UNIVERSIDAD CARLOS III DE MADRID working papers

Working Paper 10-25
Economic Series
October 2010

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Reaction to Public Information in Asset Markets: Does Ambiguity Matter?

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Abstract:

We report experiments that examine trader reaction to ambiguity when dividend information is revealed sequentially. We find that experienced traders are better at internalizing ambiguity than inexperienced subjects. No significant differences are observed in the ambiguity versus control treatments regarding prices, price volatility and volumes for experienced subjects. However, relative to the control, prices are higher, volatility greater and trading unsophisticated for inexperienced subjects in the ambiguity treatment. Price changes are consistent with news revelation regardless of subject experience and the degree of ambiguity. Further, we do not find under or over price reactions to news. Regardless of experience, market reaction to news moves in line with fundamentals.

Keywords: experimental asset markets, ambiguity, market communications, bounded rationality.

JEL codes: C92, G12

I. Introduction

I.1. Ambiguity and reaction to news

Recent research in behavioral finance has challenged the predictions of standard finance models putting forward the existence of financial anomalies such as the over- and under-reaction of asset prices to news. For example, Jegadeesh and Titman (1993) show under-reaction when average post-event returns hold the same sign as pre-event date returns. Meanwhile, in their classic study, DeBondt and Thaler (1985) show price over-reaction to information where price movements exhibit disproportional changes followed by subsequent reversions. Shefrin (2000), meanwhile, points out that investors over-react to negative news. Under-reaction tends to occur at short horizons while over-reaction occurs at longer horizons (p 87). These empirical results contrast with Fama's (1998) claim that "apparent over-reaction of stock prices to information is as common as under-reaction."

These results have led to the development of alternative models that reproduce some of these anomalies. Incorporating cognitive biases, behavioral theories have shown the presence of under- and over-reaction in asset prices. In particular, Daniel et al. (1998) examine investor overconfidence bias in how traders incorporate new information in their decision calculus. Biased self-attribution reinforces over-confidence and results in under-reaction to public, and over-reaction to private, information. Barberis et al. (1998) apply the conservatism and representative bias (i.e. new information is underweighted in updating) to investor decisions. Slow information updating of prior beliefs results in price under-reaction to new information. Over-reaction occurs as a result of the "representativeness bias" by which traders extrapolate trends in asset prices from very small samples of observations. Frazzini (2006), meanwhile, proposes that the presence of the "disposition effect" depresses prices with traders trying to lock in gains. In addition, a reluctance to sell at a capital loss allows prices to hold steady on bad news. Prices thus exhibit under-reaction due to this psychological bias.

In this paper, we follow a different route, instead of bringing multiple psychological biases into the analysis we consider whether the introduction of ambiguity may reproduce some of the anomalies that have been documented regarding asset price reaction to news. In that respect our research fits with the argument that a possible account for financial anomalies can be the existence of unmodeled risk factors such as ambiguity that can be interpreted as an additional factor regarding the evaluation of risk.

Following previous research on ambiguity, we use Ellsberg's procedure to introduce ambiguity in an experimental asset market where public information is sequentially released to traders. Our experimental design allows us to study how individual traders react to news in a context in which they receive information regarding dividend realizations. In our experiments, either the underlying process that generates dividends comes from a known probability distribution or is ambiguous.

In the baseline experiment, the probability distribution of dividends is publicly known, and subjects are informed that the dividend realization may be from two different *regimes* with high and low values, respectively. Subjects are aware about the two different regimes and are told the actual regime at the end of the first period. Given the information, subjects then trade in period two. At the end of the second trading period, participants are informed which of the dividends in the announced (dividend) regime will *not* be realized. The final dividend is realized at the end of period three. In the ambiguity treatment, the probability of occurrence of the two different dividend *regimes* is left unknown. Specifically, we tell subjects that a given regime of dividends will be selected at the end of the first period of trading by drawing a marble of a certain color from an opaque bag containing colored marbles with unknown quantities and proportions. Given that it has been shown that experience can be relevant in understanding trading behaviors experimental asset markets (Smith et al. (1988), Lei et al. (2001), Dufwenberg et al. (2005)) we repeat the experimental sessions so as to control for the effect of experience.

Our design enables us to study how ambiguity regarding the fundamental value of an asset affects trader reaction to public news. Furthermore, we can also study how ambiguity is reflected in market variables such as prices, price volatility and trading volumes. We test the following hypotheses that are motivated by the theoretical literature mentioned earlier. Our first hypothesis relates to research showing ambiguity aversion in the domain of gains in a lottery context (Ellsberg (1961), Yates and Zukowski (1976), Curley and Yates (1985), Cohen, Tallon and Vergnaud (2009)) and experimental markets (Sarin and Weber, (1993)).

Hypothesis 1: Regardless of subject experience, we expect asset prices to exhibit an ambiguity premium. That is, average asset prices under the ambiguity treatment are expected to be lower than the baseline treatment.

Our second hypothesis is related to theoretical results that predict that ambiguity can lead to inertia in trading behavior (Dow and Werlang 1992, Mukerji and Tallon 2001). Further, due to the indeterminacy in equilibrium prices (that may leave the determination of asset price equilibria to animal spirits) asset price volatility is expected to rise in the presence of ambiguity (Epstein and Wang 1994). This leads us to the following hypothesis.

Hypothesis 2:

i) Regardless of subject experience, we expect ambiguity to increase volatility in asset markets (Epstein and Wang, 1994).

ii) Regardless of subject experience, we expect ambiguity to reduce trading volumes in asset prices (Dow and Werlang 1992, Mukerji and Tallon 2001).

In terms of reactions to news, we examine the following hypothesis.

Hypothesis 3: *i*) Regardless of subject experience, asset prices in both the baseline and the ambiguity treatments increase (decrease) after good (bad) news is released.

ii) Regardless of subject experience, asset prices in both the baseline and the ambiguity treatments do not exhibit either under- or over-reaction to news.

Notice that Hypothesis 3 *ii*) relies on Fama's conjecture that, regardless of the treatment, reaction to news should be consistent with news content and exhibit neither under- nor over-reaction (Fama, 1998).

We also study individual trading behavior and base our hypothesis on Epstein and Wang (1994). They show that, because of the possible indeterminacy in equilibrium prices, the determination of asset prices may be driven by animal spirits. As a result, we expect that trader behavior is less consistent and (less) rational under the ambiguity treatment. Note that, we define subject trading behavior as being inconsistent in a given period whenever subjects are willing to sell the asset at a price lower than what they would be willing to pay for it. The analysis follows the definitions of absolute and average inconsistent trading behavior.

Hypothesis 4: Regardless of subject experience, compared to the baseline, subject trading behavior is more likely to be inconsistent with rationality under the ambiguity treatment.

In contrast with the existing literature that considers lottery choices we find the absence of any ambiguity premium in asset prices. Surprisingly, inexperienced subjects generate prices closer to fundamental value relative to the baseline treatment in the ambiguity treatment. Also, we do not observe a reduction of trading volumes (Dow and Werlang (1992) and in Mukerji and Tallon (2001)). We confirm the increased volatility predicted by Epstein and Wang (1994) as well as the exacerbation of animal spirits in the presence of ambiguity with inexperienced traders. This is the case because, compared to the baseline treatment, in the ambiguity treatment inexperienced traders tend to be more likely to exhibit unsophisticated trading behavior. For example, under ambiguity, inexperienced traders are more likely to resell an asset at the end of a period at a lower price than what they paid for it at the beginning of the period. Nevertheless, these differences are not significant with experience. In addition, the absence of significant differences in the reaction to public news (between the baseline and the ambiguity treatment in the case of experienced subjects) confirms the limited role of ambiguity in our experimental asset markets. We find support for Fama's assertion that over-reaction should be as common as under-reaction. Reaction to news is in line with fundamentals in both treatments, regardless of subject experience.

I.2. Related literature: ambiguity in asset markets

Standard finance theory and the experimental asset market literature have mostly assumed that the probabilistic structure of the process driving the fundamental value of financial assets is known. However, a substantial literature that dates back to Ellsberg (1961) has shown that ambiguity about the probability of occurrence of lottery outcomes may significantly reduce the value assigned to a lottery. Klibanoff et al. (2005) model decision makers who do not know the probability of occurrence of each state of the world but, hold some prior beliefs regarding different scenarios. Their model (of uncertainty) implies that individual decision makers use second-order beliefs. A growing literature has incorporated ambiguity regarding the dividend process (that underlies the fundamental value) of an asset in asset pricing models.

Besides considering ambiguity in the dividend process, recent research has also considered the possibility of ambiguous information (Leippold et al. (2007), Epstein and Schneider (2008)). In the presence of ambiguous information, Epstein and Schneider (2008) are able to account for the equity premium in a simple asset pricing model. Investors take the worst-case approach to new information reacting more towards bad, than good, news. Such behavior produces an ambiguity premium on these types of assets. Further, Leippold et al. (2007) show that asset prices react more strongly to bad news than to good news.

The complexity of modeling uncertainty in real market settings points towards the difficulty faced by researchers in testing the existence of ambiguity aversion when first and second order individual beliefs are not observable. In this context, experiments offer a possible solution as they allow the experimenter to control for uncertainty. For example, some experiments have controlled for uncertainty following a procedure similar to Ellsberg (1961). Subjects play a lottery that consists in drawing a ball from one of the two urns. The number of balls and their color is known in one urn while the color composition is unknown in the other urn. In line with Ellsberg, some authors have stressed the presence of significant ambiguity aversion (Yates and Zukowski (1976), Curley and Yates (1985), Cohen et al. (2009)). Meanwhile, others have argued that ambiguity aversion can be dampened, or even eliminated, if ambiguous and unambiguous lotteries are evaluated separately (Fox and Tversky (1995), Chow and Sarin (2002)). Also, Cohen et al. (1985) as well as Potamites and Zhang (2007) have put forward the heterogeneity in individual attitudes towards ambiguity. Camerer and Weber (1992) and Du and Budescu (2005) have stressed that ambiguity aversion is more significant in gains than in losses.[1]

Experimental results to date with state ambiguity show lower prices due to ambiguity aversion. In Sarin and Weber (1993) ambiguity aversion is reflected in reduced asset prices in a sealed bid and a double auction. Their result is particularly strong when the

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[1] In addition, at the brain level Smith et al. (2002) have reported ambiguity aversion in gains while no ambiguity attitudes were identified in the domain of losses.

ambiguous and the unambiguous assets are traded simultaneously. Bossaerts et al. (2010) also report significant effects of ambiguity in experimental asset markets with portfolio choices. Their results are in line with theory (Dow and Werlang (1992), Mukerji and Tallon (2001)) stressing that when some state probabilities are not known, agents who are sufficiently ambiguity averse may refuse to hold an ambiguous portfolio for a certain range of prices.

