College of Business and Public Policy
University of Alaska Anchorage

Department of Economics Working Paper
WP 2011-04
August 2011

Ambiguity in Individual Choice and Market Environments: On the Importance of Comparative Ignorance

Jonathan E. Alevy
University of Alaska Anchorage

UAA DEPARTMENT OF ECONOMICS
3211 Providence Drive
Rasmuson Hall 302
Anchorage, AK 99508

http://www.cbpp.uaa.alaska.edu/econ/econhome.aspx

Ambiguity in Individual Choice and Market Environments: On the Importance of Comparative Ignorance

Abstract: After Ellsberg's thought experiments brought focus to the relevance of missing information for choice, extensive efforts have been made to understand ambiguity theoretically and empirically (Ellsberg 1961). Fox and Tversky (1995) make an important contribution to understanding behavioral responses to ambiguity. In an individual choice setting they demonstrate that an aversion to ambiguous lotteries arises only when a comparison to unambiguous lotteries is available. The current study advances this literature by exploring the importance of Fox and Tversky's finding for market outcomes and finds support for their Comparative Ignorance Hypothesis in the market setting. Experiments in both individual choice and market settings examine behavior under risk and ambiguity. A sizeable effect of ambiguity on prices is observed – but only when the experimental treatment makes the risky and ambiguous assets easily comparable. Further, when ambiguity is salient, individual attitudes towards ambiguity and behavior in the marketplace are linked; ambiguity-averse subjects tend to avoid ambiguous assets in the marketplace. However, a simple experimental manipulation that makes the distinction between risk and ambiguity less apparent changes outcomes dramatically; the correlation between individual ambiguity attitudes and market allocations disappears, as do differences in market prices between risky and ambiguous assets.

JEL Codes: C91, C92, D81, G12

1. Introduction

Decision making under ambiguity has been of interest to economists since the 1920's, when Knight (1921) and Keynes (1921) raised issues similar to those that distinguish risk from ambiguity in the current study. Knight distinguished measurable from unmeasurable uncertainty, while Keynes argued that equal probabilities can have different impacts on behavior as a result of the weight of the evidence through which they were derived. Ellsberg's thought experiments brought into focus the relevance of missing information about probabilities, raising issues about both the descriptive and normative significance of subjective expected utility theory (SEU) (Ellsberg 1961). The paradoxes identified by Ellsberg have led to extensive work in axiomatic decision theory, applied theory, as well as to a large number of experimental studies on ambiguity.[1]

Experimental results by Fox and Tversky (1995) extended an important line of research that explores the nature of ambiguity in individual choice settings. Using a design that examines valuations, within and between subjects, they present evidence that an aversion to ambiguous lotteries arises only when a comparison to unambiguous (risky) lotteries is possible. Peter Wakker argues that "Fox and Tversky's finding seems to place the Ellsberg paradox in an entirely new light," since it suggests that "contrast effects" and not subjective preferences drive responses to ambiguity (Wakker 2000).

To date, little research has explored the implications of the contrast effects discovered by Fox and Tversky for market outcomes. In this study I conduct experiments, within subjects, in

[1] Wakker (2010) reviews much of the decision theoretic literature. Mukerji and Tallon (2004) review a variety of economic models in contract theory, finance, and other fields that explicitly incorporate ambiguity.

both individual choice and market settings to help fill this gap. The experimental results provide further evidence on the importance of the distinction between risk and ambiguity and on the role of contrast effects. In the individual choice setting heterogeneous attitudes to risk and ambiguity are observed, although on balance our subjects are averse to both. In the marketplace a sizeable effect of ambiguity on prices is observed – but only in certain situations. Prices for ambiguous assets are lower than for risky assets in markets where the experimental treatment makes the risky and ambiguous assets easily comparable, as in Ellsberg's thought experiments and Fox and Tversky's within subjects' treatments (Ellsberg 1961, Fox and Tversky 1995). Further, in the settings where ambiguity is salient, there is a clear link between attitudes towards ambiguity and market outcomes; the most ambiguity-averse subjects in the individual choice setting tend to avoid ambiguous assets in the marketplace – a novel finding. However, a simple experimental manipulation that makes the distinction between risk and ambiguity less apparent changes outcomes dramatically; the correlation between individual ambiguity attitudes and market allocations disappears, as do differences in market prices between risky and ambiguous assets.

The experimental results thus add fresh insights to the literature on ambiguity aversion and extend to an asset market setting the examination of the comparative ignorance hypothesis (CIH) first studied in individual choice settings by Fox and Tversky (1995). In addition to examining comparability effects in the marketplace, the current experiments, are, to my knowledge, the first to examine attitudes to ambiguity, within subjects, in both choice and market settings.

The evidence of the predictive value of individual ambiguity attitudes for market allocations, when ambiguity is salient, is interesting in light of the literature that suggests risk preferences are malleable. Isaac and James (2000), and Berg, Dickhaut, and McCabe (2005) find that risk attitudes differ depending on the elicitation method used; individual choice and market protocols yield different results. Johnson and Schkade (1989) show that risk attitudes are susceptible to anchoring. Extending this inquiry to ambiguity by providing initial evidence on conditions under which individual ambiguity attitudes affect market outcomes, is of interest given the view of Epstein (1999) and others that ambiguity is both a more prevalent and more fundamental aspect of economic environments than risk.

To examine the links between attitudes towards ambiguity across the individual choice and market settings, maximum likelihood estimates of individual ambiguity attitudes are compared to the final allocations of risky and ambiguous assets in the market setting. The analysis is in the spirit of Plott and Sunder's (1982) examination of information dissemination in asset markets. In that study, dividend payouts varied across subjects in order to exogenously define trader types; the final allocations were indicators of the informational efficiency of the markets. In the current study, dividends per asset are identical within a session; types are defined by decisions in the individual choice setting that reveal ambiguity attitudes. In addition to examining asset allocations, transaction prices and bidding behavior are studied to analyze how ambiguity attitudes are expressed in the market setting.

A seminal study of ambiguity in asset markets is that of Sarin and Weber (1993) who observe a significant reduction in prices of ambiguous assets when risky and ambiguous assets are traded simultaneously. The current study examines sequential exposure to risk and ambiguity an area in which Sarin and Weber report inconclusive results. More recently, Bossaerts et al. (2010) conducted an asset market experiment based on the Ellsberg paradox. Consistent with our findings they observe heterogeneous final allocations of risky and ambiguous assets, however, as in the Sarin and Weber study, they do not control for individual ambiguity attitudes nor do they examine, within subjects, the potential impact of comparative ignorance in the market setting as is done in this study.[2]

The paper proceeds as follows: Section 2 introduces the type of ambiguity – closely following Ellsberg – that is operationalized in the experimental environments, and discusses related contributions in the literature. Section 3 presents an overview of the experimental design and details on the experimental sessions. Section 4 details the methods and results in the asset market and Section 5 those in the individual choice setting. Section 6 examines the conservation of ambiguity attitudes across the choice and market environments. Section 7 concludes.

