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Experimental Asset Markets with An Indefinite Horizon *

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Abstract

We study the trade of indefinitely-lived assets in experimental markets. The traded prices of these assets are on average more than 40% below the risk-neutral fundamental value under the expected utility assumption. We examine the effects of three interrelated factors for the traded price, payoff uncertainty about the asset's dividend payments, horizon uncertainty about the duration of trade, and the expected utility assumption. Our results suggest that horizon uncertainty does not significantly affect the traded price. Incorporating risk aversion into non-expected utility models with recursive preferences and probability weighting can rationalize the low prices observed in our indefinite-horizon asset markets.

Keywords: Asset Pricing, Behavioral Finance, Experiments, Indefinite Horizon, Random Termination, Risk and Uncertainty, Expected Utility, Epstein-Zin Recursive Preferences, Probability Weighting

JEL Codes: C91, C92, 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 (FV) of the asset, as measured by the present value of the dividend flow, decreases over time, as in the canonical experimental design of Smith et al. (1988).

In this paper, we study the trade of assets in an experimental market with an indefinite horizon. An asset can be traded in each period that it exists, but there is a certain probability the asset may cease to exist, for instance, due to bankruptcy. At the end of each trading period, the asset pays a positive dividend per unit to the asset holder. The asset exists with certainty and pays a dividend in the first period. Thereafter, with a constant probability δ, the asset continues to exist in the the next period, the asset holdings of participants carry over into that next period and trade in the asset occurs in that next period. With probability $1-\delta$, the asset ceases to exist; trade in the asset is suspended and the asset has a zero continuation value. This indefinite-horizon or random-termination design, initially proposed by Roth and Murnighan (1978), is the most commonly used approach to implementing infinite horizons with discounting in the laboratory. It can be shown that, if agents are risk-neutral expected utility maximizers, then a sequence of market trading periods subject to such random termination is isomorphic to an infinitely repeated horizon with a period discount factor of δ.[1]

Unlike definitely-lived assets, the FV of the indefinitely-lived asset is constant (instead of decreasing) over time.[2] The stationarity associated with indefinite horizons may be a more natural setting for understanding asset pricing decisions. In addition, the indefinite-horizon design is also useful for studying environments with bankruptcy or default risk where the

[1]Another method of implementing infinite horizons 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 Kuhn, 2011).

[2]While it is possible to generate constant values for the FV in finite-horizon settings, this is typically done by having some known constant terminal period payoff value for 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 the indefinite-horizon design, the value of the asset is constant over time with positive dividend payments and zero terminal value.

value of the asset becomes zero with a certain probability.

Besides serving as a more natural setting for understanding asset pricing decisions, experimental asset markets with an indefinite horizon implemented by random termination are interesting to study for several additional reasons.

First, indefinitely-lived assets involve two types of risks: payoff uncertainty and trading horizon uncertainty. Payoff uncertainty refers to uncertainty about an asset's dividend realizations (or the asset's rate of return) over the period of time the asset is held. Specifically, the asset can be viewed as a lottery, as described in Table 1. The lottery involves an infinite number of states, $t = 1, 2, ..., \infty$. State t is the event that the game lasts until period t and the asset yields a payoff of td, which occurs with probability $\delta^{t-1}(1-\delta)$. Trading horizon uncertainty refers to how long one can expect to trade the asset. While payoff uncertainty affects the holding value of the asset, uncertainty about the trading horizon may affect traders' strategy, especially for speculators. If the horizon over which the asset has value was perfectly known, then speculators might time their asset purchases and sales with this information in mind. By contrast, in an indefinite horizon, timing such speculation is more difficult. Thus, an indefinite horizon for asset markets might depress prices and the volume of trade relative to known, finite horizon markets. Both types of risks (payoff and horizon) can affect the pricing and trade of the asset, and it is of interest to distinguish and quantitatively measure the effect of these two types of uncertainty associated with random termination.

Second, given the payoff risk involved, it is not clear whether the FV calculated under the assumption of risk-neutral expected utility (FV-RN hereafter), the most often used benchmark for the analysis of finite-horizon experimental asset markets and from which various mis-pricing measures have been derived, continues to be appropriate in the context of indefinite-horizon asset markets. Therefore, we propose a procedure to calculate the market FV that incorporates traders' risk attitudes and possible deviations from expected utility theory.

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

We find that in the indefinite-horizon asset market implemented by random termination (our baseline treatment), traded prices are on average more than 40% below FV-RN, and decrease further as traders gain experience. The result is astounding given that the majority of studies of experimental asset markets find asset pricing bubbles. To identify the reasons for the low traded prices (relative to FV-RN) in the indefinite-horizon asset market, we design two auxiliary treatments to isolate several confounding and interrelated factors that may affect the trading and pricing of assets: (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 expected utility maximizers.

To study the effect of horizon uncertainty, we design an auxiliary treatment with two separate stages. Stage one consists of a fixed number of trading periods and subjects do not observe dividend realizations while they trade. Stage two reveals dividend realizations and subjects do not trade in this stage. This auxiliary treatment and the baseline treatment share the same distribution of the number of dividends to be received, characterized by Table 1. Under the assumption of expected utility maximizers, the auxiliary treatment and the baseline treatment share the same risk-adjusted FV and the difference between these two treatments can be attributed to horizon uncertainty.

However, if subjects are not expected utility maximizers (for example, if they have recursive preferences), then the timing of dividend realizations (or the temporal resolution of payoff uncertainties) may affect their valuation of the asset too. To derive a clear inference about the effect of horizon uncertainty and to investigate the effect of the temporal resolution of payoff uncertainty, we run a second auxiliary treatment, which combines the uncertain trading horizon in the baseline treatment, and the two-stage design of the first auxiliary treatment. Comparing the two auxiliary treatments allows us to identify the effect of horizon uncertainty (while fixing the timing of dividend realizations). Comparing the baseline and the second auxiliary treatment allows us to identify the effect of the timing of dividend realizations (or temporal resolution of payoff uncertainty).

The traded prices in the two auxiliary treatments are much closer to FV-RN, and are not significantly different from each other. Our experimental results therefore suggest that horizon uncertainty does not have a significant effect on the traded price, while the timing of dividend realizations does. In the presence of payoff uncertainty, the timing of dividend realizations affects the temporal resolution of the payoff uncertainty. In the baseline treatment, payoff uncertainty is resolved gradually over time (in the trading stage), while in the two auxiliary treatments, the uncertainty is resolved at a single point of time (after trading ends). The importance of the timing of dividend realizations seems to be consistent with the implications of recursive preferences (Kreps and Porteus, 1979). In view of this, we incorporate Epstein and Zin (1989) recursive preferences into the calculation of risk-adjusted FV, and we find that this specification can account for a significant part of the low traded price observed in the baseline treatment. In addition, given that in the baseline treatment, the market ends and the asset becomes worthless with a small probability, probability weighting could potentially affect the traded price as well. We find the risk-adjusted FV that incorporates both of these departures from expected utility theory can rationalize the low prices observed in our indefinite-horizon asset markets in the baseline treatment. At the same time, this composite specification can also account for the traded price in the two auxiliary treatments.

There is a large literature involving experimental asset markets with a known, finite horizons beginning with Smith et al. (1988). Surveys of this literature are found in Palan (2009, 2013) 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 (it is either 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 (2015), Fenig et al.(2018), Asparouhova et al. (2016), Crockett et al. (2019) and Weber et al. (2018). Camerer and Weigelt (1993), Ball and Holt (1998), Kose (2015) study environments where subjects only engage in asset-trading activities. Hens and Steude (2009), Fenig et al. (2018), Asparouhova et al. (2016), Weber et al. (2018) and Crockett et al. (2019) consider experimental economies where subjects also participate in other activities such as consumption, employment, production decisions, or IPOs of new assets. However, none of these studies provides a rigorous comparison between indefinite-horizon and definite-horizon asset markets. Neither did they quantitatively evaluate the effects of payoff uncertainty and horizon uncertainty. Another (methodological) contribution of our study is to construct a procedure to calculate a new relevant empirical benchmark, the FV that incorporates traders' risk attitudes and possible deviations from expected utility theory.

Related to our work, some recent papers examine methodologically the effect of random termination in experiments in the context of 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 examine the effect of random termination in experimental asset markets. Experimental asset markets have several distinct features as compared to repeated games. First, heterogeneous risk attitudes, combined with random termination, can create incentives for trade in such assets in settings where the dividend process is common knowledge such as in Smith et al. (1988). Second, in most repeated games, subjects make discrete choices and risk considerations may or may not result in a change/switch in choices. In the asset-trading experiment, traded price and quantity are continuous variables, and risk considerations can be captured incrementally. Third, in repeated games, subjects typically have *no choice* but to participate in the game. Differently, in many asset market experiments, subjects can *choose* whether to participate in the asset market or not.[3] Specifically, in most 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 subject ceases to engage in further trading after the first period, 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. As a result, the risk induced by random termination may play a larger role in influencing individuals' behavior in *asset market* experiments as compared with repeated game settings.

The remainder of the paper is organized as follows. Section 2 presents the experimental design and procedures. Sections 3 and 4 report on the experimental results across treatments and provide a comparison of the estimated market FVs under different assumptions. Section 5 concludes.

[3] An exception is the literature on "learning-to-forecast" asset pricing experiments, where subjects are typically required to participate in every period via the elicitation of their forecast for future asset prices. See, e.g., Hommes et al. (2005,2008).

2 Experimental Design and Procedure

Our experimental design consists of three treatments which have the following features in common. In each treatment, subjects participate in an experimental asset market that involves trading an asset that has a constant FV-RN that is always equal to 50 EM (experimental money). Each session of a treatment consists of three consecutive markets and approximately 10 participants. These participants have no prior experience in any treatment of our experiment. At the beginning of each of the three markets, one-half of participants are endowed with 20 shares of the asset and 3,000 EM units, while the other half are endowed with 60 shares of the asset and 1,000 EM units; at the risk-neutral FV of 50 EM, the values of 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).[4]

We designed our experiment taking into consideration the results from previous studies on experimental asset markets. First, Kirchler et al. (2012) have shown that the trend of the FV process (i.e., whether it is constant, increasing, or decreasing over time) has a large impact on the formation of non-rational asset price "bubbles" (which we define as sustained departures from the FV). Giusti et al. (2014) show that in addition to the trend of the FV process, the sign of the expected dividend payment (positive, zero, or negative) also affects traded prices. Our experimental setting, which features a constant FV and a positive dividend payment in each period, serves as a more natural setting for understanding asset pricing. Second, 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 is held constant and dividend payments cannot be used to buy shares, so the C/A ratio is constant as well (more details below) so as to minimize the effects of variations in the C/A ratio on market outcomes. Finally, 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. (1988) accounts for our design of confronting subjects with three identical and consecutive markets to allow for subject learning and to examine the possibility of price convergence in indefinite-horizon

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

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. Toward that goal, we design three different experimental treatments.

Our baseline treatment, treatment A, implements the three indefinite-horizon asset markets using a modified version of the block random termination scheme proposed by Frechette and Yuksel (2017) (as discussed in further details below). We also label this treatment as "BRT," standing for block random termination. In this treatment, following the completion of each trading period, one dividend of $d = 5$ EM 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 C/A ratio. 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; if it does not continue, then each trader's asset position is set to 0. This process is repeated three times, so that we have three indefinite-horizon "markets" for each session of treatment A (or BRT).