II. Experimental design

Six sessions were run in each treatment. In each session the market was repeated. This gives us a total of 24 market observations. Subjects were recruited from an undergraduate student subject pool at a major US university. Subjects were randomly selected across gender and majors. Additionally, to the extent possible, students were recruited based on their participation in a battery of risk attitude experiments conducted earlier in the academic year. The individual risk attitude battery consisted of a series of one hundred risk choices, and it was designed to elicit subjects' risk attitudes. Specifically, after utilizing econometric methods, the data allowed the experimenters to rank the subjects based on the following indices:

- Overall risk attitude and utility function curvature.
- Attitude toward ambiguity.

Appendix A shows some of the gambles faced by subjects in the battery.[2] The data shows that from the subsample for which we had access to ambiguity aversion scores, 33 out of 60 subjects were ambiguity averse while only 13 exhibited ambiguity-seeking behavior.[3] This first step ensures that ambiguity aversion is potentially relevant in our experimental sessions and any absence of ambiguity effects cannot be due to the selection of a population of traders insensitive to ambiguity that would be insensitive to ambiguity.

[2] For more information on these tests, see Dickhaut and Wilcox (2009).
[3] We consider a significance level of 5% (see Dickhaut and Wilcox (2009)).

Each experimental session had eight traders. Initial portfolios were structured so that three traders were endowed with 450 cents in cash and 3 shares, two with 600 cents in cash and 2 shares while, the remaining three traders were endowed with 750 cents in cash and one share. Each session consisted of three trading periods lasting 4 minutes each. Information concerning the possible per share dividend was released at the end of the first and second trading periods. At the end of the third trading period, a final dividend was announced and participant profits were given according to the final cash position plus dividends earned. Each experiment (see table 1 for experimental details) began with a short practice session to allow everyone to become familiar with the trading interface and process. Subjects were informed that the final dividend would be selected from one of two sets: {50,100,150} or {100,200,300}. Dividend values were expressed in cents. The baseline treatment was conducted as follows.

- At the end of the first trading period a subject was selected at random to flip a coin. If the coin came up heads, the dividend was selected from {50,100,150}. If it was tails, the dividend came from {100,200,300}. Trading then proceeded to periods 2 and 3.

- At the end of the second trading period a subject was selected to roll a die. If numbers 1 or 2 were rolled then the dividend would NOT be the low number in the range. If numbers 3 or 4 were rolled the dividend would NOT be the middle number in the range. If numbers 5 or 6 were rolled the dividend would NOT be the high number in the range. Note that, this procedure further reduces the dividend uncertainty subject's face. Trade was then open for period 3.

- When period 3 ended, a subject flipped a coin to determine the dividend from the two remaining dividends. If the flip was heads the dividend was the lower of the two dividends and if it was tails the higher dividend was used.

Instructions for these experiments can be found in Appendix B. The experiment was repeated with the same cohort of traders and with the same procedures.[4] Earnings were paid in cash at the end of the second experimental session.

[4] The second experimental session was announced at the end of the first session.

In the ambiguity treatment, each session used five separate opaque bags containing colored marbles. The quantities and proportions of marbles in each bag were left unknown. All bags were placed in the front of the room prior to subjects entering the lab, and remained in subject view during the entirety of the experiment. The marble composition of the bags was as follows.

- Bag 1: Light Blue and Dark Blue
- Bag 2: Red, Yellow, and Green
- Bag 3: Red and Yellow
- Bag 4: Yellow and Green
- Bag 5: Red and Green

Before starting the first period of trading, a subject was selected to flip a coin and another to roll a die. The result of the coin toss was announced to everyone by the subject and this determined whether the Light Blue marbles in Bag 1 represented the high {100,200,300}, or the low set of dividends {50,100,150}. The result of the die roll was also announced. This determined what color marble (Red, Yellow, or Green) in Bag 2 represented which dividend level (high, medium or low). This procedure avoided subject suspicion regarding possible attempts of the experimenter to select the value of marbles that would minimize the cost of the experiment.

Each time subjects flipped a coin, roll a die or draw a marble, the experimenter wrote the corresponding information on a white board located above the marble bags. Both the white board and the marble bags were visible to the eight subjects in the session. Without any further information subjects then traded the asset in period 1.

At the end of period 1, a subject was chosen to draw a marble from Bag 1. Without being able to observe the contents of the bag, the subject drew a marble and announced it to everyone. Subjects were informed again that the final dividend would be selected from the set associated with the color drawn. Subjects now traded assets in period 2.

After period 2 was completed, a different subject was again chosen to draw a marble from Bag 2. Again, without being able to observe the contents of the bag, the subject drew a marble and announced it to everyone. Subjects were then informed that the final dividend would NOT be the value associated with the color drawn. Subjects now traded in period 3.

At the end of period 3, a different subject was chosen to draw a marble from Bag 3, 4 or 5 depending on the color of the marble drawn from Bag 2. If the marble drawn from Bag 2 was Green (Red) [Yellow] then the subject used the bag with the two remaining colored marbles, that is, Bag 3 (Bag 4) [Bag 5].

Without being able to observe the contents of the bag, the subject drew the final marble and announced it to everyone. The dividend value for this session was the value associated with the marble drawn.

As in the baseline, subjects were then informed that they were going to repeat a new market. The five bags used in the first experimental session were then replaced by the experimenter. In full view of the subjects the experimenter placed the old bags on the floor and the new ones on the table. As a result, no learning about the composition of the bags used in first session could occur in the second experimental session.

Given the complicated procedure, the experimenter went through a practice run inviting subjects to flip a coin, roll a die and draw marbles before each experiment actually started. The experiment was repeated with the same cohort of traders and with the same parameters. Instructions for the ambiguity treatment can be found in Appendix B. Earnings were paid in cash at the end of the second experimental session. On completion of the experiment subjects were called up individually to be paid their private earnings from both sessions plus a $7 dollar show up fee. Average earnings for both the ambiguity and the baseline sessions were $24.80.

Table 1: Experimental Design		
Number of traders per session	**Endowment**	**Trading mechanism**
8 traders for each of the 12 experimental sessions (6 baseline sessions and 6 ambiguity sessions) with a repetition	3 subjects with 450 cents in cash and 3 shares 2 subjects with 600 cents in cash and 2 shares 3 subjects with 750 cents in cash and 1 share	Continuous double auction mechanism with four-minute trading periods.

III. Experimental Results

In the first subsection, we compare the baseline and the ambiguity treatments. We look at aggregate market measures such as average asset prices, volatility, and trading volumes. This is followed by an analysis of trader reaction to news to public information released in periods 2 and 3. Finally, we analyze subjects' individual trading behavior.

III.1. Aggregate analysis: Asset prices, Volatility and Trading volumes

We first look at average asset prices in the first period of trading in the baseline and ambiguity treatments. In the baseline treatment the two dividend distributions, {50,100,150} and {100,200,300} are equally likely. Meanwhile, in the ambiguity treatment subjects are unaware of the likelihood of occurrence of each regime. Note that, no public news has been released in the first period of trading. Thus, any difference in asset prices, volatility or trading volumes across the treatments can only be attributed to the existence of ambiguity (i.e. in the likelihood of occurrence of dividend regimes). This is, however, not the case in periods 2 and 3, since information about the regime is released in the second period while information about dividends is released in the third period. As a result, differences in asset prices, volatility or trading volumes in periods 2 and 3 between treatments cannot be uniquely attributed to ambiguity effects. If observed, the differences could also be a consequence of the release of public information, as well as any interaction effect between ambiguity and trader reaction to news.

We start by testing Hypothesis 1 regarding the existence of an ambiguity premium in asset prices for inexperienced subjects. One can see from table 2 that first-period average asset prices are significantly lower than the fundamental value of 150 in the baseline treatment.[5] Interestingly, asset prices are not significantly different from the fundamental value in the ambiguity treatment. It seems that subjects disregard probabilities and average out the five possible dividend values (50, 100, 150, 200, 300).[6] For inexperienced subjects, average asset prices under the ambiguity treatment (165.2) are significantly greater (Wilcoxon rank sum test, p-value = 0.0649) relative to the baseline (118.7).[7] Our results lead us to reject Hypothesis 1 regarding the existence of an ambiguity premium in asset prices.

Our result contrasts with experimental studies that have emphasized the existence of an ambiguity premium in experimental asset markets (Sarin and Weber, (1993)). However, one should point out that the results in Sarin and Weber (1993) are obtained when ambiguous and unambiguous assets are traded simultaneously. We find that the ambiguity premium is not observed if ambiguous and unambiguous assets are not traded simultaneously. The most intriguing part of our result is that, compared to the baseline treatment, average asset prices for inexperienced subjects are significantly larger in the ambiguity treatment. This could be an indication of the presence of animal spirits as is suggested in Epstein and Wang (1994). To quote Shiller (2000, p137): "in ambiguous situations peoples decisions are affected by whatever anchor is at hand". This may make it difficult to predict asset prices in the presence of ambiguity. However, average asset prices do not significantly differ between the ambiguity and baseline treatments for experienced subjects (see table 3).

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[5] In Appendix C, we provide an analysis of asset prices for periods 2 and 3. For further periods, each experimental session is characterized by different fundamentals so that we analyze average mispricing measures instead of average asset prices. Our basic results are confirmed in the sense that no ambiguity premium appears whether we consider inexperienced or experienced subjects.

[6] A one-sided Wilcoxon Rank Sum test with alternative hypothesis: median asset prices are greater than 150 [160] leads to a p-value equal to 0.103 [0.173].

[7] Average asset prices are below the expected dividend value in the baseline suggesting the typical risk-aversion pattern of asset prices found in experimental asset markets (Smith et al. 1988, Lei et al. 2001).

Table 2: Comparison of first-period average (median) asset prices: Ambiguity vs. Baseline		
	Inexperienced subjects	**Experienced subjects**
Baseline	118.7 (109.5)	156.2 (160.7)
Ambiguity	165.2 (180.2)	163.3 (155.6)
Wilcoxon two-sided Rank Sum test (p-value)		
Mean (Median) prices Baseline vs. Ambiguity	p-value = 0.0649 (0.0198)	p-value = 0.8182 (0.6879)
Null hypothesis: Mean asset price = 150. Alternative hypothesis: Mean asset price ≠150.	**Baseline** p-value = 0.0938 (0.0452)	**Baseline** p-value = 0.6875 (0.5625)
	Ambiguity p-value = 1.000 (0.2463)	**Ambiguity** p-value = 0.4375 (0.8326)

Epstein and Wang (1994) suggest that ambiguity may result in increased volatility of asset prices (Hypothesis 2*i*). We find support for this hypothesis only for inexperienced subjects. Relative to the baseline, the presence of ambiguity increases volatility in asset prices by more than 73%. Table 3 shows the standard deviation of prices in period 1. Notice that the standard deviation of asset prices in the first period sharply decreases with experience in the ambiguity treatment. Actually, standard deviation is not significantly different between the ambiguity and baseline treatments for experienced subjects.

