly prices are significantly different from the other two treatments. Furthermore, the difference between treatments A and C indicates that the timing of the dividend realization has a significant impact on the market outcome. However, the insignificant difference of trading price between treatment B and C indicates that the uncertain trading horizon itself does not affect the market price.

Finding 1 *The average market price in market 2 and 3 is significantly lower in treatment A (BRT) than in treatment B (D-R) and treatment C (BRT-R). The average* *market price in market 3 is not significantly different between treatment B (D-R) and treatment C (BRT-R).*

4 Explanation for Results

In this section, we offer an explanation for the observed treatment differences by estimating the fundamental value of the asset under different preference assumptions and comparing our experimental results with these estimated FVs.

In addition to considering the risk-neutral, expected utility FV prediction of 50 for the price of the asset in all three treatments, we also examined two alternative measures for the fundamental value that take account of subjects' elicited risk attitudes. In the first approach, we assume that agents are expected utility maximizers and have constant relative risk aversion (CRRA) preferences. In the second approach, we relax the expected utility assumption and adopt an Epstein-Zin recursive preference (Epstein and Zin, 1989, 1991) formulation.[6]

4.1 Estimation Strategy

Our basic estimation procedure consists of three steps: In Step 1, we estimate each individual's risk parameter by using the individual data from the Holt-Laury task; In Step 2, we estimate the certainty equivalence value of of the lottery described in Table 1 for each individual under both the expected utility and recursive utility assumptions. In Step 3, combining each individual's asset profile assigned in the experiment and the estimated certainty equivalence in Step 2, we construct a demand curve and a supply curve for each session and calculate the market equilibrium price, which we refer as the FV of the asset.

Notice that the different assumption of expected utility or recursive utility specifications will not affect the estimation for the risk parameter in Step 1, since the recursive feature in Epstein and Zin (1989, 1991) only applies to a dynamic situation and it allows for the expected utility assumption when risk occurs in static environment as in the Holt-Laury task. However, the assumption on the utility specification directly affects

[6]Such preferences are commonly used in the finance literature to rationalize the equity premium and risk-free rate puzzles (see, e.g., Campbell (2018)). Epstein-Zin preferences do not restrict the elasticity of intertemporal substitution to be the reciprocal of the coefficient of relative risk aversion. Instead, this recursive preference specification has a different parameter for each, which allows agents to treat consumption in the current period and the certainty equivalence of all future values in a nonlinear way that violates the independence axiom of expected utility theory. Nevertheless, as we show, this non-expected utility approach may help account for the behavioral differences we observe when we change the timing of dividend realizations under random termination.

the calculation of individuals' certainty equivalence in Step 2, and therefore, indirectly affects the FV of the asset in Step 3.

Step 1: Estimation for Risk Parameter

Assume that subjects' utility functions take the form $u(x, \alpha) = x^\alpha/\alpha$, where α is the risk preference parameter, with $\alpha = 1$, $\alpha < 1$ and $\alpha > 1$ corresponding to risk neutrality, risk aversion and risk loving behavior, respectively. Using this functional form, we calculate the value of α such that an individual with risk parameter α is indifferent between Option A, the safe choice, and Option B, the risky choice, for each of the 10 tasks in the Holt-Laury procedure. The 10 tasks can be found in the appendix for instructions. For example, in task i, the payoff from Option A is $\bar{x}_A = \$4.0$ with probability $\pi_i = i/10$ and $\underline{x}_A = \$3.2$ with probability $1 - \pi_i$, while Option B offers $\bar{x}_B = \$7.5$ with probability π_i and $\underline{x}_B = \$0.2$ with probability $1 - \pi_i$.[7] An agent who is indifferent between the two options in task i has preferences $u(x, \alpha_i)$, with α_i solving $Eu_A(x, \alpha_i) = Eu_B(x, \alpha_i)$ or

$$\pi_i \bar{x}_A^{\alpha_i} + (1 - \pi_i)\underline{x}_A^{\alpha_i} = \pi_i \bar{x}_B^{\alpha_i} + (1 - \pi_i)\underline{x}_B^{\alpha_i}.$$

We can then infer the risk parameter for each individual according to their choices in the Holt-Laury procedure.

Table 6 below presents the calculation of α_i when subject i chooses Option A for the first n_A tasks and Option B for the remaining $10 - n_A$ tasks. For instance, if a subject chooses Option A for the first four tasks ($n_A = 4$) and switches to B since task 5, then it indicates that the α_i of this subject is between the two cutoffs that make him indifferent in task 4 and 5 respectively. Therefore, we can infer that the individual's risk parameter lies in the interval $(0.8536, 1.1426)$. We use the midpoint of the interval, i.e., 0.9981, as the estimate ($\hat{\alpha}$) for the individual's risk parameter. If a subject always chooses B, then the interval of α is open and we use the lower bound 2.7128. If the subject chooses A nine times, then the interval of α is again open and we use the upper bound -0.3684. Finally, if a subject always chooses Option A, we set α to -0.3684 too.

Step 2: Estimation for Certainty Equivalence

After finding the risk parameter, α_i, for each subject i, we can estimate each subject's certainty equivalence for the lottery presented in Table 1. In this paper, we examine subjects' certainty equivalence by adopting three different assumptions on

[7] The payoffs we used in the lottery are twice of the payoffs used in the treatment of low stakes in Holt and Laury (2002). Given the CRRA assumption, the two sets of payoffs should lead to the same estimation of α given the same switch point.