Note that the indefinite-horizon asset market involves both payoff uncertainty and uncertainty about the duration of the trading horizon. There is payoff uncertainty regarding dividend payments. There is also trading horizon uncertainty regarding how long the asset can be traded. To study the effect of trading horizon uncertainty and payoff uncertainty, we design two auxiliary treatments. In the first auxiliary treatment, treatment B, each of the three asset markets is divided up into 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)). In the following, we also label treatment B as treatment D-2, with "D" for definite horizon, and "2" for two phases. 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 only to budget and (asset) supply 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

Table 2: Summary of Treatments

Treatment	Trading Horizon	Uncertain FV_t?	Dividends Realized after Trading Phase?
A (BRT)	Random	Yes	No
B (D-2)	Definite	Yes	Yes
C (BRT-2)	Random	Yes	Yes

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

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 two-phase process is repeated three times so that we have three markets for each session of Treatment B. Note that under the assumption of expected utility maximizers, treatment D-2 and the baseline treatment share the same risk-adjusted FV and so any differences between these two treatments can be attributed to horizon uncertainty.

However, if subjects are not expected utility maximizers (for example, if they have recursive preferences), then the timing of dividend realizations (or the temporal resolution of payoff uncertainty) may affect their valuation of the asset. To make a cleaner inference about the effect of trading horizon uncertainty, as well as to investigate the effect of the temporal resolution of payoff uncertainty, we run a second auxiliary treatment, treatment C. This treatment combines the uncertain trading horizon of the baseline treatment with the two-stage design of treatment D-2, while keeping the random sequence for dividend payments identical to the first two treatments. We label this treatment "BRT-2" to reflect the random termination of the trading horizon and the two-stage design. Again, for each session of treatment BRT-2, we have results from three asset markets. Comparing the two auxiliary treatments, D-2 and BRT-2 allows us to identify the effect of horizon uncertainty while keeping the timing of dividend realizations the same. Comparing the baseline treatment with the second auxiliary treatment, BRT and BRT-2, allows us to identify the effect of the timing of dividend payments, or the temporal resolution of payoff uncertainty.

Table 2 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 (2015). 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, $t = 1, 2, 3, \cdots$. 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 U_0, is constant in all periods at

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

One consensus from the experimental asset market literature is that it takes a few periods for sustained departures from fundamental values, or non-rational "bubbles", to arise (if they occur 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 an indefinite horizon by using a modified version of the "block random termination" (BRT) design proposed by Frechette 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. The BRT thus allows us to obtain, at a minimum, a 10-period data series to analyze asset (mis-)pricing; without it, we may have sessions where markets are too short to have any meaningful discussion of whether assets are correctly priced in an indefinite-horizon setting.[5]

[5] In Frechette and Yuksel (2017), subjects play the game in fixed-length blocks and a full-length new block is played if the game has not ended in the previous block. We modify their design in that beyond the first block, the market continues with the regular random termination design, so that from period 11 on, subjects receive live information about whether the current period has ended or not. The main purpose of this modification is to save on time and guarantee that we run three markets to examine the possibility of

Treatment B (D-2) 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.[6] 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. 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 FV-RN as in treatment A, but the number of dividend payments 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-2) 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 first trading phase and no trading is allowed during the second dividend realization phase. The only difference between treatment C and treatment A is in the timing of dividend realizations or the temporal resolution of payoff uncertainty. In the baseline treatment, payoff uncertainty is resolved gradually over time (in the trading stage), while in treatment BRT-2, the uncertainty is resolved at a single point of time (after trading ends). 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 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 first 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

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price convergence in indefinite-horizon markets. Repeating 10-period blocks would make each market longer and it would be difficult to complete three markets in one session.

[6]We chose to $T_0 = 10$ periods because that is the expected number of trading periods in the indefinite horizon with a continuation probability of 0.9.

probability of $\delta = 0.9$. Thus, 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 took between 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 trading market horizons in treatment A only) for all sessions of all treatments.[7] These sequences of random numbers produce 6, 20, and 9 dividends for the three markets of all three treatments. Therefore, 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-2), 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 markets (for trading only) in treatment C is 11, 5 and 16 periods, respectively; 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 periods. Table 3 provides a summary of the number of trading periods and dividend realizations in the three markets of our three treatments.

Table 3: Number of Periods and Dividend Realizations in the 3 Markets (Mkt) of Each Treatment

	No. Trading Periods			No. Dividend Payments		
Treatment	Mkt 1	Mkt 2	Mkt 3	Mkt 1	Mkt 2	Mkt 3
A (BRT)	6	20	9	6	20	9
B (D-2)	10	10	10	6	20	9
C (BRT-2)	11	5	16	6	20	9

2.2 Hypotheses

The number (value) of dividend payments in all three treatments can be represented by the lottery shown in Table 1. Under the assumption of expected utility theory, by which the

[7]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.

timing of dividend payments does not affect agents' holding value of the asset, the FV is the same across different treatments. We therefore formulate the following hypothesis:
Hypothesis 1: Market outcomes, i.e., prices, quantities, are not significantly different between treatments A, B, and C.

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 treatments B and C captures the effect of uncertain trading durations, which may affect subjects' ability to engage in speculative transactions. The associated alternative hypothesis is therefore:

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

Since previous studies on definite-horizon experimental asset markets suggest that traded prices converges to the FV-RN after subjects repeat the same trading market three times, we will also compare traded prices in the final market with the FV of the asset under different assumptions about agents' preferences. The FV-RN is constant at 50 in all three treatments. We will also consider FVs that incorporate the risk preferences of traders and we propose a procedure to estimate the risk-adjusted FV using our experimental data (more details to follow in section 4). Based on previous experimental findings showing that most agents are risk averse (Holt and Laury, 2002), we propose the following hypothesis.

Hypothesis 2: The traded price in market 3 in all treatments is significantly lower than the FV-RN, while not significantly different from the risk-adjusted FV.

2.3 Experimental Procedure

We conducted 5 sessions for each of the three treatments. Table 4 presents information on these 15 sessions. All sessions except two involved 10 subjects. The sessions in treatment B took 30 minutes less than the sessions of treatments A and C but all sessions finished within two and a half hours.

All sessions began with subjects completing a Holt and Laury (2002) risk preference elicitation task - details are provided in Appendix A. For this individual choice task, subjects were instructed to make 10 choices between pairs of lotteries and were paid based on their choice from one randomly chosen lottery out of the 10 pairs. This procedure enables us to obtain a measure of each subject's risk aversion/seeking, 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.

Subjects' earnings from all three markets consisted of their end of market cash balance and all dividends earned over the course of each market. This amount, denominated in experimental money (EM), was converted into Canadian dollars at a fixed and known exchange rate of 500 EM = 1 Canadian dollar at the end of the experiment.[8] 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 \$26. The average total payment per subject is about \$35 (\$26 from the asset markets, plus \$4 from the Holt-Laury risk elicitation task, plus a \$5 show-up fee). Participants were paid in cash and in private at the end of the session.

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). Most subjects were students from McGill university and Concordia University in Montreal. All subjects participated in one session only.

3 Experimental Results: Comparison across Treatments

Following our hypotheses, we will analyze the experimental data from two perspectives. In this section, we compare the market outcomes between the three treatments and infer the effect of horizon uncertainty and the timing of dividend payments, as well as the relevance of using an expected utility theory approach to understanding asset pricing behavior. In

[8]In sessions B1 and C1 only, the exchange rate was 400 EM=\$1, which results in a higher payment in the asset markets as shown later in Table 4. All other sessions had an exchange rate of 500 EM=\$1.

Table 4: 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

the next section, we will focus on whether we can explain the traded price in market 3 with various calculations for the market FV.

Figure 1 shows the average prices of the asset over time in each treatment. The three vertical bars in this figure indicate the first period of each new market. The average price in the first market starts at about 50 (the FV-RN) 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 average 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 A1 in Appendix B.[9]

Table 5 shows the average price and the trading volume in each market of each session. To evaluate hypothesis 1, we conduct two-tailed Mann-Whitney tests on session-level average prices and trading volume to assess whether there are any treatment differences in these market measures. There are 9 tests (3 markets x 3 treatments) each for traded price and for volume. We present the p-values from the Mann-Whitney tests in Table 6. We have the

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

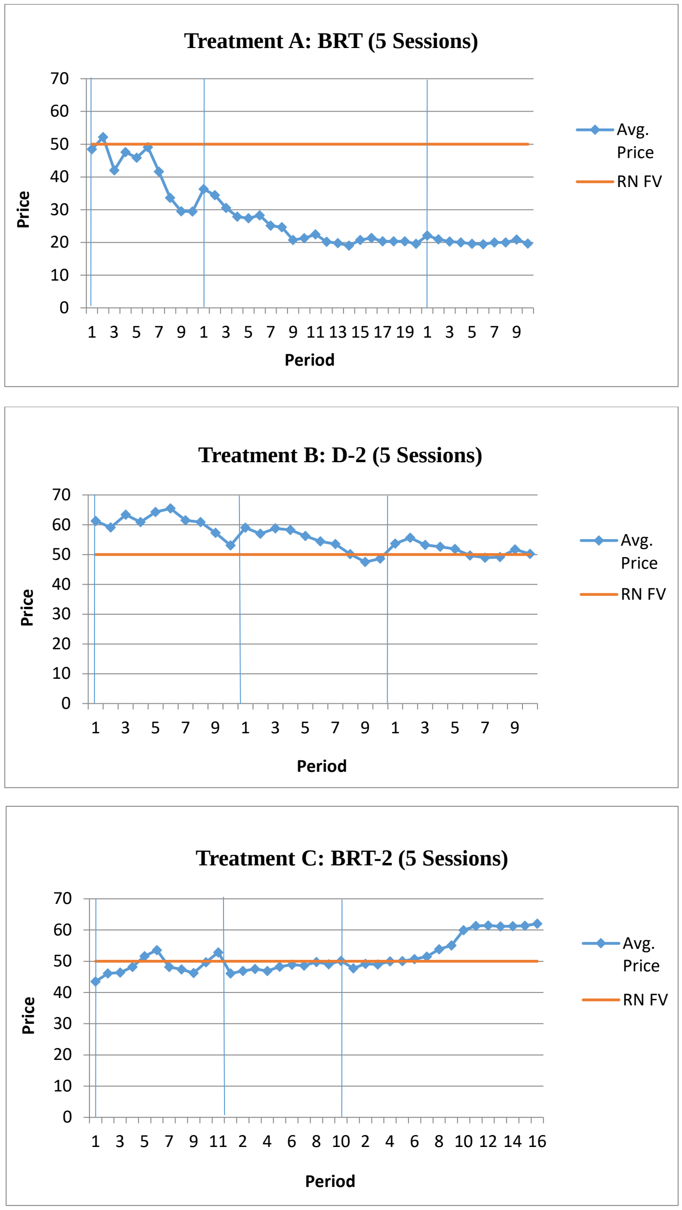

Figure 1: Average Prices over Periods in Each Treatment

following findings.