Table 3: Comparison of first-period asset prices standard deviation: Ambiguity vs. Baseline		
	Inexperienced subjects	**Experienced subjects**
Baseline	36.79	26.94
Ambiguity	63.69	41.38
Mean comparison: Baseline vs. Ambiguity treatments		
P-values: Wilcoxon two-sided [one-sided] Rank Sum tests	p-value = 0.132 [0.066]	p-value = 0.937 [0.591]

Note, however, that a general analysis of volatility requires controlling for the underlying fundamental value of the asset in each experimental period of each experimental session. To that end, we use the dispersion ratio measure proposed by Palan (2009). The dispersion ratio in period *t* is defined as the sample ratio of asset prices in period *t* divided by population standard deviation of the fundamental value of the asset in the same period. This allows us to compare across sessions and periods with different underlying fundamental values.

In the following regressions we assess the treatment effect on asset price volatility in periods 2 and 3, respectively. We control for the treatment by introducing a dummy that takes value one for ambiguity sessions and zero otherwise. We show that, regardless of experience, ambiguity does not affect volatility significantly in periods 2 and 3. The dummy variable for treatment is not statistically significant in any of the regressions displayed in table 4. This finding rejects Hypothesis 2*i*). However, one has to be cautious in the interpretation of these results. The effect of ambiguity, or its absence, can be confounded with the effect, or lack of it, of the release of public information in periods 2 and 3. Notice that in the regression results of table 4, dispersion ratios in a given period depend positively on the previous period dispersion ratio for inexperienced traders. This positive relationship, however, does not hold in the case of experienced subjects.

Table 4: OLS estimates for inexperienced and experienced traders[8]
Dependent variables: Dispersion Ratio[9]

Coefficients (P-values)	Dispersion Ratio Period 3		Dispersion Ratio Period 2	
	Inexperienced	*Experienced*	*Inexperienced*	*Experienced*
Intercept	-0.61	28.46	7.74	20.73
Treatment	-0.40	7.65	-3.07	-10.91
Dispersion	0.96***	-0.28	-	-

[8] The OLS regressions presented in the analysis passed the Jarque-Bera Normality test. In addition, we also control for heteroskedasticity by using White standard errors.
[9] We consider standard statistical significance levels of 1%, 5% and 10%. Significance at these levels are indicated in the regression table by the respective symbols ***, ** and *.

Ratio Period 2				
Dispersion Ratio Period 1	-0.10	-0.12	0.50**	0.30
R squared	0.72	0.08	0.54	0.28

Finally, we study the effect of ambiguity on trading volumes. Regardless of subject experience, trading volumes across the baseline (26) and the ambiguity treatment (26.8) are similar. Despite increased asset prices and standard deviation in the first period, ambiguity sessions do not generate significant differences in trade volumes. Table 5 presents the average volumes for the two treatments. Recall that according to Hypothesis *2ii*), regardless of experience, trading volumes are expected to be lower in the ambiguity sessions (Dow and Werlang 1992, Mukerji and Tallon 2001). Our results lead us to reject Hypothesis 2*ii*).[10]

Table 5: Comparison of first-period (total) trading volume: Ambiguity vs. Baseline		
	Inexperienced subjects	**Experienced subjects**
Baseline	26 (62.2)	14.3 (31.2)
Ambiguity	26.8 (56)	15.8 (32.8)
P-values: Wilcoxon two-sided Rank Sum tests (Mean comparison between Baseline and Ambiguity treatments)	p-value = 0.686 (0.818)	p-value = 0.630 (0.699)

We summarize the results of this subsection (where we test Hypotheses 1 and 2) below.

[10] Our results are similar to experimental asset markets that show that trading volumes decrease with experience (Smith et al.1988, Lei et al. 2001). We test this hypothesis using a Wilcoxon one-sided Rank Sum test and we obtain a p-value of 0.014 for the aggregate sample (ambiguity and baseline sessions are pooled) and p-values of 0.074 and 0.063 for the baseline and ambiguity treatments, respectively.

Result 1: First-period asset prices, volume and volatility under ambiguity.

i) For inexperienced subjects, relative to baseline experiments, average asset prices in the first period are significantly higher in the ambiguity treatment. With experienced subjects, first-period average asset prices are not significantly different between the two treatments. We find no evidence of an ambiguity premium in our environment.

ii) For inexperienced subjects, compared to the baseline treatment, the standard deviation of asset prices in the first period is significantly higher in the ambiguity treatment. With experienced subjects, first-period standard deviation of asset prices is not significantly different between the two treatments. We find support for Hypothesis 2i) for inexperienced subjects while rejecting it for experienced subjects.

iii) Regardless of subject experience, trading activity is not significantly different between the ambiguity treatment and the baseline. This leads us to reject Hypothesis 2ii).

In the next subsection we test Hypothesis 3 and analyze trader reaction to public news (released in periods 2 and 3).

III.2. Reaction to News

We now analyze the reaction of asset prices and individual trading behavior to the release of public news about dividend regimes (in period 2) and dividend values (in period 3). The main purpose of our experimental design is to analyze reaction to news in asset market with and without ambiguity. We conduct our analysis in two parts. We first focus on the direction of price changes (Hypothesis 3*i*) and then we study its magnitude (Hypothesis 3*ii*). We first analyze whether price changes are consistent with the release of either good or bad news before analyzing the possibility of under-, or over-, reaction to public news.

III.2.1. Direction of price changes

We study reaction to news by first looking at the direction of price changes following the release of public news. Any piece of news that increases (decreases) the expected value of dividend streams associated with the asset is classified as "good news" ("bad news"). We develop a simple ordinal measure of the direction of price changes with respect to the news received by traders in periods 2 and 3. We classify the evolution of average asset prices in period t (P_t) as follows.

Definition 1: (Consistent price changes) If $P_t - P_{t-1} > 0$ [$P_t - P_{t-1} < 0$] for $t \in \{2,3\}$, then a change in average prices in period t is consistent with the release of good [bad] news in period $t \in \{2,3\}$.[11]

We display the information on consistent price changes across treatments and periods in table 6.

Table 6: Proportion of consistent price changes:
Inexperienced [experienced] traders (by treatments and periods)

	Period 2	**Period 3**	**Total**
Baseline	4/6 [5/6]	2/2 [3/3]	6/8 [8/9]
Ambiguity	5/6 [5/6]	3/3 [1/3]	8/9 [6/9]
Inexperienced vs. experienced	9/12 [10/12]	5/5 [4/6]	14/17 [14/18]

We observe a very-high proportion of consistent price changes both in the baseline (82.4%) and the ambiguity treatment (77.8%). A Chi-squared proportions test tells us that the (proportions) are significantly different from 50% (p-values of 0.012 and 0.031, respectively). Subjects in experienced sessions exhibit a greater consistency levels in price changes (82.4% vs. 77.8% for inexperienced). This difference in proportions is, however, not significant (p-value = 0.7352).

In table C.1 (appendix), we summarize the rest of our results comparing the proportion of consistent price changes among treatments, periods, and levels of experience. We find that levels of consistent price changes are not significantly different across

[11] Notice that, at the end of period 2 the information delivered to subjects may be neutral. In this case we should not expect price changes. Definition 1 restricts our analysis to the case in which either bad or good news is released before the start of period 3. This is the reason why the number of price changes in period 3 considered for inexperienced and experienced sessions is only equal to five and six (table 6), respectively. A separate analysis of neutral news is available upon request. In particular, we do not find any significant differences in the reaction of asset prices with respect to neutral news across treatments.

treatments, periods or, levels of experience. In particular, the presence of ambiguity does not preclude inexperienced traders from reacting consistently to news. Interestingly, reaction to public information in the ambiguity sessions, far from being indeterminate and subject to possible animal spirits, is consistent with the news released. This tells us that, in the context of ambiguity, the release of information may lead to consistent reactions as it reduces ambiguity. In the absence of a determinate equilibrium in asset prices, following Shiller's argument, one can think of public news as a benchmark for trading. Our results on the consistency of asset prices changes are summarized in Result 2 below. We confirm Hypothesis 3*i*) under which we expect no differences in consistency of price changes across treatments and levels of experience.

Result 2: (Consistent price changes)

i) *The proportion of consistent average price changes is not significantly different between the ambiguity and the baseline treatments. This is true regardless of subject experience.*

ii) *Compared to experienced subjects, the proportion of consistent price changes is not significantly different for inexperienced subjects.*

iii) *The proportion of consistent price changes is not significantly different between periods 2 and 3.*

Even though we do not observe significant differences in price change consistency across treatments and levels of experience at the aggregate level, we still need to verify whether the results are maintained for the individual analysis. To do this we first need to provide a measure of individual reactions to news released in period *t*. This can be done by assessing trader valuation of an asset in any given period (V_t) and then measure the difference in the trader's valuation of the asset across periods *t-1* and *t*. A natural definition of a trader's valuation of the asset in period *t* has to depend on a (trader's) offers to buy and sell in the given period. In particular, this valuation has to depend on the bid-ask spread. In the following definition we determine a trader's valuation of the asset as the midpoint of the average bid-ask spread.[12]

Definition 2: (Traders' valuation of the asset) Trader *i*'s valuation of the asset in period *t* is determined as an arithmetic average of trader *i*'s bids and asks, that is, $V_{i,t}$ = ½×(Average bid of trader *i* in period *t* + Average ask of trader *i* in period *t*).

We now identify correct trading responses to news in period *t* when a trader's valuation increases (decreases) after the release of good (bad) news at the end of period *t-1*.

Definition 3: (Correct individual trading responses) If $V_{i,t} - V_{i,t-1} > 0$ [$V_{i,t} - V_{i,t-1} < 0$] for $t \in \{2, 3\}$ then we consider that the trading response of individual *i* in period *t* is correct if good [bad] news has been released in period $t \in \{2,3\}$.

We first compare the proportion of correct individual responses to news using proportion tests. This analysis is summarized in the following table.