Table 6: Calculation of CRRA Parameter from Holt-Laury Task

Task i	π_i	n_A	Interval for α_i	$\hat{\alpha}(n_A)$
		0	$(2.7128, \infty)$	2.7128
1	0.1	1	$(1.9468, 2.7128)$	2.3298
2	0.2	2	$(1.4866, 1.9468)$	1.7167
3	0.3	3	$(1.1426, 1.4866)$	1.3146
4	0.4	4	$(0.8536, 1.1426)$	0.9981
5	0.5	5	$(0.5885, 0.8536)$	0.7211
6	0.6	6	$(0.3288, 0.5885)$	0.4562
7	0.7	7	$(0.0294, 0.3288)$	0.1766
8	0.8	8	$(-0.3684, 0.0294)$	-0.1695
9	0.9	9	$(-\infty, -0.3684)$	-0.3684
10	1	10	$-\infty$	-0.3684

subjects' utility function.

Risk-neutral certainty equivalence

$$U_0 = d \sum_{\tau=t}^{\infty} \delta^{\tau-t} = \frac{d}{1-\delta} = 50. \tag{1}$$

Risk-adjusted certainty equivalence under expected utility

Specifically, we define the certainty equivalence U_1 to satisfy the following equation,

$$\frac{(U_1)^\alpha}{\alpha} = \sum_{t=1}^{\infty} (1-\delta)\delta^{t-1} \frac{(td)^\alpha}{\alpha},$$

or

$$U_1 = \left\{ \sum_{t=1}^{\infty} (1-\delta)\delta^{t-1}(td)^\alpha \right\}^{\frac{1}{\alpha}}. \tag{2}$$

The latter is the certain amount that a subject would accept now in exchange for forgoing the expected utility from the lottery under CRRA preferences and the subject's estimated value for α. Note that if $\alpha = 1$, (the risk neutral case), then $U_1 = U_0$.

Risk-adjusted certainty equivalence under recursive utility

Epstein-Zin (EZ) preferences can be expressed as $U_t = W(c_t, z_{t+1})$ where W is an increasing concave function, c_t is current consumption, and $z_{t+1} = G^{-1}(EG(\tilde{U}_{t+1}))$ is the certainty equivalence of future utilities in terms of current consumption good. An often used formulation is the CES utility function, $W(c_t, z_{t+1}) = (c_t^\rho + \delta z_{t+1}^\rho)^{1/\rho}$ with $\rho \leq 1$, and $G(U) = U^\alpha/\alpha$ with $\alpha \leq 1$, which implies $z_{t+1} = (E\tilde{U}_{t+1}^\alpha)^{1/\alpha}$. The value function measured in current consumption good is

$$U_t = [c_t^\rho + (E\tilde{U}_{t+1}^\alpha)^{\rho/\alpha}]^{1/\rho}.$$

In our experimental asset market, if subjects view the dividend realized in the current period separately from future uncertainty and if we assume current dividends are equivalent to current consumption, then the certainty equivalence of the asset under recursive preferences can be expressed as

$$\begin{aligned} U_t &= \{d^\rho + (E\tilde{U}_{t+1}^\alpha)^{\rho/\alpha}\}^{1/\rho} \\ &= \{d^\rho + [\delta U_{t+1}^\alpha]^{\rho/\alpha}\}^{1/\rho} \\ &= [d^\rho + \delta^{\rho/\alpha} U_{t+1}^\rho]^{1/\rho}, \end{aligned}$$

where $(E\tilde{U}_{t+1}^\alpha)^{1/\alpha}$ is the certainty equivalence of the asset's continuation value, $\tilde{U}_{t+1} = U_{t+1}^\alpha > 0$ with prob δ and $\tilde{U}_{t+1} = 0$ with probability $1-\delta$. Imposing $U_t = U_{t+1}$, we can calculate the recursive FV as

$$U_2 = \frac{d}{(1-\delta^{\rho/\alpha})^{1/\rho}}$$

Given that each trading period lasts for only 2.5 minutes, it is reasonable to assume in our experiment that $\rho = 1$, i.e., subjects treat each period as perfect substitutes, and there is no actual discounting from period to period. The recursive FV is therefore

$$U_2 = \frac{d}{1-\delta^{\frac{1}{\alpha}}.} \tag{3}$$

Note that if $\alpha = 1$, i.e., subjects are risk neutral, then $U_2 = d/(1-\delta) = U_0$.

Figure 2 shows the simulated certainty equivalence values, U_0, U_1, and U_2. The left panel presents these certainty equivalences as functions of the risk parameter, α and the right panel presents them as functions of the number of safe choices in the Holt-Laury task. We see from the left panel that for risk averse agents, for whom $\alpha < 1$, the certainty equivalence estimated under the recursive utility specification is less than the one estimated under the expected utility specification, and both of these are less than the certainty equivalence under the risk neutral expected utility specification, i.e., $U_2 < U_1 < U_0 = 50$. But when $\alpha > 1$, this same ordering reverses, with $U_2 > U_1 > U_0 = 50$.