Finding 1 *There is no systematic significant difference in the average trading volume across the three treatments.*

Table 5: Average traded 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
Treatment A	41.93	20.60	22.08	69.80	77.58	103.36
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
Treatment B	60.69	54.35	51.54	70.20	62.34	51.88
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
Treatment C	48.52	48.20	55.35	52.95	55.84	42.61

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.

The experimental data suggest that the treatment variables, horizon uncertainty and timing of dividend payments, have no significant effect on average trading volume. Among eight out of the nine pairwise tests, we cannot reject the hypothesis that it is equally likely that the observation is drawn from the two alternative treatments. The p-value is < 0.05 only for market 3 between treatments A and C (where trading volume is higher in treatment A).

Finding 2 *In market 1 the average traded price is not significantly different between any two treatments. However, in markets 2 and 3, the average market price in market 2 and 3 is significantly lower in treatment A (BRT) than in treatment B (D-2) and treatment C (BRT-2), which suggests that the timing of dividend realizations significantly affects the*

Table 6: p-values from Mann-Whitney Tests of Treatment Differences
Average Market Price and Trading Volume

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

traded price.

In treatment A, the average traded price in markets 2 and 3 is 20.60 and 22.08, respectively. By contrast, in treatment B, the prices in markets 2 and 3 are 54.35 and 51.54, respectively and in treatment C, they are 48.20 and 55.35, respectively. The average traded price in markets 2 and 3 is therefore significantly lower in treatment A than in the other two treatments. The p-value is < 0.01 for the Mann-Whitney test between A and B, and < 0.02 for the comparison between A and C. There is therefore strong evidence that the timing of dividend realizations affects the traded price.

Finding 3 *The average market price in market 3 is not significantly different between treatment B (D-2) and treatment C (BRT-2), which suggests that the trading horizon uncertainty does not significantly affect the traded price.*

Comparing treatments B and C, the average price is marginally lower in market 2 of treatment C ($p < 0.1$), but this difference disappears when subjects gained further experience in market 3 ($p > 0.4$). Between the two risks involved in the indefinite-horizon asset market, it seems that payoff uncertainty plays a more important role than horizon uncertainty for the traded price of the asset.

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. The insignificant difference in traded price between treatments B and C indicates that the uncertain trading horizon itself does not significantly affect the market price. The difference between the traded price in treatment A and the other two treatments indicates that the timing of the dividend realization has a significant impact on the traded price. Since the timing of dividend realizations should not affect the holding value of the asset under the assumption of expected utility maximization, our experimental results provide evidence that non-expected utility theories may be relevant to understanding the behavior of subjects. In the next section, we explain what deviations from expected utility theory might account for the observed differences in the traded price of the asset between treatment A and treatments B and C.

4 Experimental Results: traded Prices and Market FVs

Previous studies on experimental asset markets have consistently found that when the *same group* of traders interact in consecutive fixed-horizon asset markets, prices converge toward the intrinsic FV-RN by the third market having the *identical* market structure. In our treatment, the same subjects repeat the same market game for three times, so the market price in the third market might be reasonably expected to approximate the market FV of the asset.[10] The calculation of the FV depends on the assumption about the utility function, and on whether risk preferences are incorporated.

First, it is obvious that the risk neutral FV under expected utility theory (which we label as FV-RN), the most often used benchmark for the analysis of finite-horizon experimental asset markets and from which various mis-pricing measures have been derived, cannot capture the low traded price in treatment A. The average traded price in market 3 is 22.08, which is just 44% of the FV-RN. The result is confirmed by the two-tailed, Wilcoxon signed rank test that compares this traded price with the FV-RN: the p-value is 0.043 (hypothesis 2 therefore cannot be rejected). The traded price in market 3 of the other two treatments is close to the FV-RN. In the following subsections, we will explore whether considering the risk attitude and possible deviations from the expected utility theory can help to rationalize the observed traded price in all three treatments.

A first natural alternative to FV-RN is the risk-adjusted FV under the assumption of expected utility (EU) maximization (which we label as FV-EU). Given that all three treatments involve the same uncertainty in terms of the number of dividend payments and the timing of dividend realizations does not affect the holding value under expected utility, the result that treatment A has a much lower traded price than the other two treatments suggests

[10]As shown in tables 5 and 6, the traded price changes little from market 2 to market 3, so it seems that convergence is achieved in market 2 and strengthened in market 3. We focus on the comparison between the traded price in market 3 and the FV to save on unnecessary repetition.

the FV-EU cannot explain the traded price in treatment A. Nonetheless, it is still useful to compare the FV-EU, the FV adjusted for risk attitudes, with the FV-RN, the FV under the assumption of risk neutrality, and examine, quantitatively, the size of the gap between the risk-adjusted FV-EU and the actual traded prices. The estimation procedure for the FV-EU can be easily adjusted to derive FVs under non-expected utility assumptions.

4.1 Risk-adjusted FV under Expected Utility

We first describe the procedure to estimate the FV-EU using the experimental data, and then evaluate whether the estimated FV-EU can capture the traded price in each treatment.

The derivation of the FV-EU follows a three-step procedure. In Step 1, we estimate each individual's risk parameter by using individual data from the Holt-Laury risk preference elicitation task. In Step 2, we estimate the certainty equivalence or "holding value" of the asset for each individual under the assumption of expected utility. We will later do the same for a non-expected utility, recursive preference specification as well. In Step 3, combining each individual's asset profile assigned in the experiment and the estimated certainty equivalence or holding value found in Step 2, we construct aggregate demand and supply curves for each session and calculate the market equilibrium price, which we refer to as the market FV of the asset.

Step 1: Estimation of the Risk Parameter In step 1, we assume that subjects' utility functions take the form $u(x, \alpha) = x^\alpha/\alpha$, where α is a 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 A (experimental instructions). For example, in task i, the payoff from Option A is $\bar{x}_A = \$4.0$ with probability $p_i = i/10$ and $\underline{x}_A = \$3.2$ with probability $1 - p_i$, while Option B offers $\bar{x}_B = \$7.5$ with probability p_i and $\underline{x}_B = \$0.2$ with probability $1 - p_i$.[11] An agent who is indifferent between the two options in task i has preferences

[11] 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 7: Calculation of CRRA Parameter from Holt-Laury Task

		w/o Prob. Weighting ($\gamma = 1$)			with Prob. Weighting ($\gamma = 0.71$)		
Task i	n_A	p_i	α_i	$\hat{\alpha}(n_A)$	π_i	α_i	$\hat{\alpha}^{PW}(n_A)$
	0		≥ 2.7128	2.7128		≥ 2.1566	2.1566
1	1	0.1	2.7128	2.3298	0.17	2.1566	1.9151
2	2	0.2	1.9468	1.7167	0.25	1.6736	1.5272
3	3	0.3	1.4866	1.3146	0.33	1.3807	1.2688
4	4	0.4	1.1426	0.9981	0.40	1.1569	1.0601
5	5	0.5	0.8536	0.7211	0.46	0.9633	0.8716
6	6	0.6	0.5885	0.4562	0.53	0.7798	0.6851
7	7	0.7	0.3288	0.1766	0.60	0.5903	0.4812
8	8	0.8	0.0294	−0.1695	0.68	0.3721	0.2198
9	9	0.9	−0.3684	−0.3684	0.79	0.0674	0.0674
10	10	1	$-\infty$	−0.3684	1	$-\infty$	0.0674

$u(x, \alpha_i)$, with α_i solving $Eu_A(x, \alpha_i) = Eu_B(x, \alpha_i)$ or

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

Table 7 below presents the estimated α_i given each p_i.

In the Holt-Laury data elicited from the experiment, however, we only observe in which task i subjects choose to switch from the safe choice Option A to the risky choice Option B, but not directly the task in which subjects are indifferent between the two options. For instance, if a subject chooses Option A for the first four tasks ($n_A = 4$) and switches to B since task 5, it implies that the subject is indifferent between Option A and Option B when p_i takes a value between 0.4 and 0.5. Therefore, it indicates that for this subject $\hat{\alpha}$ lies between α_4 and α_5, i.e., in the interval $(0.8536, 1.1426)$. Specifically, in this case we assign $\hat{\alpha}(n_A) = \hat{\alpha}(4) = 0.9981$ as the midpoint of α_4 and α_5. Our robustness checks show that the estimation of the market FV does not change significantly when $\hat{\alpha}$ takes on values other than the midpoint of the interval (e.g., either endpoint).

If a subject always chooses B, then the interval of $\hat{\alpha}$ is open and we use the lower bound of 2.7128. If the subject chooses option A nine or ten times, then the interval for $\hat{\alpha}$ is again open, so we use the upper bound of -0.3684. According to Table 7, risk neutral agents would switch from option A to option B after the fourth task, and risk averse (loving) agents would switch later (earlier).

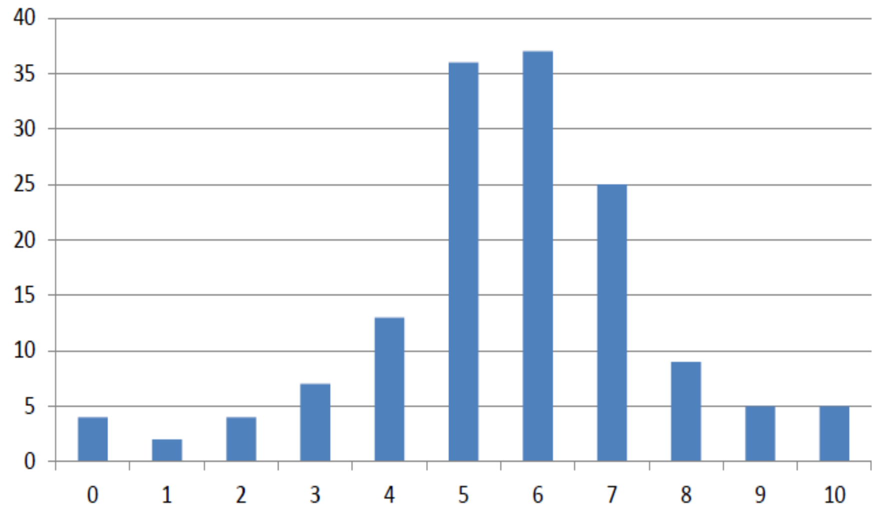

Figure 2: Distribution of the Number of Safe Choices (Lottery A) in Holt-Laury Task

Out of the 147 participants, 13, or 9% (who chose 4 safe choices), can be classified as risk-neutral, 117 or 80% (who chose more than 4 safe choices) are classified as risk-averse and 17 or 11% (who chose 0-3 safe choices) are classified as risk loving. Figure 2 shows a histogram of the number of safe choices across all sessions. The results are consistent with previous findings in the literature. [12]

Step 2: Estimation of Holding Value

After finding the risk parameter, $\hat{\alpha}(n_A)$, we can estimate each subject's holding value of the asset, equal to the the certainty equivalence for the lottery presented in Table 1 under expected utility. The probability of receiving t dividends is $(1-\delta)\delta^{t-1}$, so we can define the risk-adjusted certainty equivalence, $\hat{U}_1$, as the solution to the following equation,

$$\frac{(\hat{U}_1)^{\hat{\alpha}}}{\hat{\alpha}} = \sum_{t=1}^{\infty}(1-\delta)\delta^{t-1}\frac{(td)^{\hat{\alpha}}}{\hat{\alpha}},$$

[12] Also 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 n_A, as if the subject had chosen Option A for the first n_A tasks and Option B for the remaining tasks.

or

$$\hat{U}_1 = \left\{ \sum_{t=1}^{\infty} (1-\delta)\delta^{t-1}(td)^{\hat{\alpha}} \right\}^{\frac{1}{\hat{\alpha}}}.$$

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 $\hat{\alpha}$. Note that if $\hat{\alpha} = 1$, i.e., the risk neutral case, then $\hat{U}_1 = U_0$.

