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John Griffin
Fordham University, Department of Economics
Ph.D. Candidate

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Department of Economics
Fordham University
441 E Fordham Rd, Dealy Hall
Bronx, NY 10458
(718) 817-4048

Risk Premia and Knightian Uncertainty in an Experimental Market Featuring a Long-Lived Asset

By John Griffin*

This study examines risk premia in a laboratory market featuring a long-lived asset. The research is enabled by prevention of the persistent bubbles and crashes endemic to laboratory markets utilizing long-lived assets. Positive, statistically significant risk premia are reported, in support of standard asset pricing models. Potential determinants of the risk premia are investigated. These risk premia are not sensitive to expected variance, but do vary positively with the magnitude of potential loss. Also investigated is the influence of Knightian uncertainty on market behavior. No evidence of positive return premia related to uncertainty is found. However contrary to most of the results of prior studies, which utilize short-lived assets, in these data uncertainty is associated with significantly higher trading volume. An explanation consistent with microeconomic theory is discussed.
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In standard theoretical asset valuation models risk is a key determinant of expected returns, and by extension asset prices. Positive risk premia have not been consistently supported, however, in field research (Fama and French 2004). In the field there are measurement problems relating to both risk and expected return, and of course there is an enormous amount of noise. Laboratories are, potentially, ideal places to test theories regarding risk and expected return. In particular, ex-ante risk and expected return can be controlled and measured. And indeed in individual choice laboratory experiments, behavior that appears to be broadly consistent with risk aversion is reported (see for example Binswanger 1980, Smith and Walker 1983, and Holt and Laury 2002). Furthermore, in laboratory asset markets with short-lived assets— assets that live for typically one or two periods— positive implied risk premia are reported (Plott and Bossaerts 2004). However these results have not translated to laboratory asset markets with long-lived— typically 10 to 15 period— assets. In laboratory markets with long-lived assets, pricing which persists below expected value (hereafter EV) and which implies risk aversion is rare. One may wonder if there is some inherent feature of long-form markets that makes price resistant to the influence of risk aversion. Furthermore,

* Mr. Griffin is a Ph.D. candidate at Fordham University (email:jgriffin19@fordham.edu). He is also an economist with the U.S. Department of Defense. Sean Collins, Bartholomew Moore, Troy Tassier, Duncan James and Mark Merzon provided helpful conversations and feedback.

the inability to reveal positive implied risk premia in experimental markets featuring long-lived assets is, especially in light of the difficulties encountered in identifying positive risk premia in the field, a challenge for standard asset valuation models. I propose that a primary reason for the lack of positive implied risk premia in long-form laboratory markets is the prevalence of bubbles and crashes in such markets. In this study I encourage quick equilibration on fundamental value (hereafter FV) using a cocktail of 'best practices' developed by many researchers over the past two decades. In the context of this study, FV is the equilibrium price in a market comprised solely of informed, rational investors and devoid of speculative activity. A primary result is that clear, persistent, positive implied risk premia emerge, supporting standard economic theory. To my knowledge, this is the first study to report positive and statistically significant implied risk premia in laboratory markets with long-lived assets. (Note that henceforth I omit the word implied, but in this paper risk premia and risk aversion are always implied, as it is generally not possible to be certain about the motivations behind subjects' or investors' actions).

Having unearthed positive risk premia, I proceed to investigate what forms of risk the premia are sensitive to. My experimental design features return distributions that are non-normal and skewed, allowing for the investigation of the roles of both expected variance and upside/downside potential. The results are consistent with the notion that, at least within the context of this study, some combination of loss aversion and desire for positive skew drives expected returns. Expected variance does not appear to be priced. Variance is prominently featured in Markowitz mean-variance analysis, which is also a foundation of the CAPM (see Markowitz 1952, Sharpe 1964, Lintner 1965, Black 1972, Merton 1973, and Merton 1980). It is often held that the value of variance as a measure of risk does not persist in the context of non-normal return distributions. This thinking is not uniform, however. See for example Markowitz (2014). Variance is also used in the practitioner community, even where it is acknowledged that return distributions are not normal. Beyond being used, along with standard deviation, as a stand-alone measure of risk, variance is embedded in some Discounted Cash Flow models, where the Weighted Average Cost of Capital is a function of a CAPM-derived beta. Apart from variance, other determinants of pricing highlighted in the literature and in industry practice include downside risk and positive skew, see for example Roy (1952), Thaler and Benartzi (1995), Brunnermeier, Gollier and Parker (2007), and Barberis and Huang (2008). Broadly speaking, the basis for using downside risk or positive skew as determinants of expected returns is the proposition that investor behavior is motivated by some combination of fear and greed— investors like high upside and low downside.

In addition to exploring the role of risk in asset pricing, I investigate the effect of uncertainty on market dynamics in the context of a long-lived asset. Uncertainty, in the sense of Knight (1921), is distinct from risk. Uncertainty is present when information on the probabilities of potential future states is missing. Uncertainty may be an important factor in decision making and asset pricing, yet much remains to be done regarding exploration of the topic in laboratory asset market research. Note that many researchers refer to Knightian uncertainty as ambiguity. In this paper I use the word uncertainty in place of the word ambiguity, but the meaning is the same.

With regards to pricing, in my data there is no evidence that the presence of uncertainty lowers asset prices. This result contributes to a contentious debate that stretches back almost 100 years (see for example Knight 1921, Keynes 1921, Arrow 1951, Savage 1954, and Ellsberg 1961). Beyond effects on price, this study also examines whether uncertainty plays a role in trading activity. The data present a significantly positive relationship between uncertainty and trading volume. This result is contrary to most, but not all, of the limited previous experimental research on the topic (Corgnet, Kujal and Porter 2012, and Fullbrun, Rau and Weitzel 2014). However, an explanation consistent with microeconomic theory is apparent. Introduction of uncertainty may lead to differing opinions as to the EV of the asset or the likely actions of other traders, both of which could result in increased trading activity. Furthermore varying levels of uncertainty aversion, leading to differing preferences for the asset relative to cash, may induce trading. Based upon a period-by-period analysis of my data, it appears that these forces take time to develop— trading activity in very early periods is lower in the presence of uncertainty. This may account for the absence of a positive relationship in prior research, which consists solely of short-form studies.

In order to properly test for the effects of risk and uncertainty, the experimental design and instructions should encourage quick equilibration on FV. FV is strongly related to EV, but FV may incorporate adjustments for risk and uncertainty. Minimizing the influence of non-fundamental factors is important, as it is difficult to determine the influence of risk and uncertainty on price when price is being whipped around by speculative forces. The literature highlights three factors which promote bubble activity— confusion, lack of common expectations regarding others' behavior, and excess and variable liquidity. Guided by these factors, my experimental design includes a collection of 'best practices' in bubble minimization generated over the past 25 years by many researchers, and thus provides a robustness test of this set of best practices. In my data bubble and crash patterns are largely absent. Prices fall below EV relatively early in markets with inexperienced subjects, and very quickly in markets with once-experienced subjects. Furthermore, I observe a degree of price stability that suggests equilibration. I presume that equilibration is on FV.

I. Literature Review

A. Risk Aversion

Risk aversion is a pillar of asset valuation. Theoretical underpinnings of risk aversion in portfolio choice go back at least as far as Markowitz (1952) mean-variance optimization, proceed through the CAPM (see Sharpe 1964, Lintner 1965, and Black 1972), and continue through the intertemporal capital asset pricing model of Merton (1973, 1980). Investment analyst equity valuations often rely on discounted cash flow models, which discount expected cash flows using a rate that is meant to correspond to the riskiness of the cash flows. Field research, however, does not consistently reveal a firm relationship between risk and expected return. As discussed by Fama and French (2004), the CAPM has failed most empirical tests. Fama and French (1992), using cross sectional data, report risk premia related to firm size and to valuation, but not to market returns. The implication is that the excess returns to certain factors are due to risk associated with those factors, but this implication is difficult to confirm using field data. Lundblad (2007) argues that the lack of supporting evidence for risk aversion in field research is due to small sample sizes. Using a sample size of 200 years and using conditional volatility as the measure of risk, he reports a positive and statistically significant risk-return tradeoff. The arguable necessity of using extremely large data sets emphasizes the difficulty of revealing positive risk premia in the field.

Some of the difficulty in uncovering positive risk premia in the field may have to do with the challenge of properly characterizing risk itself. Risk is often measured by beta or by variance. It is widely held that variance is an appropriate measure of risk only when normal return distributions are assumed. However there is some controversy on this point, as for example Markowitz (2014) argues that Gaussian return distributions are not a necessary condition for the use of mean-variance analysis. Regardless, potential loss may also be relevant to behavior. Theoretical work highlighting the importance of loss aversion traces back at least as far as Roy (1952). Thaler and Benartzi (1995) offer an explanation for the equity premium puzzle that is based upon loss aversion. Empirical support for the proposition that downside risk is priced is reported, in various settings, by Harlow and Rao (1989); Harvey (2000); Estrada (2000, 2001); Chen, Chen and Chen (2009). Potential loss is often related to the skewness of the distribution of expected returns, and a desire for positive skew may be a basis, in its own right, for asset pricing. Theoretical support for preference for positive skew being a determinant of equity pricing is provided by Brunnermeier, Gollier and Parker (2007); Barberis and Huang (2008). Field research has uncovered support for skew preference in lotteries, see for example Garrett and Sobel (1999) and Forrest, Simmons and Chesters (2002).

One might posit that laboratories are well suited to the study of the relationship between risk and expected return, as risk can be isolated, controlled, and measured ex-ante. Much work has indeed been done utilizing individual choice laboratory experiments, and while the results are not uniform, on balance they support risk aversion. For example, studies such as Binswanger (1980); Smith and Walker (1993); Holt and Laury (2002) detect behavior consistent with risk aversion. In a survey paper, Harrison and Rutstrom (2008) conclude that there is systematic evidence that subjects in laboratory experiments behave as if they are risk averse. Loss aversion is also reported in individual choice experiments. A good overview of the topic incudes Kahneman, Thaler and Knetsch (1991); Kahneman, Tversky and Thaler (1997); Novemsky and Kahneman (2005); McGraw, Larsen and Kahneman (2010); Ert and Erev (2013), and recent work includes Oxoby and Morrison (2014). Preference for positive skewness in lotteries is reported by Astebro, Mata and Santos-Pinto (2009, 2015).

The results from individual choice laboratory experiments appear to conform with results from short-form laboratory asset markets. Short-form studies typically involve repeated markets that each last one or two periods. In an early study, Ang and Schwarz (1985) report that markets which consist of conservative investors consistently exhibit higher risk premia than markets with speculative investors. Plott and Bossaerts (2004) report consistent risk aversion in single-period markets. Their markets utilize a large number of subjects and feature three simultaneously traded assets. Corgnet, Kujal and Porter (2012) report risk aversion in the first period of three-period markets featuring risk but no uncertainty. Straznicka and Weber (2011) report that assets with positive skew are priced higher than assets with negative skew but the same EV and variance. In each case, prices are above EV. In a recent paper, Huber, Kirchler and Matthias (2014) report that under some conditions, prices early in a market are above EV for positively skewed assets and below EV for negatively skewed assets. By the end of a market prices for both positively and negatively skewed assets are near EV, except for negatively skewed assets that have uncertainty with respect to EV, where prices below EV are reported.

Findings of risk aversion in individual choice laboratory research and in short-form laboratory asset markets do not conform with prior studies involving long-form laboratory asset markets. Long-form studies involve markets that typically last 10 to 15 periods, featuring cash and an asset that do not reinitialize between periods. One prominent reason is the clear and consistent presence of bubbles in such markets. Bubbles may obscure our view, making it difficult to isolate a clear relationship between risk and return. Indeed, consistent pricing below EV is quite uncommon. My review of more than 60 studies involving long-form markets, including all those cited in this paper, reveals only a couple with clear and consistent pricing below EV. One of these is Caginalp, Porter and Smith (1998), who run a design that is similar in several respects to the design in this study. The authors do not explicitly examine risk aversion. Noussair and Haruvy (2006) find that allowing short sales (which are not permitted in my study) reduces prices. In the relevant markets in their study prices are below EV in the first few periods, as is not uncommon for declining EV designs such as the one they employ. In some markets prices remain below EV for virtually the entire market. In some other markets prices reach EV by the middle of the market and remain near EV thereafter. In yet other markets, prices exceed EV by a reasonable amount in middle to late periods. The authors' explanation for frequent pricing below EV is that "short selling merely influences the supply of and demand for the asset, which is in part determined by forces other than the relationship between current prices and fundamental values" (page 1154). Huber, Kircheler and Stockl (2012) employ a treatment (T4) where prices remain either on top of EV or just below EV. The average pricing for the treatment is a 2.7% discount to EV. For the majority of the six markets, prices appear to stay within 2% of EV throughout the market. The authors do not investigate the role of risk aversion in pricing. Finally, also note that in several studies with declining EVs prices are below EV in early periods but evolve to or above EV in relatively short order, with bubbles often developing.

Despite the difficulties inherent in examining risk and return in long-form laboratory asset markets, there have been a handful of studies in this area. Guth, Krahen and Rieck (1997) find no link between the elicited risk aversion of individual subjects and those same subjects' chosen portfolio allocations. Fellner and Maciejovsky (2007) report that risk averse subjects trade less frequently. Robin, Straznicka and Villeval (2012) find some evidence that mispricing is less severe and trade activity is less intense in markets with a higher share of risk averse traders. Noussair and Braeban (2014) report that greater levels of risk aversion on the part of traders in a market predicts lower market prices. With regards to preference for positive skew, Ackert, Charupat and Deaves (2006) find that traders pay a premium for an asset with lottery characteristics.