Step 3: Estimation for FV of Asset

After acquiring each individual's certainty equivalence, we can construct each individual's demand and supply for the asset. Let s and m be an individual's endowment

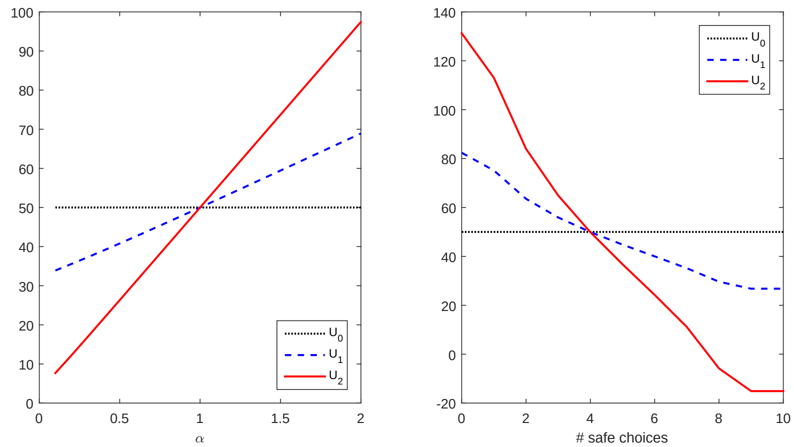


Figure 2: Simulated Certainty Equivalence under Different Utility Specifications

of shares and cash, respectively. The individual's demand for the asset is given by:

$$q^d = \begin{cases} m/p \text{ if } p < U_i \\ 0 \text{ otherwise} \end{cases},$$

and the individual's supply of the asset is given by:

$$q^s = \begin{cases} s \text{ if } p > U_i 1 unexpected'' inmath \\ 0 \text{ otherwise} \end{cases}.$$

where $i = 0{,}1{,}2$ depending on whether the certainty equivalence is derived according to risk neutral expected utility, risk-adjusted expected utility or risk adjusted recursive utility, respectively.

Finally, we construct the aggregate demands, $Q^d(p)$, and supplies, $Q^s(p)$, for each certainty equivalence measure, which are the sum of all the individual demands and supplies. The market FV, V_i, solves $Q^d(V) = Q^s(V)$. Corresponding to the certainty equivalence, we use V_0, V_1, and V_2 to denote the market FV of the asset when agents are risk neutral EU maximizers, risk averse EU maximizers and risk averse RU maximizers, respectively.

4.2 Estimation Results Using the Experimental Data

This subsection presents the estimation results by using our experimental data. We first examine the risk elicitation data from the Holt-Laury task. Out of the 147 participants, 13 (who chose 4 safe choices), are close to risk-neutral, 117 (who chose more than 4

Table 7: Estimated Fundamental Value by Session

Session	FV Risk Neutral	FV Expected Utility	FV Recursive Utility
A1	50	44.8	36.7
A2	50	44.8	36.7
A3	50	40.0	24.3
A4	50	42.7	36.7
A5	50	40.1	30.0
B1	50	44.8	36.7
B2	50	35.2	24.2
B3	50	44.8	36.7
B4	50	40.1	30.0
B5	50	44.8	36.7
C1	50	44.8	36.7
C2	50	44.8	36.7
C3	50	44.9	36.8
C4	50	40.1	30.0
C5	50	40.1	24.3

safe choices) are risk-averse and 17 (who chose 0-3 safe choices) are risk loving. Figure 3 below shows the histogram of the number of safe choices. Consistent with previous findings in the literature, around 27% of subjects had multiple switch points in the Holt-Laury task. For those cases, we count the number of times that each individual chose option A and we use that as an approximation for of n_A, as if the subject has chosen Option A for the first n_A tasks and Option B for the remainder.

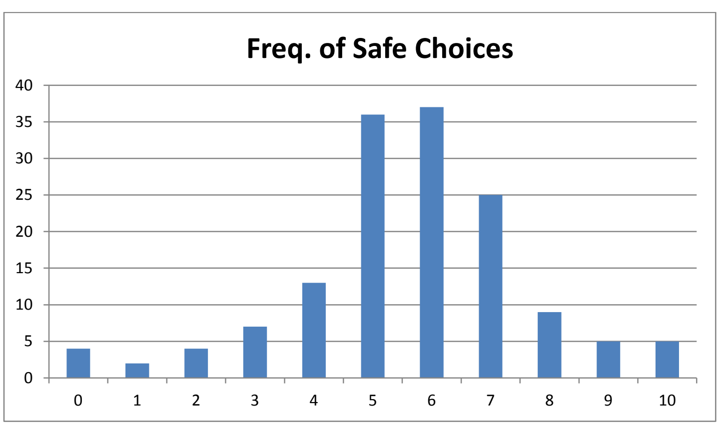


Figure 3: Distribution of the Number of Safe Choices (Lottery A) in Holt-Laury Task

Using the approach discussed in the last section, we estimated the risk-adjusted

Table 8: p-values from Wilcoxon Signed Rank Tests

Treatment	Average Price in Market 2			Average Price in Market 3		
	FV-RN	FV-EU	FV-RU	FV-RN	FV-EU	FV-RU
A	0.043	0.079	0.225	0.043	0.043	0.138
B	0.500	0.043	0.043	0.686	0.043	0.043
C	0.500	0.079	0.043	0.686	0.043	0.043
No. of Obs.	5	5	5	5	5	5

FV under expected utility and recursive preference, respectively, for each session. The estimated FVs are presented in Table 7. Given that most of subjects are risk averse, the risk-adjusted FV under expected utility is always lower than the risk-neutral FV of 50, being in a relatively small range between 35.2 and 44.9. The risk-adjusted FV under recursive preference is always lower than the estimated FV under expected utility, being in a range between 24.3 and 36.8. This result is consistent with our simulated results as shown in Figure 2. Finally, we do not find any significant difference in the estimated FV between any two treatments given the assumption for the utility specification, showing that subjects' risk preference parameter is similarly distributed across treatments.