Table 7: Proportion of correct individual responses to news:
Inexperienced [experienced] traders (by treatments and periods)

	Period 2	**Period 3**	**Total**
Baseline	69.0% [92.1%]	43.5% [88.2%]	60.0% [90.9%]
Ambiguity	76.6% [90.0%]	95.0% [47.4%]	82.1% [76.3%]
Aggregate (Baseline & Ambiguity)	73.0% [91.0%]	67.4% [66.7%]	71.2% [83.3%]

At the individual level we find significant differences in consistency of price changes across treatments and experience levels. A significant difference in the proportion

[12] We have used alternative measures of trader's valuation of the asset in period *t* (such as average bids or average asks in period *t* or last bid or ask in period *t*). Our results are maintained (summarized in Result 3) with these alternative measures.

of correct individual responses to news between inexperienced (83.3%) and experienced subjects (71.2%) is observed.[13]

It seems ambiguity leads to more accurate responses to news for inexperienced subjects (82.1% vs. 60% in baseline). This difference is statistically significant (see table C.2 in the appendix). This result confirms that ambiguity leads to surprisingly accurate reactions to news both at the aggregate (Result 2) and the individual level. This (positive) effect of ambiguity is especially relevant given that experimental asset markets with news have been characterized by a high degree of inertia where subjects fail to fully adjust to news in a given period (Lin and Rassenti, 2010). The release of information in ambiguity sessions is particularly relevant for traders as it informs them about the fundamental value of the asset and reduces uncertainty about the intrinsic value of the asset at the same time. However, the positive effect of ambiguity on trading response accuracy diminishes with time. In the baseline treatment the proportion of correct trading responses increased from 60% to 90.9% with experience. In the ambiguity treatment, the proportion of correct trading responses does not increase. This is due to the fact that the proportion of these responses was already particularly high (82.1%) in the first session with inexperienced subjects.

Reaction to news in the two treatments is highlighted by looking at experimental sessions with inexperienced traders, in the third period, with a high regime of dividends and positive news, and another session in which the regime of dividends was low and the news negative. We observe that the reaction to news in both treatments moves in line with fundamentals (Figure 1a). At the end of each period, transaction prices are particularly close to the fundamental value. However, in the inexperienced session, with a low dividend regime and bad news on dividends (Figure 1b), the baseline session is characterized by prices that do not move in the direction of the fundamental value. Meanwhile, the reaction of asset prices in the corresponding ambiguity session is correct and particularly fast.

Figure 1a: Baseline session (on the left panel) and ambiguity session (right panel) with high regime and good news

[13] The p-value of the proportion test is equal to 0.030.

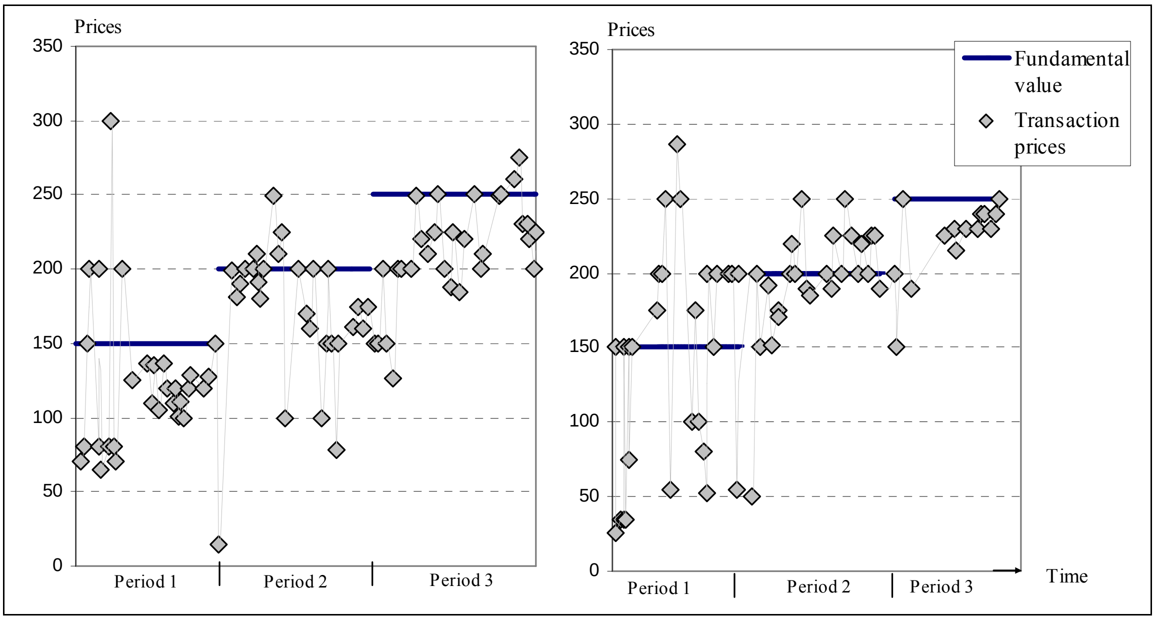
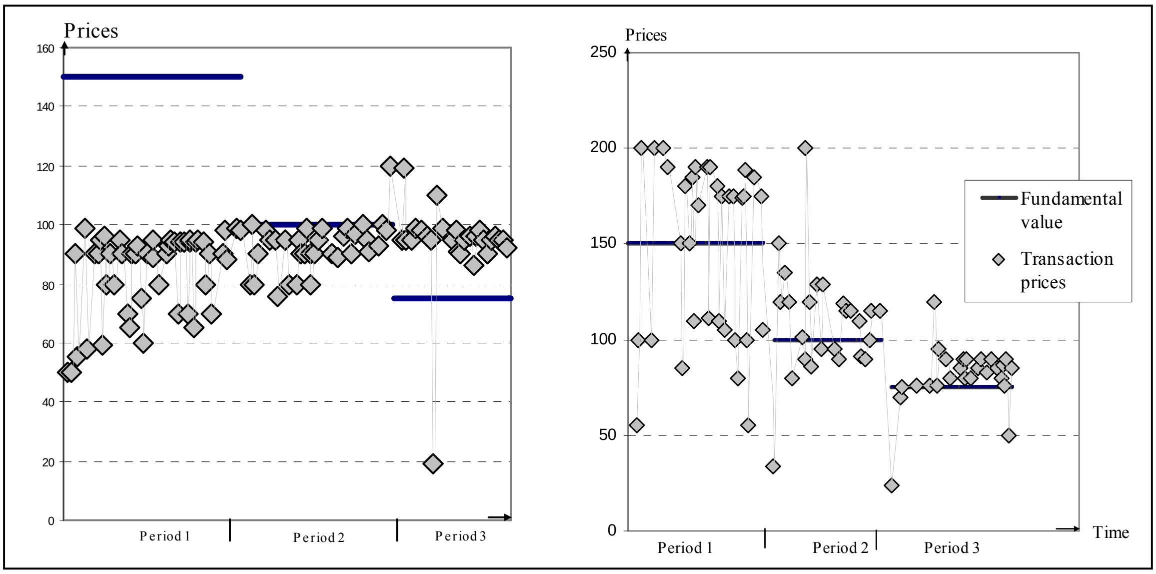


Figure 1b: Baseline session (on the left panel) and ambiguity session (right panel) with low regime and bad news



Our results on individual trading responses are summarized below.

Result 3: (Individual trading responses to news)

Compared to the baseline, for inexperienced subjects the proportion of correct trading responses is significantly higher for the ambiguity treatment.

We confirm Result 3 by using regression analysis where we control for the news that is actually released in the different experimental sessions (see table C.3 for additional regressions). Indeed, whether the dividend regime is high or low or, the news in period 3 good or bad, affects the patterns of asset prices and trading behavior.

In order to construct the dependent variable for our regression analysis, we define the binary variable $CPR_{i,t}$ for $t \in \{2,3\}$, where $CPR_{i,t} = 1$ [0] if individual *i*'s response to the news released in period *t* is [not] correct. The dependent variable is defined as the total number of correct responses to news of a given subject *i* in periods 2 and 3: $\mathrm{CPR}_{i,2} + \mathrm{CPR}_{i,3} \in \{0, 1, 2\}$. In table 8, we present the regression results of the following specification.

(1) $$\mathrm{CPR}_{i,2} + \mathrm{CPR}_{i,3} = \beta_0 + \beta_1 \times \mathrm{Treatment}(i) + \beta_2 \times \mathrm{News}_2(i) + \beta_3 \times \mathrm{News}_3(i) + \varepsilon(i)$$

We introduce a dummy treatment variable as a regressor (that takes value of one if the subjects participated in the ambiguity session). The other regressors correspond to the variable $News_t$. $News_t$ measures the change in the fundamental value of the asset in period *t*. That is, it measures the change in the expected value of dividend streams between period *t* and *t-1* after the release of the news at the end of period *t-1*. $News_t$ is positive (negative) when the news at the end of period *t-1* is good (bad). In the case of inexperienced subjects we find that the dummy treatment variable is positive and significant in the regressions of the total number of subjects' correct responses in periods 2 and 3 (table 8, left column).

Table 8: Poisson count estimates for inexperienced [experienced] traders

Dependent variables: correct trading responses in periods 2 and 3 ($\mathrm{CPR}_{i,2} + \mathrm{CPR}_{i,3}$), n=89 [n=78]

Coefficients (P-values)	Inexperienced	Experienced
Intercept	-0.09	0.75**

Treatment	0.64**	-0.35
News in period 2	0.26	-0.176
News in period 3	0.09	0.06
R squared	0.44	0.22

III.2.2. Analysis of the magnitude of price changes

We now test Hypothesis 3*ii*) and assess whether changes in asset prices are over-, or under, reaction to news. Our previous analysis on price change consistency and correct trading responses does not inform us about the magnitude of price changes. As a result, we complement the analysis by defining the concepts of over- and under-reaction to news as follows.

Definition 4: (Asset price changes classification) For $t \in \{2, 3\}$, a change in average asset prices between periods *t* and *t-1* is classified as under-reaction [over-reaction] if:

i) It is *consistent* and $P_t - P_{t-1} < News_t$ [$P_t - P_{t-1} > News_t$] in case of good news; or
ii) It is *consistent* and $P_t - P_{t-1} > News_t$ [$P_t - P_{t-1} < News_t$] in case of bad news.

The classification of price over-, under-, reaction and consistency is reported in table 9. For each treatment, we aggregate price under- and over-reaction for periods 2 and 3. A first look at the table suggests that the proportion of price changes characterized as over- and under-reactions to news is similar across treatments. Using Definition 5, we test this conjecture (Hypothesis 3*ii*).

Table 9: Classification of asset price changes for inexperienced [experienced] traders by treatments[14]			
	Over-reaction	**Under-reaction**	**Inconsistent**
Baseline	3/8 [5/9]	3/8 [3/9]	2/8 [1/9]
Ambiguity	3/9 [3/9]	3/9 [3/9]	3/9 [3/9]
Aggregate (Baseline & Ambiguity)	6/17 [8/18]	6/17 [6/18]	5/17 [4/18]

Definition 5: (Over- and under-reaction in asset markets) An asset market is characterized by under-reaction [over-reaction] if the proportion of asset price changes classified as under-reaction [over-reaction] is significantly larger than the proportion of asset price changes classified as over-reaction [under-reaction].

In table C.4 (appendix) we provide a summary of the tests for the presence of over- or under-reaction in ambiguity and baseline treatments. Our findings are summarized in Result 4.

Result 4: (Over- and under-reaction to news)
Neither the baseline, nor the ambiguity, treatments are characterized by a significantly larger proportion of asset price changes that are classified as either over- or under-reaction to news. This result holds regardless of subject experience.