This study adds to the literature in multiple ways. First, it presents a streamlined test of theoretical asset valuation models that postulate positive risk premia. The data support historical asset valuation models. Indeed I report statistically significant and positive risk premia. Within the context of laboratory asset markets featuring a long-lived asset, I am the first to do so. Second, I open a new avenue for the study of the role of risk in markets for multi-period assets, by creating a conducive laboratory environment. Third, I examine whether altering the riskiness of a laboratory asset influences the price, and by extension the expected return, of that asset. Fourth, I discriminate between risk measures relating to variance and upside/downside potential in a laboratory setting. Under the conditions of this study including the use of non-normal expected return distributions, there is no evidence that variance is positively related to risk premia. The data do suggest, however, that risk premia increase as potential loss grows. Loss aversion and preference for positive skew are potential causes.

B. Uncertainty

Analysis of the role of uncertainty in economic decision making goes back at least as far as Knight (1921) who reasons that risk, which can be represented by precise probabilities, is distinct from uncertainty, which occurs when the probability distribution of future states is not known. Knight argues that economic profits accrue to the assumption of uncertainty more so than to the assumption of risk. Keynes (1921) also highlights the significance of uncertainty, noting that weighing evidence is a separate process from balancing evidence. When making decisions people take into account not only their best judgment, but also the amount and quality of the evidence they have available. Arrow (1951) and Savage (1954) take the other side of the debate. Arrow argues that "In brief, Knight's uncertainties seem to have surprisingly many of the properties of ordinary probabilities, and it is not clear how much is gained from the distinction" (page 417), and also that "...his uncertainties produce about the same reactions in individuals as other writers ascribe to risks" (page 426). Ellsberg (1961) shows that, in certain settings at least, people do in fact treat risk and uncertainty differently. His urn experiments reveal that when faced with two prospects, one risky and one uncertain, subjects tend to, all else equal, avoid the uncertain prospect. A plethora of individual choice research corroborates Ellsberg's finding. See for example Becker and Brownson (1964); Yates and Zukowski (1976); Hogarth and Einhorn (1990), and a good summary by Camerer and Weber (1992).

At least two influential studies examine key characteristics of uncertainty aversion. The first is Heath and Tversky (1991), in which the authors report that uncertainty aversion varies with the feelings of competence that subjects have concerning the task. Uncertainty aversion is greater when subjects feel incompetent regarding the task. The authors call this the competence hypothesis. The second is Fox and Tversky (1995). Fox and Tversky observe that the aversion to uncertainty captured in the experiments of Ellsberg and others occurs in the presence of a comparison between a risky prospect and an uncertain one. They find that when subjects are presented with an uncertain prospect in isolation, aversion to uncertainty seems to disappear. They call this the comparative ignorance hypothesis.

Field research on the effect of uncertainty on asset prices is relatively sparse, in part because of the difficulty of measuring uncertainty in the field. One example, however, is Ang and Boyer (2010), who present evidence of an uncertainty return premium using IPO returns. Bianchi and Tallon (2014) study individual portfolio choices and find that "In several instances, the effects of ambiguity aversion stand in sharp contrast with those of risk aversion." For instance conditional on participation, uncertainty averse investors hold riskier portfolios. Theoretical research has been more plentiful. A broad overview of theoretical models with various applications includes Schmeidler (1989); Dow and da Costa Werlang (1992); Epstein and Wang (1994); Mukerji and Tallon (2001); Uppal and Wang (2003); Klibanoff, Marinacci and Mukerji (2005); Leippold, Trojani and Vanini (2008); Ju and Miao (2009); Ui (2011).

Several researchers investigate uncertainty in the context of short-form laboratory asset markets. The same group of subjects trade an asset that, along with cash, is reinitialized frequently, generally every period or two. On the whole, results are not consistent with premia for uncertainty, but there are exceptions which may shed light on what could be an intricate relationship. Camerer and Kunreuther (1989) design insurance markets and find that the introduction of uncertainty does not have much effect on contract prices relating to low probability losses. Sarin and Weber (1993) report evidence of uncertainty aversion. They also report that, somewhat consistent with Fox and Tversky (1995), uncertainty aversion increases when subjects trade risky and uncertain assets simultaneously. Alevy (2013) also reports uncertainty aversion, but only when the subjects have not been first exposed to a market with a risky asset. Di Mauro (2008) tests the competence hypothesis of Heath and Tversky (1991) by using assets tied to local vs. international weather, and finds supporting evidence. Bossaerts et al. (2010) report on an experiment where the distribution of portfolio allocations in markets with uncertain assets is different than the distribution of asset allocations in markets with risky assets. In particular, in many markets there are subjects who choose not to hold any of the uncertain asset at the market clearing price. This should depress the price by increasing the amount of the uncertain asset that the remaining subjects have to jointly own. Corgnet, Kujal and Porter (2012) do not find evidence of uncertainty return premia in asset prices. Indeed in their data with inexperienced subjects, uncertainty is associated with prices that are higher, and closer to EV, than in corresponding markets without uncertainty. Kocher and Trautmann (2013) study self-selection into first-price sealed-bid auctions for a risky or an uncertain prospect. Transaction prices for risky and uncertain prospects are equal. In a recent study, Huber, Kirchler and Matthias (2014) find uncertainty aversion in assets with negatively skewed dividend distributions, but not in assets with dividend distributions of zero or positive skew. This result is not judged to be due to the skew alone, as assets in their study which had negatively skewed dividend distributions but no uncertainty did not exhibit persistent pricing below EV. Fullbrun, Rau and Weitzel (2014) run sessions where a risky and an uncertain asset are traded simultaneously by the same subjects in separate markets. The authors hypothesize that uncertainty aversion is more likely to manifest in settings without market-based feedback, and with a relatively high probability of winning. And indeed their treatment with a relatively high winning probability (75%) and no intra-period feedback (call market rather than double auction) presents uncertainty aversion. Other treatments, featuring intra-period feedback, a medium probability of winning (50%), or both, do not produce return premia for the uncertain asset.

Evidence regarding the effect of uncertainty on trading activity is sparse, and completely in the realm of short-form studies. Corgnet, Kujal and Porter (2012) hypothesize that uncertainty reduces trading volume, but find no evidence of a link. Fullbrun, Rau and Weitzel (2014) also hypothesize a negative relationship between uncertainty and trading volume. They detect a relationship in only one of their treatments, but it is a positive one. The authors note that this result "corresponds, however, with the divergence of opinions literature." I hypothesize that the correspondence is not by chance— differences of opinion as to true EV and to the potential behavior of other subjects, and differences in uncertainty aversion, lead to increased trading volume.

With regards to long-form markets such as employed in this study, there has arguably been no direct investigation of Knightian uncertainty. Often, the probability distribution of returns is given to all subjects, so there is no Knightian uncertainty (although strategic uncertainty does exist). In some studies the authors employ design elements that both introduce a measure of Knightian uncertainty and also increase strategic uncertainty (where the increase in strategic uncertainty is due to more than just the introduction of Knightian uncertainty), but it is difficult to separate the results stemming from the two factors. Also, uncertainty is generally not a focus of prior studies, and thus control groups are absent and the effects of uncertainty are not evaluated. For example in some instances such as Plott and Sunder (1982); Guth, Krahen and Rieck (1997); Lin and Rassenti (2012); Sutter, Kirchler and Huber (2012), asymmetric information both introduces Knightian uncertainty and increases strategic uncertainty, however it is difficult to extricate the separate effects of asymmetric information and Knightian uncertainty. In any event, since uncertainty is often not the focus of these studies there is no control group with perfect information. Lin and Rassenti, referenced above, is the exception on this last point, as there are markets with and without asymmetric information. The authors find no evidence that asymmetric information has an effect on price. One could surmise that the uncertainty inherent in an asymmetric information design does not have an effect on price. Another way that uncertainty is introduced in prior research is via processes where the quantity of information on the EV of the asset increases over time, or where the EV evolves over time based upon new information. See Lin and Rassenti (2012); Guth, Krahen and Rieck (1997). Note again that their research purposes do not call for control groups with regards to uncertainty. A further way that uncertainty appears in prior research is via incomplete and complementary information. Kirchler et al. (2015) employ a design in which each subject is informed of only one half of the return distribution. Knightian and strategic uncertainty are not separated. Since uncertainty is not the focus of the study, there is no control group with perfect information and the effect of uncertainty is not investigated further. Yet another way to instill uncertainty is to tie the dividend to the uncertain actions of an outside actor. Kimbrough and Jaworsky (2011) accomplish this by setting the dividend of the asset equal to the profit of a monopolist producer in a (separate) goods market. The producer is human and sells to computerized buyers. There is inherent Knightian uncertainty because the subjects in the asset market do not know the future behavior of the human monopolist. Knightian and strategic uncertainty tend to diminish over time as the producer learns how to maximize profit and the asset market subjects observe this. Bubbles in this experiment are somewhat smaller than the bubbles typically reported in studies with dividends drawn from known discrete distributions. The authors attribute this result to the observable nature of the dividend process. The introduction of uncertainty may play a role as well, but there is no control group with an absence of uncertainty.

To my knowledge, this is the first long-form laboratory asset market study to measure the effect of pure Knightian uncertainty. From analysis of these data, I find no evidence that the introduction of uncertainty results in lower prices. This fails to support the implications of Knight (1921) and Ellsberg (1961), but is not inconsistent with the comparative ignorance hypothesis of Fox and Tversky (1995), the work of Arrow (1951) or Savage (1954), or with many of the reported results of Corgnet, Kujal and Porter (2012); Huber, Kirchler and Matthias (2014); Kocher and Trautmann (2013); Fullbrun, Rau and Weitzel (2014). I also present evidence on the effect of uncertainty on trading activity. In this study, I find that uncertainty is associated with an increase in trading volume. This result is contrary to the earlier finding of Corgnet, Kujal and Porter (2012), but partially consistent with the findings of Fullbrun, Rau and Weitzel (2014). I expound upon an explanation consistent with economic theory.

C. Bubble Mitigation

Successful implementation of the tests in this study with regards to risk and uncertainty requires a research environment that is relatively free of speculative behavior. As such, encouraging quick equilibration on FV is a key feature of the experimental design. This is accomplished by combining a number of 'best practices' in bubble mitigation developed by many researchers over the past twenty years. The resulting design also serves as a robustness test of key reported advances in this area. Thus an exploration of bubble elimination literature is in order.

Laboratory markets employing long-lived assets lasting 10-15 periods and featuring cash and assets that do not reinitialize between periods were pioneered by Smith, Suchanek and Williams (1988), hereafter SSW. SSW discover that even under perfect information and other design parameters conducive to efficiency, mispricing is common. They characterize the phenomenon as price bubbles followed by crashes.

In the SSW design, each subject begins a market with an endowment of cash and assets. At the end of each period each asset is paid a dividend drawn from a known probability distribution (e.g. 0, 8, 28, or 60 with equal probability). There are generally 15 periods in a market, and the asset expires worthless at the end of the market. The asset's dividend value (EV) diminishes in a stair-step manner as the market proceeds, as fewer and fewer dividends remain to be paid. Subjects trade the asset using software that runs a continuous double auction each period.

Prior to each period, traders are reminded of the dividend distribution and informed of the average, minimum, and maximum possible dividend earnings for each asset for the remainder of the market. Also, each trader is verbally informed that the dividend structure and actual dividends will be the same for every trader. Further, at the end of each period, market participants are shown a table giving the average, minimum, and maximum contract price, as well as the dividend awarded, in all previous periods.

Traders have perfect information. They are informed, each period, of the exact EV of the asset at that period. Yet bubbles occur most of the times that SSW run variants of the experiment.

SSW report that the only thing that consistently eliminates price bubbles in their experiments is running the experiment three times with the exact same subjects. By the third time the experiment is run, bubbles often do not occur.

Much research has investigated whether the presence of bubbles and crashes in the SSW experiments is due to any particular design feature of the experiments. The broad answer to this question is: No. King, Smith and Van Boening (1993) find that speculative bubbles are robust to margin, brokerage fees, endowment distributions, and the sophistication of the subjects, among other factors. Van Boening, Williams and LeMaster (1993) find that bubbles are robust to the choice of trading mechanism (call market vs. continuous double auction). Fischer and Kelly (2000) report that adding a second asset to the marketplace does not eliminate bubbles. Lei, Noussair and Plott (2002) find that the imposition of large capital gains taxes does not eliminate bubbles. King, Smith and Van Boening (1993), Ackert, Charupat and Deaves (2006), and Noussair and Haruvy (2006) investigate the effect of short selling on bubbles. The evidence here is mixed. King, Smith and Van Boening (1993) report that bubbles and crashes are robust to short selling, Ackert, Charupat and Deaves (2006) report that bubbles and crashes are moderated when subjects are allowed to short sell, and Noussair and Haruvy (2006) find evidence for short selling reducing and even eliminating bubbles. Porter, Corgnet and Hernan-Gonzalez (2013) report that eliminating the house money effect does not eliminate bubbles, although it does moderate them. Cheung and Palan (2012) report that replacing individual traders with teams of two can substantially reduce bubbles. Lahav (2011) finds that bubbles and crashes persist even in markets with 200 periods.