2. Definition and Implementation of Ambiguity

Ambiguity has been defined as "a quality depending on the amount, type, and 'unanimity' of information, and giving rise to one's degree of 'confidence' in an estimate of relative likelihoods," (Ellsberg 1961) or more concisely as "known-to-be-missing information" (Frisch and Baron (1988), see also Camerer (1999)).[3] These verbal definitions have been supplemented by axiomatic approaches that modify the SEU frameworks developed by Savage (1954) or Anscombe and Aumann (1963).

---

[2] Di Mauro (2008) conducts a market experiment to examine the relation of ambiguity and competence in judgments. Her implementation of ambiguity differs from the current study in the use of natural events and so results are not directly comparable. She finds evidence of ambiguity seeking and ambiguity aversion in the marketplace consistent with Heath and Tversky's (1991) investigation on the role of competence for choice under uncertainty.

[3] Savage (1954) also took note of the issue, remarking that "there seem to be some probability relations about which we seem relatively 'sure' as compared with others…The notion of sure and unsure introduced here is vague, and my complaint is precisely that neither the theory of personal probability, as it is developed in this book, nor any device known to me renders the notion less vague."

In this study missing information is operationalized as in Ellsberg's examples. Subjects are exposed to risky and ambiguous lotteries, in both choice and market settings. Under ambiguity the probability of some outcomes are not disclosed. The stylized fact, that many individuals are averse to ambiguity, has been demonstrated for both choice and pricing behavior although there is evidence that the effect is stronger in choice settings (Maffioletti et al. 2009). One way to understand ambiguity aversion theoretically is to assume that ambiguity has an effect directly on utility; the choice setting has implications for utility along with the outcomes (Smith 1969). Other theoretical approaches have assumed that the utility of outcomes are the same under risk and ambiguity, and behavioral differences are attributed to differences in decision weights (e.g. Schmeidler 1989, Epstein 1999, Ghirardhato and Marinacci 2002, Ghirardhato et al. 2004, Wakker 2010).

Individual choice experiments have shed light on the conditions under which ambiguity is likely to matter. Heath and Tversky (1991) demonstrated that in situations characterized by a lack of competence about a judgment task, ambiguity aversion is likely. However, when individuals feel competent in a situation they are likely to seek ambiguity. Fox and Tversky (1995) extend the investigation of this result by examining the conditions under which competence may arise. The experimental protocols vary joint and separate evaluation of risky and ambiguous lotteries, between subjects. When jointly pricing both risky and ambiguous lotteries, Fox and Tversky's subjects, on average, exhibit an aversion to ambiguity. In contrast, valuations of ambiguous and risky lotteries are statistically indistinguishable when the valuations are made, between subjects, in isolation. Thus, missing information is made salient when a simultaneous comparison with more complete information is possible. Summarizing their findings, the authors state their Comparative Ignorance Hypothesis; "ambiguity aversion will be present when subjects evaluate clear and ambiguous prospects jointly, but it will greatly diminish or disappear when they evaluate each prospect in isolation." (Fox and Tversky 1995).

The fact that values for ambiguous assets or lotteries do not differ from risky ones is a surprising result and, as noted, it has been argued that "Fox and Tversky's finding seems to place the Ellsberg paradox in an entirely new light," since it suggests that "contrast effects" and not subjective preferences related to uncertainty aversion drive behavior (Wakker 2000). Other research provides mixed evidence on this point. Chow and Sarin (2001) find that ambiguity responses are smaller between subjects than within – evidence of a contrast effect - but that the differences remain statistically significant in both settings – evidence for subjective uncertainty aversion. Dolan and Jones (2004) examine decisions across a broader range of probability distributions than the previous work. Their extension suggests that the comparative ignorance hypothesis explains only a subset of results. Summarizing, and also anticipating subsequent results, Wakker (2000) notes that "the truth thus seems to be somewhere in the middle," with both uncertainty aversion and comparative contexts contributing to observed behavioral effects.[4]

The mixed results suggest the need for additional research. In particular the relative importance of subjective preferences and contrast effects in market settings has received little attention. The experimental protocol parallels aspects of Fox and Tversky's design and so allows the observation of the impact of source and contrast effects, but by moving to the market setting it also possible to observe whether interactions among heterogeneous subjects may mitigate anomalous results.

[4] Contrast effects are also behaviorally important in settings other than the uncertainty associated with Ellsberg urns. Preference reversals have been observed when joint and isolated evaluations are compared in judgment tasks, in market and non-market settings (see e.g. Hsee et al. 1999; List 2002).

3. Experimental Protocol

To conduct experiments with ambiguity in a laboratory setting a method for implementing and resolving ambiguity is required. In this study, in both the individual choice and market settings ambiguity about probabilities is presented as a question mark "?" that is associated with known outcomes. A uniform distribution is used to determine probabilities and this information is provided transparently to subjects to avoid concerns that subjects may have about potential experimenter deception. As a result, the effects observed may be a lower bound on ambiguity responses when the underlying distribution is not provided

Our experimental sessions contained both an individual choice and an asset market protocol. Subjects first completed a computerized questionnaire that elicited preferences over pairs of lotteries, some with known and some with unknown probabilities. A complete list of the questions is in Appendix 1. Following the elicitation task, subjects became traders in a double auction asset market for ten rounds, with five rounds each in the risky and ambiguous conditions. The assets had three possible outcome states, and after each round of trade a random draw determined the underlying state on which the asset value depended. In five rounds of each session the probabilities of all of the three possible states were known and in five rounds two of the three state probabilities were unknown. The sessions were distinguished by the order of presentation of the risky and ambiguous assets. In session RA, subjects traded risky assets for the first five rounds and ambiguous assets in the last five. In session AR, subjects traded ambiguous and then risky assets, also each for five rounds.

Subjects were paid for the individual choice portion, through the random selection of one elicitation question and then by resolving the uncertainty with respect to the preferred lottery for that question. This procedure was conducted after the double auction was completed to mitigate income effects, but subjects were informed of the process before making their choices. Note that if an ambiguous lottery was selected a two-stage procedure was required to resolve the uncertainty. In the first stage, the probability distribution for ambiguous lotteries was determined by drawing a ball numbered from 0 to 100 from a bingo cage. The number chosen, X, represented the probability weight given to the larger of the two outcomes with unknown probabilities. In the second stage, another number was drawn to determine the outcome the subject received; a draw less than or equal to X yielded the higher value. Payments for the elicitation section ranged between $0 and $15 with an average payment of $3.75. Subjects received an average of $27.33 for the market segment, and an additional $5 for timely arrival. Total earnings ranged from $5.00 to $101.90 with an average of $36.08 for sessions that were about 2 hours and 30 minutes long. Subjects were recruited from undergraduate economics classes at the University of Arizona.

4. Asset Market

Asset Market Design and Hypotheses

The asset market implemented in this study adopted many features of the markets used in studies of the informational efficiency of markets under risk (Plott and Sunder (1982, 1988); Sunder (1992)). It is also similar to the design used by Sarin and Weber (1993). Key features of these markets are the following:

1) Subjects are in the role of traders, able to either buy or sell assets.

2) Traders are endowed with a single asset and with cash in each round.

3) The asset expires at the end of each round and pays a state contingent dividend.