This finding is in line with Fama's critique (1998) that downplays the robustness of studies showing under- or over-reaction of asset prices to news. We confirm Hypothesis 3*ii*) that states that over-reaction in asset prices is not more likely than under-reaction in asset prices. This is true regardless of whether the underlying asset value is ambiguous or not. Result 4 is in line with Results 2 and 3 where we show that price changes are highly consistent to news regardless of subject experience and the ambiguity of the environment.

[14] We classify a total of 17 price changes (8 inexperienced sessions and 9 experienced sessions) for the baseline sessions and 18 (9 inexperienced sessions and 9 experienced sessions) price changes for the ambiguity sessions. Recall that over the 24 price changes in the baseline (ambiguity) sessions, 7 (6) of them could not be qualified as either consistent or inconsistent.

Using regression analysis we confirm Result 4 where we assess the impact of news on average asset prices in periods 2 and 3. The dependent variable is the average asset price in periods 2 and 3 in a given experimental session. We control for the level of mispricing in the previous period. We define it as the difference between average asset prices in period *t* and the fundamental value of the asset in that period. The fundamental value of the asset in period *t* is computed as the expected dividend stream given the information released up to that period.

Controlling for asset mispricing in previous periods is important in order to measure asset prices reaction to the release of news in a given period. For example, an increase in asset prices in the second period of trading may be either due to the release of good news or to a positive trend in asset prices (i.e. prices were much lower than the fundamental value in the first period). We also introduce a treatment dummy variable that takes a value of one if the session corresponds to the ambiguity treatment.[15] In addition, we incorporate an interaction variable between the treatment dummy and the news variable (Treatment×News). This variable measures whether reaction to news is significantly different across treatments. Finally, we introduce a dummy variable that takes value of one for experienced subjects.[16]

We estimated the following regressions.

(2) $P_2(i) = \beta_0 + \beta_1 \times \text{News}_2(i) + \beta_2 \times \text{Treatment}(i) + \beta_3 \times [\text{Treatment}(i) \times \text{News}_2(i)] + \beta_4 \times \text{Mispricing in period } 1(i) + \beta_5 \times \text{experience}(i) + \varepsilon(i)$

(3) $P_3(i) = \beta_0 + \beta_1 \times \text{News}_3(i) + \beta_2 \times \text{News}_2(i) + \beta_3 \times \text{Treatment}(i) + \beta_4 \times [\text{Treatment}(i) \times \text{News}_3(i)] + \beta_5 \times \text{Mispricing in period } 2(i) + \beta_6 \times \text{experience}(i) + \varepsilon(i)$

Table 10: OLS estimates of the regression of average asset prices on news

Coefficients (P-values)	P_2	P_3
Intercept	152.18***	157.02***
News,*2*	0.90***	1.07***
News,*3*	-	1.11***

[15] This variable allows us to control for the fact that prices may be systematically different across treatments (as seen in the case of inexperienced traders in Result 1).

[16] In contrast with individual trading behavior regressions (table 8) we do not consider separate regressions for experienced and inexperienced sessions. The rationale is that we have much less data available in our aggregate analysis compared to the analysis of individual data.

Treatment	9.42	-9.77
Treatment×News,*2*	-0.36	-
Treatment×News,3	-	-1.09**
Mispricing in previous period	0.08	1.06***
Experience	-9.92	-1.99
R squared	0.54	0.79

In both the regressions the coefficient for news is highly significant. This confirms that asset prices significantly react to news. Using a Wald test we cannot reject that the β_1 coefficient (associated with current period news) is equal to one. For the regression of asset prices in period 2 and 3, the p-values are 0.690 and 0.730, respectively. This means that an increase (decrease) of one monetary unit in the fundamental value of the asset is followed by an increase (decrease) of the same magnitude in average asset prices in the period in which the news have been released. This result confirms the absence of under- or over-reaction as established previously using non-parametric tests. The only effect associated with ambiguity is due to the significance of the interaction coefficient between the treatment dummy and news in period 3. This coefficient tells us that in the ambiguity treatment the reaction to news in period 3 is significantly more negative. This result is consistent with Epstein and Schneider (2008) and Leippold et al. (2007) that show that asset prices react more strongly to bad news than to good news in a context of ambiguous information.[17]

III.3. Individual trading behavior

In this section, we study individual trading behavior. Our main objective is to assess the level of sophistication of trading behavior and study how it is affected by ambiguity (Hypothesis 4). From Epstein and Wang 1994, we know that the possible indeterminacy in equilibrium prices may imply that asset prices follow animal spirits in the presence of

[17] Period 3 results should be interpreted with care since our aggregate analysis of price reaction to news is based on only 11 sessions (5 sessions with inexperienced subjects and 6 sessions with experienced subjects). This is due to the fact that we drop the observations corresponding to the release of neutral news in period 2.

ambiguity. As a result, behavior would be less consistent and (less) rational under ambiguity, than under the baseline treatment.

We first establish some measures that capture different aspects of subject trading behavior. We start by defining subject trading behavior as being inconsistent in a given period whenever he is willing to sell an asset at a price lower than what he would be willing to pay for it. The analysis follows the definitions of absolute and average inconsistent trading behavior.

Definition 5.1: (Basic inconsistency) Basic inconsistent trading behavior is observed for a subject in a given period if his minimum offer to sell is strictly lower than his maximum offer to buy. The index of basic inconsistency of a given trader is measured as the sum of all periods for which the subject exhibits absolutely inconsistent behavior. This index equals 3 for fully inconsistent subjects and is equal to 0 when subjects are fully consistent.

Definition 5.2: (Average inconsistency) Average inconsistent trading behavior is observed for a subject in a given period if his average offer to sell is strictly lower than his average offer to buy. The index of average inconsistency of a given trader is measured as the sum of all periods for which the subject exhibits average inconsistent behavior. This index equals 3 for fully inconsistent subjects and is equal to 0 when subjects are fully consistent.

Next, we consider another measure of trading behavior following Lei et al. (2001). We define extreme market behavior of participants as follows:

Definition 6: (Extreme under- and over-pricing) A subject exhibits extreme pricing behavior whenever his transaction price is higher than the maximum possible (300 in period 1), or lower than the minimum possible (50 in period 1), dividend.

Below, we define individual mispricing behavior. This is a measure that captures how far from the fundamental value each subject is actually trading.

Definition 7: (Individual mispricing behavior) A subject's individual mispricing behavior is defined as $\sum|P_{it} - f_t| / (100\times16)$. Where, P_{it} is the price of the i^{th} transaction in period t, the total number of shares is 16 and 100 is a normalization scalar. Also, f_t is the fundamental value of the asset in period *t* measured as the expected value of dividend streams given the information released up to period *t*. For a given subject we only consider the transactions for which he is buying [selling] at a price that is larger [lower] than fundamentals.

Using correlation analysis, we observe that the four measures are positively and significantly correlated (see table C.5 in appendix). This positive and significant correlation is in line with our initial objective that consisted in developing alternative measures of the same construct: traders' sophistication. In table 11, we report the average values of the different measures for the two treatments.

Table 11: Average measures of individual trading behaviour for the baseline and the ambiguity treatments for inexperienced [experienced] traders (n=192)

	Basic inconsistency	**Average inconsistency**	**Extreme pricing**	**Individual mispricing behavior**
Baseline	1.12 [0.90]	0.52 [0.38]	1.67 [0.33]	25.18 [34.99]
Ambiguity	1.44 [0.95]	0.70 [0.35]	7.17 [0.83]	66.89 [50.54]
Aggregate (Baseline & Ambiguity)	1.28 [0.93]	0.61 [0.37]	4.42 [0.58]	41.86 [45.36]

We compare these measures across treatments and experience levels in table C.6 in the appendix. We report significant differences across treatments for the four measures. The ambiguity sessions are characterized by much higher levels of inconsistency, extreme pricing, mispricing and trading than the baseline treatment. These differences are not significant for experienced subjects. Ambiguity modifies individual trading behavior resulting in inexperienced subjects to be more likely to exhibit inconsistent behavior and trade at prices that are far away from the fundamental value of the asset.

Result 5: (Individual trading behavior and ambiguity)

Compared to the baseline, inexperienced subjects in the ambiguity treatment exhibit significantly greater inconsistency in trading behavior, extreme pricing and mispricing. No *significant differences are observed in individual trading behavior between the ambiguity and the baseline treatments for experienced subjects.*

Result 5 confirms Hypothesis 4 that states that the sophistication in trading behavior is likely to be lower in the presence of ambiguity. This implies that asset prices may be driven by animal spirits (Epstein and Wang 1994). Interestingly, the different measures of trader sophistication are not magnified by the presence of ambiguity for experienced subjects. This result is in line with Results 1 to 4 as it confirms that the effect of ambiguity on asset prices, volatility, reaction to news or, traders' sophistication, is not robust to experience.[18]

IV. Conclusion

Research in behavioral finance makes specific predictions about the existence of price under- and over-reaction (e.g. Daniel et al. 1998 and Barberis et al. 1998). In this paper, we use a standard double auction experimental asset market to study the reaction of asset prices to public news. We find that prices do not over or under-react to news and consistently move in the direction of the fundamental value. Interestingly, the absence of under-or over-reaction to news is robust to the introduction of ambiguity in the fundamental value of the asset. Specifically, we control for the presence of ambiguity in our experimental asset markets by designing two distinct environments in which the distribution of dividends is either known (risky asset) or unknown (ambiguous asset) to the traders.

Furthermore, we compare market variables in the risky and ambiguous environments and find no support for the existence of an ambiguity premium. Contrary to expectations, prices in the ambiguity treatment are actually higher than the baseline, and are closer to the fundamental value. This difference is only significant for inexperienced subjects. In the absence of experience ambiguity tends to generate greater levels of volatility in asset prices compared to the risky environment. In addition, we find that ambiguity sessions are characterized by greater amount of inconsistent behavior, extreme pricing and mispricing than the baseline treatment. This may be due to the existence of

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[18] We ran tests to see if there was a correlation between individual ambiguity aversion, as measured in Dickhaut and Wilcox (2009), and individual trading behavior as measured by basic and average inconsistency, extreme pricing and mispricing and found no significant correlations. We did find some evidence that risk-averse subject trade less.

animal spirits that drive the evolution of asset prices in a context of ambiguity in which equilibrium prices are indeterminate (Epstein and Wang 1994).

However, any difference in asset prices, volatility and individual behavior disappears with experience. This suggests that any anomaly in trading behavior that would follow from the presence of ambiguity is only short-lived.

Our experiments point towards several future directions of research. For example, it would be interesting to analyze asset markets with different forms of ambiguity. A possibility could be to introduce ambiguity both in the fundamental value of the asset as well as in the information. Another possibility would be to consider not only public but, also private, information (Daniel et al. 1998) to further study the effect of ambiguity on price reaction to news.

