Are you experienced? How the time spacing of traders' market experience impacts bubble formation in experimental asset markets

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Abstract: We demonstrate when market experience is spaced out over a longer period of time (weeks instead of minutes), the increase in pricing efficiency is very small - if at all - for the same population of traders. However pricing efficiency gains are substantial for a situation involving new trader cohorts and a new asset. This is demonstrated via controlled laboratory experiments which implement a setting that commonly leads to the formulation of pricing bubbles. In our first study, we compare massed cohorts who complete a sequence of three markets in a single experimental session, and spacing cohorts whose sequence of three markets are spaced a week apart.Massed cohorts do not generate larger bubbles than spaced cohorts in the first two markets, and there is weak evidence that they do in the third market. In contrast we find in an exploratory study, experience gained through spaced repetitions rather than massed repetitions generates smaller bubbles when subjects are recruited to new cohorts and participate in a market for a different asset.

Keywords: Spacing effects; learning; asset market; bubble; laboratory experiment

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1 Introduction

There is some evidence in the literature that less experienced individuals make poorer financial decisions, ceritus paribus, than experienced ones (Ben Zion et al., 2004; Feng and Seasholes, 2005; Chen et al., 2007; Nicolosi et al., 2009; Seru et al., 2010; Ben Zion et al., 2010). Additionally, the larger the contingency of inexperienced traders populating an asset market, the more likely the occurrences of inefficiencies like bubbles and other mispricing (Kandel et al., 1993; Dufwenberg et al., 2005; Greenwood and Nagel, 2009; Korniotis and Kumar, 2011). But what constitutes experience? Is it purely the amount of market participation, or does the calendar time this participation spans matter as well? Using laboratory experiments, we address these questions by controlling the number and timing of cohorts' participation in asset markets.

Overpricing and then crashing to fundamental value is a robust phenomenon in experimental markets for assets with declining fundamental value, and was first discovered by Smith et al. (1988).[1] Their study - and a variety of subsequent ones - showed the incidence and severity of bubbles reduces when traders accrue repeated experience in markets with the identical asset. The procedures for how subjects are exposed to market repetitions have varied across these studies. Some studies (Smith et al., 1988; Porter and Smith, 1995; Fisher and Kelly, 2000; Hussam et al., 2008) use *spaced* exposures in which subjects participate in a series of experimental sessions, each on a different day, with only one market per session. Other studies (Dufwenberg et al., 2005; Haruvy and Noussair, 2006; Haruvy et al., 2007; Kirchler et al., 2012) use *massed* exposures in which subjects attend a single session and participate in consecutive markets.

Our interest in the timing of market exposures stems from the psychology literature on memory recall - particularly studies on learning names (Carpenter and DeLosh, 2005; Ofen-Noy et al., 2003) and advertising effectiveness (Janiszewski et al., 2003) - and skills learning - such as classroom instruction (Smith and Rothkopf, 1984) and motor skills (Lee

and Genovese, 1988). In both literatures spaced repeated presentations of a stimulus led to better learning outcomes - in measurements like recall, retention, and performance - than massed repeated presentations.

There are a multitude of proposed mechanisms for why spaced presentations are more effective than massed presentations. Some mechanisms concern moving knowledge from short-run (working) to long-run memory. For example, elaborative rehearsal is the process of reflecting on the meaning of a new item in short-term memory and associating it with other items in memory. The rehearsal hypothesis (Rundus, 1971), argues there is a capacity on the items that can be held in short-term memory and a massed presentation can disrupt elaborative rehearsal. In other mechanisms, spacing leads to a reconstruction of previous repetitions which are stored in long-term memory (Jacoby, 1983). This reconstruction reinforces the previous exposure and establishes cues for future recall. However, when there is a previous exposure already in the short-term memory, as in a massed presentation, no reconstruction is required and cues are not formed. Neuroscientists have also found correlated differences in neural activity under spaced versus massed presentations (Xue et al., 2010, 2011).

Asset market participation differs from the learning activities considered in these extensive literatures. Market participation is an interactive and complex task. Further, in practice, asset markets are rarely pure replications of past market instances. Hence understanding the effectiveness of alternative ways of garnering experience extends to similar but not identical scenarios is important.

We consider two ways replications of market participation are imperfect. First, we consider a scenario in which the asset and portfolio endowments do not change, but the sequences of realized dividends and prices likely do. Second, we consider the case in which the asset (as defined by its distribution over dividends) and portfolio endowments do change. This latter case is likely more reflective of participation in naturally occurring financial markets.

In this paper, we assess the relative effectiveness of spaced versus massed presentation

of market experience in a controlled way. In our first study, called Baseline, we compare the market and trader performance of cohorts when they are inexperienced, experienced, and twice-experienced in asset market replications that do not change with respect to the asset traded, individual endowments, and the cohort composition. One set of trader cohorts experiences these repetitions in a massed sequence. A second set of trader cohorts experiences them spaced exactly one week apart. The environment of the asset market - endowments, information, and dividend process - is the same as Hussam et al. (2008), but we differ by using a continuous double auction rather than a call market. We observe no difference between spaced and massed cohorts when once-experienced, and weak evidence of greater pricing efficiency in markets when twice-experienced.

In our second study, called Rekindled, we evaluate the impact of massed versus spaced training. We recruit participants from the Basline study to participate in a single market which consists of an alternative asset, different endowments, removing traders with relatively poor performance in the Basline stud, and an exogenous reduction in common knowledge of rationality as subjects no longer can infer level of experience of all other traders. We recruit subjects from across the population of thrice-massed-experienced subjects to form three rekindled massed cohorts; and do likewise to form three rekindled spaced cohorts. With these new cohorts, we test whether thrice-experienced traders create bubbles in the altered environment as Hussam et al. did with twice experienced subjects. Both rekindled massed and spaced cohorts create price bubbles, but the massed cohorts create more severe bubbles. This provides some evidence that learning from spaced repetitions better extrapolates to a market for a similar, but not identically structured, asset.

2 Experimental Design

Our experimental design, presented in Table 1, consists of the Baseline and Rekindled studies. In the Baseline study, eighteen cohorts of nine subjects each participate in a sequence of three asset markets with fifteen trading periods apiece. The primary treatment variable

is the timing between market instances. Ten cohorts experience the massed sequencing of markets in a single session. The other eight cohorts experience the sequencing with exactly one week spacing; sessions take place at the same time on the same day of three consecutive weeks.

Table 1: Experimental design summary: There are 9 traders playing 15 periods in all treatments.