4) Traders pay a fixed fee of their endowed cash in each round in order to limit earnings in each round to the sum of dividends and trading profits.

In contrast to Sarin and Weber (1993), the market is an electronic not an oral double-auction, and the assets have three states instead of two.

The three-state asset paid \$0.00, \$0.50, or \$5.00 depending on the state revealed by the draw of a random number. All traders faced the same draw and dividend earnings per asset were the same for all traders. There was 40% probability of receiving \$0.50 in all rounds. The distribution of the balance of the probability for all assets in a given round was determined by drawing from a uniform distribution. In the rounds with risky assets, the probability of all states was made known prior to trade. In the rounds with ambiguous assets, only the probability of the \$0.50 payoff, uniformly 40%, was known to the subjects. For both risky and ambiguous assets draws to determine the underlying distribution were independent across rounds of trade.

The trading sessions exposed subjects to risky and ambiguous assets sequentially, with the two sessions controlling for order effects. This design was chosen because treatments conducted by Sarin and Weber in which risky and ambiguous assets were traded simultaneously demonstrated significant evidence of lower prices in response to ambiguity. The sequential study of ambiguity exposure enables the study of the comparative ignorance hypothesis, since asset trading in both isolated and comparative settings exist and hypotheses can be tested by combining within and between subject tests across RA and AR sessions.

Comparing the first five rounds across sessions yields a market analog of the between group test of Fox and Tversky (1995) since market prices of risky and ambiguous assets are directly compared, absent any contamination due to previous exposure to the marketplace. I also consider, between subjects, whether prices for ambiguous assets differ, conditional on whether there has been previous exposure to an unambiguous asset; the type of contrast that has given support to the CIH in individual choice settings. Finally, I examine within each session whether prices differ for the different types of assets. Does the market reflect ambiguity aversion even in this setting where assets are not compared simultaneously? These questions are formalized in the following hypotheses:

Hypothesis 1: Between subject test of initial pricing of risky and ambiguous assets.

H_0: Prices of risky assets in Session RA are indistinguishable from prices of ambiguous assets in Session AR (Comparison of rounds 1-5 in both sessions).

Hypothesis 2. Between subject test of order effects in exposure to ambiguous assets.

H_0: Prices of ambiguous assets are indistinguishable across the two sessions (Comparison of session RA: Rounds 6-10 and Session AR: Rounds 1-5)

Hypothesis 3. Within subject test of the existence of an ambiguity price effect.

(a) H_0: Session RA risky and ambiguous assets are indistinguishable in price.

(b) H_0: Session AR risky and ambiguous assets are indistinguishable in price.

Asset Market Results

In this section, I report three sets of results that include (i) descriptive statistics on trading prices and bidding behavior, (ii) nonparametric randomization tests on data aggregated at the level of trading rounds, and (iii) the parametric estimation of an error components model at the level of the individual trades. The results, collectively, highlight the existence of strong contrast effects, revealing that ambiguous and risky assets differ in price only when traders have first been exposed to the risky asset.

Table 1 presents the asset market results for each round of trade. Mean prices are presented as deviations from expected values, and the bid/ask ratio is also presented. Since the probability of two of the states is determined independently in each round, the expected value of the dividend changes for the risky assets. When ambiguous assets are traded the probability of the \$0.50 outcome is always forty percent and I assume the remaining probability is distributed equally to each of the remaining states. Thus, for ambiguous assets, the expected value remains constant across all rounds. The nonparametric statistical tests of the hypotheses are conducted on the data derived from the deviations from expected values. The test used is a randomization test that pairs the mean deviations by round in the relevant trading sessions in the order traded (Siegel (1956)).

[Table 1 about here]

Table 2 reports the results on the effects of trading sequence on pricing for all the hypotheses. The null hypotheses of no difference in asset prices is rejected in two cases: (i) for Hypotheses 2, which examines prices of ambiguous assets between subjects, and (ii) for Hypothesis 3.a., which examines prices within Session RA. The first of these results reveal that the prices of ambiguous assets differ across sessions – they are lower in Session RA. The second that ambiguity has an effect on prices, within sessions, but only when there is prior exposure to risky assets. In short, the ambiguous assets in session RA, contain the only prices that differ significantly from any of the others, demonstrating that a response to ambiguity occurs when the order of the risky and ambiguous conditions provide exposure to an unambiguous standard.

Without any prior exposure to risky assets the ambiguous assets do not differ in price from those of the risky assets either within (Hypotheses 3b) or between subjects (Hypothesis 1).

[Table 2 here]

A parametric random-effects model complements the randomization test results. Rather than looking at mean trading prices per round, observations are at the level of specific trades, with the error components model controlling for individual-specific effects that are constant over time. The dependent variable, *price-diff*, is calculated as the difference between the trade price and the expected value of the asset. Independent variables include *ambi* which is one (zero) when the asset traded is ambiguous (risky); a dummy variable for the *session* which is one (zero) for the session that trades risky (ambiguous) assets first. The model also includes the interaction between the *session* and *ambi* variables, *ambiXsession*, which is one for the ambiguous condition in Session RA and zero otherwise. Thus, the interaction term allows the impact of the rounds identified as different by the nonparametric tests to be cleanly estimated. To control for learning effects unrelated to the treatment, the trend variable *round* is also included in the model.

The regression results are presented in Table 3 and provide further evidence of the importance of the contrast effects associated with the comparative ignorance hypothesis. While the asset type and session are not individually significant, the interaction between the two is both statistically and economically significant. The coefficient value of -160.32 indicates that in Session RA the prices of ambiguous assets are $1.60 lower than average prices in the other trading rounds, a reduction of more than 30%. These findings extend the findings of Fox and Tversky (1995) and Sarin and Weber (1993) and demonstrate that in the market environment sequential trade is sufficient to generate a price response to ambiguity, contingent on the order of exposure.

[Table 3 here]

To summarize, the rounds in bold type in Table 1 and, which are the ambiguous rounds six through ten in session RA, are the only rounds that differ significantly from any of the others in terms of price and relative frequency of bids and offers. Aggregate ratios of bids and offers in the relevant rounds are also presented in Table 4. These ratios provide a further indication of the selling pressures peculiar to these rounds – on average only one bid for three offers was observed when ambiguity was made salient by comparability, while in the other rounds the bids and offers were more evenly matched. A Kruskal-Wallis test rejects that the ratio of bids to offers is equal across the relevant rounds ($p<.01$).