There is a substantial amount of research regarding the causes of bubbles and methods for eliminating them. A good survey is provided by Palan (2013). One clear contributor to bubbles is excess and variable liquidity. Several studies find that increasing the initial ratio of cash/assets aggravates bubbles. See Caginalp, Porter and Smith (1998); Porter, Smith and Caginalp (2000, 2001); Caginalp (2002); Noussair and Haruvy (2006); Smith, Porter and Hussam (2008). Sometimes, the measure of assets used is EV (C/EV). Sometimes, the number of shares is used (C/S). Theoretical support for C/S being a determinant of asset prices is discussed in Caginalp and Balenovich (1999) and Porter, Smith and Caginalp (2000). In most studies C/EV and C/S move together, such that limited discriminatory analysis can be made between the two measures. Adding liquidity during the course of a market has been shown to aggravate bubbles, although the evidence here is not quite uniform. Smith, Van Boening and Wellford (2000); Porter, Smith and Caginalp (2001); Porter, Deck and Smith (2014) and Huber, Kircheler and Stockl (2012) all support the proposition. In one treatment (T2, with a constant EV) however, Huber, Kircheler and Stockl (2012) report that cash additions do not result in bubbles. Noussair and Tucker (2014) replicate that result, and argue that the timing of the cash additions— late in the markets— is what prevents bubbles from forming. Kirchler et al. (2015) report another treatment where cash additions do not lead to bubbles. The majority of the cash additions occur in the latter half of the markets.

Another very common finding is that when the exact same group of subjects is brought back to participate in the exact same experiment for the third time, bubbles generally disappear. (One notable exception is James and Isaac (2000) who incorporate tournament incentives). The strong tendency for bubbles to disappear with subject experience provides clues as to what may be causing the bubbles in the first place. When subjects participate in an experiment for the second or third time with the same set of fellow participants, at least a couple of things may happen: First, the subjects may understand the EV process better than they did before. Second, the subjects may figure that the other subjects all understand the EV process well, leading to common expectations of others' behavior.

Efforts to reduce subject confusion often bear fruit in reducing the occurrence and amplitude of bubbles. For instance, Porter and Smith (1995) introduce a futures market and find that this helps subjects anticipate the future price path of an asset. Lei and Vesely (2009) show that having the subjects experience the dividend process prior to the start of the experiment can eliminate bubbles. Huber, Kircheler and Stockl (2012) report that declining EV treatments have more mispricing than constant EV treatments, and that questionnaires reveal that the declining EV process confuses subjects. Indeed, in their treatment four (T4), which combines a constant EV with constant liquidity, bubbles are completely absent. This result is replicated by Noussair and Tucker (2014). Johnson and Joyce (2012) also report that markets with constant or increasing EV do not routinely exhibit bubbles and crashes. Huber and Kirchler (2012) show that modifying instructions to make the EV process more intuitive to the subjects, by for example using a graph instead of a table, or by describing the asset as a depleting gold mine, or by encouraging subjects to think about EV (by asking them to estimate EV at the beginning of every period), significantly reduces bubbles.

Another hypothesis for the prevalence of bubbles is lack of common expectations concerning others' behavior. Under this hypothesis, traders themselves generally understand the EV process, but they think that the other traders may not. So, a trader understands that the dividend value of the asset will fall to zero by the end of the experiment, but that trader thinks that the other traders may not understand this. The first trader proceeds to purchase the asset above EV, in the hope of selling even further above EV. Palan, Hedegaard and Cheung (2014) show that when all subjects are well trained to understand the EV process but this is not public knowledge— when a subject knows she has been properly trained but doesn't know that the other subjects have been as well— bubbles are as common and as large as when none of the subjects are properly trained. When the training is common knowledge, though, mispricing is substantially reduced.[1] Also note that the pre-experiment dividend training conducted by Lei and Vesely and noted in the previous paragraph could well foster common expectations, as it is public. However, there is also some evidence against the common expectations hypothesis. Akiyama, Hanaki and Ishikawa (2012) run a treatment where there is one human trader and five computer traders, and the human in the experiment is told that the computers will trade based upon EV. They also run a treatment with six human traders and no computer traders. Although prices deviate from EV much more in the all-human treatment, human traders' initial forecasts of the future path of prices relative to EV do not appear to depend upon whether the other traders are computers or humans.

II. Experimental Design

Minimizing bubbles and crashes helps to produce a stable research environment suitable for the study of risk and uncertainty. In the creation of the instructions and experimental design of this study, I aim to incorporate as many as practical of the techniques discussed above with regards to bubble elimination, while simultaneously endeavoring to maintain simplicity.

Subjects trade "tickets" that are redeemed for cash at the end of a market. The redemption amount is either \$0.50 (low) or \$1.50 (high), based upon a simulated random draw of one ball from a container of a hundred. Adjusting the proportion of high and low balls in the container from market to market changes EV, expected variance, potential loss, and skew. If subjects are informed of the exact number of high and low balls in the container, then there is risk but no uncertainty with regard to EV. If the subjects are not informed of the exact number of high and low balls, but instead are only shown a sample from the container, then Knightian uncertainty is present. In each case subjects are instructed on how to calculate EV, and are also told what EV is.

The RISK treatment has risk but no uncertainty. Subjects are informed how many \$0.50 balls and how many \$1.50 balls are in the container. They are also instructed that the EV is the average of the balls in the container. The UNCERTAINTY treatment has uncertainty. Subjects are not informed how many \$0.50 balls and how many \$1.50 balls are in the container. Instead they are shown a sample of five balls drawn from the container, with replacement. Subjects are instructed that the EV is the average of the sample.

Trade is accomplished via a continuous double auction using the z-Tree software, developed by Fischbacher (2007). Each market consists of 10 subjects. Subjects can place orders to buy or sell one or more tickets, and they can accept orders

[1]In addition, Porter, Smith and Caginalp (2000) report one market within a study where the subjects are advanced graduate students in economics, and where no bubble develops. Supposing that the subjects all know that the other subjects are advanced graduate students in economics, and trained in the concepts of EV and efficient markets, I postulate that the reason for the lack of a bubble is common expectations.

posted by other subjects. After two practice periods, which unlike the subsequent paying periods are devoid of strategic interaction, there are 15 paying periods each lasting 90 seconds. Each subject begins with an endowment of $8 and eight tickets. Short selling is not allowed. A screen displaying EV is shown prior to each period. The trading screen displays subjects' own current cash and ticket inventory, the entire order book, and the trade history of the current period. It also reminds subjects which trades during the current period, if any, they were party to. The simulated draw is conducted by the computer program after the 15th period. Each ticket is redeemed for the amount on the ball that is drawn, either $0.50 or $1.50. Subject earnings include cash on hand at the end of the market, redemption proceeds, and a show up fee. The instructions, delivered only in writing, describe the rules and procedures of the market, the mechanics of the trading screen, the concept of a sample, the redemption process, and the calculation of earnings. The calculation of EV is presented in detail, and a graph of EV is given as well. Each subject must pass a quiz prior to participation. The quiz covers the rules, details and mechanics of the experiment. The complete instructions for each treatment, including the quiz and a screenshot of the trading screen, are presented in the Appendices.

A total of twenty-four markets are run. Sessions were conducted at Fordham University in 2014. There are 120 subjects in total, and average earnings are roughly $40. Each treatment has six markets with subjects who are inexperienced and six markets with subjects who are once-experienced. Inexperienced subjects had never participated in this particular experiment before. Most had never previously participated in any laboratory asset market experiment. After completing a market as inexperienced subjects, the same group of subjects returns and completes a market as once-experienced subjects.

The proportion of high and low balls in the container varies from market to market. Four markets have 20 high balls ($1.50) and 80 low balls ($0.50) for an EV of $0.70. Eight markets have 40 high balls and 60 low balls for an EV of $0.90, eight have 60 high balls and 40 low balls for an EV of $1.10, and four have 80 high balls and 20 low balls for an EV of $1.30. The spread of expected variances is symmetric. In the markets with EVs of $0.90 and $1.10, expected variance is 0.24. In the markets with EVs of $0.70 and $1.30, expected variance is 0.16. However potential loss varies positively with EV, and skew varies negatively with EV. Within each of the four treatment and experience level combinations there are six markets. The distribution of EVs in each of the four groups is identical—one market has an EV of $0.70, two have an EV of $0.90, two have an EV of $1.10, and one has an EV of $1.30. This arrangement is depicted in Table 1.

When subjects return to participate in a market with once-experienced subjects, they are kept in the same treatment. In RISK markets with once-experienced subjects, the EV is the same as in the corresponding RISK market with the same (then) inexperienced subjects. This is done to keep as much as possible constant

Table 1. Details of the Experimental Design

Treatment and Experience Level	No. of Markets	EV	Expected Variance	Potential Loss	Skew
RISK Inexperienced	1	\$0.70	0.16	29%	1.50
	2	\$0.90	0.24	44%	0.41
	2	\$1.10	0.24	55%	-0.41
	1	\$1.30	0.16	62%	-1.50
RISK Once-Experienced	1	\$0.70	0.16	29%	1.50
	2	\$0.90	0.24	44%	0.41
	2	\$1.10	0.24	55%	-0.41
	1	\$1.30	0.16	62%	-1.50
UNCERTAINTY Inexperienced	1	\$0.70	0.16	29%	1.50
	2	\$0.90	0.24	44%	0.41
	2	\$1.10	0.24	55%	-0.41
	1	\$1.30	0.16	62%	-1.50
UNCERTAINTY Once-Experienced	1	\$0.70	0.16	29%	1.50
	2	\$0.90	0.24	44%	0.41
	2	\$1.10	0.24	55%	-0.41
	1	\$1.30	0.16	62%	-1.50

except the experience level of the subjects, to further reduce confusion, and to encourage common expectations with regards to others' behavior. In UNCERTAINTY markets with once-experienced subjects, the sample is different than in the corresponding UNCERTAINTY market with the same (then) inexperienced subjects.[2]

Quick equilibration on FV allows for clearer observation of the effects of risk and uncertainty on price. To accomplish this, I incorporate successful design features from literature discussed in the previous section.

I aim to reduce confusion in several ways. First, EV remains constant throughout the market. Huber, Kircheler and Stockl (2012) and others report that this reduces bubbles. Second, the entire dividend value is concentrated at one point, at the end of the market. Smith, Van Boening and Wellford (2000) report that this reduces or eliminates bubbles. Third, the dividend process is relatively easy to understand, as it is simply the weighted average of two numbers. Fourth, the dividend process is presented to the subjects in a way that aims to make it easy for them to understand— as a simple lottery (although the word lottery is not used)— and the EV progression is also described with a graph. Huber and Kirchler (2012) show that modifying instructions to make the EV progression more intuitive to the subjects, by for example using a graph instead of a table

[2]In UNCERTAINTY markets with once-experienced subjects, keeping the sample the same could result in subjects believing, however incorrectly, that they had obtained information about the container from the prior draw.

or describing the asset using an analogy they can identify with, significantly reduces bubbles. Fifth, the subjects are provided the opportunity to participate in two practice periods, to gain familiarity with the trading mechanism. Sixth, every subject is required to pass a quiz on the trading mechanics, the EV process, and the rules of the market. A 100% score is required prior to participation in the experiment. Seventh, the current order book is shown to all subjects. Porter, Smith and Caginalp (2001) find limited statistical support for an open order book limiting price bubbles.

In addition to encouraging an understanding of the EV process and the rules and mechanics of the experiment, I implement design features to encourage all subjects to understand that all other subjects are encouraged to understand the EV process and the rules and mechanics of the experiment. The instructions, including the quiz, play an important role in engendering common expectations. The last question of the quiz is "Did each participant have to score a 100% on this quiz before starting the experiment?" All subjects are thus informed that every other subject has been trained. Palan, Hedegaard and Cheung (2014) provide evidence that when training is public knowledge, bubbles are reduced. Also, some of the steps taken to minimize confusion, such as implementing practice periods and using a constant EV process with no interim dividends, may likewise engender common expectations.

Multiple methods are employed to attempt to prevent excess and variable liquidity from influencing price. First, there are no periodic dividends. This prevents extra cash from entering the market. The importance of this is discussed above. Second, the initial cash/asset ratios are set at moderate levels. As discussed above, prior research indicates that higher ratios of cash/EV and cash/share count are associated with larger bubbles. The cash/share ratios in this study are constant at 1:1. The C/EV ratios in this study range from 0.77 to 1.43. Both measures are lower than in studies showing a link between liquidity and prices.[3]

I also strive to keep the level of liquidity the same across all 24 markets. In this study I use C/S as my measure of liquidity, and I maintain that liquidity is constant across markets. Each market has the same amount of cash and the same number of shares. Furthermore in my study the guaranteed minimum and the maximum redemption values of the tickets—which could be important facets of subjects' perception of ticket value— are constant. However one could argue that C/EV may be an appropriate measure of liquidity in this study as well. As measured by C/EV, liquidity does vary between markets.