In order to test Hypotheses 2 and 3, we compare the average price in markets 2 and 3 of each treatment with the risk-neutral FV, the risk adjusted FV under expected utility and the risk-adjusted FV under recursive utility, respectively, using two-tailed, Wilcoxon signed rank tests. These tests inform us as to whether the observed market prices are significantly different from the three different FV predictions. Table 8 provides the p-values from these tests. Consistent with the patterns displayed in Figure 1, the average price in markets 2 and 3 of treatment A (BRT) *are* significantly lower than both the risk-neutral FV and the risk-adjusted FV under expected utility ($p < 0.1$ or $p < 0.05$). However, the average price in markets 2 and 3 of treatment A are *not* significantly different from the risk-adjusted FV estimated under the recursive utility specification ($p > 0.1$). By contrast, in treatments B and C, in both markets 2 and 3, the average price is not significantly different from the risk-neutral FV ($p > 0.5$) but is significantly greater than both of the risk-adjusted FVs under expected utility or recursive utility, respectively ($p < 0.1$ or $p < 0.05$).

Finding 2 *Prices in markets 2 and 3 of treatment A (BRT) suggest significant* under-pricing *of the asset compared with the risk-neutral FV or the risk-adjusted FV under expected utility. However, these same prices are not significantly different from the risk-adjusted FV under recursive utility. Prices in markets 2 and 3 of treatment B (D-R) and C (BRT-R) exhibit significant* overpricing *compared to both of the risk-adjusted FV predictions but are not significantly different from the risk-neutral FV prediction.*

What accounts for the ability of the risk-adjusted FV under recursive preferences to explain the very low prices observed in markets 2 and 3 of treatment A but not the prices in the later markets of treatments B and C? Clearly, the difference must lie in the timing with which dividend payments are received, as this is the main difference between treatment A and treatments B and C. If agents have recursive, Epstein-Zin preferences and are risk averse, (i.e., $\alpha < 1$), then they prefer earlier to later resolution of the uncertainty regarding future dividend realizations (consumption). If dividend realizations are coincident with trade in the asset as in treatment A, this preference for earlier uncertainty resolution will manifest itself in a lower certainty equivalence value for the asset which implies that the asset should trade at prices lower than the FV value under expected utility, with or without an adjustment for risk. By contrast, if dividend realizations cannot occur until the trading phase is complete as in treatments B and C, then preferences to resolve uncertainty earlier cannot actively affect the pricing of the asset; in that case, subjects effectively act as though they were risk neutral expected utility maximizers, pricing the asset very close to the risk neutral FV. It is *not* the case that subjects' preferences differ across our three treatments; we think that in general, a recursive specification may always be operative. However, the ability to resolve uncertainty early (e.g., by selling off the asset) in a manner that immediately affects the price of the asset is not possible in treatments B and C, and thus this feature of subjects' preferences is simply not operational in those two treatments.

5 Conclusion

Most asset pricing models employ infinite horizons, as the duration of assets, such as equities, is typically unknown. By contrast, many experimental asset pricing models employ finite horizons, making it difficult to test the predictions of infinite horizon models. While infinite horizons cannot be studied in the laboratory, indefinite horizon environments, where the asset continues to yield a flow of payoffs with a known constant probability, *can* be implemented in the laboratory. If agents are risk neutral, expected utility maximizers, the probability that the asset continues to yield payoffs plays the role of the discount factor and the price predictions under the infinite horizon economy extend to the indefinitely repeated environment.

In this paper, we study the empirical relevance of the indefinite horizon model for understanding the predictions of infinite horizon asset pricing models. In our baseline treatment A, which implements a random termination design, we find that experienced subjects consistently price the asset *below* the level predicted by infinite horizon models under the assumption of risk neutral expected utility maximization. We consider whether this outcome is due to subjects' risk preferences by eliciting subjects' tolerance for risk, and we further consider in two additional treatments, whether the timing of dividend payments or uncertainty about the trading horizon matters for the prices observed. We find that uncertainty about the trading horizon cannot explain the pricing behavior in our baseline treatment, but that the timing with which dividend payments are received does matter; if the sequence of dividends is received after (separately from) the trading phase, the asset is priced according the risk neutral expected utility prediction. Since the dividend sequence is the same across all three treatments, but pricing is quite different, risk preferences *alone* cannot explain the different pricing outcomes that we observe. Rather, we suggest that the difference can be explained by replacing the expected utility assumption with a non-expected utility, recursive preference specification, which differentiates between current dividend realizations and the future certainty equivalence value of the asset.

For moderately risk averse subjects (as we have in our experiment and which are typically found in asset pricing experiments), this recursive specification for utility can rationalize the lower prices that we observe in our baseline treatment A, where uncertainty about dividend realizations coexists with uncertainty about the trading horizon. Risk averse subjects with recursive, Epstein-Zin preferences can resolve uncertainty about the future value of the asset early, by selling off their asset holdings, which affects the market price of the asset. By contrast, in our other two treatments B and C, where dividend uncertainty is separate from horizon uncertainty, there is no means for subjects to resolve uncertainty about future consumption (dividend) flows any earlier than the end of the trading phase, and thus expected utility and recursive utility specifications effectively coincide in predicting the higher prices that we observe in those two treatments.