	Baseline study		Rekindled study	
Design variable	Massed	spaced	Massed	spaced
Cohorts	10	8	3	3
Market repetitions	3	3	1	1
Sessions to complete	1	3	1	1
Subjects' prior experience	None	None	Massed	spaced

In the Rekindled study, we create two new types of cohorts. We form a population of potential participants by pooling the top seven highest earners in each baseline massed session. We invite randomly selected members from this population to form the three rekindled massed cohorts. We follow the same recruiting protocol for the baseline spaced sessions to form the three rekindled spaced cohorts. Each of these cohorts attend a single session with a single asset market. This session is approximately four weeks after the participants attended their first session.

The specifics of the asset structures and endowments are as follows. In the Baseline study, each unit of the asset pays a random dividend at the close of each period. A dividend's value is determined by a draw from the uniform multinomial distribution on the set of peso amounts[2] $\{0, 0.8, 2.8, 6\}$. Accordingly, the expected dividend in each period is 2.4 pesos. The fundamental value - defined as the sum of all expected dividends remaining - is 36 pesos in the first period and 0 pesos at the end of the fifteenth period. There are three different endowment portfolio types, varying in their cash/equity ratio but having the same expected value. See Table 2. Three subjects within a cohort are assigned to each portfolio endowment type. Subjects' endowments are the same in each of the three markets.

In the Rekindled study, we change four things. First, the distribution of dividends is uniform over the five potential peso amounts $\{0, 0.1, 0.8, 2.8, 9.8\}$. Hence, the expected dividend amount is 2.7 pesos, and the initial fundamental value is 40.5 pesos. Second, we change the set of three different endowment portfolio types. Again, see Table 2. Notice these first two changes respectively increase both the dividend variance and the market cash/equity ratio. The cohort formation procedure introduces two additional changes. Participants in these new cohorts observe that some of the other participants are not part of their previous Baseline study cohort. Thus participants do not mutually know each other's level of experience. Cheung et al. (2014) showed that this type of common knowledge of rationality is an important influence on the precipitation of bubble formation. By excluding the bottom two earners we introduce a selection effect that can lead to a greater incidence of future bubbles (Gladyrev et al., 2014).

Table 2: Endowment portfolios in the markets of the Baseline and Rekindled studies

Study	Portfolio type [a]	Cash	Asset units	Expected value
Baseline	High cash/equity ratio	108	3	216
	Medium cash/equity ratio	72	4	216
	Low cash/equity ratio	36	5	216
Rekindled	High cash/equity ratio	189	1	220.5
	Medium cash/equity ratio	153	2	234
	Low cash/equity ratio	117	3	238.5

[a] There are nine traders, with three allocated to each portfolio.

Trading in each market takes place in a continuous double auction. Each of the fifteen periods lasts one minute and forty-five seconds. Subjects can submit limit orders (bids and asks) for a single unit subject to improving upon the current bid or ask. The order book is open. Subjects can also make a market buy (sale) at the current bid (ask) if available. The order book is flushed at the conclusion of each trading period. All of the subjects' actions are restricted by the prohibition of borrowing or leveraged purchasing, and a prohibition on short sales. The user interface provides a graphic display and list of all contract prices.[3]

All sessions are conducted at, and cohorts recruited from, Xiamen University, China. Potential subjects are randomly selected from a ORSEE system (Greiner, 2015) recruiting database of undergraduate and graduate students. These selected individuals are sent invitations to join either a massed baseline or spaced baseline cohort. A subject in a massed cohort receives the sum of his earnings from the three markets plus a 10 RMB show-up fee at the end of the experimental session. A subject in a spaced cohort receives the sum of his earnings from the three markets plus a 30 RMB show-up fee, 10 RMB for each session, only at the conclusion of the third session.[4] Subjects in a rekindled session receive their earnings from the single market participation plus a 10 RMB show-up fee.

3 Hypotheses

The fundamental value of an asset in our experiment, assuming all subjects are risk neutral, is the sum of expected future dividends. Given the common knowledge of the asset structure, subjects should calculate the same fundamental value for the asset in each period. Consequently their common maximum willing-to-pay for the asset should equal its fundamental value. Therefore trading with others will not bring more profits than simply holding their asset endowment. So the market should reach a no-trade equilibrium.

The predictions of no-trade equilibrium have been systematically wrong in laboratory asset markets. Previous studies show subjects trade with each other, and that trade prices deviate from the fundamental value. However, increased collective experience amongst the traders leads to outcomes closer to those predicted by the no-trade equilibrium. We expect to replicate such results in our baseline treatments. In addition, we also speculated this experience is more effectively gained through spaced participation in markets rather than massed participation. This greater effectiveness should be reflected in greater price efficiency, lower trade volume, and less variation in final portfolio valuations in the second and third market repetitions of the baseline spaced treatment when compared to the baseline massed treatment.

Our first hypothesis concerns pricing efficiency.

Hypothesis 1 *In the Baseline study, pricing efficiency is greater for spaced than massed cohorts in market repetitions two and three.*

Our second hypothesis states that trading volumes for spaced cohorts is lower than those of massed cohorts. This hypothesis reflects convergence towards a no-trade equilibrium. If the spacing of repetitions leads to more effective learning than massed repetitions, then subjects in spaced cohorts should have understand the structure of the market faster and better than those in the massed cohorts. Having better information about the markets, spaced cohorts should trade less than massed cohorts.

Hypothesis 2 *In the Baseline study, there is lower trade volume in market repetitions two and three for spaced cohorts than massed cohorts.*

Also consistent with the more rapid convergence towards the no-trade equilibrium, are the decreasing opportunities for expected wealth improving trades. Thus, expect lower variance in the terminal portfolio values - earnings - of traders in spaced baseline cohorts.

Hypothesis 3 *In the Baseline study, the variance of traders' final portfolio values is lower in market repetitions two and three for spaced cohorts than massed cohorts.*

Our final hypothesis concerns the extent to which experience translates to non-identical asset markets. Given the findings in psychology that spaced presentations lead to greater cue formations and stronger commitment to long run memory, we formulate our last hypothesis.