In the design and the instructions I endeavor to focus subjects' attention on risk and uncertainty, and to encourage the subjects to understand the risk and uncertainty involved in the market. To begin with, risk is concentrated in one

[3]For example, in Porter, Smith and Caginalp (2000), C/S ranges from 1.8 to 7.2, and C/EV from 0.5 to 2.0. In Caginalp, Porter and Smith (1998), the C/S ratio ranges from roughly 3 to 6.5, and the C/EV ratio from 0.9 to 1.8. Porter, Smith and Caginalp (2001) use markets where the C/S ratios range from 1.8 to 7.2. The C/EV ratios start at 0.5, 1, or 2, but quickly and sharply rise throughout the market as EV declines.

event, at the end of the market. Subjects may notice risk more when it is concentrated in one event— even though this can be irrational, see Samuelson (1963). It may also be intuitively easier for subjects to get a handle on risk when risk is concentrated in one event. For example it may be easier to grasp the risk involved in a single coin flip than in a series of ten. Further when risk does not taper off over the course of a market as it does in the standard SSW framework which utilizes periodic dividend payments, e.g. when the expected variance to a buy and hold strategy does not decline over the course of the market, subjects may deem the risk to be of a 'permanent' rather than of a 'temporary' nature, and thus may be more likely to focus on risk. In addition, a distribution of two potential dividend values is employed, rather than the more standard three or four. Two values is relatively simple, tractable, and may avoid any centering biases that can come into play with a symmetric three value set. Also, the instructions attempt to focus subjects' attention on risk and uncertainty as well as on returns. In the RISK treatment quiz, subjects are asked to state the number of high and low balls in the container and the probabilities of each potential redemption amount. In the UNCERTAINTY treatment quiz, subjects are asked whether they know the proportions of the balls in the container and the probabilities of the redemption amounts. Further, in both treatments subjects have to acknowledge the certainty of losing money if they purchase at a price above \$0.50, hold until redemption, and the redemption amount is \$0.50. Finally, the level of risk is set relatively high. For example, the expected variance is either 0.24 or 0.16, depending upon the EV. Similar studies often involve lower expected variances.[4]

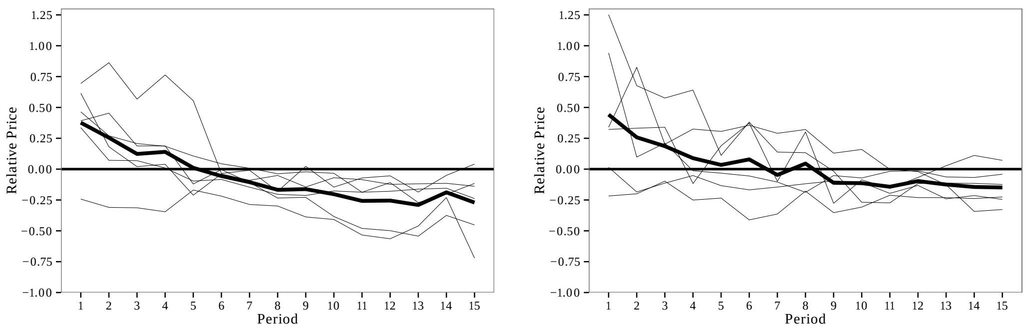
III. Results

A. Robustness Test of Prior Research on Bubble Mitigation

A great deal of research investigates the causes of bubbles and crashes in the laboratory, and results in methods for minimizing bubbles. Individually these methods, which focus on managing liquidity, reducing confusion, and engendering common expectations with regards to others' behavior, exhibit success in reducing bubbles. In this study I incorporate a number of measures which each, in isolation, diminish bubbles in prior research. Can using a collection of best practices eliminate bubbles entirely?

Result 1: In markets with inexperienced subjects bubbles and crashes are largely absent. In markets with once-experienced subjects bubbles and crashes are completely absent.

[4]When rebasing EV to \$1.00 to aid comparability with this study. For example, Caginalp, Porter and Smith (1998) is 0.04. Huber, Kircheler and Stockl (2012) is at 0.10 in Period 1, 0.05 mid-way through a market, and so on. Smith, Van Boening and Wellford (2000) has single dividend markets with expected variances of 0.03, 0.04, and 0.17.



(a) RISK (b) UNCERTAINTY

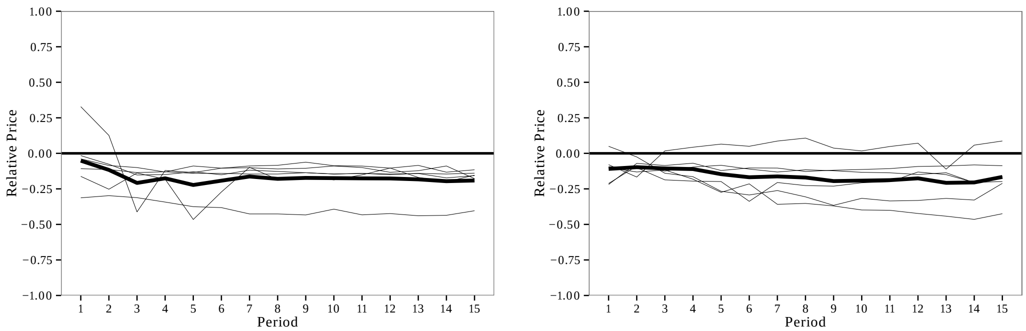
Figure 1. Relative Price in Markets with Inexperienced Subjects

Notes: *Relative Price* is (Price/EV)-1. Thicker lines represent the average value of each period of the respective treatment.

In markets with inexperienced subjects, prices approach FV from above during an adjustment period. Recall, FV in this study incorporates EV and any return premia for risk and uncertainty. See Figure 1, which displays *Relative Price* for all 12 markets with inexperienced subjects. The left panel displays results from the six RISK markets with inexperienced subjects, and the right panel displays results from the six UNCERTAINTY markets with inexperienced subjects. *Relative Price* is defined as (Price/EV)-1, where price is the volume weighted average price (VWAP) for a period. The thicker lines represent the average *Relative Price* in each period for the associated group of six markets. The absence of bubble and crash patterns in the data supports the collective findings of many researchers. The cocktail approach to bubble elimination pursued in this paper does appear to work. Mispricing, however, is not completely eliminated. A typical price pattern for a market with inexperienced subjects is as follows: Price is above EV in period one, quickly trends toward EV, crosses EV near period seven, and then continues below EV toward FV. The design features implemented do not produce immediate equilibration on FV.[5]

In markets with once-experienced subjects, the data reveal quick equilibration on FV. See Figure 2, which displays *Relative Price* for all 12 markets with once-experienced subjects. The left panel displays results from the six RISK markets with once-experienced subjects. The right panel displays results from the six UNCERTAINTY markets with once-experienced subjects. Again, the thicker lines represent the average *Relative Price* in each period for the associated group

[5]Interestingly two markets— a RISK treatment market with inexperienced subjects and an UNCERTAINTY treatment market with once-experienced subjects (and thus also not the same cohort)— exhibit multiple periods of VWAPs slightly below the low payout amount of $0.50.



(a) RISK (b) UNCERTAINTY

Figure 2. Relative Price in Markets with Once-Experienced Subjects

Notes: *Relative Price* is (Price/EV)-1. Thicker lines represent the average value of each period of the respective treatment.

of six markets. Period one price is below EV in 10 of the 12 markets.[6]

The prevention of bubbles and crashes and the reasonably quick equilibration on FV create a stable operating environment for the study of risk and uncertainty.

B. Results Related to Risk

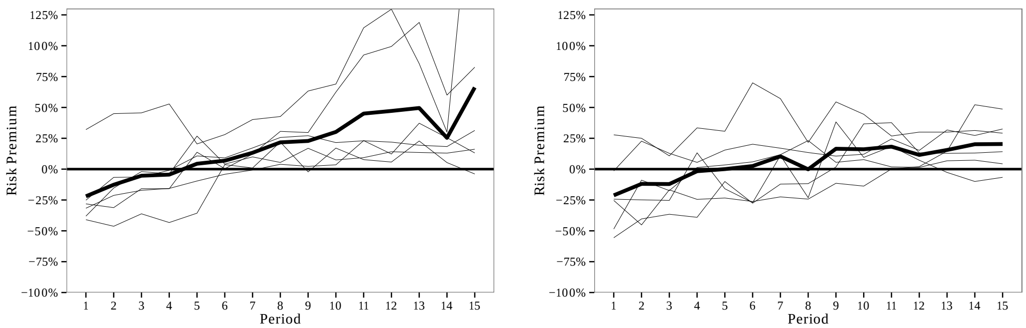
In this study bubbles and crashes are avoided, quick equilibration on FV is encouraged, and there is a relatively high level of risk. I posit that these contribute to the following result.

Result 2: The data reveal positive and statistically significant *Risk Premia*.

See Figure 3, which shows *Risk Premia* for all 12 markets with inexperienced subjects. The left panel displays results from the six RISK markets with inexperienced subjects, and the right panel displays results from the six UNCERTAINTY markets with inexperienced subjects. The thicker lines represent the average *Risk Premium* in each period for the associated group of six markets.[7] *Risk Premium* is defined as (EV/Price)-1, where price is the VWAP for a period. In words, *Risk Premium* is the return that would accrue to purchasing a ticket at the market price and redeeming at EV. In essence, it is the expected compensation demanded by traders in exchange for taking on risk.

[6]One of the markets had zero trades during five periods. Price was inferred via interpolation of the best bid and best offer. Specifically, the best bid and best offer were averaged. This bid/ask spread was never more than 2 cents.

[7]One observation in the left panel occurs outside the range of the graph. The *Risk Premium* for the 15th period of one of the markets— the market associated with the line seen exiting the graph after period 14— is 257%.



(a) RISK (b) UNCERTAINTY

Figure 3. Risk Premia in Markets with Inexperienced Subjects

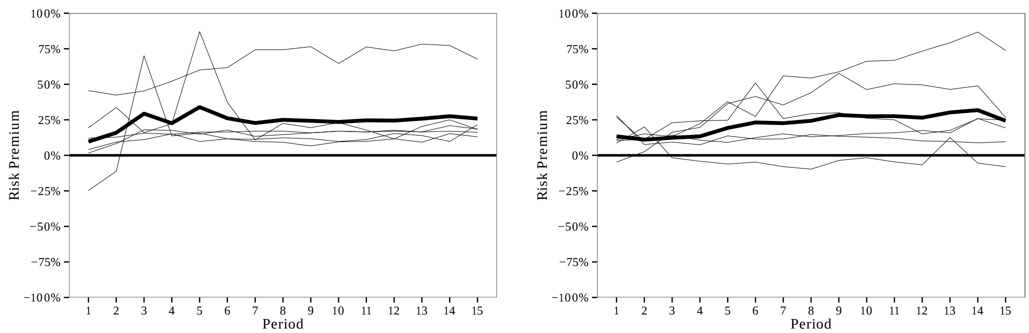
Notes: *Risk Premium* is (EV/Price)-1. Thicker lines represent the average value of each period of the respective treatment.

In testing whether risk premia exist in markets with inexperienced subjects, data from the RISK and UNCERTAINTY treatments are pooled. As discussed later in this paper, the introduction of uncertainty does not have a statistically significant influence on price. Each market is one observation, providing a total of 12 observations for each experience level (inexperienced and once-experienced). Each observation is the average of the *Risk Premia* over the last five periods of the associated market. The average of the *Risk Premia* over the last five periods is used, rather than the average over the entire market, in order to avoid interference from the price adjustment process that occurs early in markets with inexperienced subjects. A one-sample Wilcoxon signed rank test is employed. The null hypothesis is that the median of the *Risk Premia* is zero. The null hypothesis is rejected. The two-sided p-value is less than 0.001.

When the data are not pooled, the results are still significant. Using the last five periods of each market, one-sample Wilcoxon signed rank tests with a null hypothesis of median *Risk Premia* of zero are run for each of the two treatments. There are only six observations in each sample. The two-sided p-value is 0.031 in each case.

Risk Premia in markets with once-experienced subjects are displayed in Figure 4. The left panel displays results from the six RISK markets with once-experienced subjects, and the right panel displays results from the six UNCERTAINTY markets with once-experienced subjects.

The results with regards to once-experienced subjects are also significant. Data from the two treatments are pooled. Since equilibration on FV is very quick in markets with once-experienced subjects, each of the 12 observations is the average of the *Risk Premia* over the entire 15 periods of the associated market. As above, a one-sample Wilcoxon test is employed. The null hypothesis is that the difference



(a) RISK (b) UNCERTAINTY

Figure 4. Risk Premia in Markets with Once-Experienced Subjects

Notes: *Risk Premium* is *(EV/Price)-1.* Thicker lines represent the average value of each period of the respective treatment.

in medians is zero. The two-sided p-value is less than 0.001.[8] When the data are not pooled, the two-sided p-value of the one-sample Wilcoxon test for the RISK treatment is a still very significant at 0.031. The two-sided p-value for the UNCERTAINTY treatment is 0.062.[9]

Having established that positive risk premia exist, a logical next step is to investigate what factors risk premia are sensitive to. One candidate is expected variance. In this experiment there are two expected variances, 0.24 and 0.16, which are unrelated to the direction of EV. When EV is \$1.10 or \$0.90, expected variance is 0.24. When EV is \$1.30 or \$0.70, expected variance is 0.16. These data do not support the notion that, at least in the context of non-normal return distributions, increases in expected variance increase risk premia.

Result 3: There is no evidence that *Risk Premia* vary with expected variance.

One way to examine whether *Risk Premia* are sensitive to expected variance is with a two-sample Wilcoxon test, also known as the Mann-Whitney test. One sample consists of the 16 markets with expected variance of 0.24 and the other sample consists of the eight markets with expected variance of 0.16. Within each sample, markets with inexperienced subjects and markets with once-experienced subjects are pooled. Each observation is the average of the *Risk Premia* over the last five periods of the associated market. The test reveals little evidence of a positive relationship between expected variance and *Risk Premia*. Using a null hypothesis of a difference in median *Risk Premium* of zero, the resulting two-

[8]Using data from the last five periods of each market, rather than all 15, also produces a p-value of less than 0.001.