An important take-away from our study for experimental economists is that the miss-pricing behavior found in experimental asset markets may be quite different under random termination, as compared with the more typically studied finite horizon case, which follows the lead of Smith et al. (1988). Rather than finding over-pricing relative to the risk neutral, FV ("bubbles") among inexperienced subjects as in the Smith et al. literature, we find under-pricing relative to the risk neutral benchmark in our baseline random termination treatment with experienced subjects. Further, we can rationalize this departure from fundamentals using elicited risk attitudes. An important take-away for finance researchers is that we have provided some empirical support for the widely used Epstein-Zin recursive preference specification in the context of asset markets where subjects both trade and receive dividends from their asset holdings.

References

[1] Asparouhova, E., P. Bossaerts, N. Roy, and W. Zame (2016), ”Lucas in the Laboratory,” Journal of Finance 71(6), pp. 2727-2779.

[2] Ball, S.B. and C.A. Holt (1998), “Classroom Games: Speculation and Bubbles in an Asset Market,” Journal of Economic Perspectives, Volume 12(1), pp. 207-218.

[3] Berry, J., G. Fischer and R. Guiteras (2012), “Eliciting and Utilizing Willingness to Pay: Evidence from Field Trials in Northern Ghana,” Working paper.

[4] Becker, G., M. DeGroot, and J. Marschak (1964), “Measuring utility by a single-response sequential method,” Behavioral Science, 9, 226–236.

[5] Bohm, P., J. Linden, and J. Sonnegård (1997), “Eliciting Reservation Prices: Becker-DeGroot-Marschak Mechanisms vs. Markets,” Economic Journal, 107 (443), 1079–1089.

[6] Bostian, A.J. and C.A. Holt. (2009), “Price bubbles with discounting: a web-based classroom experiment,” *Journal of Economic Education* 40, 27-37.

[7] Campbell, J.Y. (2018), *Financial Decisions and Markets: A Course in Asset Pricing*, Princeton: Princeton University Press.

[8] Camerer, C.F. and K. Weigelt (1993), “Convergence in Experimental Double Auctions for Stochastically Lived Assets,” in: The Double Auction Market: Institutions, Theories, and Evidence, Proceedings Volume in the Santa Fe Institute Studies in the Sciences of Complexity (14). Addison-Wesley, Reading, MA, pp. 355-396.

[9] Crockett, S., J. Duffy and Y. Izhakian (2017), “An Experimental Test of the Lucas Asset Pricing Model” Working paper, UC Irvine.

[10] Fenig, G., M. Mileva, and L. Peterson (2014), “Asset trading and monetary policy in production economies,” Working paper, Simon Fraser University.

[11] Fischbacher, U. (2007), “z-Tree: Zurich toolbox for ready-made economic experiments,” Experimental Economics 10(2), 171-178.

[12] Fréchette G. and S. Yuksel (2017) “Infinitely Repeated Games in the Laboratory: Four Perspectives on Discounting and Random Termination,” Experimental Economics 20, 279-308.

[13] Greiner, B. (2004), "An Online Recruitment System for Economic Experiments." Forschung und wissenschaftliches Rechnen GWDG Bericht 63. edited by K. Kremer and V. Macho. Göttingen, Gesellschaft für Wissenschaftliche Datenverarbeitung, pp. 79–93.

[14] Giusti, G., J.H. Jiang and Y. Xu (2014), "Interest on Cash, Fundamental Value Process, and Bubble Formation on Experimental Asset Markets," Manuscript.

[15] Hens, T. and S.C. Steude (2009), "The Leverage Effect Without Leverage," Finance Research Letters, Volume 6, pp. 83-94.

[16] Holt, C.A., and S.K. Laury (2002), "Risk Aversion and Incentive Effects." American Economic Review, 92(5): 1644-1655.

[17] Karni, E., and Z. Safra (1987). "Preference Reversal' and the Observability of Preferences by Experimental Methods." Econometrica 55(3): 675-685.

[18] Kirchler, M., J. Huber and T. Stöckl (2012), "Thar she bursts–Reducing confusion reduces bubbles," American Economic Review 102, 865-83.

[19] Mazar, N., B. Koszegi, and D. Ariely (2010), "Price-Sensitive Preferences," SSRN eLibrary.

[20] Normann H-T. and B. Wallace (2012), "The impact of the termination rule on cooperation in a prisoner's dilemma experiment," International Journal of Game Theory, 41, 707-718.

[21] Noussair, C.N., S. Robin, and B. Ruffieux (2001), "Price bubbles in laboratory asset markets with constant fundamental values," Experimental Economics, 4, 87-105.

[22] Noussair, C.N. and S. Tucker (2013), "Experimental Research on Asset Pricing," *Journal of Economic Surveys*, 27: 554–569. doi:10.1111/joes.12019

[23] Palan, S. (2009), Bubbles and crashes in experimental asset markets. Vol. 626. Springer Science & Business Media.

[24] Palan, S. (2013), "A Review of Bubbles and Crashes in Experimental Asset Markets," *Journal of Economic Surveys*, 27: 570–588. doi:10.1111/joes.12023.

[25] Roth, A.E., and Murnighan, J.K. (1978), "Equilibrium Behavior and Repeated Play of the Prisoners' Dilemma," Journal of Mathematical Psychology 17, 189-198.

[26] Sherstyuk, K., N. Tarui, and T. Saijo (2013), "Payment schemes in infinite-horizon experimental games," Experimental Economics, 16, 125–153.