[Table 4 here]

5. Individual Choice Experiment: Methods and Results

Elicitation Method

To better understand behavior in the asset market, risk and ambiguity attitudes for each trader were elicited from a computerized questionnaire that elicited preferences over pairs of lotteries. Responses to a total of 45 questions, 21 containing two risky lotteries, and 24 containing one risky and one ambiguous lottery were used to estimate the risk and ambiguity attitudes. Subjects were paid for the individual choice portion through the random selection of one question, and then by resolving the uncertainty associated with the preferred lottery in the selected question.Lotteries under risk are of the form $(x, p; y)$, where p is the probability of outcome x and $1-p$ the probability of outcome y. A series of eight lottery lists, four each for risk and ambiguity, were used to elicit risk and ambiguity attitudes. A representative list is shown in Table 5, and the full set of questions is in Appendix 1. Note that one of the lotteries (Lottery A) is held constant within a list. In the Table 5 example Lottery A is (15, 0.33, 0). For Lottery B, *p*, and *y* are held constant, while *x* varies across the range of values $x^1 = 6, x^2 = 8, x^3 = 10,$ and $x^4 = 11$, where the superscript represents the order of the presentation of the lottery within the specific list. Thus, subjects are presented with lotteries in a multiple price list format that change in a simple way from choice to choice within a list.[5] The approach is similar in that sense to that of Holt and Laury (2002), which has been adopted and extended by numerous researchers (Anderson et al. 2008; see also Harrison and Cox 2008). The major differences between this procedure and the bulk of the work in this area is that (i) the protocol contains multiple (though shorter) lists, and (ii) payoffs of one of the lotteries is altered while holding probabilities (or uncertainty about probabilities) constant within a list. More typically payoffs have remained constant while probabilities have changed for elicitations in the multiple price list format. Bruner (2009) examines the difference between protocols that vary probability and those that vary reward and finds no significant differences between estimates of CRRA.

[Table 5 here]

The measures of ambiguity attitudes are generated parametrically for each subject in a two-stage process. In stage one, cardinal utility is estimated using the risky lottery pairs. For all subjects, models that assume maximization of Subjective Expected Utility (SEU) and Rank Dependent Expected Utility (RDEU) maximization are estimated. The Aikake Information

[5] In addition to the systematic presentation described for the lists, a small number of questions test for consistency and violations of dominance.

Criteria (AIC) was used to choose between models. The estimation methodology is similar to that developed by Anderson et al. (2008) for their risk preference studies.

The functional form used to estimate the expected utility of the lotteries in stage one satisfies constant relative risk aversion (CRRA), and is given by

$$EU(\bullet) = \pi_1 \frac{x^{1-\rho}}{1-\rho} + \pi_2 \frac{y^{1-\rho}}{1-\rho}. \tag{2}$$

The parameter ρ is a measure of risk attitude, with $\rho = 0$ indicating risk neutrality and $\rho > (<) 0$ characterizing risk aversion (risk seeking). The decision weights for SEU preferences are $\pi_1 = p_1, \pi_2 = 1 - p_1$, and for RDEU $\pi_1 = w(p_1)$ and $\pi_2 = w(p_1 + p_2) - w(p_1) = 1 - w(p_1)$, with $w(0) = 0$, $w(1) = 1$. The functional form used to estimate the probability transformation for the RDEU decision weights is a one-parameter model introduced by Tversky and Kahneman (1992), that accounts for a dimension of risk attitude associated with probability distortions; it is given by $w(p) = \frac{p^{\gamma}}{\left[p^{\gamma} + (1-p)^{\gamma}\right]^{1/\gamma}}$. Maximum likelihood estimates of ρ and γ are derived from a probit model that estimates the probability of individual *i* choosing lottery A in question *t*. The probability is given by $\Pr_{it}(A \mid \beta) = \Pr(U_i(A^t) - U_i(B^t) > \varepsilon_{it})$ where $\beta = \rho$ $(\beta = [\rho, \gamma])$ for the SEU (RDEU) models.

Letting $[U_i(A^t) - U_i(B^t)] = \Delta_{it}$, $\Phi(\bullet)$ be the cumulative normal distribution with $\varepsilon_i \sim N(0, \sigma^2)$, and $y_{it} = 1$ when lottery *A* is chosen and zero otherwise. The likelihood function is given by

$$L(\beta \mid Y, X \mid) = \prod_{y_i} \left[\Phi(\Delta_i)^{y_i} \right] \left[\Phi(\Delta_i)^{1-y_i} \right]$$

where Y is the vector of responses and X a matrix containing the lottery payoffs and probabilities.

To elicit individual ambiguity attitudes, ambiguous and risky lotteries are compared directly. Predicted values of the expected utility of the risky lotteries are calculated from the parameters $\hat{\beta}$ estimated in the first stage. Utility consequences for the ambiguous lotteries are also calculated from stage 1 estimates of $\hat{\rho}$. Thus, in stage 2 decision weights π_i, i =1,2 remain as parameters to be estimated for the ambiguous lottery. Ambiguity attitude, A, is measured as the sum of the estimated weights, $A = \hat{\pi}_1 + \hat{\pi}_2$, and so ambiguity aversion is represented by $A < 1$.

Elicitation Results

Experimental results yield evidence of heterogeneous attitudes towards risk and ambiguity that are uncorrelated within subjects.[6] The lack of correlation between risk and ambiguity attitudes is consistent with previous findings, and appears to be related to distinct neural activations for decisions under risk and ambiguity (Huettel et al. 2006). In stage one choices are better explained by SEU for about half of the subjects while the probability weighting function improves the model for the rest. Parameter estimates from the preferred model, as determined by the AIC were used in estimating probability weights. The measures of ambiguity attitudes represented by the sum of the estimated probability weights are presented in Table 6.[7]

---

[6] The Spearman Rank correlation between risk and ambiguity measures is 0.1593 (p = 0.6031). Table 7 presents rank correlations for a variety of measures including those for risk and ambiguity attitudes.

[7] Full results from the two-stage estimation procedure that includes parameter estimates of $\rho, \gamma,\ \pi_1$, and π_2 for each subject are available by request.

[Table 6 here]

6. Attitudes in Choice and Market Environments

This section examines whether ambiguity attitudes observed in the individual choice setting are correlated with market outcomes. The descriptor used in the analysis from the individual choice data is the ambiguity attitude, *A*. For the asset market, the descriptor depends on the final allocation of risky and ambiguous assets for each individual. The allocation variable, Al_j, is the difference between the number of risky and ambiguous assets accumulated by trader *j* in the different market environments. Thus, $Al_j = \sum_{i=1}^{5} r_{ij} - \sum_{k=1}^{5} a_{ij}$ with *i,k=1,…,5* represent the five risky and ambiguous trading rounds, respectively, for trader *j*. Table 6 presents the asset allocation measure, *Al* along with its components alongside the measure of ambiguity attitude for each trader. Note that the data is presented by session and decreasing in ambiguity aversion. The test statistic for the correlation between the ranks of the *Al* and *A* measures is the Pearson Correlation Coefficient r_s.

The correlation between the two measures is not significant in aggregate, but we do observe a significant correlation in session RA where comparability effects in pricing were observed. In the RA session, r_s= -.8728 (p = 0.0232), with the negative correlation indicating that the most ambiguity averse subjects held, on balance, more risky assets. In session AR we find no evidence of a correlation between ambiguity attitudes and asset allocations, r_s= .2979 (p = 0.5163). The correlations between ambiguity attitudes and asset allocations, and their statistical significance, as well as the results on the correlation between risk and ambiguity attitudes are presented in Table 7.[8]

[table 7 here]

7. Conclusion

Risk, ambiguity and the difference between them remain an important research topic fifty years after Ellsberg's seminal contributions. Experimental methods have made significant contributions to the literature, uncovering basic facts about patterns of behavior, and testing the novel theories that can resolve the paradoxes identified by Ellsberg (Halevy 2007). In this study I focus on patterns of behavior, extending the study of the relative importance of subjective uncertainty aversion and contrast effects. The primary treatment examines contrast effects in an asset market in which and risky and ambiguous are traded sequentially. The elicitation of ambiguity attitudes in an individual choice setting complements the asset market study and sheds light on the underlying reasons effects.