[9]Using data from the last five periods of each market, rather than all 15, produces the same p-values.

sided p-value is 0.61.[10] Also note, the median of the high-variance sample is lower than the median of the low-variance sample, contrary to what one would expect if increases in expected variance caused increases in risk premia. When the data are not pooled— when within each experience level the eight high variance markets are compared with the four low variance markets, the result for inexperienced subjects is not significant. The corresponding result for once-experienced subjects is also not significant.

One possible reason that expected variance is not significant is that it captures upside as well as downside potential. Subjects may instead focus mainly on downside potential when contemplating risk. In this study I define *Potential Loss* as ($0.50/EV)-1. In words, this is the return to purchasing a ticket at EV and having it redeemed at the low redemption value.

Result 4A: *Risk Premia* vary positively with *Potential Loss*.

In these data, *Risk Premia* are associated with *Potential Loss*. Figures 5 and 6 segregate the 24 markets by *Potential Loss* and experience level, and display *Risk Premia*.[11] The thicker lines represent the average *Risk Premium* in each period in the associated panel. Visually, and focusing on the averages, it is clear that in the markets with inexperienced subjects *Risk Premia* are higher when *Potential Loss* is higher.[12] With regard to once-experienced subjects the *Risk Premia* are generally higher, by a modest amount, in markets with higher *Potential Loss*.

Non-parametric Mann-Whitney tests for difference in medians is one way to investigate the statistical significance of the relationship between *Risk Premia* and *Potential Loss*. Markets with inexperienced and once-experienced subjects are pooled. Markets with relatively high *Potential Loss* (EV of $1.30 or $1.10) comprise one sample of 12 observations, and markets with relatively low *Potential Loss* (EV of $0.90 or $0.70) comprise the other sample of 12 observations. The unit of observation is the average of the *Risk Premia* over the last five periods of a market. With a null hypothesis of a difference in medians of zero, the two-sided p-value is 0.024. When the data are not pooled, there are only six observations per sample. Even so, markets with inexperienced subjects and relatively high potential loss exhibit significantly higher *Risk Premia* than markets with inexperienced subjects and relatively low potential loss. With a null hypothesis of difference in medians of zero, the two-sided p-value is 0.04. The corresponding result for markets with once-experienced subjects is not significant, with a p-value of 0.24.[13]

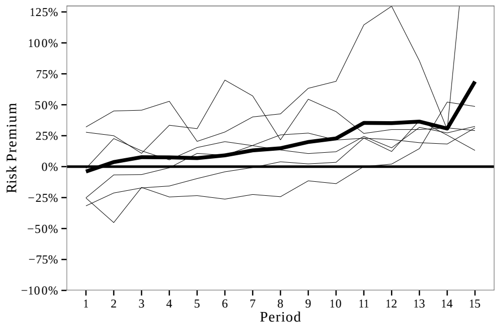
Using pooled data, the result relating to downside risk is significant. Testing

[10]Using data from all 15 periods, the p-value is 0.88.

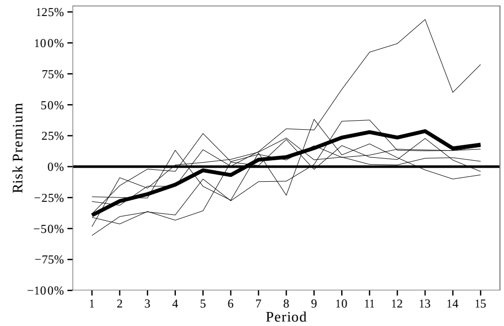
[11]One observation in the left panel of Figure 5 occurs outside the range of the graph. The *Risk Premium* for the 15th period of one of the markets— the one associated with the line seen exiting the graph after period 14— is 257%.

[12]Perhaps more specifically, when the absolute value of *Potential Loss* is higher.

[13]When using all 15 periods of a market, the p-value for once-experienced subjects is 0.31.



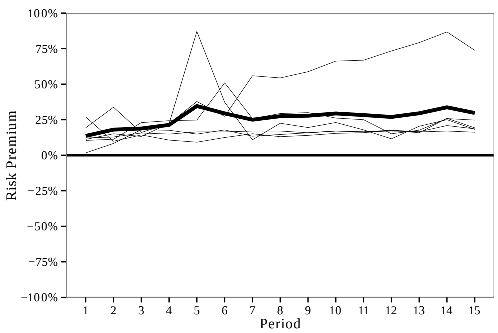
(a) High Potential Loss



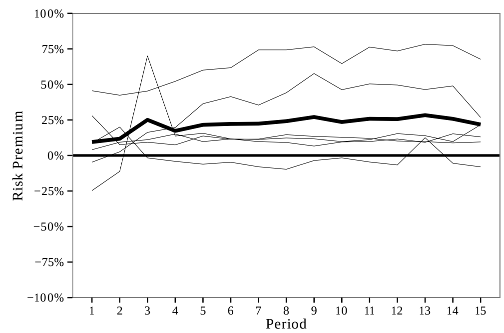
(b) Low Potential Loss

Figure 5. Risk Premia by Magnitude of Potential Loss, Inexperienced Subjects

Notes: The thicker lines represent the average *Risk Premium* in each period of the respective panel. Markets with high potential loss include those with EV of \$1.30 or \$1.10. Markets with low potential loss include those with EV of \$0.90 or \$0.70.



(a) High Potential Loss



(b) Low Potential Loss

Figure 6. Risk Premia by Magnitude of Potential Loss, Once-Experienced Subjects

Notes: The thicker lines represent the average *Risk Premium* in each period of the respective panel. Markets with high potential loss include those with EV of \$1.30 or \$1.10. Markets with low potential loss include those with EV of \$0.90 or \$0.70.

separately by experience level, the result is significant for markets with inexperienced subjects but not for markets with once-experienced subjects. When pooling the data, some of the observations are not completely independent of another observation in the same sample. My analysis suggests that this is unlikely to bias the results.[14] However, it is worthwhile to conduct statistical tests that

[14]One potential issue regarding the pooling of inexperienced and once-experienced subjects is that

allow for a larger sample size while avoiding the pooling of inexperienced and once-experienced subjects.

One way to enhance the sample size without pooling markets with inexperienced and once-experienced subjects is to use averages for a period (across markets) as the observational unit.[15] The procedure follows Noussair and Haruvy (2006). Each of the six inexperienced markets with relatively high *Potential Loss* (EV of $1.10 or $1.30) are placed in a group. Next, the average *Risk Premium* for each period is calculated, resulting in 15 observations, one for each period. The same procedure is carried out with the six inexperienced markets with relatively low *Potential Loss*, resulting in a second set of 15 observations. The two sets of 15 observations are then compared using a paired t-test. The two-sided p-value for the null hypothesis that the two sets are drawn from the same distribution is less than 0.001. With regards to markets with once-experienced subjects, the two-sided p-value is 0.07.[16]

My results are consistent with theoretical research including Roy (1952) and Thaler and Benartzi (1995), and with much work in the individual choice setting, for example Kahneman, Tversky and Thaler (1997); Novemsky and Kahneman (2005); Oxoby and Morrison (2014). The results are also consistent with Harlow and Rao (1989); Harvey (2000); Estrada (2000, 2001) and Chen, Chen and Chen (2009), who find that downside risk is priced.

Result 4B: *Risk Premia* are consistent with preference for positive skew.

In this study, loss aversion and skew preference are inextricably linked. As *Potential Loss* grows, skew becomes more negative. Much existent literature reports that subjects, in general, like positive skew. As reported above, in these

within each sample of 12 observations, three observations are not completely independent of one other observation in the same sample. Each group of subjects participates in two markets, once as inexperienced subjects and then again as once-experienced subjects. In the RISK treatment, the EV is the same in both markets, and thus both of that group's observations land in the same sample when pooling inexperienced and once-experienced markets. There may be unobserved effects owing to some natural proclivity for risk-taking amongst the subjects, or perhaps owing to the activity in the first market. Analysis of the results suggests that this is not a significant issue in this case. Within the RISK treatment, cohorts who participate in markets with high (low) *Risk Premia* when they are inexperienced subjects do also produce high (low) *Risk Premia* when they are once-experienced subjects. However, in the RISK treatment cohorts have the same EV in both of their markets. In contrast, in the UNCERTAINTY treatment, cohorts who participate in markets with high (low) *Risk Premia* when they are inexperienced subjects produce low (high) *Risk Premia* when they are once-experienced subjects. In the UNCERTAINTY treatment cohorts have different EVs in each of their markets (one time $1.30 or $1.10, the other time $0.90 or $0.70). Somewhat more formally, consider the six RISK treatment markets with inexperienced subjects. These markets are ranked one through six based upon *Risk Premium.* The same is done for the six RISK treatment markets with the same subjects that return for their once-experienced market. For the RISK treatment, there is a high and positive correlation between the rankings for each cohort when they are inexperienced and when they are once-experienced. The same procedure is carried out for the UNCERTAINTY treatment, and the result is a strong negative correlation. It thus appears that it is the EV, and not any unobserved effects, that leads to the relationship between cohort and *Risk Premia* in RISK markets.

[15]Note, RISK and UNCERTAINTY markets are still pooled.

[16]The data appear to be normally distributed. In any event, Mann-Whitney tests deliver results that are at least as significant.

data lower *Potential Loss* (equivalent to lower EV and thus more positive skew) is associated with lower *Risk Premia*. This is consistent with the hypothesis that positive skew produces higher equilibrium price. This result is consistent with the individual choice results of Astebro, Mata and Santos-Pinto (2009), the short-form asset market result of Straznicka and Weber (2011), and with the long-form asset market result of Ackert, Charupat and Deaves (2006). The positive *Risk Premia* in these data could be the result of, among other things, loss aversion, skew preference, or both.

C. *Results Related to Uncertainty*

Knight's argument that entrepreneurs in competitive markets face positive expected returns in exchange for accepting uncertainty implies that assets with inherent uncertainty should be priced lower than assets with no uncertainty. The results of Ellsberg's urn experiment and corroborating research, which show uncertainty aversion, also imply that uncertain assets should trade at lower prices than merely-risky assets with the same EV. Yet in short-form laboratory asset market studies this is often not the case. It is also not the case in this long-form study.

Result 5: There is no evidence that uncertainty decreases market prices.

Recall Figures 1 and 2. Now, for each market the average *Relative Price* is calculated, by taking the average of the 15 *Relative Prices* (one for each period) in that market. In UNCERTAINTY markets with inexperienced subjects, there are six such observations. Averaging those six observations yields an average of average *Relative Prices* of positive 1.3%. The corresponding number for the six RISK markets is negative 7%. In markets with once-experienced subjects, the average of the average *Relative Prices* is negative 16% for UNCERTAINTY markets and negative 17% for RISK markets.[17]

The higher prices in UNCERTAINTY markets with inexperienced subjects are not significant. Two-sample t-tests are run, with a null hypothesis of a true difference in means of zero. Pooling markets with inexperienced subjects and markets with once-experienced subjects, and using all 15 periods of a market, the two-sided p-value is 0.47. Using only markets with inexperienced subjects, the two-sided p-value using all 15 periods of a market is 0.43. Using only markets with once-experienced subjects, the two-sided p-value is 0.86.

Differences in *Risk Premia* between markets with and without uncertainty are not significant either. In general, the data are not normally distributed. Two-sample Mann-Whitney tests are run, with a null hypothesis of a difference in medians of zero. Pooling markets with inexperienced and once-experienced subjects, and using the last five periods of a market as the unit of observation, the

[17] Using data from the last five periods, the spreads between the two treatments are similar.

two-sided p-value is 0.80. Using only markets with inexperienced subjects, the two-sided p-value is 0.59.[18] Using only markets with once-experienced subjects, the two-sided p-value is 0.70.

Upon visual inspection of the data, it appears that the presence of uncertainty may increase prices in the middle periods of markets with inexperienced subjects. T-tests are run for each of periods six through 10. In each test, one sample consists of the six *Relative Prices* for that period corresponding to the six markets with inexperienced subjects in the UNCERTAINTY treatment, and the other sample consists of the six *Relative Prices* for that period corresponding to the six markets with inexperienced subjects in the RISK treatment. Using a null hypothesis of a difference in means of zero, the two-sided p-values for the tests for periods six through 10 are, respectively, 0.38, 0.59, 0.08, 0.60, and 0.36.

These results do not support the theoretical work of Knight, or the experimental results of Ellsberg and others. These results are not inconsistent with Savage and Arrow. Finally, my results are consistent with the results of many, but not all, short-form laboratory market studies.

While, at least in these data and in this setting, there is no evidence that uncertainty plays a significant role in price determination, it does appear to play a role in trading activity.

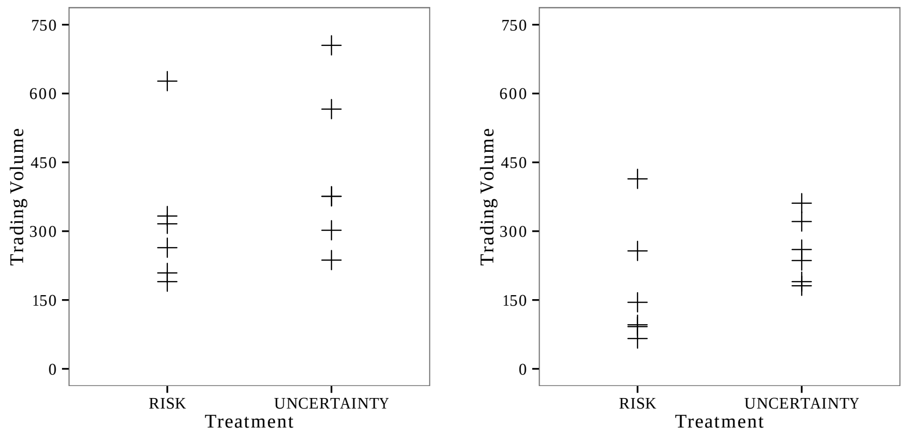
Result 6: Uncertainty is associated with increased trading volume.