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

[28] Stöckl, T., J. Huber, and M. Kirchler (2010). "Bubble measures in experimental asset markets." Experimental Economics, 13: 284–298.

[29] Weber, M., J. Duffy and A. Schram (2017), "An Experimental Study of Bond Market Pricing," forthcoming, Journal of Finance.

Appendix A: Instructions

Welcome

Welcome to this experiment on economic-decision making. You will receive $5 for showing up in the session. Your additional earnings will depend on your own decisions, other participants' decisions and some random events as explained below. Please read the instructions carefully as they explain how you earn money from the decisions that you make. Please do not talk with other participants and silence your mobile device during the experiment.

Part I Instructions (Holt-Laury Task)

Your screen shows ten decision Tasks listed below. Each Task is a paired choice between "Option A" and "Option B." Each Option is a lottery of two possible realizations with different probabilities. For Option A, the two realizations are $4 and $3.2. For Option B, the two realizations are $7.7 and $0.2. For each Task, choose which lottery option, A or B, you would like to play. As you move down the table, the chances of the higher payoff for each option increase. In fact, for Task 10 in the bottom row, each option pays the higher payoff for sure, so your choice here is between $4 and $7.7.

Task	Option A Two possible realizations: $4.0 and $3.2		Option B Two possible realizations: $7.7 and $0.2	
1	**1/10** of $4.0.	**9/10** of $3.2	**1/10** of $7.7.	**9/10** of $0.2
2	**2/10** of $4.0.	**8/10** of $3.2	**2/10** of $7.7.	**8/10** of $0.2
3	**3/10** of $4.0.	**7/10** of $3.2	**3/10** of $7.7.	**7/10** of $0.2
4	**4/10** of $4.0.	**6/10** of $3.2	**4/10** of $7.7.	**6/10** of $0.2
5	**5/10** of $4.0.	**5/10** of $3.2	**5/10** of $7.7.	**5/10** of $0.2
6	**6/10** of $4.0.	**4/10** of $3.2	**6/10** of $7.7.	**4/10** of $0.2
7	**7/10** of $4.0.	**3/10** of $3.2	**7/10** of $7.7.	**3/10** of $0.2
8	**8/10** of $4.0.	**2/10** of $3.2	**8/10** of $7.7.	**2/10** of $0.2
9	**9/10** of $4.0.	**1/10** of $3.2	**9/10** of $7.7.	**1/10** of $0.2
10	**10/10** of $4.0.	**0/10** of $3.2	**10/10** of $7.7.	**0/10** of $0.2

Although you make 10 decisions, only one of them will be used in the end to determine your earnings. However, you will not know in advance which decision will be used. Each decision has an equal chance of being used in the end.

After you have made all of your choices, the computer will draw two numbers randomly between 1 and 10. The **first draw** is used to select one of the ten decisions to be used. For example, if the first draw is 4, then Task 4 is selected to determine your earnings. The **second draw** determines what your payoff is for the option you chose, A or B, for the particular decision selected. Continue to suppose that Task 4 is selected, and you chose Option A for Task 4. Your earnings will be \$4 if the second draw is between 1 and 4 and \$3.2 if the second draw is between 5 and 10. Alternatively, if you chose Option B for Task 4, then your earnings will be \$7.7 if the second draw is between 1 and 4 and \$0.2 if the second draw is between 5 and 10.

To summarize, you will make ten choices: for each decision row you will have to choose between Option A and Option B. You may choose A for some decision rows and B for other rows, and you may change your decisions and make them in any order. When you are finished, the computer will draw two random numbers. The first random number determines which of the ten tasks will be used. The second number determines your money earnings for the option you chose for that task.

Part II Instructions (for Treatment A)

General Information

This part of the experiment consists of several asset markets, in which 10 participants (including yourself) trade stocks of a fictitious company.

Market Description

At the beginning of each market, half of the participants are endowed with 20 shares and 3,000 units of cash measured in experimental money (EM), and the other half participants are endowed with 60 shares and 1,000 EM of cash.

Each market consists of an indefinite number of rounds, which will be explained later. Each round lasts for 2 minutes, during which you can sell and/or buy shares. At the end of each round, for each share you own, you receive a dividend of 5 EM. Dividends are collected in a separate account: they will count toward your earnings, but cannot be used to buy shares. If the market continues, then your shares and cash, as well as the dividend account balance, will be carried over to the next trading round.

Length of A market

Each market consists of an indefinite number of rounds. The length of the market is determined by the following rules. At the end of each round, the computer will draw a random number between 1 and 100 to determine whether the market will continue or not. Specifically, if the computer draws a random number between 1 and 90 (inclusively), the market will continue; otherwise, if the random number is between 91 and

100 (inclusively), then the market ends. Therefore, after each round, the market will continue with a chance of 90%, and end with a chance of 10%.

However, in the first 10 rounds, called a **block**, you will trade without being informed of the realization of the random draws, even if a random number greater than 90 has been drawn. At the end of round 10, you will be shown the realization of the random draws for all 10 rounds in the block and learn whether or not the market has actually ended within the block. If the market has ended within the block of the first 10 rounds, the **final round** of the market will be the first round in which the realization of the random draw exceeds 90, and your decisions after the final round will be ignored. If the market has not ended within the block, the market continues to round 11. From round 11 on, you will be informed of the realization of the random draw at the end of each round. The **final round** of the market is reached once the random draw exceeds 90.