The primary conclusion from the study is that contrast effects remain important in the market setting. Prices for ambiguous assets differ from those of risky assets only when prior exposure to a risky asset makes the ambiguity apparent to traders. The individual choice protocol utilizes contrast effects and the point estimates of ambiguity attitude for all subjects reflect ambiguity aversion. A secondary conclusion is that individual ambiguity attitudes drive the price effects, when they are observed. Accumulation of ambiguous assets is negatively correlated with ambiguity attitude as the the most ambiguity-averse individuals tend to shun ambiguous

[8] I also find no correlation between either risk or ambiguity attitudes and the total number of assets accumulated.

assets. As with the pricing effect, the correlation across choice and market environments is only observed when the sequential comparability of ambiguity to risk is possible.

The evidence of stability of ambiguity attitudes across choice and market settings, conditional on contrast effects, appears to be a new finding and the result suggests that attitudes towards ambiguity may be more stable than those for risk in these settings. Given the importance of ambiguity in field environments these findings deserve further study.

The results in the asset market in this study complement and extend the work of Sarin and Weber (1993). Together they demonstrate that responses to ambiguity in markets can be found in both simultaneous and sequential treatments. Thus the notion that comparative ignorance motivates ambiguity responses, first discussed by Fox and Tversky (1995) with respect to individual choice behavior, receives support also in the market environment.

Reference List

Andersen, S., Harrison, G. W., Lau, M. I., and E. E. Rutstrom. "Eliciting Risk and Time Preferences." *Econometrica*, 2008, *76* (3), 583-618.

Anscombe, F. J., and R. Aumann. "A Definition of Subjective Probability." *Annals of Mathematical Statistics*, 1963, *34*, 199-205.

Berg, J., J. Dickhaut, and K. McCabe. "Risk Preference Instability Across Institutions: A Dilemma." *Proceedings of the National Academy of Science*, 2005, *102*, 4209-4214.

Bossaerts, P., P. Ghirardato, S. Guarnaschelli, and W. R. Zame. "Ambiguity in Asset Markets: Theory and Experiment." *Review of Financial Studies*, 2010, *23* (4), 1325-1359.

Bruner, D. M. "Changing the Probability versus Changing the Reward." *Experimental Economics*, 2009, *12*, 367-385.

Camerer, C. F. "Ambiguity Aversion and Non-additive Probability: Experimental Evidence, Models and Applications," in Luini, L., *Uncertain Decisions: Bridging Theory and Experiments*. Boston, Ma.: Kluwer Academic, 1999, 53-79.

Chow, C. C., and R.K. Sarin. "Comparative Ignorance and the Ellsberg Paradox." *Journal of Risk and Uncertainty*, 2001, *22* (2), 129-139.

Di Mauro, C. "Uncertainty Aversion Vs. Competence: An Experimental Market Study." *Theory and Decision*, 2008, *64* (2-3), 301-331.

Dolan, P., and M. Jones. "Explaining Attitudes Towards Ambiguity: An Experimental Test of the Comparative Ignorance Hypothesis ." *Scottish Journal of Political Economy* , 2004, *51* (3), 281-301.

Ellsberg, D. "Risk, Ambiguity, and the Savage Axioms." *Quarterly Journal of Economics*, 1961, *75*, 643-69.

Epstein, L. "A Definition of Uncertainty Aversion." *Review of Economic Studies*, 1999, *66* (3), 579-608.

Fox, C. R., and A. Tversky. "Ambiguity Aversion and Comparative Ignorance." *Quarterly Journal of Economics*, 1995, *110* (3), 585-603.

Frisch, D., and J. Baron. "Ambiguity and Rationality." *Journal of Behavioral Decision Making*, 1988, *1*, 149-57.

Ghirardato, P., F. Maccheroni, and M. Marinacci. "Differentiating Ambiguity and Ambiguity Attitude." *Journal of Economic Theory*, 2004, *118* (2), 133-173.

Ghirardato, P., and M. Marinacci. "Ambiguity Made Precise: A Comparative Foundation." *Journal of Economic Theory*, 2002, *102* (2), 251-289.

Gilboa, I., and D. Schmeidler. "Maximin expected utility with a non-unique prior." *Journal of Mathematical Economics*, 1989, *18*, 141-153.

Halevy, Y. “Ellsberg Revisited: An Experimental Study.” *Econometrica*, 2007, *75* (2), 503-536

Harrison, G. W., and J. C. Cox. *Risk Aversion in Experiments*. Bingley, UK: JAI Press, 2008.

Heath, C., and A. Tversky. "Preference and Belief - Ambiguity and Competence in Choice under Uncertainty." *Journal of Risk and Uncertainty*, 1991, *4* (1), 5-28.

Hogarth, R. M., and H. J. Einhorn. "Venture Theory: A Model of Decision Weights." *Management Science*, 1990, *36* (7), 780-803.

Holt, C., and S. Laury. "Risk Aversion and Incentive Effects." *American Economic Review*, 2002, *92* (5), 1644-1655.

Hsee, C. K, G.F. Loewenstein, S. Blount, and M.A. Bazerman. "Preference Reversals Between Joint and Separate Evaluations of Options: A Review and Theoretical Analysis." *Psychological Bulletin*, 1999, *125* (5), 576-90.

Huettel, S. A., C. J. Stowe, E. M. Gordon et al. "Neural Signatures of Economic Preferences for Risk and Ambiguity." *Neuron*, 2006, *49*, 765-775.

Isaac, M., and D. James. "Just Who are You Calling Risk Averse?" *Journal of Risk and Uncertainty*, 2000, *20* (2), 177-187.

Jaffray, J., and F. Philippe. "On the Existence of Subjective Upper and Lower Probabilities." *Mathematics of Operations Research*, 1997, *22*, 165-185.

Johnson, E., and D. Schkade. "Bias in Utility Assessments: Further Evidence and Explanations." *Management Science*, 1989, *35*, 406-424.

Keynes, J. M. *A Treatise on Probability*. London: Macmillan, 1921.

Knight, F. H. *Risk, Uncertainty, and Profit*. Boston: Houghtoun Mifflin, 1921.

List, J. A. "Preference Reversals of a Different Kind: The "More is Less" Phenomenon." *American Economic Review*, 2002, *92* (5), 1636-1643.

Maffioletti, A., U. Schmidt , and C. Schroder. "The Effect of Elicitation Methods on Ambiguity Aversion: An Experimental Investigation." *Economics Bulletin*, 2009, *29* (2), 638-643.

Mukerji, S., and J. Tallon. "An overview of economic applications of David Schmeidler's models of decision making under uncertainty," in Gilboa, I., *Uncertainty in economic theory: Essays in honor of David Schmeidler's 65th birthday*. New York: Routledge, 2004, 283-302.