Hypothesis 4 *In the Rekindled study, there is greater pricing efficiency in the spaced cohorts than in the massed cohorts.*

4 Data Analysis

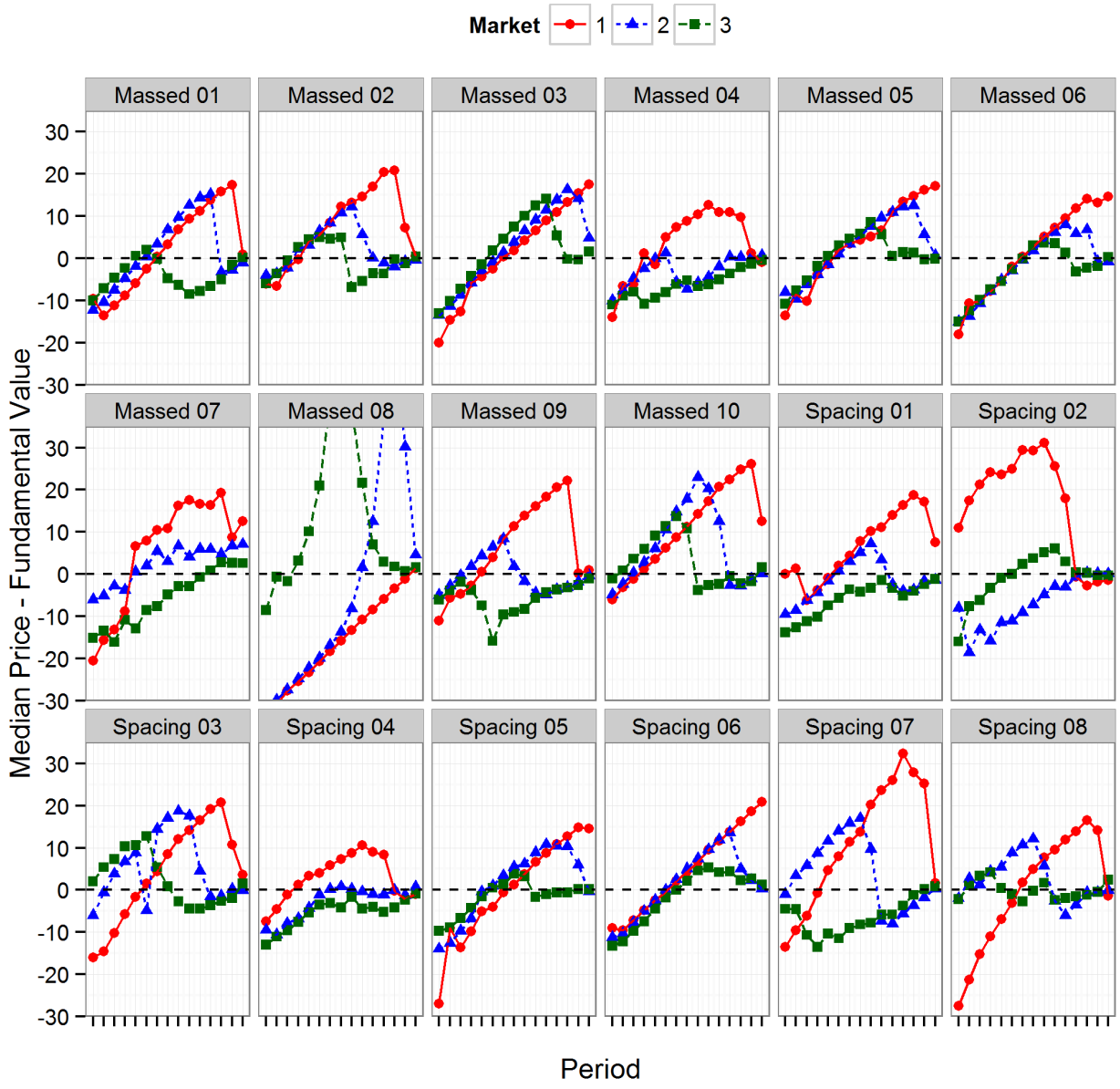
4.1 Baseline study

We start with a data visualization of the baseline cohort market price data that informally exhibits the typical pattern of bubbles with inexperienced subjects that dissipates by the third repetition. Figure 1 is an array of eighteen data plots: one for each of the ten baseline massed cohorts, and one for each of the eight baseline spaced cohorts. Each data plot has three time series of the deviation of the median period price from the fundamental value, one for each market repetition. Casually stated, markets with inexperienced subjects start with initial underpricing. Then the price level does not change much, eventually becoming overpricing. In the majority of cases, the price crashes to the fundamental value in the last period or two. Typically in the second market repetition we still observe a similar price pattern, except the overpricing collapses sooner. This leads to smaller bubbles of a shorter duration. The third repetition usually reflects even less mispricing.[5]

When we aggregate the three time series across cohorts we find similarities and differences between the impacts of massed and spaced presentations. Figure 2 shows the time series for the baseline massed and spaced treatments of the difference between median price and fundamental value averaged across cohorts and weighted by the square-root of volume.[6] For both treatments, repetition clearly reduces bubbles. In addition, the spaced repetitions exhibits earlier and lower bubble peaks in market 2, and no overpricing in market 3. Somewhat unsettling, neither massed nor spaced garnered experience diminish initial underpricing in early market periods.

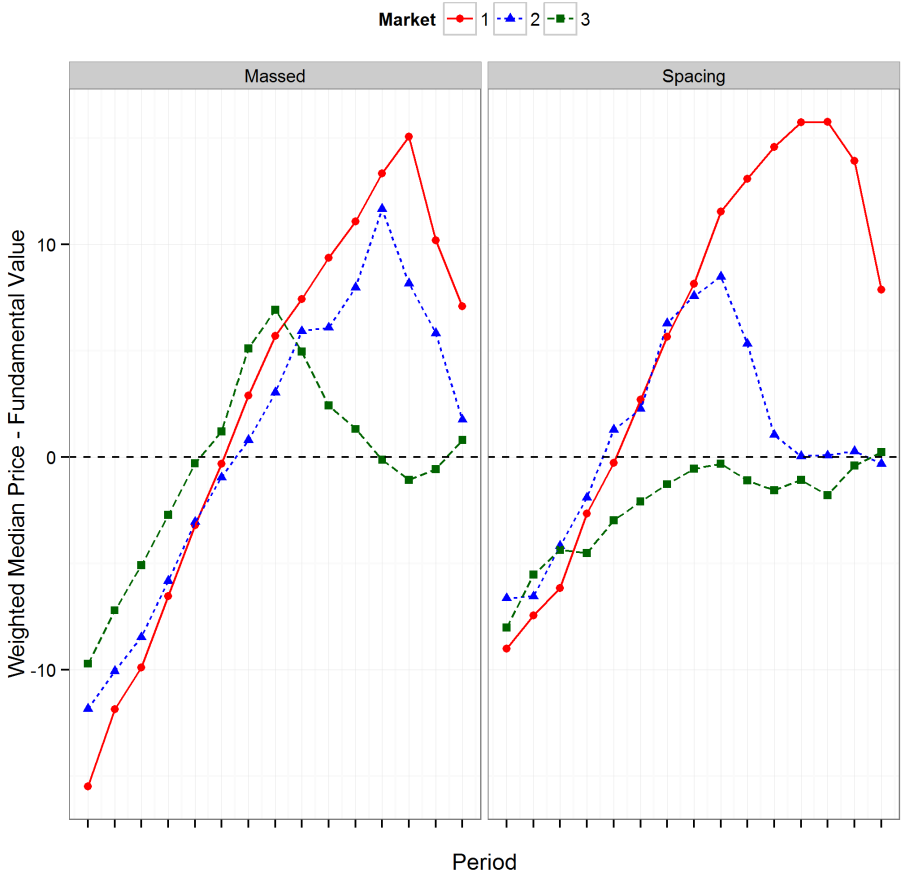
We quantitatively evaluate mispricing, volume, and the variance of portfolio values in our baseline studies. In developing our empirical strategy, we need to account for serial dependence likely present within the data of a market and cohort. So we take an empirically conservative approach and treat the market repetition within a cohort as the unit of observation. We consider the following six statistics.