In these data, trading activity increases in the presence of uncertainty. An explanation is as follows. Uncertainty may cause divergences of opinion as to the true value of an asset or the likely actions of other traders. In addition, traders with differing levels of uncertainty aversion may find trade mutually beneficial.

In markets with inexperienced subjects, trading volume is 32% higher in the presence of uncertainty, and the number of trades is 43% higher. In markets with once-experienced subjects, trading volume is 45% higher in the presence of uncertainty, and the number of trades is 40% higher. Using the medians of the six observations (markets) in each treatment/experience group, the trading volume of markets with inexperienced subjects is 30% higher in the UNCERTAINTY treatment than in the RISK treatment, and the number of trades is 79% higher. Considering markets with once-experienced subjects, median trading volume is 106% higher in the UNCERTAINTY treatment than in the RISK treatment, and the median number of trades is 96% higher.

See Figures 7 and 8. In Figure 7, the left panel depicts trading volume in markets with inexperienced subjects. Within the panel, markets in the RISK treatment appear on the left, and markets in the UNCERTAINTY treatment appear on the right. There are six observations for each treatment. The obser-

[18]In the case of inexperienced subjects and using a Shapiro-Wilk normality test, the null hypothesis of normality cannot be rejected at the 5% significance level for either sample (the p-value for the RISK treatment is 0.054, and the p-value for the UNCERTAINTY treatment is 0.29). The two-sided p-value for a t-test with the null hypothesis of no difference in means is 0.20.



(a) Inexperienced Subjects

(b) Once-Experienced Subjects

Figure 7. Trading Volume by Treatment and Experience Level

Notes: Each point represents the total trading volume over the course of a particular market. In the UNCERTAINTY treatment with inexperienced subjects, two observations completely overlap at 376.

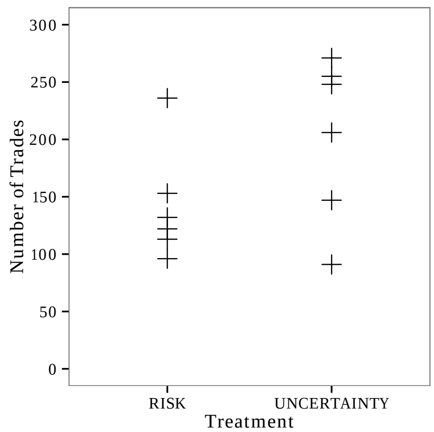
vational unit is the total trading volume over all 15 periods of a market. Note that for the UNCERTAINTY treatment, two observations overlap at 376. The right panel depicts the same information for markets with once-experienced subjects. Figure 8 uses the total number of trades over the course of a market as the observational unit, rather than total trading volume.

Multiple tests are run to investigate the statistical significance of the data relating to trading activity. Taken together, the results of these tests provide strong support for Result 6.

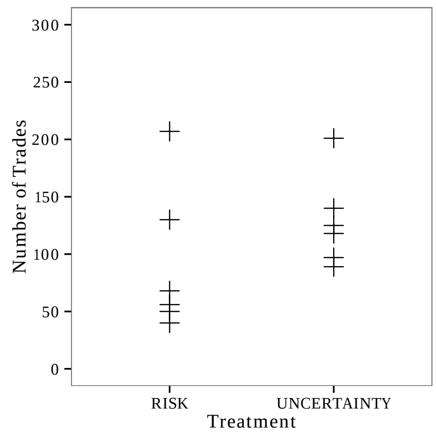
Nonparametric Mann-Whitney tests are used to compare the RISK and UNCERTAINTY treatments.[19] Using unpooled data, there are only six observations in each sample. The null hypothesis is that the difference in medians is zero. The tests produce results that are suggestive of a positive relationship between uncertainty and trading activity, but are lacking in statistical significance. Using markets with inexperienced subjects, and the total trading volume over the course of a market as the unit of observation, the two-sided p-value is 0.24. Using number of trades as the observational unit, the two-sided p-value is 0.18. The two-sided p-values for markets with once-experienced subjects are 0.18 using volume as the observational unit and 0.24 using number of trades as the observational unit.

Pooling raw trading activity data from markets with inexperienced and once-experienced subjects in a difference-of-medians setting is not very informative. There is a well-known tendency for inexperienced subjects to trade more fre-

[19]The observations are not normally distributed.



(a) Inexperienced Subjects



(b) Once-Experienced Subjects

Figure 8. Number of Trades by Treatment and Experience Level

Note: Each point represents the total number of trades over the course of a particular market.

quently than once-experienced subjects, and as a result the underlying difference between the samples is masked. In addition there is an independence issue. The trading activity in a particular market with once-experienced subjects seems to be related to the trading activity in the market with the same (then inexperienced) subjects. Scaling the observations from markets with once-experienced subjects (utilizing the average difference between markets with inexperienced subjects and markets with once-experienced subjects within the same treatment), and using a null hypothesis of a difference in medians of zero, provides two-sided p-values of 0.078 for volume and 0.028 for number of trades. Caution is warranted, however, due to the aforementioned independence issue.

One way to increase statistical power without pooling inexperienced and once-experienced markets is to use averages within a period as the observational unit. This provides 15 observations per sample, and follows Noussair and Haruvy (2006). The process is described above under Result 4A, although here the markets are separated by treatment rather than by *Potential Loss*. The data pass normality tests, so t-tests are run. The null hypothesis is that the populations have the same mean. Using inexperienced subjects and volume as the observational unit, the two-sided p-value is less than 0.01. Using inexperienced subjects and number of trades as the observational unit, the two-sided p-value is less than 0.001. Using once-experienced subjects also produces two-sided p-values below 0.01 for volume and below 0.001 for number of trades. Interestingly, in each case (inexperienced subjects and once-experienced subjects) trading volume and number of trades are higher in the RISK treatment than in the UNCERTAINTY treatment in each of the first two periods. In every one of the remaining periods,

Table 3. Dependent Variable = Total Trading Volume

Variable	Coefficient	t-stat	p-value
Intercept	181.7	2.844	0.010
Uncertainty	91.8	1.928	0.068
Experience	-156.8	-3.293	0.004
Group	42.1	3.023	0.007

[1] Ordinary Least Squares. 24 observations. Each observation corresponds to the total trading volume over all 15 periods of a particular market.

[2] The *Uncertainty* variable is equal to zero for markets in the RISK treatment and equal to one for markets in the UNCERTAINTY treatment. The *Experience* variable is equal to zero for markets with inexperienced subjects and equal to one for markets with once-experienced subjects. The *Group* variable accounts for the relative trading activity of the same cohort of traders in their other market, see text footnote for details.

Table 4. Dependent Variable = Total Number of Trades

Variable	Coefficient	t-stat	p-value
Intercept	92.80	3.391	0.003
Uncertainty	48.75	2.389	0.027
Experience	-62.42	-3.059	0.006
Group	15.81	2.646	0.015

[1] Ordinary Least Squares. 24 observations. Each observation corresponds to the total number of trades over all 15 periods of a particular market.

[2] The *Uncertainty* variable is equal to zero for markets in the RISK treatment and equal to one for markets in the UNCERTAINTY treatment. The *Experience* variable is equal to zero for markets with inexperienced subjects and equal to one for markets with once-experienced subjects. The *Group* variable accounts for the relative trading activity of the same cohort of traders in their other market, see text footnote for details.

both trading volume and number of trades are higher in the UNCERTAINTY treatment than in the RISK treatment. This suggests that the initial, but short-lived, influence of uncertainty may be one of inducing caution. It might also explain why uncertainty has not often been observed to increase trading activity in short-form laboratory markets.

Potential problems associated with pooling raw trading activity data from markets with inexperienced and once-experienced subjects in a difference-of-medians setting can also be avoided by instead utilizing regression analysis. Ordinary least squares is employed. There are 24 observations, one for each market. The *Uncertainty* variable is a dummy that is equal to zero for markets in the RISK treatment and equal to one for markets in the UNCERTAINTY treatment. The effect of experience on trading activity is accounted for with the *Experience* variable, which is a dummy equal to zero for markets with inexperienced subjects and equal to one for markets with once-experienced subjects. There is one more variable, *Group*, which captures the trading activity in the other market with the same subjects. *Group* accounts for the independence issue discussed earlier.[20] Using the total trading volume in a market as the dependent variable, the p-value for the *Uncertainty* variable is 0.068. See Table 2. Using the total number of trades in a market as the dependent variable, the p-value for the *Uncertainty* variable is 0.027. See Table 3.

IV. Conclusion

In this paper I report statistically significant, positive risk premia in a long-form laboratory asset market study. Previously, risk aversion had been documented in individual choice laboratory experiments and in short-form laboratory asset markets. However, due partly to the prevalence of bubbles, risk premia had not previously been studied within the context of long-form laboratory asset markets, and positive risk premia had not been reported. Also, it has proven quite difficult to isolate risk aversion in the field. The lack of observed risk premia in the laboratory and the difficulty of isolating risk aversion in the field could lead one to ask: Is there something inherent in markets for long-lived assets that prevents risk aversion from influencing prices? The data in this study suggest that, at least in the absence of bubbles, the answer is no, in support of standard asset pricing theory.

Beyond the question of the existence of risk premia lies the issue of the proper characterization of risk. That is, what form or forms of risk are priced? Within the realm of long-form laboratory asset markets little has been said on this topic, with the exception of Ackert, Charupat and Deaves (2006) who report preference for positive skew. In my data, which feature non-normal return distributions, expected variance is not priced. However my results are consistent with a growing body of field, theoretical, and experimental research that highlights the roles of downside risk and skew preference. The results of my study suggest that some

[20]For each combination of treatment and experience level there are six observations. These are ranked from one (low) to six (high) based upon trading activity (either volume or number of trades, to correspond to the dependent variable). Then, for each observation, the rank of that cohort in the other market it participated in is gathered to create the variable *Group*. An observation where that cohort had the highest trading activity in the other market it participated in, of the six relevant markets, carries a value of six for the *Group* variable. An observation where the cohort in question had the lowest trading activity in the other market it participated in, of the six relevant markets, carries a value of one for the *Group* variable. And so forth.

combination of downside risk and skewness is priced.

Knightian uncertainty is also closely examined in this study. A central question is whether market prices are influenced by its presence. This question has never before been a focus of a laboratory asset market study featuring a long-lived asset. My data indicate that, in the context of this study, the presence of uncertainty does not significantly influence market prices. This finding adds to a longstanding debate, and highlights the complexities of the issue. Further research is warranted.

In this paper I also explore the effect of Knightian uncertainty on trading volume. The prevailing thinking has been that the introduction of uncertainty decreases trading activity, but prior experimental research fails to support this proposition. In a recent paper, Fullbrun, Rau and Weitzel (2014) report evidence that, under some circumstances, uncertainty increases trading activity in short-form laboratory asset markets, and suggest a rationale having to do with divergences of opinion. I present further evidence that uncertainty does indeed increase trading activity. Differing levels of uncertainty aversion, as well as divergences of opinion as to EV, may be at work. Furthermore, my data suggest that subjects' reaction to uncertainty may evolve over time. In my study subjects initially appear to react to uncertainty with caution, as within the first two periods of a market trading activity is lower when uncertainty is present. After two periods, however, trading activity is higher in the presence of uncertainty.

Finally, this paper presents an experimental design that eliminates bubbles and crashes. The design includes a collection of 'best practices' in bubble mitigation developed by many researchers over the past 25 years. These mitigation measures had each exhibited success in bubble reduction, but bubble elimination was uncommon. It appears that a 'cocktail' of mitigation techniques can eliminate bubbles. By eliminating bubbles and crashes, my design promotes a stable research environment with minimal interference from speculative activity. This design can assist in future investigations relating to how various non-speculative factors influence market behavior.

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Instructions for RISK Treatment

Introduction
This is an experiment in the economics of market decision-making. You will be paid in cash at the end of the experiment. Your cash earnings will depend upon your performance in the experiment. We encourage you to carefully read these instructions, as a thorough understanding of these instructions and good decision making are likely to increase your earnings. Each participant has been given the exact same instructions. Please do not speak with any other participants during this experiment. If you have a question, please raise your hand and wait for the experimenter to come by and assist you.

General Information
This experiment is concerned with replicating an asset market where traders can trade tickets for 15 consecutive periods. The market consists of ten participants (traders). Each trader gets an initial endowment of 8 tickets and $8 in cash. At the end of the experiment, each ticket will be redeemed for cash. You will also get to keep any cash that you have on hand prior to the redemption of the tickets.

Draw Rules
At the end of the 15th period, the computer program will conduct a random draw to determine the redemption amount for each ticket. The process is as follows. The computer will simulate one ping pong ball drawn at random from a container filled with 100 balls (with each having an equal chance of being drawn). Each ball has an amount written on it. The amount written on the ball that is chosen will be the redemption amount. Each ticket will be redeemed for that amount. Every ball in the container has one of two amounts written on it: $0.50 or $1.50. 40 balls have $0.50 written on them and 60 balls have $1.50 written on them.