Plott, C., and S. Sunder. "Rational Expectations and the Aggregation of Diverse Information in Laboratory Security Markets: An Application of Rational-Expectations Models."

Econometrica, 1988, *56* 1088-118.

Plott, C. R., and S. Sunder. "Rational Expectations and the Aggregation of Diverse Information in Laboratory Security Markets." *Journal of Political Economy*, 1982, *90*, 663-698.

Sarin, R. K., and M. Weber. "Effects of Ambiguity in Market Experiments." *Management Science*, 1993, *39* (5), 602-615.

Savage, L. J. *The Foundations of Statistics*. New York: Wiley, 1954.

Schmeidler, D. "Subjective-Probability and Expected Utility Without Additivity." *Econometrica*, 1989, *57* (3), 571-587.

Siegel, S. *Nonparametric Statistics for the Behavioral Sciences*. New York: McGraw Hill, 1956.

Smith, V. L. "Measuring Nonmonetary Utilities in Uncertain Choices: The Ellsberg Urn." *Quarterly Journal of Economics*, 1969, *83*, 324-9.

Sunder, S. "Market for Information: Experimental Evidence." *Econometrica*, 1992, *60* (3), 667-95.

Tversky, A., and D. Kahneman. "Advances in Prospect Theory: Cumulative Representations of Uncertainty." *Journal of Risk and Uncertainty*, 1992, *5* (4), 297-323.

Wakker, P. *Prospect Theory for Risk and Ambiguity*. Princeton, NJ: Princeton University Press, 2010.

Wakker, P. "Uncertainty Aversion: A Discussion of Critical Topics in Health Economics." *Health Economics*, 2000, *9*, 261-263.

Appendix 1: Individual Choice Elicitation Questions

The lottery pairs used to elicit risky and ambiguous utilities are below in sequence. Lotteries are of the form *(x,p;y)*, where *x* is a payoff received with probability *p*, and *y* a payoff received with probability *(1-p)*. "?" implies an ambiguous lottery where the second probability is also presented as "?".

Question	Lottery A	Lottery B
1	(15,33;0)	(6,33;4)
2	(15,33;0)	(8,33;4)
3	(15,33;0)	(10,33;4)
4	(15,33;0)	(11,33;4)
5	(6,33;0)	(0,?;4)
6	(6,33;0)	(1,?;4)
7	(6,33;0)	(2,?;4)
8	(6,33;0)	(3,?;4)
9	(12,33;0)	(3,33;4)
10	(12,33;0)	(5,33;4)
11	(12,33;0)	(6,33;4)
12	(12,33;0)	(7,33;4)
13	(12,33;0)	(8,33;4)
14	(9,33;0)	(2,?;4)
15	(9,33;0)	(3,?;4)
16	(9,33;0)	(4,?;4)
17	(9,33;0)	(5,?;4)
18	(9,33;0)	(6,?;4)
19	(9,33;0)	(7,?;4)
20	(15,50;0)	(20,?;0)
21	(15,33;0)	(10,100;0)
22	(10,50;0)	(20,?;10)
23	(20,50,10)	(50,?,10)

Question	Lottery A	Lottery B
24	(50,50,10)	(50,?,10)
25	(50,50,10)	(25,?,10)
26	(9,33;0)	(2,33;4)
27	(9,33;0)	(3,33;4)
28	(9,33;0)	(4,33;4)
29	(9,33;0)	(5,33;4)
30	(9,33;0)	(6,33;4)
31	(9,33;0)	(7,33;4)
32	(12,33;0)	(3,?;4)
33	(12,33;0)	(5,?;4)
34	(12,33;0)	(6,?;4)
35	(12,33;0)	(7,?;4)
36	(9,33;0)	(8,?;4)
37	(6,33;0)	(0,33;4)
38	(6,33;0)	(1,33;4)
39	(6,33;0)	(2,33;4)
40	(15,33;0)	(6,?;4)
41	(15,33;0)	(8,?;4)
42	(15,33;0)	(10,?;4)
43	(15,33;0)	(11,?;4)
44	(20,25;12)	(50,25;9)
45	(25,25; 12)	(10,25;9)

Appendix 2: Experimental Instructions

Part 1: General and Individual Choice Instructions

Welcome to the Economic Science Laboratory.

Today you will participate in an experiment that is aimed at understanding economic behavior and individual decision-making. Funds for this research were provided by a private research institution.

The experiment will be conducted in two distinct parts. In the first part of the session you will answer questions about different types of choices using an electronic questionnaire. The second portion of the experiment you will be a trader in an electronic market. Details about how the auction market functions will be explained just prior to beginning that portion of the experiment with online instructions.

In order for you to feel comfortable with the format of the questionnaire, a few sample screens are attached to these directions. The first shows a choice between a fifty /fifty chance of winning $0 and $15 dollars, versus a sure win of $6.25.

Choices are labeled A and B, and you can select your preferred choice in the box on the right of the screen. If you are indifferent between the two choices, you may also indicate that. There are no right or wrong answers to any of the questions. It is simply a matter of choosing which situation, or which branch of the choice tree, you would prefer to be on. The way you answer the questions will affect your payment as discussed below.

Here is how your profits are made:

At the end of the experiment one of the questions from 1-45 will be selected at random by choosing a numbered ball from a bingo cage. Your preferred choice for that question will be played, by randomly drawing balls from another cage. You will receive the value of that choice in cash before you leave. As an example look again at the first screen print. In this case the top choice, **A**, represents a 50/50 chance of winning $0 or $15. The **B** alternative is a sure win of 6.25. If you had indicated a preference for A, a random draw will determine your payment. If you had indicated a preference for B you will receive the $6.25 as your payment for this portion of the experiment.

If you had a preference for **A**, the following procedures are used to determine the outcome.

First a numbered ball will be drawn from an urn with numbers ranging from 1 to 100.

The probability of each payout in option **A** is 50% in this example. If any number from 51 to 100 is drawn from the urn the higher payout ($15) is received and if a number between 1 and 50 is drawn from the urn the low payout ($0) is received. If the probability for the lottery is not

50/50 but the numbers are given in the question, the same procedure is conducted, with the dividing line at the appropriate probability. For example if the high payout has a probability of 65% and the low payout 35% a number from 36 to 100 will yield the high payout and a number from 1 to 35 will yield the low payout.

Note that for some of the question the probabilities for one of the lotteries may be replaced by question marks "?". The question marks represent a situation where there is an uncertain probability of receiving either payoff. It may be helpful to think of the probabilities in the following way. A 50/50 chance may be represented by an urn full of 100 balls. 50 of the balls are red and 50 are black. Drawing a red ball randomly from the urn yields the first value in the lottery and a black ball the second value. An 80/20 chance implies that there are 80 red balls and only 20 black. The question marks represent a situation where there are 100 balls in the urn but the distribution between red and black is completely unknown before you must make your decision.

If the preferred option in the selected question involves a lottery with a "?" your payoffs are determined as follows: We first add one more ball to the urn labeled zero. We then draw a ball from the urn and the number indicates the probability of the high valued option for the lottery in question. Note that by having 101 balls in the urn means that the number probability of the high payout could range from 0% to 100% when the second draw is made. The same is true of course for the probability of the low valued option. After determining the probability according to the above procedure, the zero ball is removed and the original 100 balls are used to determine the payoffs exactly as in the examples for which the probability is given.