Figure 3 (top panel A) shows the holding value, $\hat{U}_1$ as a function of the risk parameter, α (left panel), and the number of safe choices in the Holt-Laury task (right panel).

Step 3: Estimation of the Market FV

After acquiring each individual's holding value (certainty equivalence) we can construct each individual's demand and supply for the asset. Let s and m be an individual's endowment of asset shares and cash (EM) respectively. The individual's demand for the asset is therefore 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:

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

Finally, we construct the aggregate demand, $Q^d(p)$, and supply, $Q^s(p)$, as the sum of individual demands and supplies. The market FV, V, solves $Q^d(V) = Q^s(V)$. In Table 8, we report the estimated market FV-EU.

Given that most (80%) of our subjects are risk averse, the risk-adjusted FV under expected utility is always lower than the FV-RN of 50, being in a relatively small range between 35.2 and 44.9. For treatment A, the FV-EU averages 42.5 across the five sessions. Under the assumption of expected utility maximization, incorporating risk attitudes brings the FV-EU closer to the market traded price. However, there is still a large gap: recall that the average traded price in market 3 of treatment A is 22.08. For treatments B and C, the FV-EU is significantly below the average traded price. A Wilcoxon signed rank test that compares the traded price with the the FV-EU has a p-value of 0.043 for all three treatments. The risk adjusted FV-EU therefore is unable to capture the traded price in our experiment (hypothesis

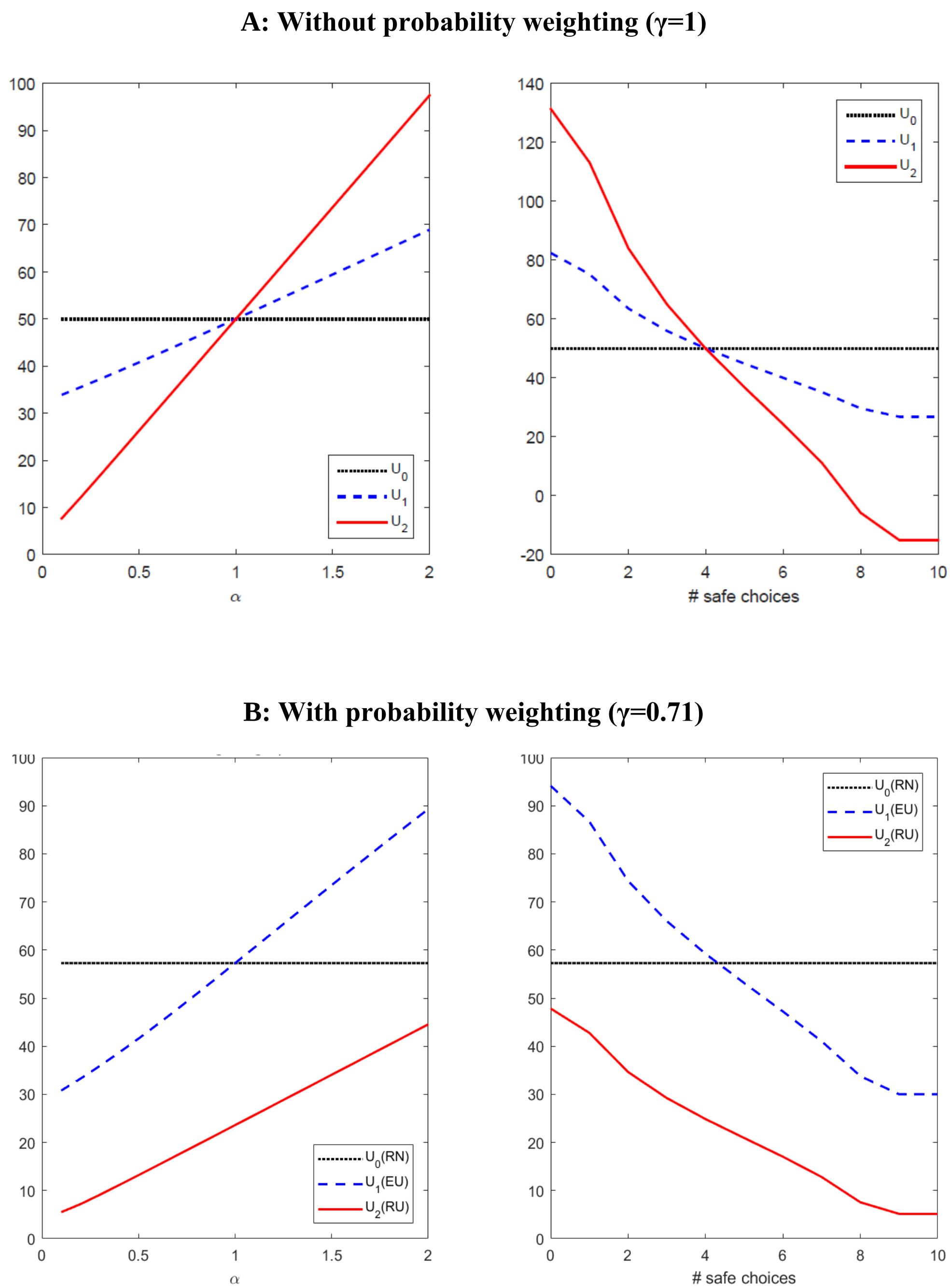

Figure 3: Holding Value under Different Utility Specifications

Table 8: Estimated Fundamental Value by Session

	w/o Prob. Weighting ($\gamma = 1$)			with Prob. Weighting ($\gamma = 0.71$)		
Session	FV-RN	FV-EU	FV-RU	FV-RN	FV-EU	FV-RU
A1	50	44.8	36.7	57.3	50	21
A2	50	44.8	36.7	57.3	53.1	21
A3	50	40.0	24.3	57.3	47.2	17.1
A4	50	42.7	36.7	57.3	47.3	24.8
A5	50	40.1	30.0	57.3	47.3	21
Treatment A	50	42.5	32.9	57.3	49.0	21.0
B1	50	44.8	44.8	57.3	50	50
B2	50	35.2	35.2	57.3	41.1	41.1
B3	50	44.8	44.8	57.3	53.1	53.1
B4	50	40.1	40.1	57.3	47.3	47.3
B5	50	44.8	44.8	57.3	50	50
Treatment B	50	41.9	41.9	57.3	48.3	48.3
C1	50	44.8	44.8	57.3	50	50
C2	50	44.8	44.8	57.3	53.1	53.1
C3	50	44.9	44.9	57.3	53.1	53.1
C4	50	40.1	40.1	57.3	47.3	47.3
C5	50	40.1	40.1	57.3	47.3	47.3
Treatment C	50	42.9	42.9	57.3	50.2	50.2

2 is therefore rejected under expected utility).

4.2 Recursive Preferences

The experimental results suggest that the timing of dividend realizations significantly affects the traded price. The timing of dividends affects the temporal resolution of payoff uncertainty: in treatment A, payoff uncertainty is resolved gradually over time as subjects trade the asset, while in treatments B and C, payoff uncertainty is resolved altogether after the trading stage ends. In view of the importance of the temporal resolution of payoff uncertainty, a key feature of the recursive preferences specification(Kreps and Porteus, 1978), we derive the FV under this specification (label it as FV-RU) and investigate whether this specification for preferences along with adjustment for risk attitudes can account for the observed traded prices in all three treatments of our experiment.

First note that for treatments B and C, subjects do not observe dividend realizations in the trading stage, so the FV under expected utility is the same as under the non-EU, recursive preference specification for these two treatments. The two utility specifications will lead to different FV calculations only for treatment A, where the uncertainty regarding the dividend payment is only resolved gradually, over time, while subjects trade for units of the asset.

We adopt the Epstein and Zin (1989) specification for recursive preferences, using a CES time aggregator to combine the current payoff and the certainty equivalence of future payoffs.[13] For the risk aggregator, we follow what we did in the previous subsection, using the CRRA utility function to aggregate the risk associated with future payoffs. The holding value of the asset in treatment A under recursive preferences can be expressed by

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

where the first term on the right hand side, which involves the current dividend payment d, represents current consumption, and the second term represents the risk adjusted certainty equivalence value of future consumption.

The derivation of the FV-RU in treatment A follows the same 3-step procedure as described earlier for estimation of the FV-EU. Notice that in step 1, the different assumption of expected utility or a non-EU recursive utility specifications will not affect the estimation of the risk parameter, $\hat{\alpha}$, since the Holt-Laury task consists of static gambles. The assumption regarding the utility specification directly affects the calculation of individuals' holding value (certainty equivalence) only in Step 2, and therefore, indirectly affects the FV of the asset

[13] The Epstein-Zin recursive 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 inter-temporal 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. Brown and Kim (2014) report experimental results from a choice menu elicitation (such as the Holt-Laury risk elicitation as well as time and uncertainty resolution preferences) which reveal that most human subjects have an estimated coefficient of relative risk aversion that differs from their estimated inter-temporal elasticity of substitution, consistent with an Epstein-Zin preference specification. We show that this non-expected utility approach can help to account for differences that we observe in market traded prices when we change the timing of dividend realizations under random termination.

in Step 3.

Using the estimated risk parameter, the holding value of the asset in treatment A under recursive preferences can be expressed as

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

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

$$\hat{U}_2 = \frac{d}{(1 - \delta^{\rho/\hat{\alpha}})^{1/\rho}}.$$

Note that if $\hat{\alpha} = 1$ and $\rho = 1$, i.e., the risk neutral case under expected utility, then $\hat{U}_2 = U_0$.

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's payoff as perfect substitutes, and there is no actual discounting from period to period. The recursive holding value is therefore

$$\hat{U}_2 = \frac{d}{1 - \delta^{\frac{1}{\hat{\alpha}}}.} \tag{1}$$

In Figure 3 (Upper panel A), the estimated holding value under recursive preferences, $\hat{U}_2$, is graphed together with U_0 (FV-RN) and $\hat{U}_1$ (FV-EU) against the risk parameter, α (left panel), and for comparison purposes, against the number of safe choices in the Holt-Laury task (right panel). Note that for risk averse agents, for whom $\alpha < 1$, the holding value estimated under the recursive utility specification is lower than that under the expected utility specification, and further lower than the value under the risk neutral expected utility specification, i.e., $\hat{U}_2 < \hat{U}_1 < U_0 = 50$. When $\alpha > 1$, this ordering reverses, with $\hat{U}_2 > \hat{U}_1 > U_0 = 50$. Finally, for risk neutral agents, the three holding values coincide with each other at 50.