Trading
During each period you will have the opportunity to attempt to buy and / or sell tickets. The rules governing trading in this experiment are as follows.

- Each trading period lasts 90 seconds.
- Trade is accomplished in form of a double auction, i.e. each trader can attempt to buy and sell at the same time, if they so desire. Each trader can also attempt to buy (but not sell) or to sell (but not buy) if they so desire. Finally, each trader can refrain from attempting to trade, if they so desire.
- If you would like to sell one or more of your tickets, you have two options. The first is to go to the list of existing buy orders (posted by traders who are trying to buy tickets) in the box above and to the left of the Price box, select an order, and push "Sell". You should take great care to make sure that you are selecting an order at the top of the list, with the highest price

if possible. You may need to scroll up to see the best offer. The second option is to submit a new sell order, and hope someone accepts it. Enter the price you wish to sell at in the Price box, the quantity you wish to sell in the Volume box, and hit the "Submit sell order" button. Any sell offers you make must be at a lower price than the lowest priced existing offer. You may have multiple sell orders outstanding at one time. You may cancel your sell order(s) if you wish, by highlighting your order and pushing "Cancel".

- If you would like to buy one or more ticket(s), you have two options. The first is to go to the list of existing sell orders (posted by traders who are trying to sell tickets) in the box above and to the right of the Price box, select an order, and push "Buy". You should take great care to make sure that you are selecting an order at the top of the list, with the lowest price if possible. You may need to scroll up to see the best offer. The second option is to submit a new buy order, and hope someone accepts it. Enter the price you wish to buy at in the Price box, the quantity you wish to buy in the Volume box, and hit the "Submit buy order" button. Any buy offers you make must be at a higher price than the highest priced existing offer. You may have multiple buy orders outstanding at one time. You may cancel your buy order(s) if you wish, by highlighting your order and pushing "Cancel".

- The number of tickets you may offer to buy is limited only by the amount of cash in your cash account. The number you may offer to sell is limited by the number that you own (you may not sell short).

- You may attempt to make multiple trades in the same period.

- You do not have to place any orders or make any trades during the experiment.

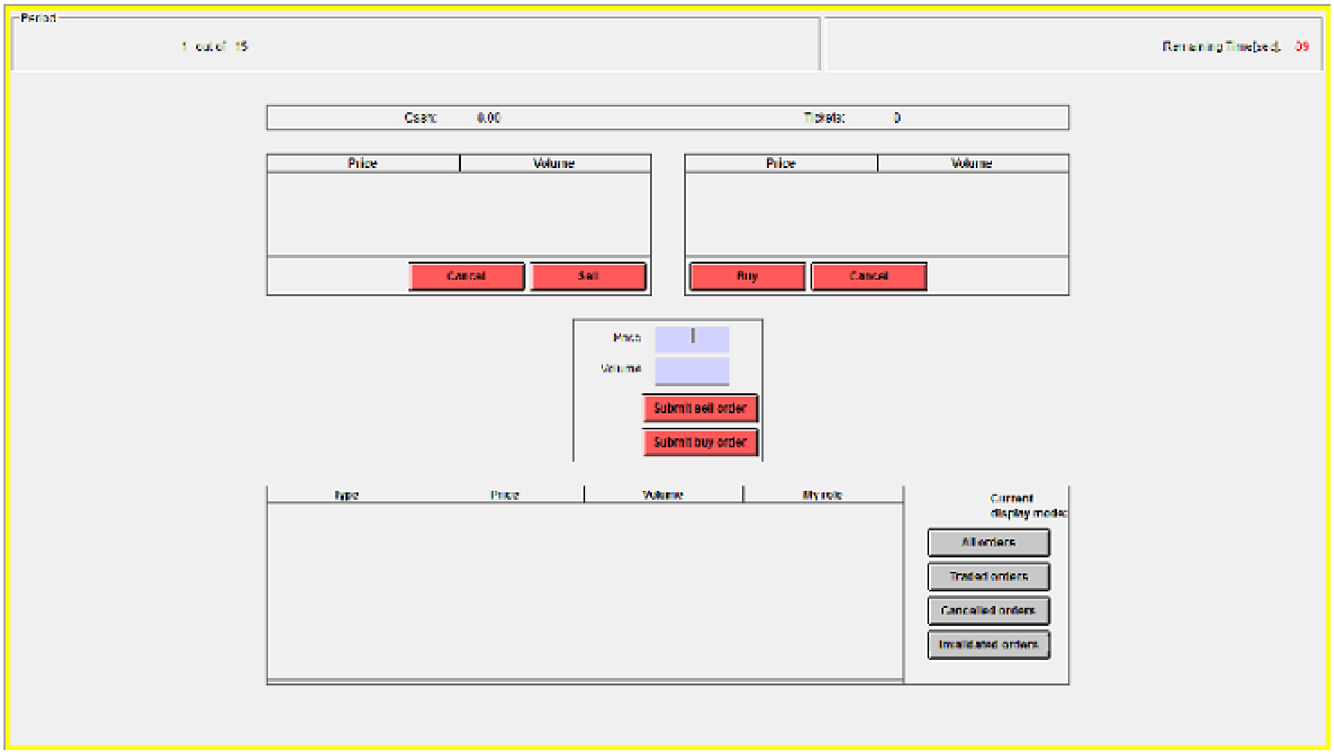
- Enter prices on your orders in the format of 2 decimal places, i.e. cents.

- All traders will be able to see the orders that all other traders have submitted and that are currently outstanding.

- If you purchase tickets, the cost of the tickets (price*volume) will be deducted from your cash account. If you sell tickets, the proceeds (price*volume) will be added to your cash account.

Screenshot of Trading Interface

A screenshot of the trading interface is shown below.



Practice Periods

There will be 2 practice periods at the beginning of the experiment, followed by the 15 paying periods. You will earn no money during the practice periods, and your trades will not carry over into the paying periods. So, at the beginning of the first paying period, you will have \$8 in cash and 8 tickets, no matter what you did in the practice periods. The purpose of the practice periods is to allow you to familiarize yourself with the program interface. In fact, you will not be interacting with the other traders during the practice periods. The two orders that will be on your screen at the start of the practice periods were created by the computer.

Samples from a Distribution

If you did not know what the combination of the container was, a sample could have helped you. Here is the procedure for obtaining a sample with replacement: we take one ball out of the container at random, record the number on that ball, replace the ball in the container, mix the contents of the container, and then pick another ball, repeating this process until we have 5 observations. The contents of the sample may or may not accurately reflect the contents of the container. And, if we take repeated samples, each sample may be different. To illustrate, let's assume that a container contains 50 $2.00 balls and 50 $4.00 balls. Below are 3 random samples from that container. You can see that in Sample 1, there were 3 $2.00 balls and 2 $4.00 balls. In Sample 2, there were 4 $2.00 balls and 1 $4.00 ball. In Sample 3, there were 3 $2.00 balls and 2 $4.00 balls.

	Sample 1	Sample 2	Sample 3
Obs. 1	$2.00	$2.00	$2.00
Obs. 2	$4.00	$4.00	$4.00
Obs. 3	$2.00	$2.00	$4.00
Obs. 4	$4.00	$2.00	$2.00
Obs. 5	$2.00	$2.00	$2.00
Sample Average	$2.80	$2.40	$2.80
Distribution Average	$3.00	$3.00	$3.00

One Sample from the Container

In this experiment, you know the combination of the container. You know that there are 40 $0.50 balls in the container and 60 $1.50 balls in the container. For illustrative purposes, you are now shown 1 sample from the distribution. 5 balls were drawn at random from the container in this experiment with replacement, with each ball having an equal chance of being drawn. The results were:

	Sample
Obs. 1	$1.50
Obs. 2	$0.50
Obs. 3	$1.50
Obs. 4	$1.50
Obs. 5	$0.50
Average	$1.10

Expected Value

The Expected Value of the lottery tickets may help you make your decisions. The concept of expected value can be explained with the example of a coin flip. If I were to flip a coin and give you \$0.00 if the result was heads and \$2.00 if the results were tails, the expected value of the coin flip would be \$1.00— a 50% chance of no payout and a 50% chance of a \$2.00 payout. Notice that the \$1.00 expected value is the weighted average of the possible results. In this experiment we have ping pong balls rather than coins, but expected value is calculated in the same way. The expected value is the average of the amounts on the balls in the container, which is \$1.10:

$$((\$0.50 * 40) + (\$1.50 * 60))/100$$

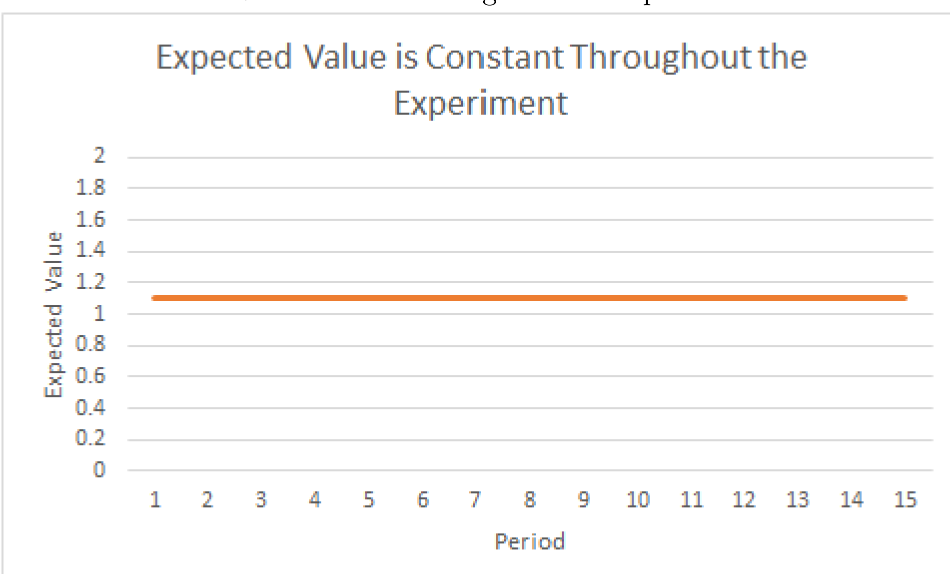
$$= (\$20.00 + \$90.00)/100$$

$$= \$110.00/100$$

$$= \$1.10$$

Graph of Expected Value

As shown below EV is constant throughout the experiment.



Display of Expected Value
Prior to the beginning of every period, the expected value will be displayed on your screen for 5 seconds.

Redemption of Tickets
The draw will take place after period 15 is over, and will be carried out by the computer program. The computer will simulate one ball drawn from the container at random (with each ball having an equal chance of being drawn). The cash amount on that ball will be the redemption amount. Each ticket will be redeemed for that amount of cash. The cash will be deposited in the traders' cash accounts.

Calculate Your Earnings
At the end of the experiment, your earnings will equal: your cash balance after period 15 but prior to the redemption of tickets + any cash received from the redemption of tickets.

Quiz
Before being allowed to start the experiment, every trader must pass a quiz. The passing grade on the quiz is 100%— everyone must get every question correct before being allowed to participate in the experiment. You may retake the quiz until you get 100%. The questions on the quiz are the following:

1) What are the 2 potential redemption amounts?
2) Do we know the probability that the redemption amount will be $0.50?
3) If so, what is that probability?
4) Do we know the probability that the redemption amount will be $1.50?
5) If so, what is that probability?
6) How many $0.50 balls are in the container?
7) How many $1.50 balls are in the container?
8) What is the Expected Value of the tickets?
9) Do you have to place any orders during the experiment?
10) If you want purchase ticket(s) by selecting an existing sell order that another trader has made, should you select the lowest priced order available?
11) May you have to scroll up to the top of the list to see that order?
12) If you want sell ticket(s) by selecting an existing buy order that another trader has made, should you select the highest priced order available?

13) May you have to scroll up to the top of the list to see that order?

14) If (hypothetically, as the price is not realistic for this experiment) in period 15 you buy 1 ticket for a price of $20, and if you hold that ticket until the end of the period (which is also the end of the experiment), and if the redemption amount is less than $20, did you gain or lose money on your trade?

15) If (hypothetically, as the price is not realistic for this experiment) in period 4 you buy 1 ticket for a price of $15, and if you hold that ticket until the end of the experiment, and if the redemption amount is more than $15, did you gain or lose money on your trade?

16) Assume that after the 15th period you hold 8 tickets and have $8 in cash. Then, the draw occurs and a $0.50 ball is drawn. What would your total earnings (not including the show-up fee) be?

17) Do the practice periods count at all towards your earnings from this experiment?

18) Will your cash and tickets be reset to $8 and 8 at the start of the first paying period?

19) Did all traders in the experiment have to score 100% on this quiz before starting the experiment?

Instructions for UNCERTAINTY Treatment

Introduction
This is an experiment in the economics of market decision-making. You will be paid in cash at the end of the experiment. Your cash earnings will depend upon your performance in the experiment. We encourage you to carefully read these instructions, as a thorough understanding of these instructions and good decision making are likely to increase your earnings. Each participant has been given the exact same instructions. Please do not speak with any other participants during this experiment. If you have a question, please raise your hand and wait for the experimenter to come by and assist you.

General Information
This experiment is concerned with replicating an asset market where traders can trade tickets for 15 consecutive periods. The market consists of ten participants (traders). Each trader gets an initial endowment of 8 tickets and $8 in cash. At the end of the experiment, each ticket will be redeemed for cash. You will also

get to keep any cash that you have on hand prior to the redemption of the tickets.