This concludes the instructions for the first portion. If you have questions please raise your hand and the monitor will come to your station. If you are ready to begin using the program, click "Begin."

Part 2: Auction Market Instructions

In this experiment, you will participate in a series of market trading periods. There will be a total of 10 trading periods in today's experiment. You will be a TRADER today, which means you will have the opportunity to both buy and sell units of a fictitious good with the other agents in the market.

You can SELL units by either making an OFFER which another agent accepts or by accepting a BID which another agent has made.

You can BUY units by either making a BID which another agent accepts or accepting an OFFER which another agents has made.

Each unit you own at the end of each trading period will earn a dividend.

The amount of the dividend you will receive for each unit you own will be determined randomly each period. You will be given a "Dividend Distribution", similar to the one shown on your screen that will indicate all the possible values of the dividend. The chance of each possible dividend value will be represented by either a percentage, or by a '?' if the chance is unknown to you.

Look at the sample Dividend Distribution on the right. It indicates that there is a 20% chance that the dividend will be $0.00, a 50% chance that it will be $0.10, a 20% chance that it will be $0.25, and a 10% chance that it will be $1.00. Note: this is an example for instructional purposes and the distribution you see during the session will be different.

What this means is that if you were paid a dividend 100 times, you would expect to receive $0.00 twenty times, $0.10 fifty times, $0.25 twenty times, and $1.00 ten times. The "expected dividend" for this distribution is $0.20. $0.20 is called the "expected dividend" for this distribution because it is the average amount one would expect to receive over a large number of draws.

Please use Page Down to continue.

If the some part of the Dividend Distribution is represented by a "?" the determination of the value of the "?" is done the same way as for the individual choice survey you have just completed. For example suppose that the sample distribution noted above was modified so that there is a 20% chance that the dividend will be $0.00, a 50% chance that it will be $0.10, a "?" chance that it will be $0.25, and a "?" chance that it will be $1.00. In this case the outcomes are known for 70% of the probability and the remaining 30% is distributed across the outcomes with"?". A computerized random number generator will pick a value from 0 to 30 with the number chosen representing the probability of the larger outcome ($1.00). Each number within the range is equally likely to be chosen.

Your Dividend Earnings each period are the number of units that you own at end of the period multiplied by the ACTUAL value of the dividend for that period. If you own 8 units at the end of a period and the dividend drawn is $0.25, then your Dividend Earnings for that period would be 8 x $0.25 = $2.00. If the dividend drawn had been $0.00, your Dividend Earnings for that period would have been $0.00.

Each period, the dividend will be randomly chosen, so it may be different each period. However, for any given period, the dividend is the same for all the units of the good. During the experiment, you may examine the Dividend Distribution at any time by pressing F1.

Remember that the numbers used in the examples are for instructional purposes only and may not look at all like the numbers you will see during the experiment.

Please use Page Down to continue.

We will now consider how the trading in this market will take place. First we will discuss the screen you will see during the experiment. Then you will learn how to make and accept bids and offers.

First, examine the left side of your screen. "Working Capital" will constantly be displayed during the experiment. You will also be able to see the "Time remaining" in the current trading period. Beneath that, the "Current Offer" and the "Current Bid" will be displayed.

The Current Bid and the Current Offer are the highest bid and the lowest offer currently in the market. In order for another agent to accept either a bid or offer that you have made, it must be the Current Bid or Offer (the highest bid or the lowest offer).

The list of commands above will allow you to interact in the market. Pressing "B" or "O" will allow you to make a bid or an offer. Pressing "P" or "S" will allow you to either purchase or sell at the Current Offer or Bid.

To enter an offer, press the "O" key. Then type in the price you are asking for. For this example, type "9.55" and press the ENTER key on your keyboard.

Please DO THIS NOW. (Use the BACKSPACE key to erase any errors)

Notice that your offer of $9.55 is now displayed as the Current Offer for the entire market. This information is displayed to everyone in the market. In a similar manner, you can press "B" to make a bid. Practice by making a bid of 6.24. (Note, this bid is only for practice and will not show up in the queue.)

Please DO THIS NOW.

When you have a bid or offer in the queue, you may "Retract" that bid/offer from the queue by pressing the "R" key."   You may NOT retract a bid or offer if it is the standing - or current - bid or offer.

Suppose that upon seeing your offer of $9.55, a buyer decides to respond by making a bid to buy a unit at $8.70.

The buyers's bid to buy at $8.70 is now displayed as the Current Bid for the entire market.

Given the Current Bid and Offer above, any bid to buy at more than 8.70 would become the new Current Bid for the market. Any offer to sell at less than 9.55 would become the new Current Offer.

Suppose now that you wish to accept the Current Bid of $8.70. Press the S key now to sell a unit.

You made a sale:Price: 8.70, Quantity: 1 unit

Note that after a contract has been made the Current Bid and Offer are both erased and a new market begins.

Upon making a trade, your profit from that trade will be calculated and posted in your Record Sheet. The profits from each unit traded will add up to the "Profit this period".

Similarly, if you wish to buy at the Current Offer, you can do so by pressing "P" instead of "S". Note that when a trade occurs, the price is written on the bottom of your screen next to the word "Trades:".   Your trades will be written in **bold** print. Upon making a sale, your sales revenue will increase. Likewise, when making a purchase, your expenditures increase.

Your actions each period will be summarized in a "Record Sheet" similar to the one on the right. "Starting Capital" is the capital you have available to you at the beginning of the period.   "Sales Revenue" is the revenue you make selling units to other agents during the period.

"Expenditures" is the amount you spend buying units from other agents. "Working Capital" is the amount of capital you have left at the end of the period. Your Profits in each period will be the sum of your Dividends and Sales Revenue, less any Expenditures on purchases.

Your Profits in each Round can be calculated by subtracting your Starting Capital from your Working Capital.

The sample Record Sheet summarizes the actions of a sample trader for one trading period. You can see he started with 3.20 of capital. He owned 4 units at the end of the period, and with a dividend of .20, his Dividend Earnings were 4 x .20 = .80. He sold 3 units for 3.00 each, so his Sales Revenue was 3.00 x 3 = 9.00. He bought 2 units for 3.50 each, so his Expenditures were 2 x 3.50 = 7.00. His Working Capital at the end of period 3 was therefore 3.20 + .80 + 9.00 - 7.00 = 6.00. That means his Profit in Period 3 totals 6.00 - 3.20 = 2.80 which is end of period Working Capital minus Starting Capital.

You may scroll through your Record Sheets from previous periods using the PGUP and PGDN keys.

You will begin each round with $20.00 of starting capital and an inventory of 1 unit.

The table on the right shows you an example of the Bid and Offer Queues. Offers are written in yellow above the center line, and bids are written in green below the line. As you go up from the center line, the offers get higher, and as you go down from the center line, the bids get lower. The highest bid (or the Current Bid) and the lowest offer (or the Current Offer) are nearest the line and are considered to be first in their queues. In order for a trade to occur, either the Current Bid or the Current Offer must be accepted.