After estimating the holding value, we can construct the individual and aggregate supply and demand curves to calculate the FV-RU following the same procedures as in the esti-

Table 9: p-values from Wilcoxon Signed Rank Tests: Average Market Price and FV

Treatment	Average Price in Market 2			Average Price in Market 3		
	FV-RN	FV-EU	FV-RU	FV-RN	FV-EU	FV-RU
	w/o Prob. Weighting					
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	0.079	0.686	0.043	0.043
	with Prob. Weighting ($\gamma = 0.71$)					
A	0.043	0.043	0.893	0.043	0.043	0.686
B	0.500	0.500	0.500	0.225	0.686	0.686
C	0.080	0.686	0.686	0.686	0.500	0.500
No. of Obs.	5	5	5	5	5	5

mation of FV-EU. The estimated FV-RU is shown in Table 8. The p-values from Wilcoxon signed rank tests comparing the market 3 traded prices with the estimated FV-RU values are shown in Table 9. As mentioned above, in treatments B and C, payoff uncertainty is resolved at a single point in time, just after trading ends, so the holding value and therefore the market FV are the *same* under both expected and recursive utility specifications. In other words, in treatments B and C, even if subjects have a recursive utility specification, it degenerates to a special case, i.e., the expected utility function. For treatment A, the two specifications lead to very different FV values. The FV-RU is always lower than FV-EU, with the former being in a range between 24.3 and 36.8, with a treatment average of 32.9. Compared with the FV-EU, which averages 42.5, the FV-RU is significantly closer to the average traded price at 22.08. A signed rank test suggests that average traded prices in market 3 of treatment A are *not* significantly different from the estimated FV-RU ($p = 0.138$) at the 10% significance level. For treatments B and C, the results are the same as for the analysis using FV-EU (given that FV-EU is the same as FV-RU). Thus under recursive utility, hypothesis 2 is partially rejected (it is rejected for treatments B and C, but not for treatment A)

4.3 Probability Weighting

As shown in the previous subsection, risk adjusted FV under recursive utility greatly improves over FV-EU in terms of capturing the low traded price in the indefinite-horizon asset market (treatment A). However, there is still a small gap between the estimated market

FV and the actual market price: FV-RU is higher than the market price (by about 50%) in treatment A, and lower than the market price (by about 20%) in treatments B and C. We therefore continue to search for additional/alternative explanations for the traded price, especially for the low traded price in treatment A. For this purpose, we consider the possibility from cumulative prospect theory (Tversky and Kahneman, 1992) that subjects employ probability weighting in evaluating the lotteries that characterize the asset.[14] In treatment A, the market ends and the asset becomes worthless with a small probability 0.1. It may be that subjects overweight this small probability, thereby lowering their valuation of the asset. In the following, we will examine bow probability weighting affects the calculation of the three alternative FVs considered so far: FV-RN, FV-EU and FV-RU, and evaluate its contribution in capturing the traded price.

Probability weighting works as follows. Suppose agents face a risky prospect with n (ordered) outcomes $x_1 < x_2 < x_i < ... < x_n$, each with probability $p_1, p_2, ..., p_i, ..., p_n$. Probability weighting transforms each of the original probabilities, p_i, through two functions $\pi_i(\cdot)$ and $w(\cdot)$, with commonly used functional forms $\pi_i = w\left(\sum_{j=i}^{n} p_j\right) - w\left(\sum_{j=i+1}^{n} p_j\right)$ and $w(q) = \frac{q^\gamma}{[q^\gamma+(1-q)^\gamma]^{1/\gamma}}$. The effect is that small probabilities are over-weighted while large probabilities are under-weighted relative to their true values.

We set $\gamma = 0.71$ following Wu and Gonzalez (1996).[15]

To derive the FV with probability weighting, we follow the same 3-step procedure. The only difference is that we will use the transformed probabilities, π_i in place of the original probabilities p_i in *both* the Holt-Laury tasks and in the lotteries characterizing the asset being traded.

In step 1, the estimation of the risk parameter uses the transformed probabilities π_i in place of the original probabilities p_i. We update Table 7 to include the transformed probabilities and the estimated risk parameter with probability weighting, $\hat{\alpha}^{PW}$. Probability weighting increases small probabilities (for $p_i < 0.4$) and decreases large probabilities (for $p_i > 0.4$). In both estimations with and without probability weighting, risk neutral agents

[14] Probability weighting, together with loss aversion and reference dependence, are fundamental principles of prospect theory, and alternative to expected utility theory. Given that it is not clear what the appropriate reference point is in the context of the market game that we study, we focus only on the probability weighting aspect of Prospect Theory.

[15] Other values of γ suggested in the literature are 0.56 in Camerer and Ho (1994) and 0.61 in Tversky and Kahneman (1992). We use the highest value of γ among the three, 0.71, as it involves the least distortion of the objective probabilities.

would switch from option A to option B after the fourth task. As a result, probability weighting makes estimated CRRA parameter as a function of the number of safe choices *pivot* at the risk neutral value for n_A, i.e., 4, and become flatter. The estimated $\hat{\alpha}^{PW}$ is smaller than $\hat{\alpha}$ for risk-seeking individuals and $\hat{\alpha}^{PW}$ is larger than $\hat{\alpha}$ for risk-averse individuals. The distribution of $\hat{\alpha}^{PW}$ is therefore more condensed in the direction of the risk-neutral case ($\alpha = 1$).

In step 2, for the estimation of the holding value under expected utility, we use the risk parameter estimated in step 1, $\hat{\alpha}^{PW}$, and the transformed probabilities for the lotteries characterizing the asset. In the case of expected utility, the (weighted) probability of receiving t dividends becomes the following equation (refer to Appendix C for more details):

$$\pi(td) = w(\delta^{t-1}) - w(\delta^t).$$

As a result, the extreme outcomes (i.e., receiving t dividends when $t \geq 22$ or when $t \leq 2$) are overweighted and other outcomes are underweighted, given the functional form of $w()$, our choice of $\delta = 0.9$ and the value $\gamma = 0.71$. Correspondingly,

$$\hat{U}_1^{PW} = \left\{ \sum_{t=1}^{\infty} [w(\delta^{t-1}) - w(\delta^t)](td)^{\hat{\alpha}^{PW}} \right\}^{\frac{1}{\hat{\alpha}^{PW}}}. \tag{2}$$

In the case of recursive utility, the estimation is similar except that $\tilde{U}_{t+1} = U_{t+1}^{\hat{\alpha}^{PW}} > 0$ with probability $\pi_2 = w(0.9) - w(0) = w(0.9) < \delta = 0.9$ and $\tilde{U}_{t+1} = 0$ with probability $\pi_1 = w\,(1) - w\,(0.9) = 1 - w(0.9) > 1 - \delta = 0.1$, so the bad outcome is overweighted and the good outcome is underweighted. Correspondingly,

$$\hat{U}_2 = \frac{d}{1 - \pi_2^{\frac{1}{\hat{\alpha}^{PW}}}}. \tag{3}$$

Figure 3 (lower panel B) shows estimated holding values *with* probability weighting. Probability weighting affects the estimated holding value as follows. With expected utility, the estimated holding value decreases slightly for very risk averse agents ($\alpha < 0.43$) and increases for other α values. For an average subject (with $\alpha = 0.6$), it increases slightly from 42.6 to 44.6. For risk neutral agents, it increases slightly from 50 to 57.3. With recursive utility, probability weighting uniformly reduces the holding value (as agents overreact to the small probability event of termination). For risk-neutral agents, probability weighting substantially reduces the holding value under recursive utility from 50 to 23.6. For an average risk averse subject (with $\alpha = 0.8$), it decreases substantially from 40.52 to 19.43.[16]

Step 3 remains the same as before (using the holding value derived from step 2). The effect of probability weighting on the market FV estimates is consistent with its effect on the holding value of the average subject. Under expected utility, it increases the treatment average FV-EU moderately, from 42.5 to 49.0 for treatment A, from 41.9 to 48.3 for treatment B, and from 42.9 to 50.2 for treatment C, bringing the FV-EU closer to the average traded prices (51.5 in treatment B and 55.3 in treatment C). Under recursive utility, probability weighting reduces the treatment average FV-RU from 32.9 to 21.0, which is very close to the average traded price of 22.1. Recall that FV-EU and FV-RU are the same for treatments B and C. In terms of the Wilcoxon signed rank test, with probability weighting, the average price in treatment A is not significantly different from FV-RU, while it is significantly different from FV-RN and FV-EU. For the other two treatments, the traded price is not significantly different from all three FVs. These results suggest that the market FV under recursive utility with probability weighting *can* account for the traded price in *all three* treatments, so that we would not reject hypothesis 2.

We have discussed how to estimate different forms of FV and evaluate their ability to account for the traded price in market 3. It is useful to summarize this discussion in the following findings.

Finding 4 ***Market Price and FV: Treatment A (BRT).***

1. *For treatment A, the traded price in market 3 is significantly lower than the risk-neutral FV or the risk-adjusted FV under expected utility, regardless of whether or not probability weighting is considered.*

2. *The average traded prices are not statistically significantly different (at 10% significant level) from the risk-adjusted FV under recursive utility, regardless of whether or not probability weighting is considered. Probability weighting brings the FV-RU closer (from 32.9 to 21.0) to the average traded price (20.3).*

Finding 5 ***Market Price and FV: Treatments B (D-2) and C(BRT-2).***

[16] Note that probability weighting changes the estimate of α. The average α is about 0.6 without probability weighting, and 0.8 with probability weighting.

1. *Without probability weighting, the traded prices in market 3 of treatments B and C are significantly higher than the risk-adjusted FV predictions, and are not significantly different from the risk-neutral FV prediction.*

2. *With probability weighting, the traded prices in market 3 of treatment B and C are not significantly different from FV-RN, FV-EU or FV-EU.*

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 preferences and are risk averse (i.e., if $\alpha < 1$), then they prefer earlier to later resolution of the uncertainty regarding future dividend realizations. If dividend realizations are coincident with trade in the asset as they are in treatment A, a 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. By contrast, in treatments B and C, all dividend realizations occur after the trading phase is complete, so preferences to resolve uncertainty earlier cannot actively affect the pricing of the asset. Note that we are *not* suggesting that subjects' preferences differ across our three treatments; rather, we think that in general, a recursive specification may always be operative. However, due to the difference in the timing of dividend payments, the preference for earlier uncertainty resolution only reduces the fundamental price (relative to the FV under expected utility) in treatment A.

In addition to consider the non-EU recursive utility specification, combining this specification with probability weighting provides the best explanation for our experimental data. The effect of probability weighting under the recursive utility specification has an opposite direction in treatment A and treatments B and C: it lowers the FV-RU in treatment A and (slightly) increases the FV-RU (which is same as FV-EU) in treatments B and C. In the former, in every period agents only consider two possible outcomes and overweight the probability of the bad outcome, while in the latter, agents overweight both extremely good outcomes and extremely bad outcomes, resulting in a slightly higher FV-RU (FV-EU).

Note that to better account for trade prices, especially the traded prices in treatment A, we make three modifications to the benchmark FV under expected utility and assuming risk neutrality (FV-RN): risk preferences, recursive utility and probability weighting. The first two are more crucial. Irrespective of whether we assume expected or recursive utility and whether we apply probability weighting or not, the risk neutral FV cannot account for the low traded price in treatment A. The risk-adjusted FV under expected utility, FV-EU, is substantially higher than the traded price in treatment A, regardless of whether probability weighting is used or not. The FV under recursive utility (FV-RU) without probability weighting can account for a significant amount of the low traded price in treatment A; adding probability weighting further improves the ability of FV-RU to capture the low traded price in treatment A (and enables FV-RU to simultaneously match the traded price in the other two treatments).