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VI. Appendices

Appendix A: Individual choice tests

Figure A.1: Example of choice between risky lotteries

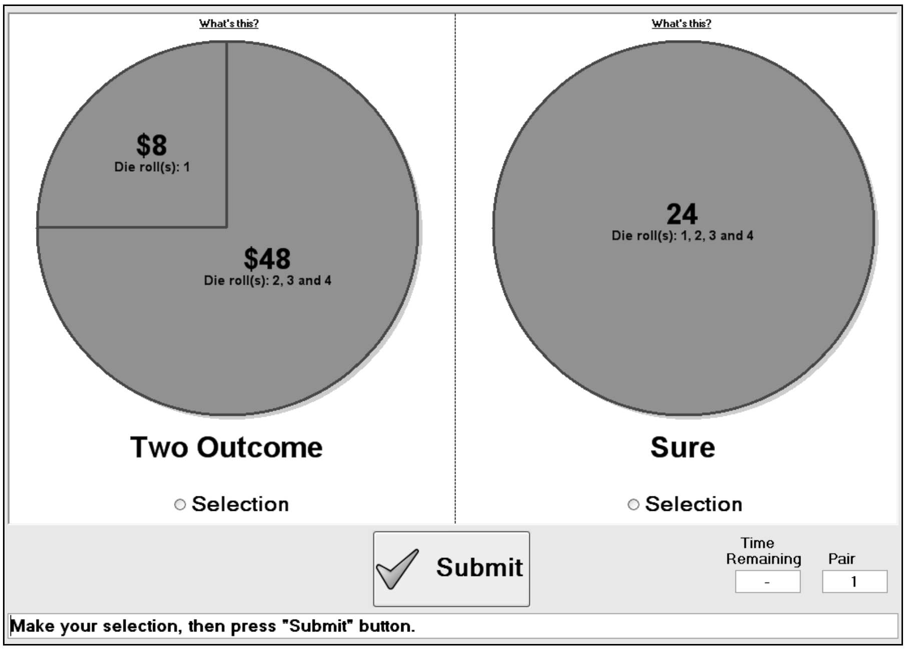


Figure A.2: Example of choice between an ambiguous lottery and a risky lottery

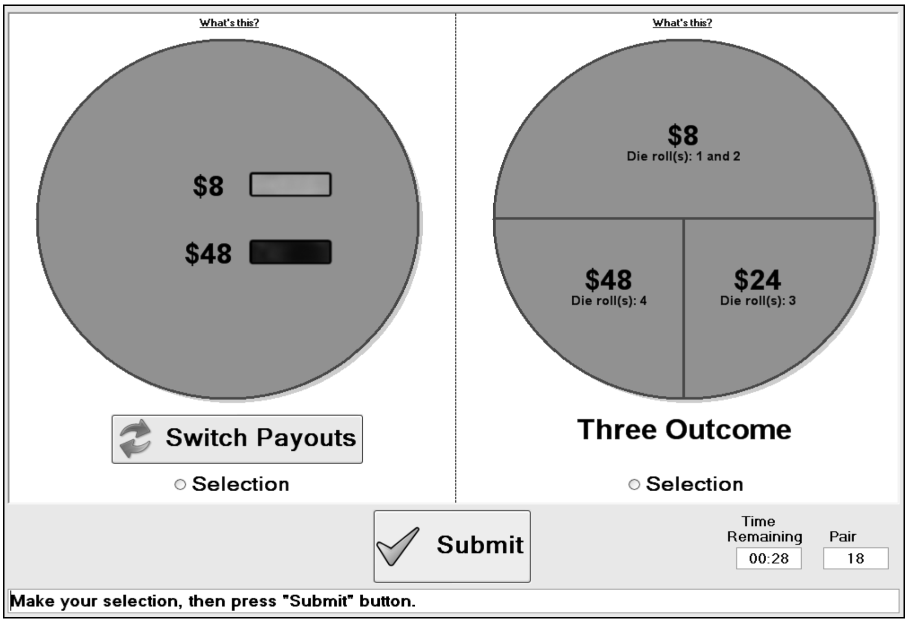
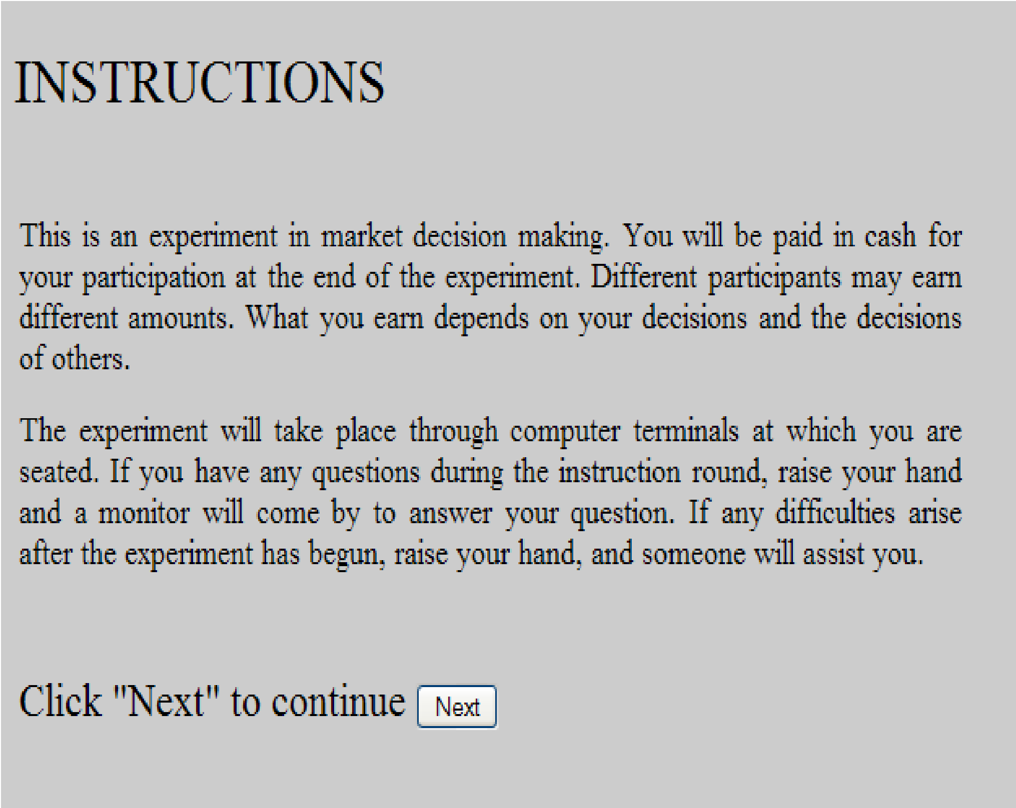


Figure A.1 represent examples of lottery choices presented to the subjects. The subjects' choice task involves indicating their preference of lotteries. In Figure 1, the choice is between the sure outcome of $24 and the lottery with outcomes of $48 with probability ¾ and $8 with probability ¼.

In Figure A.2, the choice is between the probabilistically known lottery ($8 with probability ½, $24 with probability ¼, and $48 with outcome ¼) and the probabilistically ambiguous lottery ($8 with unknown probability α, and $48 with unknown probability 1-α).

Appendix B: Instructions

I. Instructions for the baseline treatment (full set of instructions with screenshots)



INSTRUCTIONS

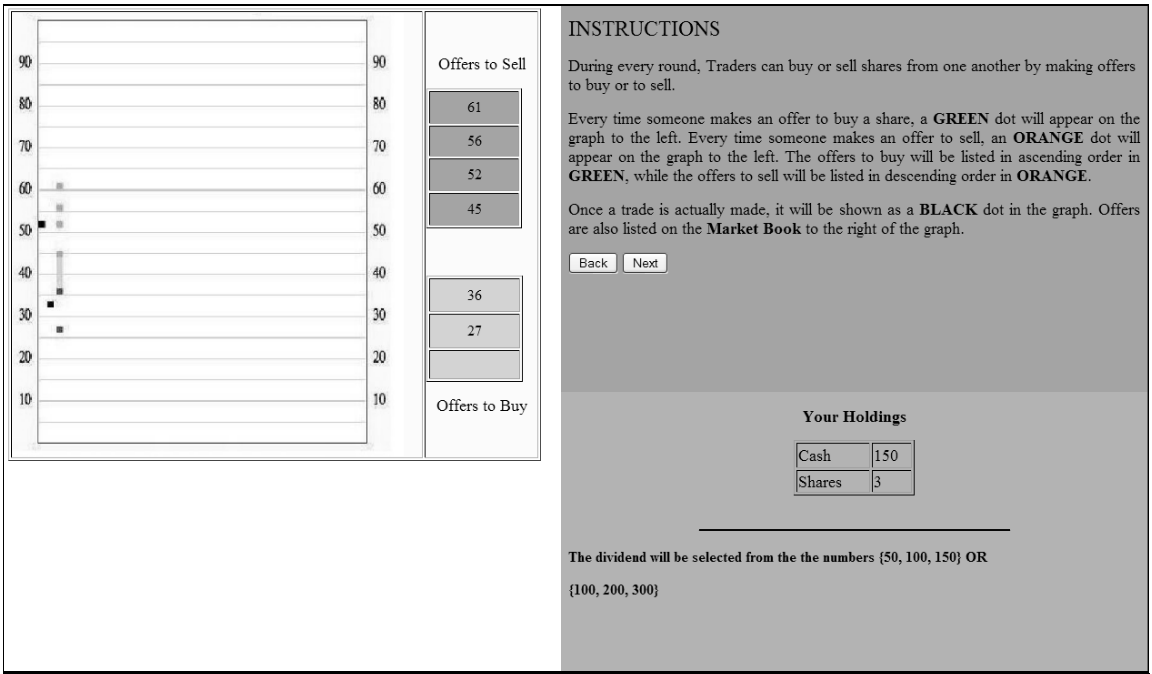
In this experiment you will be able to buy and sell a commodity, called **Shares**, from one another.