Figure 1: Time series of the difference in median period price and fundamental value for all baseline cohorts and market repetitions



1. *Relative Deviation*: This variable measures the deviation of average period prices from the fundamental value for market repetition r of cohort type c from period 1 to 15. It is defined as $RD_{cr} = \frac{\sum_{t=1}^{15}(P_{crt}-X_{crt})w_{crt}}{\sum_{t=1}^{15} X_{crt}w_{crt}}$, where P_{crt} is the average price in period t, X_{crt} is the fundamental value of the asset in period t, and w_{crt} the weight given for the observations. If there is no weighting, w_{crt} is always one; when there is weighting w_{crt} is the square root of the volume of trade in period t.

Figure 2: Time series of the square root of trade volume weighted average difference in median period price and fundamental value by baseline cohort type - including session Massed 08



2. *Relative Absolute Deviation*: This variable measures the absolute deviation of average prices from the fundamental value for market repetition r of cohort type c from period n to N. It is defined as $RAD_{crnN} = \frac{\sum_{t=n}^{N} |P_{crt} - X_{crt}| w_{crt}}{\sum_{t=1}^{15} X_{crt} w_{crt}}$.
3. *Relative Median Deviation*: This variable measures the deviation of median period prices from the fundamental value for market repetition r of cohort type c from period n to N. It is defined as $RMD_{crnN} = \frac{\sum_{t=n}^{N} (P'_{crt} - X_{crt}) w_{crt}}{\sum_{t=1}^{15} X_{crt} w_{crt}}$, where P'_{crt} is the median price in period t.
4. *Relative Absolute Median Deviation*: This variable measures the absolute deviation of median prices from the fundamental value for market repetition r of cohort type c from period n to N. It is defined as $RAMD_{crnN} = \frac{\sum_{t=n}^{N} |P'_{crt} - X_{crt}| w_{crt}}{\sum_{t=1}^{15} X_{crt} w_{crt}}$.
5. *Turnover*: This variable measures the trading activity for market repetition r of cohort

type c. It is measured as $Z_{cr} = \sum_{t=1}^{15} V_{crt}/S$, where S is the total units of the asset in the market.

6. *Standard Deviation of Portfolio Values*: This variable measures the variation of subjects' earnings at the end of market repetition r of cohort type c. It is defined as the standard deviation of the final market cash holdings of the nine subjects in a cohort possess when period 15 of a market concludes and the final dividend has been paid.

Differences in pricing efficiency are not significant between the massed and spaced cohorts for markets 1 and 2. Pricing efficiency is marginally greater for the spaced cohorts in market 3 according to the RAD and $RAMD$ criteria when using weighted versions of the measures. We report the average values of RD, RAD, RMD and $RAMD$ measures in Table 3 for the various markets repetitions and cohorts, using weighted and unweighted observations. The p-value columns report the results of the Wilcoxon rank sum tests for the null hypothesis that RD (RAD, RMD, $RAMD$) was the same for massed and spaced cohorts with the one-sided alternative that it is greater for the massed cohorts. Weakly significant differences, at the 10% level of significance, are found for both RAD and $RAMD$ in market 3 when observations are weighted. Overall, there is scant support for Hypothesis 1; pricing efficiency is not clearly greater in spaced presentations.

There is no difference in the turnover or standard deviation of final market portfolio values between baseline massed and spaced treatments. Panel A of Table 4 shows the average turnover for the massed and spaced baseline cohorts, as well as the p-value of the Wilcoxon rank sum tests of differences in cohort averages, for each of the three market repetitions. While turnover is decreasing in market repetitions, the levels at each repetition are very similar for both cohort types and not statistically different. Panel B of Table 4 shows the standard deviation of final portfolio values for the massed and spaced baseline cohorts, as well as the p-value of the Wilcoxon rank sum tests of differences in cohort averages, for each of the three market repetitions. Again we find the variation in traders' market earnings declines with market repetitions, but find no difference whether the experience is garnered

Table 3: Pricing efficiency in the Baseline study: Average RD,RAD,RMD, $RAMD$, and p-values of the Wilcoxon rank sum tests of equal price efficiency in massed and spaced cohorts

Panel A: RD price efficiency measures

	Obs. weighted			Obs. unweighted		
Market	Massed	Spaced	p-value	Massed	Spaced	p-value
1	14.3%	32.3%	0.71	14.0%	30.6%	0.65
2	3.6%	0.6%	0.38	5.5%	1.3%	0.41
3	−6.0%	−12.0%	0.35	−4.6%	−13.0%	0.26

Panel B: RAD price efficiency measures

	Obs. weighted			Obs. unweighted		
Market	Massed	Spaced	p-value	Massed	Spaced	p-value
1	52.0%	55.2%	0.59	52.7%	56.4%	0.65
2	39.3%	32.5%	0.55	39.4%	31.3%	0.38
3	30.9%	23.1%	0.10	31.5%	24.1%	0.26

Panel C: RMD price efficiency measures

	Obs. weighted			Obs. unweighted		
Market	Massed	spaced	p-value	Massed	spaced	p-value
1	13.5%	31.5%	0.71	13.4%	29.8%	0.71
2	2.8%	1.4%	0.38	4.6%	1.7%	0.48
3	−6.0%	−11.6%	0.35	−4.6%	−12.6%	0.29

Panel D: $RAMD$ price efficiency measures

	Obs. weighted			Obs. unweighted		
Market	Massed	Spaced	p-value	Massed	Spaced	p-value
1	52.9%	54.7%	0.59	53.6%	56.0%	0.68
2	38.7%	31.4%	0.48	38.7%	30.5%	0.41
3	30.7%	22.7%	0.07	31.3%	23.7%	0.20

in a massed or spaced manner. We reject both hypotheses 2 and 3; while there is evidence that experience led volume and portfolio variation toward the no-trade equilibrium levels, for these variables the rate of convergence did not depend upon the calendar time of repetitions.