4.4 Individual Trading Behavior

Our analysis so far focuses on whether the FV can account for the aggregate (average) market traded price. In addition to rationalizing the aggregate results, we examine the trading behavior of *individual* subjects in the final market, or market 3. In particular, we ask how well do the different FV specifications – risk neutral (RN) or risk adjusted, with expected or recursive preferences, and without or with probability weighting – explain individual trading decisions. We characterize an individual as employing a fundamental trading strategy if the buying price is $\leq (1+\epsilon)$FV, or the selling price is $\geq (1-\epsilon)$FV, where we set $\epsilon = .10$, and FV the market FV estimated using our procedures. This 10% band around the market FV allows for a certain level of experimentations close to the FV. We then calculate the percentage of fundamental trading with reference to each of the FV that we have estimated for each subject.

Table 10 presents the percentage of fundamental trading averaged across all subjects in each treatment with reference to the FV-RN, FV-EU and FV-RU, with and without probability weighting, respectively. We see that for treatment A, the FV under the recursive utility specification captures the highest percentage of fundamental trading, no matter whether or not probability weighting is considered. Probability weighting increases the percentage of fundamental trading for FV-RU from 52.9% to 58.3%, slightly increases the percentage of fundamental trading for FV-EU from 47.5% to 50.2%, and marginally reduces the percentage of fundamental trading for FV-RN (from 47.4% to 47.2%). For treatments B and C, FV-EU and FV-RU are the same. Without probability weighting, the percentage of fundamental trading explained by FV-RN, is higher and the opposite is true with probability weighting.

Table 10: Average Percentage of Fundamental Trading

	Treatment A	Treatment B	Treatment C
	w/o Prob. Weighting		
FV-RN	47.4	77.5	83.0
FV-EU	47.5	63.4	68.4
FV-RU	52.9	63.4	68.4
	with Prob. Weighting ($\gamma = 0.71$)		
FV-RN	47.2	58.8	63.7
FV-EU	50.2	67.6	75.5
FV-RU	58.3	67.6	75.5
No. of Obs.	49	47	46

Probability weighting improves the "fit" of FV-RU and FV-EU (from 63.4% to 67.6%), while it reduces the "fit" of FV-RN (from 77.5% to 58.8% for treatment B, and from 83.0% to 63.7% for treatment C). Figures 4 and 5 report on the percentage of fundamental trading for the 49 subjects in treatment A under no probability weighting ($\gamma = 1$, upper panels) and under probability weighting ($\gamma = .71$, lower panels). The horizontal axis is the percentage of fundamental trading, which runs from 0 to 100 percent with 50 equal-sized bins. Figure 4 graphs the probability density of fundamental trading while Figure 5 shows the cumulative density. The two figures convey similar results, which together with the results of Table 10 can be summarized as follows.

Finding 6 ***Individual trading strategies.***

1. *In treatment A, (with or without probability weighting) the percentage of fundamental trading is highest under the assumption of a recursive utility specification, followed by the risk-adjusted expected utility specification, and then by the risk neutral utility specification.*

2. *In treatments B and C, without probability weighting, a higher percentage of fundamental trading is associated with FV-RN than with FV-EU (and FV-RU). With probability weighting the reverse is true.*

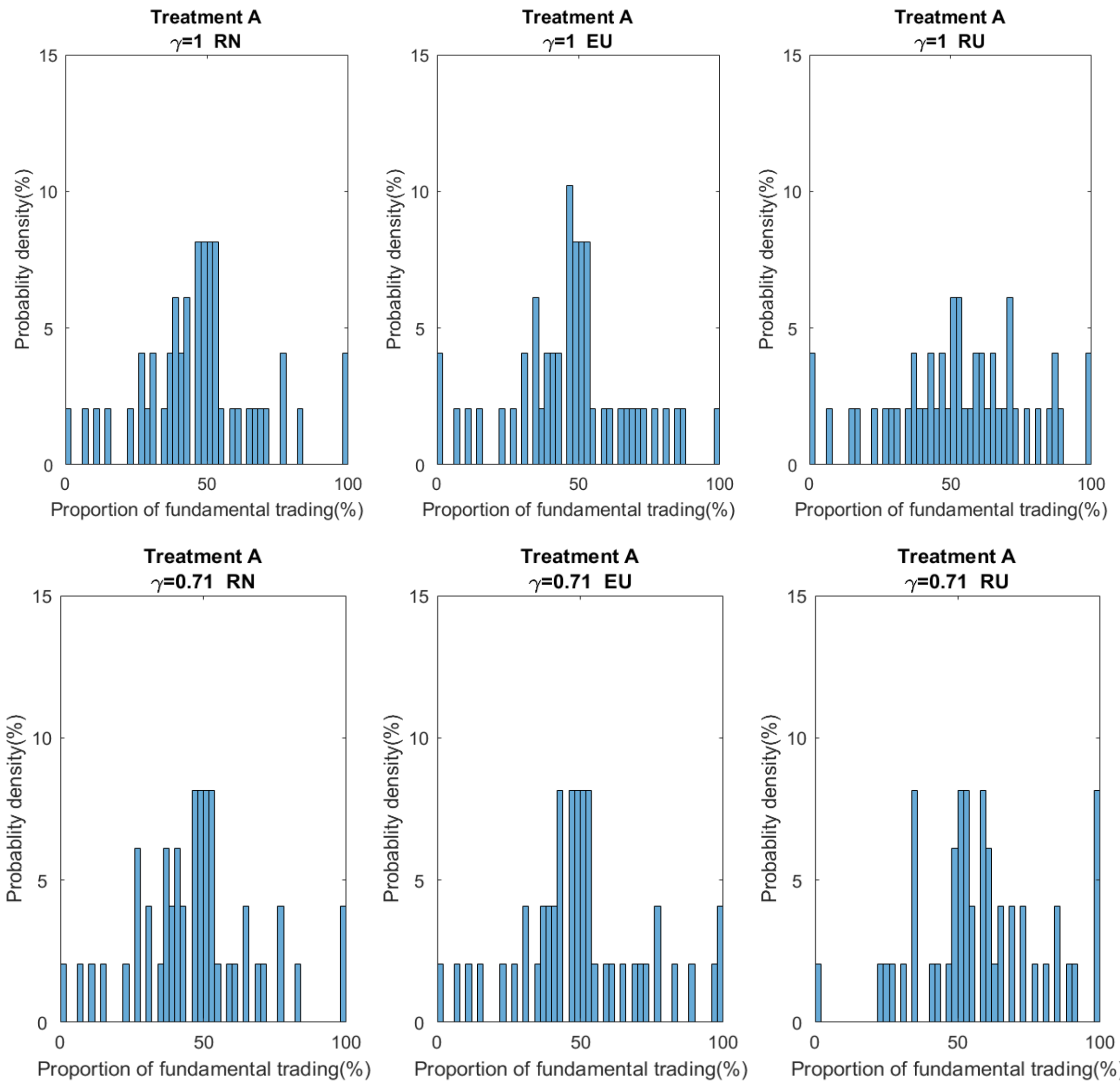

Figure 4: Histogram of the Percentage of Fundamental Trading in Treatment A—Probability Density

Notes: We characterize an individual as employing a fundamental trading strategy if the buying price is $\leq$ (1 + 10%)FV, or the selling price is $\geq$ (1-10%)FV.

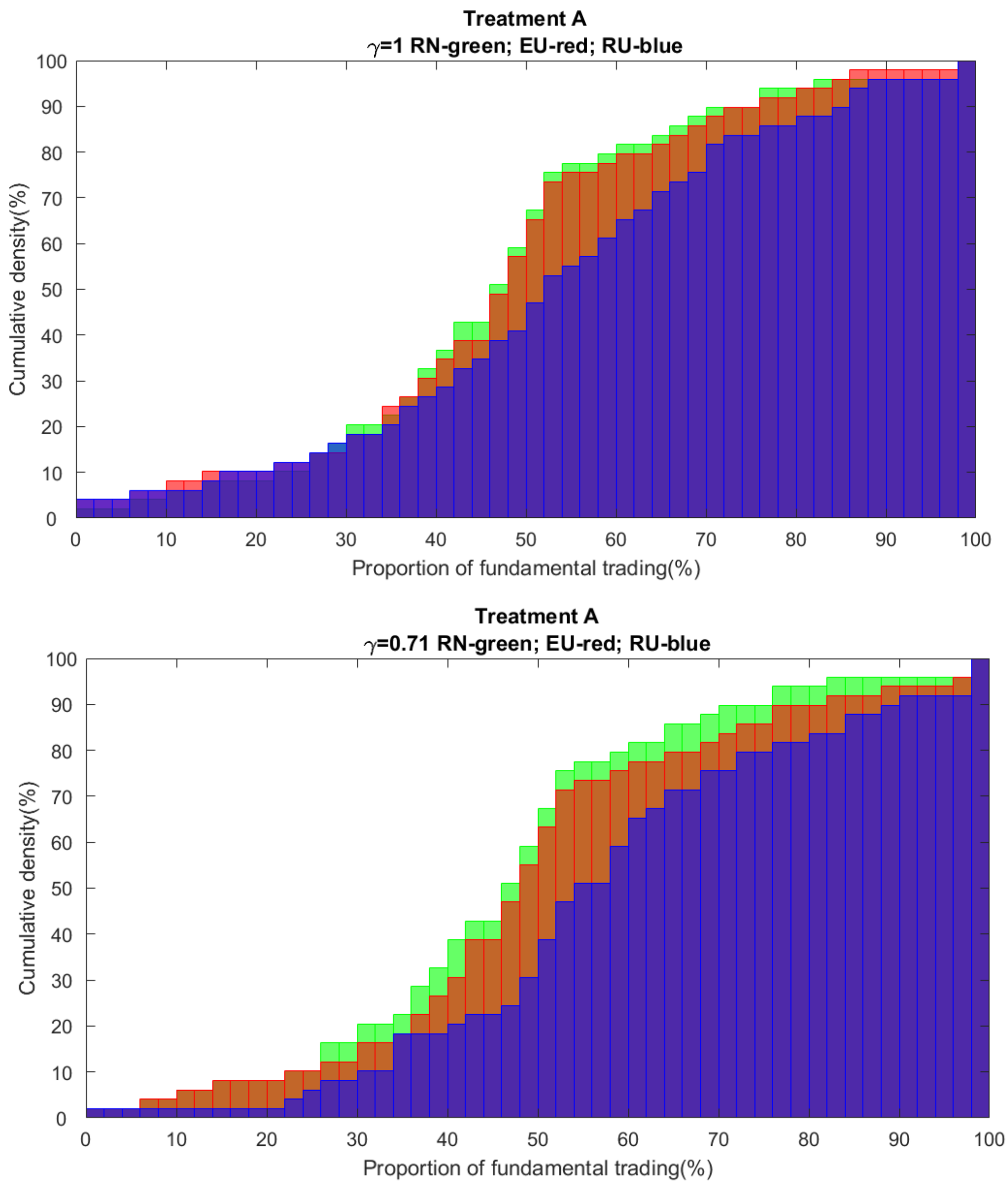

Figure 5: Histogram of the Percentage of Fundamental Trading in Treatment A—Cumulative Density

Notes: We characterize an individual as employing a fundamental trading strategy if the buying price is $\leq (1 + 10\%)$FV, or the selling price is $\geq$ (1-10%)FV.