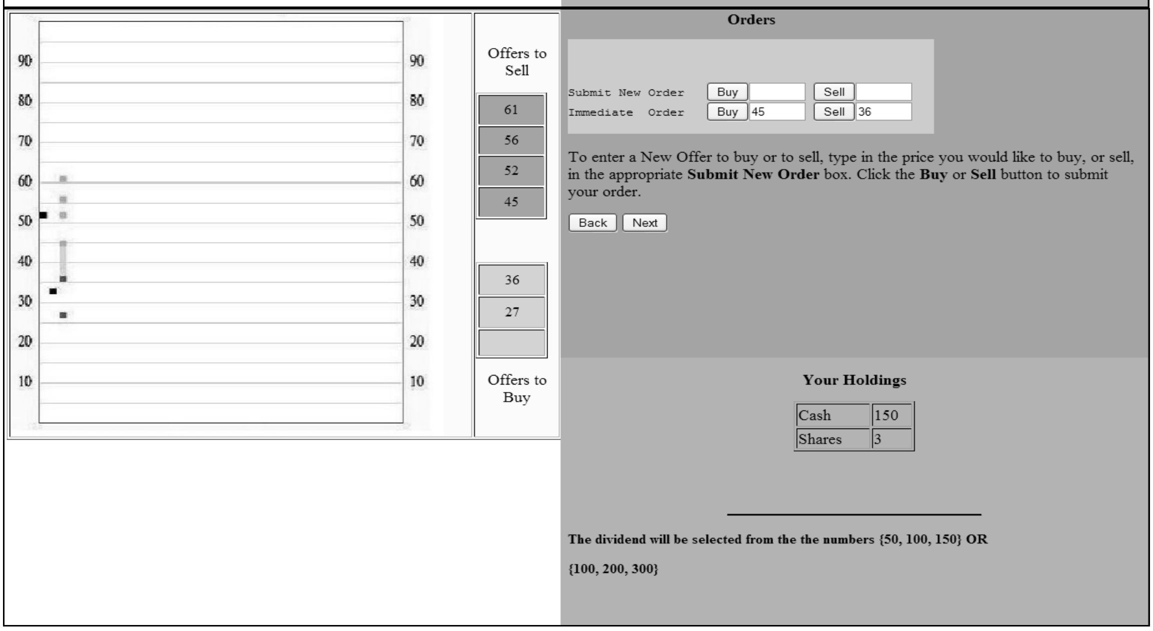
At the start of the experiment, every participant will be given some Cash and Shares.

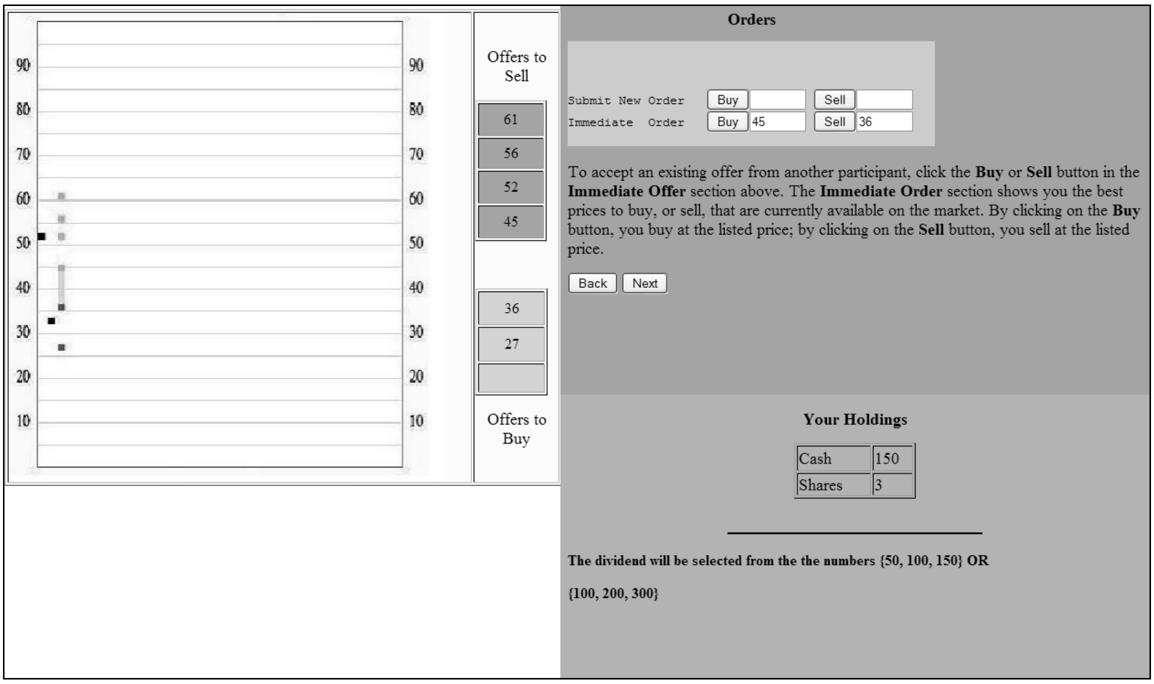
Each share will pay a dividend when the last period of trading ends. The amount you make is equal to the dividends you earn and the remaining cash you have after making buys and sells in the market.

The amount of the dividend is unknown but you will receive information during the experiment that will assist you in narrowing what the dividend will be at the end of trading.

Click "Next" to continue Back Next


90
80
70
60
50
40
30
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
INSTRUCTIONS
During every round, Traders can buy or sell shares from one another by making offers to buy or to sell.
Every time someone makes an offer to buy a share, a GREEN dot will appear on the graph to the left. Every time someone makes an offer to sell, an ORANGE dot will appear on the graph to the left. The offers to buy will be listed in ascending order in GREEN, while the offers to sell will be listed in descending order in ORANGE.
Once a trade is actually made, it will be shown as a BLACK dot in the graph. Offers are also listed on the Market Book to the right of the graph.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR
{100, 200, 300}


90
80
70
60
50
40
30
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Orders
Submit New Order Buy Sell
Immediate Order Buy 45 Sell 36
To enter a New Offer to buy or to sell, type in the price you would like to buy, or sell, in the appropriate Submit New Order box. Click the Buy or Sell button to submit your order.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR
{100, 200, 300}


90
80
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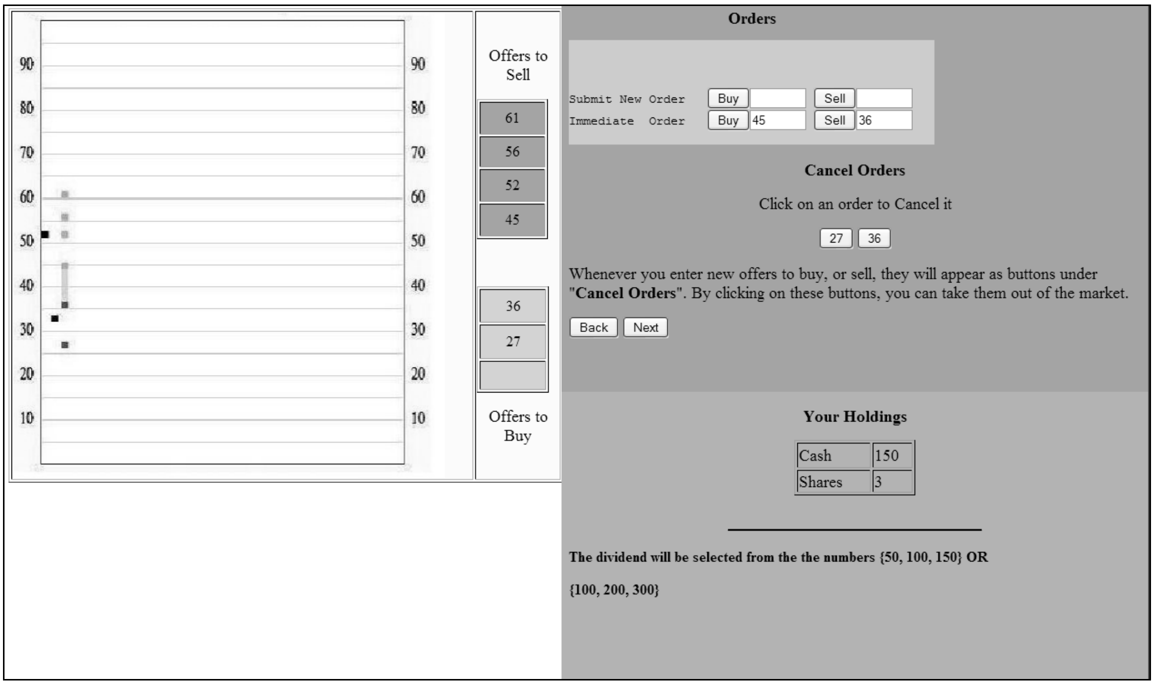
60
50
40
30
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Orders
Submit New Order
Buy
Sell
Immediate Order
Buy 45
Sell 36
To accept an existing offer from another participant, click the **Buy** or **Sell** button in the **Immediate Offer** section above. The **Immediate Order** section shows you the best prices to buy, or sell, that are currently available on the market. By clicking on the **Buy** button, you buy at the listed price; by clicking on the **Sell** button, you sell at the listed price.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR
{100, 200, 300}