Your entries in the queues will have asterisks (*) after them. Thus you can tell where your offer stands in the offer queue can tell where your ask stands in the ask queue and/or where your bid stands in the bid queue.

In this example, you are shown to have an offer of 6.40 for one unit in the offer queue. One offer is ahead of yours in the queue. Those two units must be sold before your offer of 6.40 becomes the Current Offer

However, you could lower your ask (below 6.20) or accept the Current Bid at any time. Note that if you sell units and you have an offer in the queue, the number of units you sell will be deducted from that offer. If you buy units and have a bid in the queue, the number of units you buy will be deducted from that bid. If this would bring your bid or offer to 0 units, it will be removed from the bid or ask to 0 units, it will be removed from the queue entirely.

As bids and asks occur in the market, they are placed in their proper position in the queues. When trades occur, units are removed from the queues. In the case of a tie, positions in the queues are based on arrival time. In order to be first in either of the queues (the Current Bid/Ask), you have to make a better bid ask. This means you must either make a higher bid or a lower ask. Note that you can only have one bid and one ask in the queues at a time. However, you may change your bid or ask as many times as you wish as long as the change is an IMPROVEMENT. This means that you must raise the price on a bid and lower the price on an offer.

This is the end of the instructions. In today's experiment, all monetary values -- Unit Values, Unit Costs, Profits, etc. will be denominated in Experimental Dollars. We will convert your total earnings in Experimental Dollars into U.S. dollars at the exchange rate listed below.

The more Experimental Dollars you earn, the more U.S. dollars you will be paid at the end of the experiment.

1 Experimental Dollars = 1 U.S. Dollar,

Table 1: Asset Market Results by Session and Round

Session	Round	Asset Type	EV Deviation	Bid/Ask Ratio
RA	1	R	482.67	0.929
RA	2	R	540.17	1.053
RA	3	R	367.82	1.111
RA	4	R	472.22	0.654
RA	5	R	446.43	0.773
RA	**6**	**A**	**366.67**	**0.297**
RA	**7**	**A**	**333.33**	**0.355**
RA	**8**	**A**	**351.78**	**0.278**
RA	**9**	**A**	**325.13**	**0.233**
RA	**10**	**A**	**256.67**	**0.458**
AR	1	A	414.00	2.625
AR	2	A	448.50	2.083
AR	3	A	434.67	1.077
AR	4	A	431.00	0.773
AR	5	A	445.17	1.118
AR	6	R	402.87	1.529
AR	7	R	466.37	0.926
AR	8	R	357.31	0.955
AR	9	R	430.15	1.077
AR	10	R	511.47	1.250

Mean prices and deviations from the expected value for each session and round of trade are listed along with the asset type, either risky (R) or ambiguous (A). The ratio of bids to asks in a trading period are also listed. Session 1, periods 6 through 10, in bold type, reveal an effect of ambiguity through lower prices and many fewer bids per offer.

Table 2: Asset Pricing Hypotheses

Hypothesis	**Rounds Tested**	**P value**
1. Between Subjects: Comparative Ignorance	RA:1-5,AR:1-5	0.15625
2. Between Subject: Ambiguous	**RA:6-10**,AR:1-5	0.03125
3. a) Within Subjects: Session 1	RA:1-5,**RA:6-10**	0.03125
3. b) Within Subjects: Session 2	AR:1-5,AR:6-10	0.46875

AR and RA identify sessions. Bold type indicates the rounds in which a significant ambiguity effect was observed. Statistical significance is determined through the use of a randomization test on mean difference of asset price from expected value for each round.

Table 3: Asset Pricing - Random Effects Model

	Coefficient	Standard error	p-value
ambi	24.32	18.34	0.19
session	25.49	19.48	0.19
ambiXsession	-160.32	33.79	0.00
round	4.99	3.32	0.13
Constant	401.50	25.54	0.00
n=176	*rho*=0.12	$\chi^2_{(4)} = 90.95$	R^2=0.38

The random-effects model estimates the difference between the expected-value and trade price for each completed transaction as a function of the asset type (risky or ambiguous), session, and the interaction of the two, as well as a trend variable for the round. *Rho* represents the proportion of the variance associated with individual-specific effects across rounds.

Table 4: Average Bid/Ask by Treatment

Session	Rounds	Asset	Avg. Bid/Ask
RA	1-5	R	0.88
RA	6-10	A	0.32
AR	1-5	A	1.33
AR	6-10	R	1.12

This table summarizes the bids per ask that are listed by round in Table 1. A Kruskal-Wallis test rejects equality of the bid-ask ratio across the specified rounds ($\chi^2_{(3)}$ = 39.52, p = 0.0001)

Table 5: Example Lottery Choice Menu

	Lottery A	Lottery B
1	(15,.33;0)	(6,.33;4)
2	(15,.33;0)	(8,.33;4)
3	(15,.33;0)	(10,.33;4)
4	(15,.33;0)	(11,.33;4)

Lotteries are of the form (x,p;y) where p is the probability of receiving x and 1-p the probability of receiving y. The experimental protocol asks for a preference between lottery A and lottery B in each of the four rows. For the examination of ambiguity attitudes a question mark “?” replaced the probability for Lottery B and the determination of the probability distribution was conducted using a mechanical device simulating a uniform distribution when an ambiguous lottery was chosen to be payoff relevant.

Table 6: Ambiguity Attitudes and Asset Allocations

Session	Trader #	Individual Choice Results: Ambiguity Attitude	Rank	Final Asset Market Allocations by Trader: Risky	Ambiguous	Net Allocation	Allocation Rank
RA	1	0.510321	1	8	3	5	1
RA	2	0.510503	2	8	6	2	3
RA	3	0.678880	3	9	6	3	2
RA	4	0.830122	4	0	2	-2	4
RA	5	0.895627	5	4	7	-3	5
RA	6	0.911603	6	2	7	-5	6
AR	12	0.346704	1	8	9	-1	5
AR	10	0.415417	2	7	4	3	1
AR	11	0.455013	3	8	6	2	2.5
AR	13	0.512092	4	0	2	-2	6
AR	7	0.584591	5	1	1	0	4
AR	8	0.739369	6	3	7	-4	7
AR	9	0.979842	7	8	6	2	2.5

Ambiguity attitude is the sum of probability weights associated with ambiguous lotteries based on maximum likelihood estimates reported in Appendix. Ambiguity aversion is therefore measured as 1-Ambiguity Attitude. Rank column indicates the ranking of ambiguity aversion, within each session. Results for Asset Market Allocations include number of Risky and number of Ambiguous assets held, summed over the 10 trading periods. Net Allocation = Risky-Ambiguous. Allocation Rank's are within session values.

Table 7: Correlations with Ambiguity Attitudes (A)

	Pooled	Session RA	Session AR
ρ	0.3005	0.3887	0.6493
	(0.3184)	(0.4464)	(0.1145)
Al	-0.2576	-0.8728	-0.2979
	(0.3955)	(0.0232)	(0.5163)

Correlations of ambiguity attitudes with risk attitudes and asset market allocations are displayed, with p-values in parentheses.