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 two additional treatments, by which we can examine 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 close to the risk neutral expected utility prediction. Since the dividend sequence is the same across all three treatments, but pricing is quite different, risk preferences under expected utility cannot explain the different pricing outcomes that we observe (the timing of dividend realizations does not matter with expected utility). 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 account for a significant fraction of the low traded price that we observe in our baseline treatment A, where uncertainty about dividend realizations coexists with uncertainty about the trading horizon. With recursive preferences, risk-averse agents prefer earlier to later resolution of the uncertainty regarding future dividend realizations. If dividend realizations are coincident with trade in the asset as they are in the baseline treatment, this preference for earlier uncertainty resolution will manifest itself in a lower holding value for the asset which implies that the asset should trade at prices lower than the FV value under expected utility. 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.

Combining a recursive utility specification risk adjustment and probability weighting (according to which subjects overreact to the small probability of market termination) can fully rationalize the low traded prices observed in our baseline treatment. The risk-adjusted FV with recursive utility and probability weighting is also consistent with the traded price observed in the other two treatments.

An important take-away from our study for experimental economists is that the mis-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 literature initiated by Smith et al. (1988), we find substantial under-pricing relative to the risk neutral benchmark under expected utility 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 and probability weighting in the context of asset markets where subjects both trade and receive dividends from their asset holdings.

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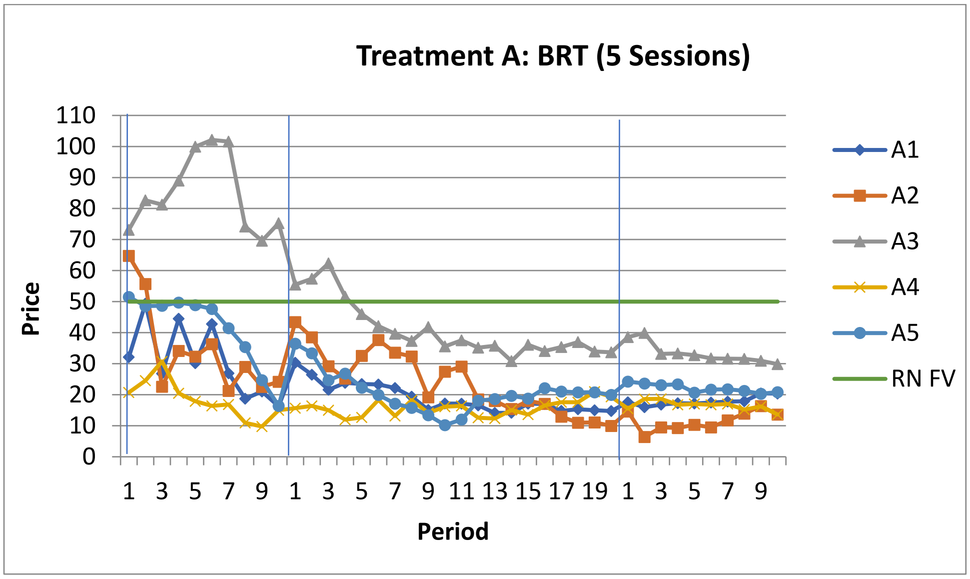
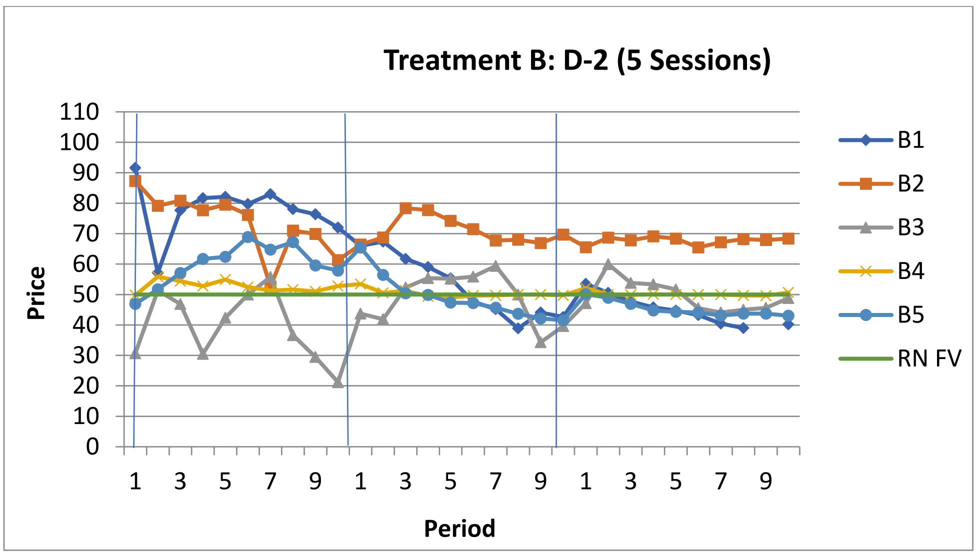
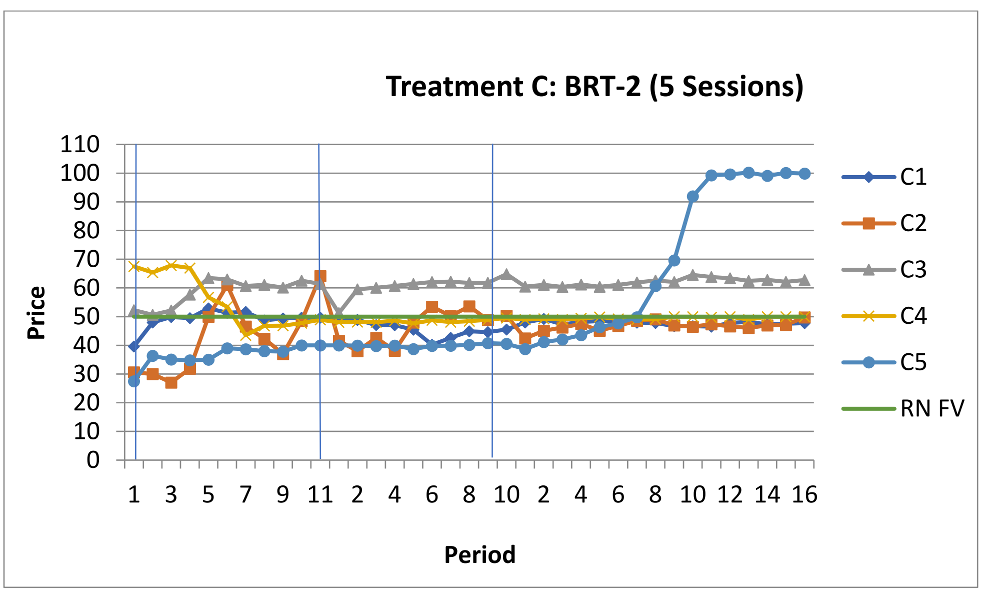
Internet Appendix A: Figure A1—Prices over Periods in Each Session, Grouped by Treatment







Internet Appendix B: Experimental 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 (Same for all three treatments)

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 (Treatment BRT)

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).

Quiz

After you have read the instructions, please answer the following quiz questions. The experimenter will check whether your answers are correct. If you answer any question incorrectly, the experimenter will discuss with you why your answer is wrong and explain what the correct answer is. The purpose of this quiz is to ensure that you fully understand the instructions prior to the start of the experiment.

1. Suppose in a market, after the block of 10 rounds finishes, the random draws are revealed as:

round	1	2	3	4	5	6	7	8	9	10
Random draw	52	3	86	74	21	8	93	5	24	12

The **final round** of the market is ______

2. Suppose in a market, the random draw sequence is

round	1	2	3	4	5	6	7	8	9	10	11	12
Random draw	41	9	88	41	31	29	33	5	24	2	14	96

The **final round** of the market is ______

3. Suppose a market has lasted for 15 rounds already. The chance that a market continues to new round is

   A. 90%

   B. Lower than 90%

   C. Higher than 9%

   D. None of the above

4. Suppose at the end of the final round of the market, you have 22 shares, 4,500 EM in cash, and 2,000 EM in the dividend account, your earnings in this market is ________ EM

5. If you hold on to a share from the beginning to the end of the market, on average, you earn ____ EM of dividends.

Part II Instructions (D-2)

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 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.

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 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.

Quiz

After you have read the instructions, please answer the following quiz questions. The experimenter will check whether your answers are correct. If you answer any question incorrectly, the experimenter will discuss with you why your answer is wrong and explain what the correct answer is. The purpose of this quiz is to ensure that you fully understand the instructions prior to the start of the experiment.

6. For each share you hold at the end of the trading stage, you receive
    a. nothing.
    b. on average 10 dividend payments.
    c. exactly 10 dividend payments.
    d. exactly 50 EM of dividend payments.
7. In each new market, you
    a. start with the same endowment of shares and cash.
    b. inherit cash and shares from the previous market.
8. Suppose we are in the trading stage, trading round 5 of market 1, you
    a. start with the same endowment of shares and cash as in round 1.
    b. inherit cash and shares from the previous trading round.
9. Suppose we are in the dividend realization stage of a market. There have been 15 dividend payments already. The chance that you receive more dividend payments is
    a. 90%.
    b. lower than 90%.
    c. higher than 90%.
    d. none of the above.
10. Suppose at the end of the trading stage of a market, you have 20 shares and 4,500 EM in cash. In the dividend realization stage, there are 6 dividend payments. Your earning from this market is ________ EM.

Part II Instructions (BRT-2)

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 two stages: a **trading stage** and a **dividend realization stage**.

Trading Stage

The trading stage consists of an indefinite number of 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.

The length of the trading stage 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 trading stage will continue or not. Specifically, if the computer draws a random number between 1 and 90 (inclusively), the trading stage will continue; otherwise, if the random number is between 91 and 100 (inclusively), then the trading stage ends. Therefore, after each round, the trading stage 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 trading stage has actually ended within the block. If the trading stage has ended within the block of the first 10 rounds, the **final round** of the trading stage 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 trading stage has not ended within the block, then it 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 trading stage is reached once the random draw exceeds 90.

Dividend Realization Stage

After the trading stage finishes, the dividend realization stage starts, where you collect dividends for the shares you own at the end of the final round 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 final round 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.

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 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:

(3) cash at the end of the **final round** of the trading stage
(4) the number of shares at the end of the **final round** of the trading stage * the number of dividend payments in the dividend realization stage * 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 an indefinite number of trading rounds. In any trading round, the trading stage may continue with probability 0.9 and end with probability 0.1. Therefore, on average the length of the trading stage is 10 rounds.
- Within the block of the first 10 rounds of the trading stage of a market, you will not be informed of whether the trading stage has ended or not.
- 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.
- Your earnings in a market will be determined by your cash holdings at the end of the **final round** of the trading stage plus the total dividends received during the dividend realization stage; the final round could be within the block or outside of the block.
- In the dividend realization stage, you collect dividends for the shares you own at the end of the **final round** 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 final round of the trading stage.