Table 4: Average turnover and standard deviation of cohort's final portfolio values with results of Wilcoxon rank sum tests for treatment differences

Panel A: Average turnover

Market	Massed	Spaced	p-value
1	4.8	4.9	0.27
2	3.2	3.1	0.41
3	2.4	2.2	0.24

Panel B: Average standard deviation of cohort's final portfolio values

Market	Massed	Spaced	p-value
1	112.8	108.6	0.32
2	74.1	65.7	0.52
3	53.9	47.6	0.23

4.2 Rekindled study

Our analysis now turns to the Rekindled study and the question of whether experience garnered with spaced repetitions led to more effective pricing efficiency and effective learning of the no-trade equilibrium. We start by presenting the plots of the time series of the differences in median period price and fundamental value for each of the three rekindled massed and rekindled spaced cohorts in Figure 3. From this figure, we can see all six cohorts generated bubbles as in Hussam et al.. This extends the domain of their"recipe" for rekindling bubbles to thrice-experienced subjects in continuous double auctions under either massed or spaced repetitions. Further, we can see that the bubbles are generally larger in the rekindled massed cohorts than the rekindled spaced cohorts. Figure 4 presents the square root of volume weighted averages of these mispricing series for both massed and spaced cohorts. The average bubble is larger and more pronounced for the massed cohorts.

We next provide a statistical assessment of this difference in mispricing. Since we only have three independent observations for each cohort type the Wilcoxon rank sum tests are quite weak. Despite this weakness we find statistical significance in all RD, RAD, RMD and $RAMD$ price efficiency measures. In Panel A and B of Table 5 we show some performance statistics similar to those in our baseline treatments.RD, RAD, RMD and $RAMD$ are

Figure 3: Time series of the difference in median period price and fundamental value for all rekindled cohorts and market repetitions

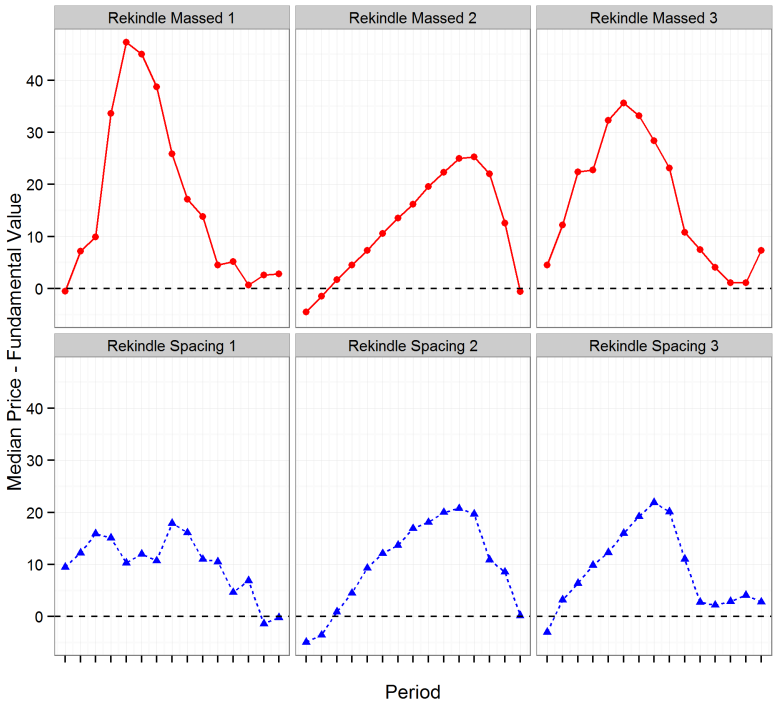
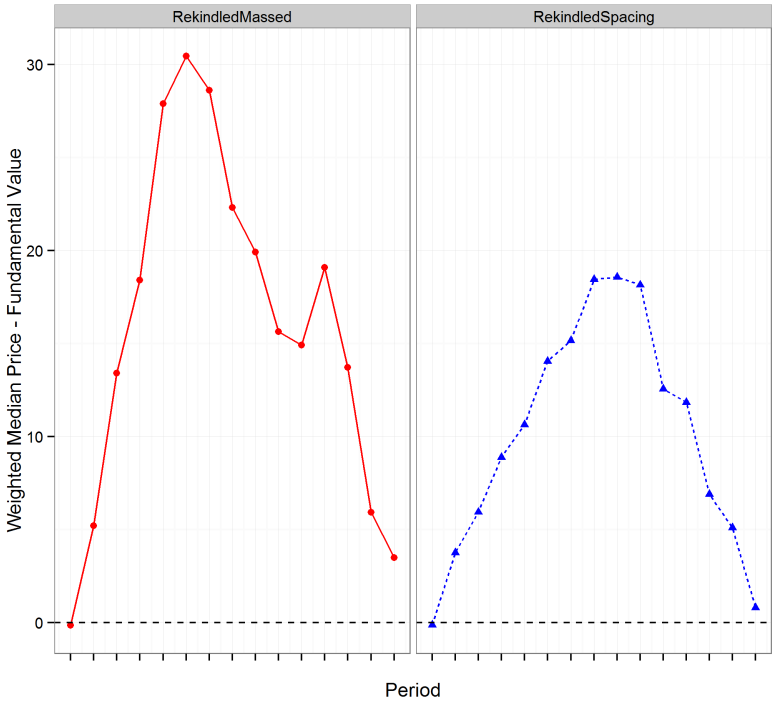


Figure 4: Time series of the square root of trade volume weighted average difference in median period price and fundamental value by rekindled cohort type



statistically smaller at the 5% level of significance in the rekindled-spaced treatment than in the rekindled-massed treatment This is true whether we use weighted or unweighted observations. At the same time, we do not see meaningful differences in turnover or the variance of earnings which are reported in Panel C of Table 5. In summary, we find mild evidence that spacing of market repetitions led to more effective learning in non-identical but similar market environments, confirming hypothesis 4.