Trading Interface

In each trading round, you will trade using an interface similar to figure 1 (you will have the opportunity to practice with the interface for 3 minutes before the formal experiment starts).

Trade is organized as a double auction: all traders can submit offers to buy and offers to sell, and accept others' offers. Each offer has two parts, the price and quantity. The price quote can be any integer from 1 to a maximum of 500 EM. The quantity is the number of shares you intend to trade at this price. You must have enough cash to support your offer to buy and enough shares to support your offer to sell. Otherwise, you will receive a reminder and your offer will not go through. All offers are listed in the order book. Your own offers are in blue, and other people's offers are in black. The offers are ordered according to prices, with the best offer at the top. For your convenience, the best offer posted by others is highlighted. The following rules will apply when you post or accept offers to buy and offers to sell.

- When you post an offer to buy, the price has to be lower than the lowest offer to sell in the order book. (Otherwise, you can simply accept the lowest offer to sell.)
- When you post an offer to sell, the price has to be higher than the highest offer to buy in the order book. (Otherwise, you can simply accept the highest offer to buy.)
- When you accept an offer by others, the offer has to be the best offer available. That is, when you accept an offer to buy, it has to be the highest offer to buy. When you accept an offer to sell, it has to be the lowest offer to sell.

- You cannot accept your own offers.

Trade is realized whenever an offer is accepted. If you would like to accept the highlighted offer, enter a number in the field "quantity" located at the bottom of the screen, then click on the "Sell" or "Buy" button.

Your share and cash inventories will be updated to reflect your trading activities. If you buy shares, your shares increase by the quantity traded, and your cash is diminished by the amount = price*quantity. The reverse happens if you sell shares.

Number of Markets

After a market ends, depending on the time remaining, the experimenter will inform you whether or not a new market will start. If yes, you repeat the same procedure: your endowment of shares and cash will be **reset**, and the market will last for an indefinite number of rounds as described above. If there is no new market open, you will be informed of your total earnings in this part of the experiment.

Calculate Your Earnings

Your earnings for a market is calculated as

Market earnings = cash at the end of the **final round**
+ balance in the dividend account at the end of the **final round**

Your total earnings in this part of the experiment are the summation of earnings from all markets, which are converted into Canadian dollars at a rate of 500 EM = $1.

Review of Important Information

- In any trading round, the current market may continue with probability 0.9 and ends with probability 0.1. Therefore, on average the length of a market is 10 rounds.
- If you decide to hold on to a share without ever selling it, on average, you will receive 10x5=50 EM in terms of dividend payment.
- Your earnings in a market will be determined by your cash holdings and dividends in the final round of the market; the final round could be within the block or outside of the block.
- Within the block of the first 10 periods of a market, you will not be informed of whether the market has ended or not.
- Each round in a market lasts for 2 minutes (120 seconds).

Part II Instructions

(Treatment B, different parts from Treatment A)

Market Description

At the beginning of each market, half of the participants are endowed with 20 shares and 3,000 units of cash measured in experimental money (EM), and the other half participants are endowed with 60 shares and 1,000 EM of cash.

Each market consists of two stages: a **trading stage** and a **dividend realization stage**.

The trading stage of each market consists of 10 trading rounds. Each round lasts for 2 minutes, during which you can sell and/or buy shares using an interface described later. At the end of each trading round and before the trading stage ends, your shares and cash will be carried over to the next trading round.

After the trading stage finishes, the dividend realization stage starts, where you collect dividends for the shares you own at the end of the trading stage. All shares receive an indefinite number of 5-EM dividend payments; the number of payments is determined as follows. You receive one dividend payment for sure. After each dividend payment, the computer will draw a random number between 1 and 100: if the number is greater than 90, then there will be no further dividend payments; otherwise, there will be a new dividend payment followed by another random draw. The number of dividend payments can potentially run from 1 to infinity. On average, you will receive 10 dividend payments, or 50 EM, for each share you own at the end of the trading stage. In the dividend payment stage, you no longer make decisions: the computer will decide how many dividends you receive, and you simply watch dividends accrue.

Number of Markets

After a market ends, depending on the time remaining, the experimenter will inform you whether or not a new market will start. If yes, you repeat the same procedure: your endowment of shares and cash will be **reset**, and the market will consist of a trading stage and a dividend realization stage as described above. If there is no new market open, you will be informed of your total earnings in this part of the experiment.

Calculate Your Earnings

Your earnings (in EM) in each market are the sum of two parts:

(1) cash at the end of the trading stage

(2) the number of shares at the end of the trading stage *the number of dividend payments * 5

Your total earnings in this part of the experiment are the summation of earnings from all markets, which will be converted into Canadian dollars at a rate of 500 EM = \$1.

Review of Important Information

- There will be several markets, each consisting of a trading stage and a dividend realization stage. You start with the same endowment of cash and shares in each new market.

- The trading stage consists of 10 trading rounds. Each trading round lasts for 2 minutes.

- In each market, during the trading stage, your share and cash holdings at the end of a trading round will be carried over to the next trading round.