Quiz

After you have read the instructions, please answer the following quiz questions. The experimenter will check whether your answers are correct. If you answer any question incorrectly, the experimenter will discuss with you why your answer is wrong and explain what the correct answer is. The purpose of this quiz is to ensure that you fully understand the instructions prior to the start of the experiment.

11. Suppose in the trading stage of a market, after the block of 10 rounds finishes, the random draws are revealed as:

round	1	2	3	4	5	6	7	8	9	10
Random draw	52	3	86	74	21	8	93	5	24	12

The **final round** of the trading stage is _______

12. Suppose in the trading stage of a market, the random draw sequence is

round	1	2	3	4	5	6	7	8	9	10	11	12

Random draw	41	9	88	41	31	29	33	5	24	2	14	96

The **final round** of the market is ______

13. Suppose the trading stage of a market has lasted for 15 rounds already. The chance that the trading stage continues to a new round is
    E. 90%
    F. Lower than 90%
    G. Higher than 9%
    H. None of the above
14. For each share you hold at the end of the final round of the trading stage, you receive
    a. nothing.
    b. on average 10 dividend payments.
    c. exactly 10 dividend payments.
    d. exactly 50 EM of dividend payments.
15. In each new market, you
    a. start with the same endowment of shares and cash.
    b. inherit cash and shares from the previous market.
16. Suppose we are in the trading stage, trading round 5 of market 1, you
    a. start with the same endowment of shares and cash as in round 1.
    b. inherit cash and shares from the previous trading round.
17. Suppose we are in the dividend realization stage of a market. There have been 15 dividend payments already. The chance that you receive more dividend payments is
    a. 90%.
    b. lower than 90%.
    c. higher than 90%.
    d. none of the above.
18. Suppose at the end of the final round of the trading stage of a market, you have 20 shares and 4,500 EM in cash. In the dividend realization stage, there are 6 dividend payments. Your earning from this market is ________ EM.

Internet Appendix C: Probability Weighting

We first provide a short description about probability weighting. Suppose agents face a risky prospect with n outcomes $x_1 < x_2 < x_i < ... < x_n$, with probability $p_1, p_2, ..., p_i, ..., p_n$. Probability weighting transforms the original probability p_i to w_i through

$$\pi_i = w\left(\sum_{j=i}^{n} p_j\right) - w\left(\sum_{j=i+1}^{n} p_j\right) = w\left(q_i\right) - w\left(q_{t+1}\right),$$

and one often-used functional form for $w(\cdot)$ is

$$w(q) = \frac{q^\gamma}{[q^\gamma + (1-q)^\gamma]^{1/\gamma}}.$$

Note the following:

1. The function $w(\cdot)$ is applied to the cumulative density function, where $q_i = \sum_{j=i}^{n} p_j$ is the cumulative probability of getting an outcome weakly better than x_i, i.e., $\Pr(x \geq x_i)$, and $q_{i+1} = \sum_{j=i+1}^{n} p_j$ is the the probability of outcomes strictly better than x_i. The transformed density probability π_i is derived from the transformed cumulative probabilities.

2. The transformed probabilities π_i satisfy $\sum_{i=1}^{n} \pi_i = 1$.

3. We say event i is overweighted if $\pi_i > p_i$, and underweighted if $\pi_i < p_i$. Note that since

   $$\frac{\pi_i}{p_i} = \frac{w\left(q_i\right) - w\left(q_{i+1}\right)}{p_i},$$

   whether event i is over/under weighted depends on the slope of the line that connects the two points $(q_i, w(q_i))$ and $(q_{i+1}, w(q_{i+1}))$. If there are many events, the the slope of this line can be appoximated by the slope of the function w at point q_i. Note that q_i is cumulative probability counting events better than event i (not counting downward as in convention). Roughly speaking, event i is overweighted if $w'(q_i) > 1$ and underweighted if $w'(q_i) < 1$.

Next we describe how to apply probability weighting to our experimental treatments. **In treatment A,** at the end of each period after the dividend payment of 5 points, there is a random draw that determines whether the market will continue. With probability $\delta = 0.9$, the market continues, and with probability $1 - \delta = 0.1$, the market ends. So from a subject's point of view, there are two outcomes, the bad outcome has a small probability of 0.1.

outcome i	prob (p_i)
1: market ends (bad)	$p_1 = 1 - \delta = 0.1$
2: market continues (good)	$p_2 = \delta = 0.9$

We can calculate transformed probabilities π_i as follows:

$$\begin{aligned}\pi_1 &= w\,(1) - w\,(0.9) = 1 - w(0.9) > 0.1 \\ \pi_2 &= w(0.9) - w(0) = w(0.9) < 0.1\end{aligned}$$

so that the bad outcome is overweighted and the good outcome is underweighted.

In treatments B and C, subjects trade the asset first (for a fixed 10 periods in treatment B and a random number of periods in treatment C), and then learn about the dividend realizations of the underlying asset in a separate stage. In the dividend realization stage, subjects get one dividend for sure, after that, there is a random draw, with probability 0.1, dividend payment stops, and with probability 0.9, dividend payment continues. The asset can be viewed as the following lottery: outcome i (i.e., i dividends) with probability $p_i = \delta^{i-1}(1-\delta)$ for $i = 1, 2, ...\infty$.

outcome i	prob (p_i)
d	$1 - \delta = 0.1$
$2d$	$\delta(1-\delta) = 0.09$
...	...
id	$\delta^{t-1}(1-\delta)$
$\ldots$	...

Define D as the random variable of accumulated dividends. According to the probability weighting function, the weighted probability of receiving i dividends is

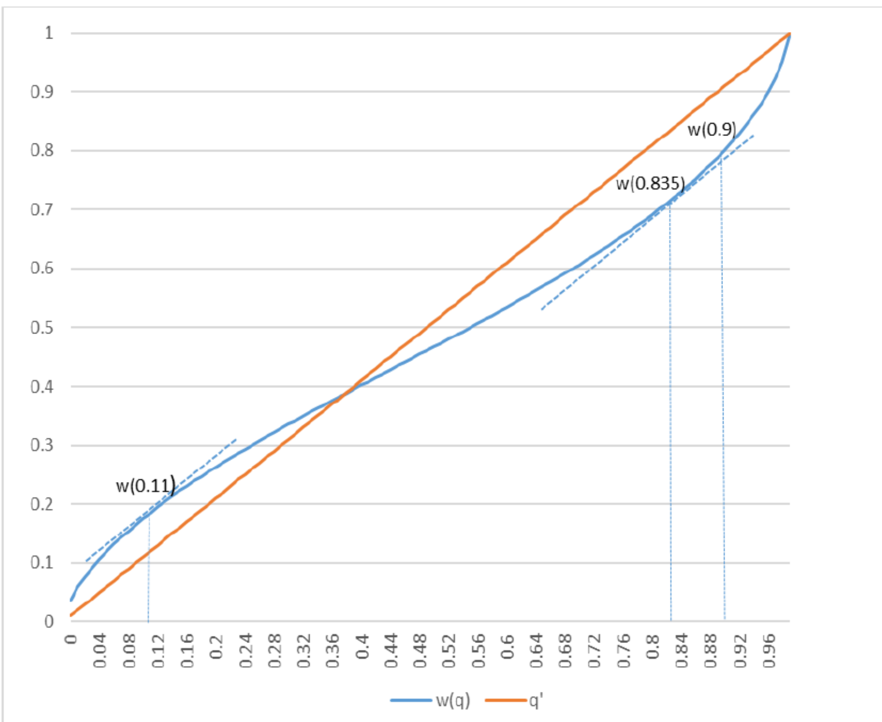
$$\begin{aligned}\pi_i &= \pi(id) \\ &= w(\Pr(D \geq id)) - w(\Pr(D > id)) \\ &= w(q_i) - w(q_{i+1}) \\ &= w(\delta^{i-1}) - w(\delta^i)\end{aligned}$$

For examples,

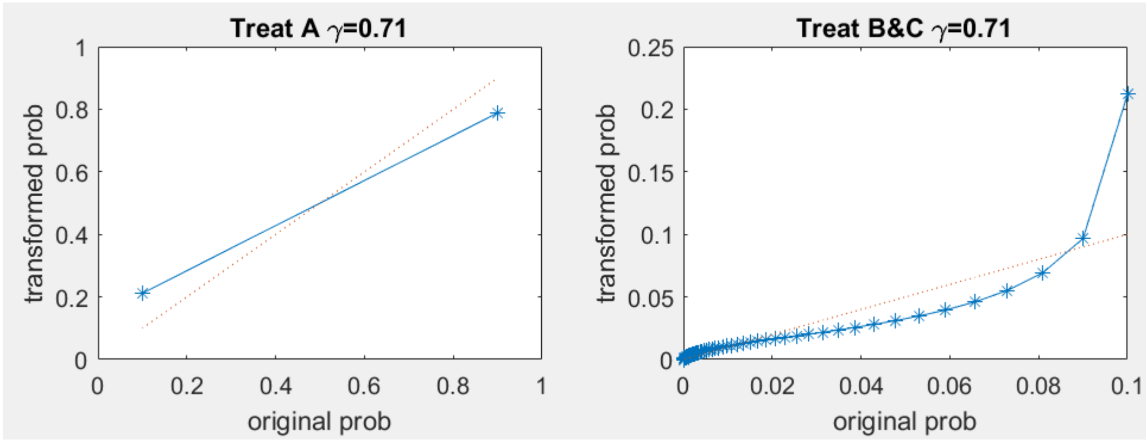
$$\begin{aligned}\pi_1 &= \pi(d) = w\,(1) - w\,(0.9) = 1 - w(0.9), \\ \pi_2 &= w(0.9) - w(0.81).\end{aligned}$$

Note that $\pi(d)$ for treatments B and C is the same as $\pi(bad)$ in treatment A.

As mentioned earlier, for a prospect involving many outcomes, whether an event i is over/under weighted can be approximated by whether $w(q_i) > 1$. In the graph below, we draw the function $w(q)$ using $\gamma = 0.71$ ad the 45^0 line (which corresponds to $\gamma = 1$ and leads to the objective probabilities per se). We solve $w'(q) = 1$ which has two solutions $\underline{q}= 0.11$ and $\bar{q} = 0.835$. Roughly speaking, events with q_i lying within the interval [$\underline{q}$,$\bar{q}$] are underweighted, while those with q_i lying outside the interval are overweighted. In the case of treatments B and C, extremely good and bad outcomes are overweighted, while the outcomes in the middle are underweighted. With $\gamma = 0.71$, we know d and $2d$ are overweighted, and events with more than 22 dividends are also overweighted. The rest are underweighted. The solution 22 is acquired from solving the equation $q_i = \delta^{i-1} = \underline{q}$ or $\bar{\imath} = \frac{\log \underline{q}}{\log \delta} + 1$.



The figure below shows the effect of probability weighting using $\gamma = 0.71$, plotting the transformed probabilities π against the original probabilities (the dotted line is the 45 degree line). For treatment A, after probability weighting, the bad outcome is overweighted, and the good outcome is underweighted. For treatments B and C, the worst two outcomes and very good outcomes are overweighted, and the rest outcomes are underweighted.


Treat A γ=0.71
transformed prob
original prob
0
0.2
0.4
0.6
0.8
1
Treat B&C γ=0.71
0.25
0.2
0.15
0.1
0.05
0.02
0.04
0.06
0.08