Table 5: Performance statistics and hypothesis tests for the Rekindled study

Panel A: RD and RAD price efficiency measures

	RD measure			RAD measure		
	Massed	Spaced	p-value	Massed	Spaced	p-value
Observations weighted	72.2%	45.1%	0.05	73.8%	47.2%	0.05
Observations unweighted	69.2%	43.8%	0.05	70.6%	46.0%	0.05

Panel B: RMD and $RAMD$ price efficiency measures

	RMD measure			$RAMD$ measure		
	Massed	Spaced	p-value	Massed	Spaced	p-value
Observations weighted	72.5%	45.8%	0.05	74.3%	48.4%	0.05
Observations unweighted	69.4%	44.2%	0.05	70.8%	46.9%	0.05

Panel C: Averages of turnover and standard deviation of final portfolio values

Statistic	Massed	Spaced	p-value
Turnover	8.3	11.1	1.00
σ portfolio	80.8	68.1	0.20

5 Discussion

We examine the relative impacts of experience gained through massed and spaced repetitions of an experimental asset market. We learned that while spacing repetitions does not improve pricing efficiency in the baseline study, those with spaced experience generated smaller bubbles when participating in a later market for an asset with greater liquidity, a lack of common knowledge of rationality, and greater dividend variance. We believe this makes a significant contribution to the methodology of conducting experimental asset mar-

kets. In these studies, the level of experience is often an important, and sometimes the only, factor leading to improved market efficiency. We show that how the researcher chooses to cultivate and control that experience is can be influential for studies that repeat the same environment, and that spaced participation is more desirable. Although we suggest these insights come from the caveat that are exclusively Chinese university student subject pool, and that researchers should consider the external validity of these results.

We also make a smaller contribution to a larger problem: How to regulate new individual investors to financial markets. With the increasing size and access to financial markets in large and developing markets like China, there is potential for exploitation of new investors by unscrupulous financial institutions, high incidence new investors suffering losses due to poor decisions borne by their inexperience, or greater likelihood for the precipitation of large asset bubbles such as experienced by Chinese stock exchanges in the 2015-2016 period. An important policy issue is how to best regulate such new participants. Our results suggest potential benefits to moderating the trading activities of these new investors by forcing spacing of their decisions rather than simply letting them "take their lumps." For example, our results suggest it may be prudent to force first time home buyers to wait a certain time before they can purchase additional properties. At the same time we caution that since our results are the first to rigorously control the timing between financial decisions; further investigation is warranted and advisable.

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Notes

[1]See Palan (2013) for a recent survey on this extensive literature.

[2]Prices and earnings in our experiments are measured in pesos. The conversion rate to the local currency Renminbi is 1 RMB per 7 pesos.

[3]The experimental software is developed in z-Tree (Fischbacher, 2007).

[4]Subject attrition is an *ex ante* concern for the baseline spaced cohorts. One cohort experienced attrition for the second session. We responded by conducting the market with the eight remaining subjects, and cancelled the third session. Another cohort had two no-shows for the last session. Again we conducted the market with the remaining subjects. We do not report the data from these two cohorts. While the no-shows came from the lower half performers of their cohorts, there is not enough data to establish any selection bias in returning for further sessions.

[5]Our baseline massed cohort 8 is an interesting outlier. There is no bubble in market 1, just simply low median prices throughout. In markets 2 and 3, one subject buys most of the assets at the early low prices, establishing a monopoly position. He then sells the assets while other subjects bid the prices up. Our statistical results do not change if we exclude the data from this cohort.

[6]In our analyses we use both arithmetic averages and averages weighted by the square root of trade volume. The latter can be a more asymptotically efficient estimate of a point θ for which the distribution function F has finite variance and a continuous density function f symmetric around θ. Consider a collection of M independent random samples, indexed by m, each with the numbers of independent observations k_m. A typical sample is denoted $\{x_1, \ldots, x_{k_m}\}$ and the sample mean is $\bar{x}_m$. Then each of the sample means converges in distribution to $N(\theta, \sigma_F^2/k_m)$, and $\tilde{\theta} = \sum_{m=1}^{M} \bar{x}_m \sqrt{k_m} / \sum_{m=1}^{M} \sqrt{k_m}$ is more efficient than $\hat{\theta} = \sum_{m=1}^{M} \bar{x}_m / M$. Likewise each of the sample medians converges in distribution to $N(\theta, 1/4k_m f(\theta)^2)$, and $\tilde{\theta} = \sum_{m=1}^{M} Med_m \sqrt{k_m} / \sum_{m=1}^{M} \sqrt{k_m}$ is more efficient than $\hat{\theta} = \sum_{m=1}^{M} Med_m / M$ (Serfling, 2009).

APPENDICES NOT INTENDED FOR PUBLICATION

Appendix A: Experiment instructions for massed cohort session - translated from Mandarin

I: General instructions

Today you are participating in an experiment that studies asset markets. Your decisions will determine your earnings. Please read these instructions carefully.

Do not use mobile phones, laptop computers, or use the lab's desktop computer other than for the experiment. During the experiment, please refrain from talking or looking at the computer monitors of others. If at some point you have a question, please raise your hand and we will address it as soon as possible.

In today's experiment you will participate in a sequence of 3 separate and independent asset markets. The currency used in the market is called pesos. When a market is closed, your pesos earnings from the market will be converted to RMB at a rate of 1 RMB per 7 pesos. Your final cash payoff will be the sum of all markets' cash payoffs plus a 10 RMB participation fee.

After the trading in the first market, there will be a 10-minute break. During the break, please refrain from talking or looking at the computer monitors of others. If you want to use the bathroom, please go one by one. At the conclusion of the experiment, please sit quietly. We will call participants up one at a time to the sign-in counter. There you will privately receive your earnings. We will not reveal your earnings to any other subject, or any other subject's earnings to you. Nor will we provide any information about how your earnings compare to the earnings of others.

II: Asset market participation

Today you will sequentially participate in 3 asset markets. These 3 markets are independent in the sense your peso earnings in each market are unrelated. Despite this independence, these markets have a similar structure. The trading system, trading rules and assets traded are the same in all 3 asset markets. Also, every market lasts for 15 trading periods, and each period lasts 1 minute and 45 seconds.

We next will answer the following three questions.
1) What is the asset that you will trade in a market?
2) How does the trading system work?
3) How to make trades in a market?

What is the asset we will trade?

In all markets there is a single type of asset you can buy or sell. Before the start of each market, every participant is given several units of the assets and a certain amount of pesos. The amount of pesos you hold at any point in time is called your currency holdings.

At the end of each trading period, every unit of the asset pays a dividend. A dividend is an amount of pesos paid to the owner of each asset unit. This amount is the same for each asset unit, but the amount may differ across periods. When you receive a dividend, that amount is added to your currency holdings. There are four possible dividend values: 0, 0.8,

2.8 and 6 pesos. Each dividend value has a probability of 1/4 to appear in every period. For example, if you have 3 assets at the end of period 4 and the dividend for that period is 2.8 pesos, then 8.4 pesos ($2.8 * 3 = 8.4$) will be added to your currency holdings at the end of period 4.