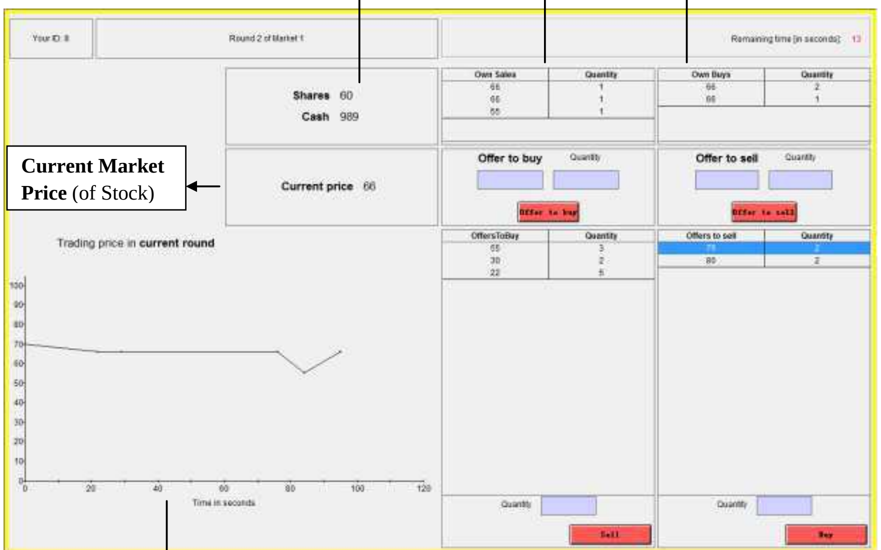
- In the dividend realization stage, you collect dividends for the shares you own at the end of the trading stage for an indefinite number of times. After each dividend payment, there will be more dividends with a chance of 90%, and no further dividends with a chance of 10%. On average, you will receive 10 dividend payments, or 50 EM, for each share you own at the end of the trading stage.

- Your earnings in a market will be determined by your cash holdings at the end of the trading stage plus the total dividends received during the dividend realization stage.

Distributed Figure for Trading Interface

Information about current Stock and Money

Summary of Own Sales and Purchases in the current round (Including Price and Quantity)



Offer to buy: you have to enter Quantity and Price. Trade does not take place until another participant accepts your offer!!!

Offer to sell: analogue to Offer to buy – see above.

List of Offers to buy: from all traders – your own Offer to buy are written in blue. The highlighted offer is always the best, i.e., it yields the highest revenues for the seller.

List of Offers to sell: from all traders – your own Offer to sell are written in blue. The highlighted offer is always the best, i.e., it is the cheapest one for the buyer.

Current Market Price (of Stock)

Price-Chart of current

Sell : You sell the entered Quantity, given the highlighted Price with the blue background. If you enter a higher amount than offered in the blue box, you sell the offered Quantity at most.

BUY: You buy the entered Quantity, given the highlighted Price with the blue background. If you enter a higher amount than offered in the blue box, you buy the offered Quantity at most.

Appendix B: Additional Graphs and Tables

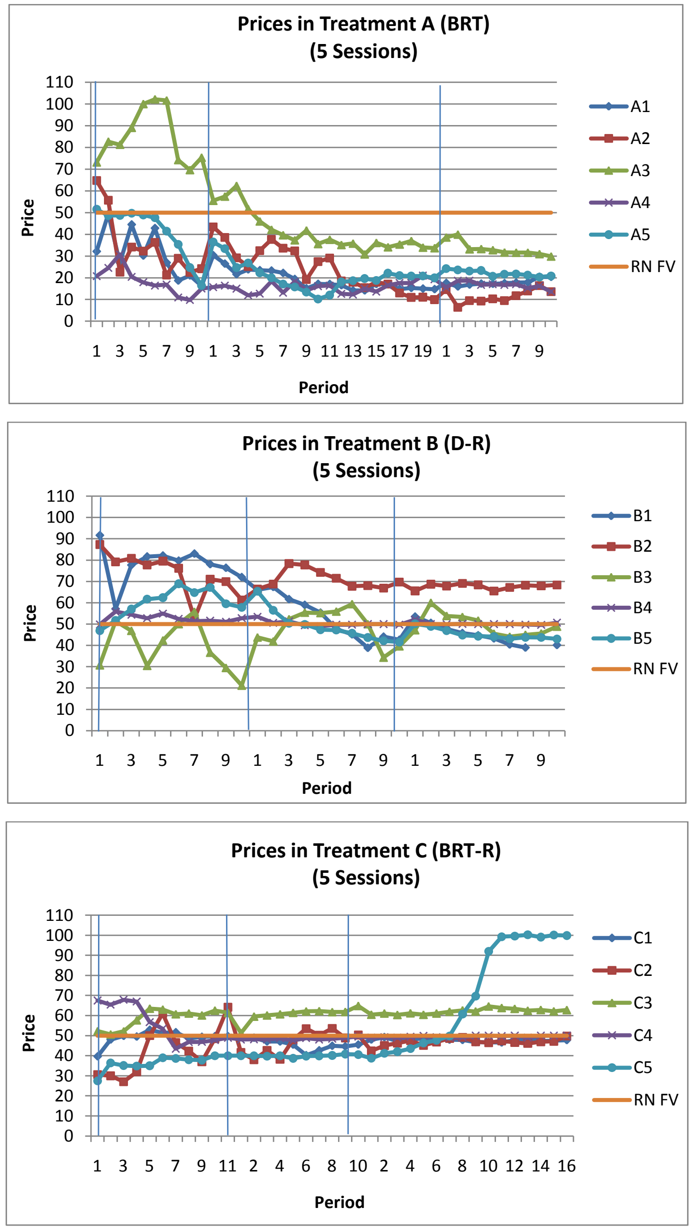


Figure 4: Prices over Periods in Each Session, Grouped by Treatment