Ticket Redemption Rules
At the end of the 15th period, the computer program will conduct a random draw to determine the redemption amount for each ticket. The process is as follows. The computer will simulate one ping pong ball drawn at random from a container filled with 100 balls (with each having an equal chance of being drawn). Each ball has an amount written on it. The amount written on the ball that is chosen will be the redemption amount. Each ticket will be redeemed for that amount. Every ball in the container has one of two amounts written on it: \$0.50 or \$1.50. You do not know how many balls have \$0.50 written on them and how many have \$1.50 written on them.

Trading
During each period you will have the opportunity to attempt to buy and / or sell tickets. The rules governing trading in this experiment are as follows.

- Each trading period lasts 90 seconds.
- Trade is accomplished in form of a double auction, i.e. each trader can attempt to buy and sell at the same time, if they so desire. Each trader can also attempt to buy (but not sell) or to sell (but not buy) if they so desire. Finally, each trader can refrain from attempting to trade, if they so desire.
- If you would like to sell one or more of your tickets, you have two options. The first is to go to the list of existing buy orders (posted by traders who are trying to buy tickets) in the box above and to the left of the Price box, select an order, and push "Sell". You should take great care to make sure that you are selecting an order at the top of the list, with the highest price if possible. You may need to scroll up to see the best offer. The second option is to submit a new sell order, and hope someone accepts it. Enter the price you wish to sell at in the Price box, the quantity you wish to sell in the Volume box, and hit the "Submit sell order" button. Any sell offers you make must be at a lower price than the lowest priced existing offer. You may have multiple sell orders outstanding at one time. You may cancel your sell order(s) if you wish, by highlighting your order and pushing "Cancel".
- If you would like to buy one or more ticket(s), you have two options. The first is to go to the list of existing sell orders (posted by traders who are trying to sell tickets) in the box above and to the right of the Price box, select an order, and push "Buy". You should take great care to make sure that you are selecting an order at the top of the list, with the lowest price if possible. You may need to scroll up to see the best offer. The second option is to submit a new buy order, and hope someone accepts it. Enter the price you wish to buy at in the Price box, the quantity you wish to

buy in the Volume box, and hit the "Submit buy order" button. Any buy offers you make must be at a higher price than the highest priced existing offer. You may have multiple buy orders outstanding at one time. You may cancel your buy order(s) if you wish, by highlighting your order and pushing "Cancel".

- The number of tickets you may offer to buy is limited only by the amount of cash in your cash account. The number you may offer to sell is limited by the number that you own (you may not sell short).

- You may attempt to make multiple trades in the same period.

- You do not have to place any orders or make any trades during the experiment.

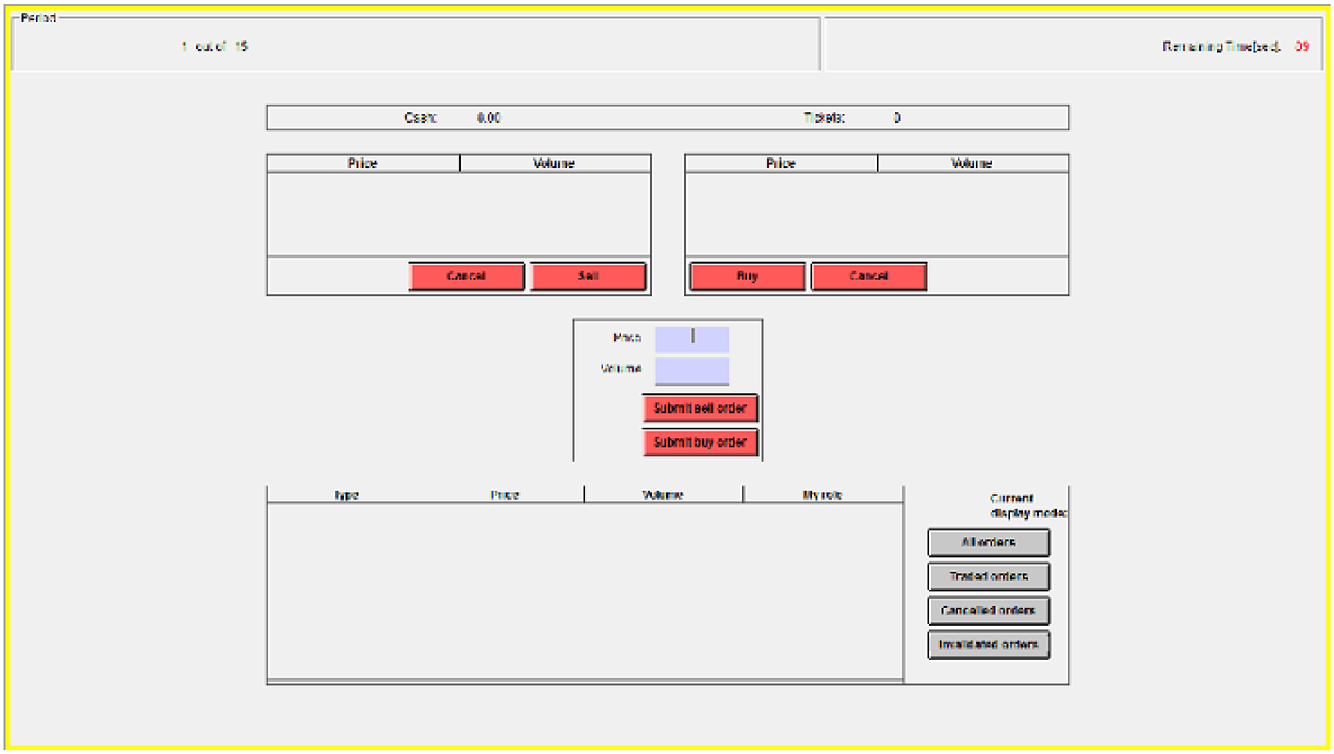
- Enter prices on your orders in the format of 2 decimal places, i.e. cents.

- All traders will be able to see the orders that all other traders have submitted and that are currently outstanding.

- If you purchase tickets, the cost of the tickets (price*volume) will be deducted from your cash account. If you sell tickets, the proceeds (price*volume) will be added to your cash account.

Screenshot of Trading Interface

A screenshot of the trading interface is shown below.



Practice Periods

There will be 2 practice periods at the beginning of the experiment, followed by the 15 paying periods. You will earn no money during the practice periods, and your trades will not carry over into the paying periods. So, at the beginning of the first paying period, you will have \$8 in cash and 8 tickets, no matter what you did in the practice periods. The purpose of the practice periods is to allow you to familiarize yourself with the program interface. In fact, you will not be interacting with the other traders during the practice periods. The two orders that will be on your screen at the start of the practice periods were created by the computer.

Samples from a Distribution

A sample cannot tell you with certainty what the combination of the container is. However it provides you with your best statistical guess. Here is the procedure for obtaining a sample with replacement: we take one ball out of the container at random, record the number on that ball, replace the ball in the container, mix the contents of the container, and then pick another ball, repeating this process until we have 5 observations. The contents of the sample may or may not accurately reflect the contents of the container. And, if we take repeated samples, each sample may be different. To illustrate, let's assume that a container contains 50 \$2.00 balls and 50 \$4.00 balls. Below are 3 random samples from that container. You can see that in Sample 1, there were 3 \$2.00 balls and 2 \$4.00 balls. In Sample 2, there were 4 \$2.00 balls and 1 \$4.00 ball. In Sample 3, there were 3 \$2.00 balls and 2 \$4.00 balls.

	Sample 1	Sample 2	Sample 3
Obs. 1	\$2.00	\$2.00	\$2.00
Obs. 2	\$4.00	\$4.00	\$4.00
Obs. 3	\$2.00	\$2.00	\$4.00
Obs. 4	\$4.00	\$2.00	\$2.00
Obs. 5	\$2.00	\$2.00	\$2.00
Sample Average	\$2.80	\$2.40	\$2.80
Distribution Average	\$3.00	\$3.00	\$3.00

One Sample from the Container

In this experiment, you do not know the combination of the container. You do not know how many \$0.50 balls are in the container and how many \$1.50 balls are in the container. However, you are now shown 1 sample from the container. 5 balls were drawn at random from the container in this experiment with replacement, with each ball having an equal chance of being drawn. The results were:

	Sample
Obs. 1	\$0.50
Obs. 2	\$1.50
Obs. 3	\$0.50
Obs. 4	\$1.50
Obs. 5	\$0.50
Average	\$0.90

Expected Value

The Expected Value of the tickets may help you make your decisions. The concept of expected value can be explained with the example of a coin flip. If I were to flip a coin and give you \$0.00 if the result was heads and \$2.00 if the result was tails, the expected value of the coin flip would be \$1.00— a 50% chance of no payout and a 50% chance of a \$2.00 payout. Note that the \$1.00 expected value is the weighted average of the possible results— when you add \$0.00 and \$2.00, and divide the resulting sum of \$2.00 by 2, you get \$1.00. In this experiment we have ping pong balls rather than coins, but expected value is calculated in a similar way. The Expected Value of the tickets is the average of the amounts on the balls in the sample, which is \$0.90:

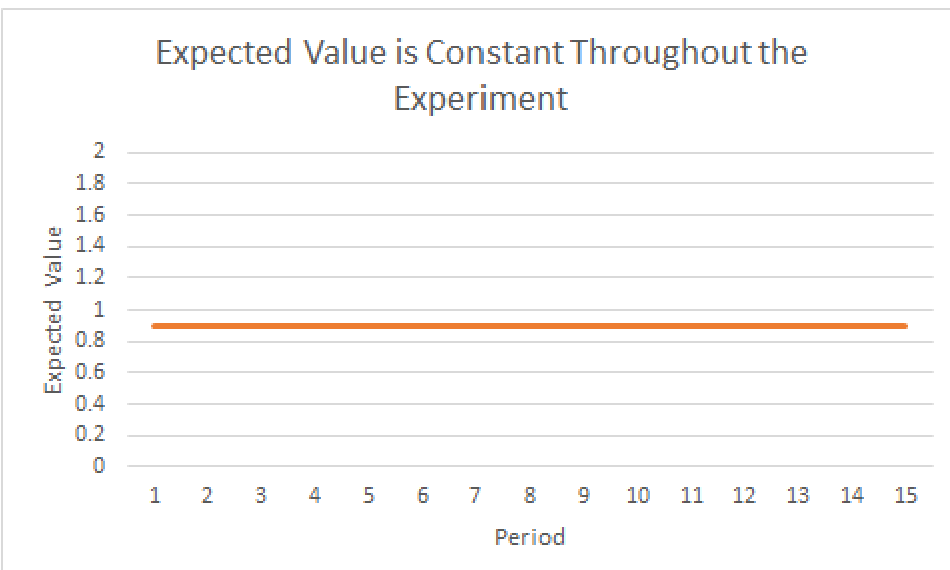
$$(\$0.50 + \$1.50 + \$0.50 + \$1.50 + \$0.50)/5$$

$$= \$4.50/5$$

$$= \$0.90$$

Graph of Expected Value

As shown below, EV is constant throughout the experiment.



Display of Expected Value
Prior to the beginning of every period, the expected value will be displayed on your screen for 5 seconds.

Redemption of Tickets
The draw will take place after period 15 is over, and will be carried out by the computer program. The computer will simulate one ball drawn from the container at random (with each ball having an equal chance of being drawn). The cash amount on that ball will be the redemption amount. Each ticket will be redeemed for that amount of cash. The cash will be deposited in the players' cash accounts.

Calculate Your Earnings
At the end of the experiment, your earnings will equal: your cash balance after period 15 but prior to the redemption of tickets + any cash received from the redemption of tickets.

Quiz
Before being allowed to start the experiment, every trader must pass the following quiz. The passing grade on the quiz is 100%— everyone must get every question correct before being allowed to participate in the experiment. You may retake the quiz until you get 100%. The questions on the quiz are the following:

1) What are the 2 potential redemption amounts?
2) Do you know the probability that the redemption amount will be $0.50?
3) Do you know the probability that the redemption amount will be $1.50?
4) Do you know what the combination of balls in the container is?
5) Do you know if the proportion of balls in the sample is the same as the proportion of balls in the whole container?
6) Can the average of the observations in the sample be different from the average of the whole container?
7) What is the Expected Value of the tickets?
8) Do you have to place any orders during the experiment?
9) If you want purchase ticket(s) by selecting an existing sell order that another trader has made, should you select the lowest priced order available?
10) May you have to scroll up to the top of the list to see that order?
11) If you want sell ticket(s) by selecting an existing buy order that another trader has made, should you select the highest priced order available?

12) May you have to scroll up to the top of the list to see that order?

13) If (hypothetically, as the price is not realistic for this experiment) in period 15 you buy 1 ticket for a price of $20, and if you hold that ticket until the end of the period (which is also the end of the experiment), and if the redemption amount is less than $20, did you gain or lose money on your trade?

14) If (hypothetically, as the price is not realistic for this experiment) in period 4 you buy 1 ticket for a price of $15, and if you hold that ticket until the end of the experiment, and if the redemption amount is more than $15, did you gain or lose money on your trade?

15) Assume that after the 15th period you hold 8 tickets and have $8 in cash. Then, the draw occurs and a $0.50 ball is drawn. What would your total earnings (not including the show-up fee) be?

16) Do the practice periods count at all towards your earnings from this experiment?

17) Will your cash and tickets be reset to $8 and 8 at the start of the first paying period?

18) Did all traders in the experiment have to score 100% on this quiz before starting the experiment?