During an asset market, each period's dividend will be revealed at the end of the period. The only information you will receive regarding current and future dividend amounts is the four possible values for dividend. (This information is provided in the upper left of the trading screen.)

You currency balance – adjusted for any dividend income - and inventory of assets will carry over in each trading period of an asset market. For example, if you have 4 assets and 80 pesos dollars at the end of period 2, and the dividend of period 2 is 0.8 pesos, then you will have 4 assets and 83.2 pesos ($80 + 0.8 * 4 = 83.2$) at the beginning of period 3. However, the inventory of assets and your currency balance will not carry over in different asset markets, i.e. different sub-experiments.

At the conclusion of the market i.e., after dividend payments of period 15 - the experimenter will redeem each unit of the asset for 0 pesos. Your total redemption amount, which is always 0, will be added to your final currency holdings to determine your market earnings. For example, if at the conclusion of the 15th period you own 2 assets and 100 pesos, and the dividend of period 15 is 6 pesos, then the experimenter will buy your 2 assets by paying you 0 peso. Thus, in this example, the asset market earnings would be $100 + 0 + 6 * 2$ or 112 pesos.

To summarize, your earnings will be:
+ the sum of your dividends;
+ the sum of currency you receive from selling assets;
- the sum of currency you used in purchasing assets;
+ the redemption value of any asset units held after the last period of trading, which is 0 for all asset markets.

How does the trading system work?

In the trading system for the asset market, as a trader, you can act as both a seller and a buyer of units of the asset. Once you enter the trading screen, you can trade until the remaining time (showed in the upper right-hand of the screen) turns to zero.

The market view has six areas:

1) In the upper left-hand corner you will find a table showing the four possible values of dividend, and the final asset redemption value.

2) Below the first area is another table which shows the current number of assets you own, the number of assets you have available to sell or offer for sale, the amount of pesos you currently hold, and the amount of currency available you have to purchase or to make bids to purchase units of the asset.

3) The top right-hand side of the screen provides for each trading period you final currency and asset holdings, the dividend value, period dividend income, and final currency holding adjusted for this dividend income. Below this area is a pair of tables showing lists of the units sold and purchased for the current trading period.

4) The center area of your screen is where you take market actions and can observe current market conditions. Here you can enter a bid price at which you are willing to purchase a unit in the 'Enter Bid' box, then click "Bid", or you can click on the 'Buy' button in the

'Market Buy' to purchase a unit at the current lowest ask (offer to sell) price in the market. You can enter an ask price at which you are willing to sell a unit in the 'Enter Ask' box, or you can click on the 'Sell' button in the 'Market Sell' box to sell a unit at the current highest bid in the market.

The 'List of Bids' and 'List of Asks' provide public information on current market conditions (all participants see this information except which Bid/Ask prices belong to specific other participants.) 'List of Bids' gives all of the available (waiting to be accepted) Bids in the market and the 'List of Asks' gives all of the available Asks in the market. Your outstanding bids and asks will be given in Blue text. Note that you can delete one of your bids or asks by selecting it using your mouse and then clicking on the delete button.

5) On the right hand side of your screen you find two summaries for contract prices for the current period. First, there is a table which gives the last trade price at the top and then sequence of previous trading prices. Below this table, you will find a graph displaying the current trading period asset prices.

6) Finally, the bar at the top of the screen shows the current trading period and the time remaining in the period.

How to make trades?

As suggested there are four types of actions you can take in a trading period; (1) submit a bid price to purchase a unit, (2) submit an ask price to sell a unit, (3) purchase a unit by accepting the lowest outstanding ask, and (4) sell a unit by accepting the highest outstanding bid. You can also do these in any sequence you want. For example, you can simultaneously have an outstanding bid, an outstanding ask, and then purchase at the lowest ask in the market (as long as it isn't your outstanding ask.) You may also have multiple outstanding bids and/or asks at a given time.

There are some basic rules governing what bids and asks you may submit or accept. 1) When you submit a new bid, it must be larger than the current highest bid and you must have at least the bid amount of currency available. 2) When you submit a new asks, it must be smaller than the current lowest ask and you must have at least one unit of the Asset in inventory (Note, whenever you successfully submit an ask your inventory of available assets is reduced by one.) 3) If you attempt to buy a unit at the current lowest ask, then you must have enough available currency and you can't purchase from yourself. 4) If you attempt to sell at the current bid, you must have a unit available and you can't sell to yourself. 5) You may delete any bid or ask you submit as long as it is neither the current highest bid or lowest ask. 6) If you submit a new bid higher than the current lowest ask, the contract price will be the current lowest ask; if you submit a new ask lower than the current highest bid, the contract price will be the current highest bid. For example, if the current lowest ask is 30 pesos while you submit a new bid at 40 pesos, the contract occurs and the price will be 30 pesos.

When a contract occurs, the associated bid or ask is removed to from the List of Bids or Asks. If you are involved in the contract, your currency holdings and asset inventory will be automatically adjusted. Finally, when the trading period ends all bids and asks are removed from the appropriate lists (and the associated asset units and currency are credited back to the participants)

To summarize, you may purchase a unit of the asset in two ways; you may submit a bid price to buy that becomes the current highest bid and another participant 'sells' to you, or

you may choose to 'buy' at the current lowest ask. Likewise you may sell an asset in two ways; you may submit an ask price to sell that becomes the current lowest ask and another participant 'buys' from you, or you may choose to 'sell' at the current highest bid.

Appendix B: Experiment instructions for spacing cohorts - translated from Madarin

I: General instructions

Today you are participating in an experiment that studies asset markets. Your decisions will determine your earnings. Please read these instructions carefully.

Do not use mobile phones, laptop computers, or use the lab's desktop computer other than for the experiment. During the experiment, please refrain from talking or looking at the computer monitors of others. If at some point you have a question, please raise your hand and we will address it as soon as possible.

This experiment consists of three same sub-experiments. You are required to participate in ALL of the three experiments which will be conducted at the same time each week, and each time you will read the same instruction.

Each time, you will participate in a separate and independent asset market. The currency used in the market is called pesos. When a market is closed, your pesos earnings from the market will be converted to RMB receivable at a rate of 1 RMB per 7 pesos. Besides, you will earn 10 RMB participation fee receivable each time. Your final cash payoff will be the sum of all of the three experiments' cash payoffs plus 30 RMB participation fee. You will receive your total earnings only after you have finished ALL of the three experiments. If you cannot participate in any one of them, you will receive nothing.

When one experiment ends, please sit quietly. We will call participants up one at a time to the sign-in counter. At the end of the first two experiments, you will check your earnings in the experiment; at the end of the third experiment, you will privately receive your earnings for all three experiments. We will not reveal your earnings to any other subject, or any other subject's earnings to you. Nor will we provide any information about how your earnings compare to the earnings of others.

II: Asset market participation

Each time, you will participate in 1 asset markets. In total you will sequentially participate in 3 markets, which are independent in the sense your peso earnings in each market are unrelated. Despite this independence, these markets have a similar structure. The trading system, trading rules and assets traded are the same in all 3 asset markets. Also, every market lasts for 15 trading periods, and each period lasts 1 minute and 45 seconds.

We next will answer the following three questions.

1) What is the asset that you will trade in a market?
2) How does the trading system work?
3) How to make trades in a market?

What is the asset we will trade?

In all markets there is a single type of asset you can buy or sell. Before the start of each market, every participant is given several units of the assets and a certain amount of pesos.

The amount of pesos you hold at any point in time is called your currency holdings.

At the end of each trading period, every unit of the asset pays a dividend. A dividend is an amount of pesos paid to the owner of each asset unit. This amount is the same for each asset unit, but the amount may differ across periods. When you receive a dividend, that amount is added to your currency holdings. There are four possible dividend values: 0, 0.8, 2.8 and 6 pesos. Each dividend value has a probability of 1/4 to appear in every period. For example, if you have 3 assets at the end of period 4 and the dividend for that period is 2.8 pesos, then 8.4 pesos ($2.8 * 3 = 8.4$) will be added to your currency holdings at the end of period 4.

During an asset market, each period's dividend will be revealed at the end of the period. The only information you will receive regarding current and future dividend amounts is the four possible values for dividend. (This information is provided in the upper left of the trading screen.)

You currency balance – adjusted for any dividend income - and inventory of assets will carry over in each trading period of an asset market. For example, if you have 4 assets and 80 pesos dollars at the end of period 2, and the dividend of period 2 is 0.8 pesos, then you will have 4 assets and 83.2 pesos ($80 + 0.8 * 4 = 83.2$) at the beginning of period 3. However, the inventory of assets and your currency balance will not carry over in different asset markets, i.e. different sub-experiments.

At the conclusion of the market i.e., after dividend payments of period 15 - the experimenter will redeem each unit of the asset for 0 pesos. Your total redemption amount, which is always 0, will be added to your final currency holdings to determine your market earnings. For example, if at the conclusion of the 15th period you own 2 assets and 100 pesos, and the dividend of period 15 is 6 pesos, then the experimenter will buy your 2 assets by paying you 0 peso. Thus, in this example, the asset market earnings would be $100 + 0 + 6 * 2$ or 112 pesos.

To summarize, your earnings will be:
+ the sum of your dividends;
+ the sum of currency you receive from selling assets;
- the sum of currency you used in purchasing assets;
+ the redemption value of any asset units held after the last period of trading, which is 0 for all asset markets.

How does the trading system work?

In the trading system for the asset market, as a trader, you can act as both a seller and a buyer of units of the asset. Once you enter the trading screen, you can trade until the remaining time (showed in the upper right-hand of the screen) turns to zero.

The market view has six areas:

1) In the upper left-hand corner you will find a table showing the four possible values of dividend, and the final asset redemption value.

2) Below the first area is another table which shows the current number of assets you own, the number of assets you have available to sell or offer for sale, the amount of pesos you currently hold, and the amount of currency available you have to purchase or to make bids to purchase units of the asset.

3) The top right-hand side of the screen provides for each trading period you final currency and asset holdings, the dividend value, period dividend income, and final currency holding

adjusted for this dividend income. Below this area is a pair of tables showing lists of the units sold and purchased for the current trading period.

4) The center area of your screen is where you take market actions and can observe current market conditions. Here you can enter a bid price at which you are willing to purchase a unit in the 'Enter Bid' box, then click "Bid", or you can click on the 'Buy' button in the 'Market Buy' to purchase a unit at the current lowest ask (offer to sell) price in the market. You can enter an ask price at which you are willing to sell a unit in the 'Enter Ask' box, or you can click on the 'Sell' button in the 'Market Sell' box to sell a unit at the current highest bid in the market. The 'List of Bids' and 'List of Asks' provide public information on current market conditions (all participants see this information except which Bid/Ask prices belong to specific other participants.) 'List of Bids' gives all of the available (waiting to be accepted) Bids in the market and the 'List of Asks' gives all of the available Asks in the market. Your outstanding bids and asks will be given in Blue text. Note that you can delete one of your bids or asks by selecting it using your mouse and then clicking on the delete button.

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6) Finally, the bar at the top of the screen shows the current trading period and the time remaining in the period.

How to make trades?

As suggested there are four types of actions you can take in a trading period; (1) submit a bid price to purchase a unit, (2) submit an ask price to sell a unit, (3) purchase a unit by accepting the lowest outstanding ask, and (4) sell a unit by accepting the highest outstanding bid. You can also do these in any sequence you want. For example, you can simultaneously have an outstanding bid, an outstanding ask, and then purchase at the lowest ask in the market (as long as it isn't your outstanding ask.) You may also have multiple outstanding bids and/or asks at a given time.

There are some basic rules governing what bids and asks you may submit or accept. 1) When you submit a new bid, it must be larger than the current highest bid and you must have at least the bid amount of currency available. 2) When you submit a new asks, it must be smaller than the current lowest ask and you must have at least one unit of the Asset in inventory (Note, whenever you successfully submit an ask your inventory of available assets is reduced by one.) 3) If you attempt to buy a unit at the current lowest ask, then you must have enough available currency and you can't purchase from yourself. 4) If you attempt to sell at the current bid, you must have a unit available and you can't sell to yourself. 5) You may delete any bid or ask you submit as long as it is neither the current highest bid or lowest ask. 6) If you submit a new bid higher than the current lowest ask, the contract price will be the current lowest ask; if you submit a new ask lower than the current highest bid, the contract price will be the current highest bid. For example, if the current lowest ask is 30 pesos while you submit a new bid at 40 pesos, the contract occurs and the price will be 30 pesos.

When a contract occurs, the associated bid or ask is removed to from the List of Bids or Asks. If you are involved in the contract, your currency holdings and asset inventory will be

automatically adjusted. Finally, when the trading period ends all bids and asks are removed from the appropriate lists (and the associated asset units and currency are credited back to the participants)

To summarize, you may purchase a unit of the asset in two ways; you may submit a bid price to buy that becomes the current highest bid and another participant 'sells' to you, or you may choose to 'buy' at the current lowest ask. Likewise you may sell an asset in two ways; you may submit an ask price to sell that becomes the current lowest ask and another participant 'buys' from you, or you may choose to 'sell' at the current highest bid.

Appendix C: Screen capture of the trading screen