90
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Offers to Sell
61
56
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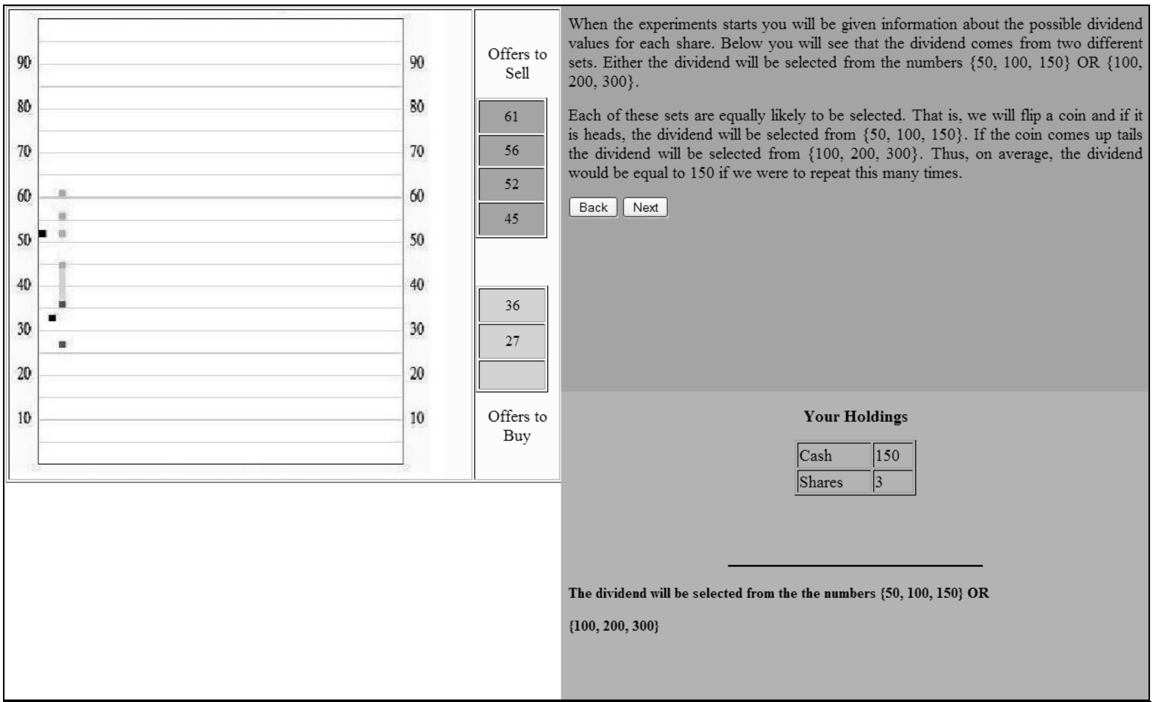
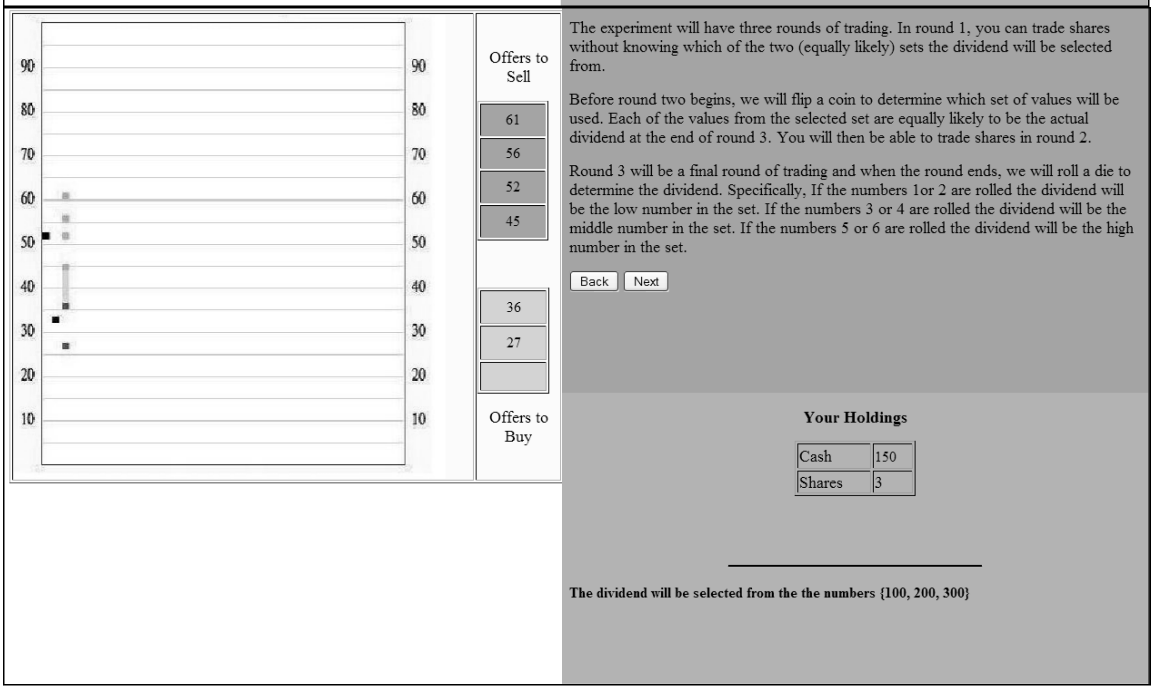
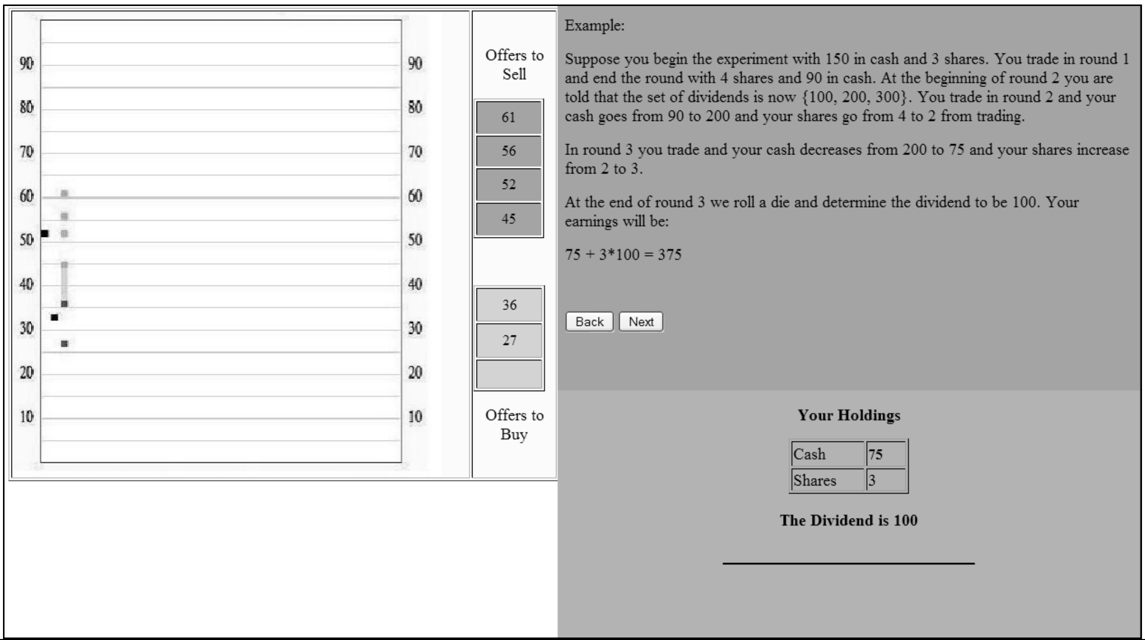
45
36
27
Offers to Buy
Orders
Submit New Order
Buy
Sell
Immediate Order
Buy 45
Sell 36
Cancel Orders
Click on an order to Cancel it
27
36
Whenever you enter new offers to buy, or sell, they will appear as buttons under "**Cancel Orders**". By clicking on these buttons, you can take them out of the market.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR
{100, 200, 300}


Offers to Sell
61
56
52
45
36
27
Offers to Buy
When the experiments starts you will be given information about the possible dividend values for each share. Below you will see that the dividend comes from two different sets. Either the dividend will be selected from the numbers {50, 100, 150} OR {100, 200, 300}.
Each of these sets are equally likely to be selected. That is, we will flip a coin and if it is heads, the dividend will be selected from {50, 100, 150}. If the coin comes up tails the dividend will be selected from {100, 200, 300}. Thus, on average, the dividend would be equal to 150 if we were to repeat this many times.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR
{100, 200, 300}


Offers to Sell
61
56
52
45
36
27
Offers to Buy
The experiment will have three rounds of trading. In round 1, you can trade shares without knowing which of the two (equally likely) sets the dividend will be selected from.
Before round two begins, we will flip a coin to determine which set of values will be used. Each of the values from the selected set are equally likely to be the actual dividend at the end of round 3. You will then be able to trade shares in round 2.
Round 3 will be a final round of trading and when the round ends, we will roll a die to determine the dividend. Specifically, If the numbers 1or 2 are rolled the dividend will be the low number in the set. If the numbers 3 or 4 are rolled the dividend will be the middle number in the set. If the numbers 5 or 6 are rolled the dividend will be the high number in the set.
Back
Next
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {100, 200, 300}


90
80
70
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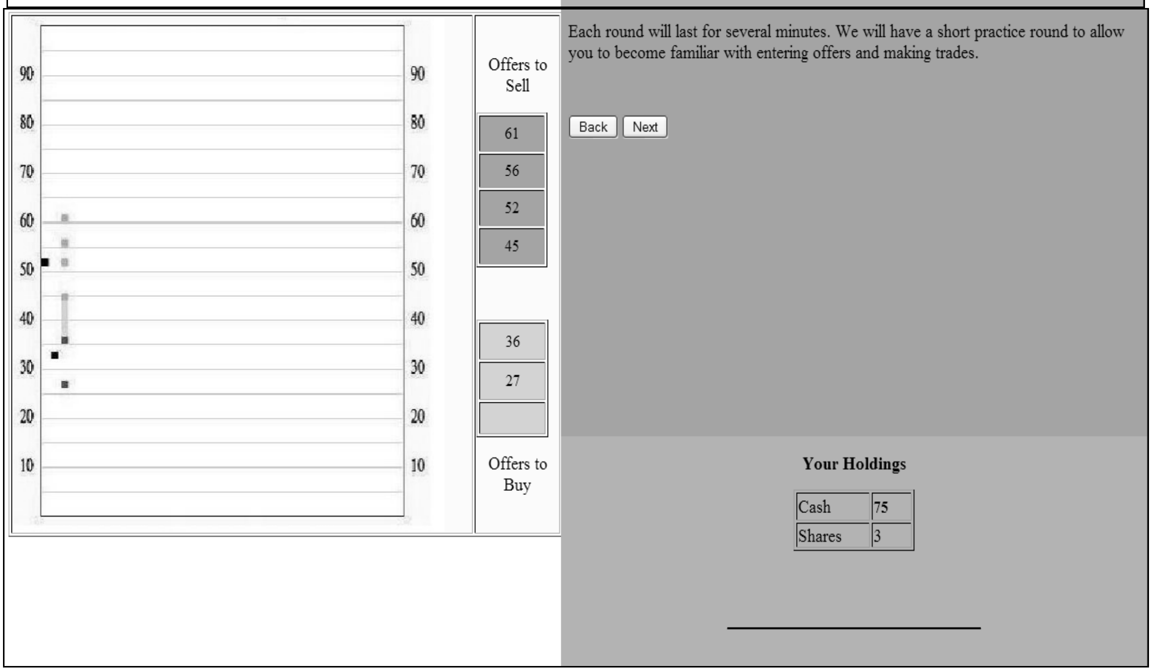
50
40
30
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Example:
Suppose you begin the experiment with 150 in cash and 3 shares. You trade in round 1 and end the round with 4 shares and 90 in cash. At the beginning of round 2 you are told that the set of dividends is now {100, 200, 300}. You trade in round 2 and your cash goes from 90 to 200 and your shares go from 4 to 2 from trading.
In round 3 you trade and your cash decreases from 200 to 75 and your shares increase from 2 to 3.
At the end of round 3 we roll a die and determine the dividend to be 100. Your earnings will be:
75 + 3*100 = 375
Back
Next
Your Holdings
Cash 75
Shares 3
The Dividend is 100


90
80
70
60
50
40
30
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Each round will last for several minutes. We will have a short practice round to allow you to become familiar with entering offers and making trades.
Back
Next
Your Holdings
Cash 75
Shares 3

Summary

1. You will be given an initial amount of Cash and Shares.

2. Every share generates a dividend from the set {50, 100, 150} or {100, 200, 300} both of which are equally likely to be selected. We will flip a coin , if the toss is heads the set will be {50, 100, 150}, if it is tails the set will be {100, 200, 300}.

3. You can submit offers to BUY shares and offers to SELL shares.

4. You make trades by buying at the current lowest offer to sell or selling at the current highest offer to buy.

5. The experiment will have three trading rounds. At the beginning of round 2 we will announce which of the sets was selected from the coin flip.

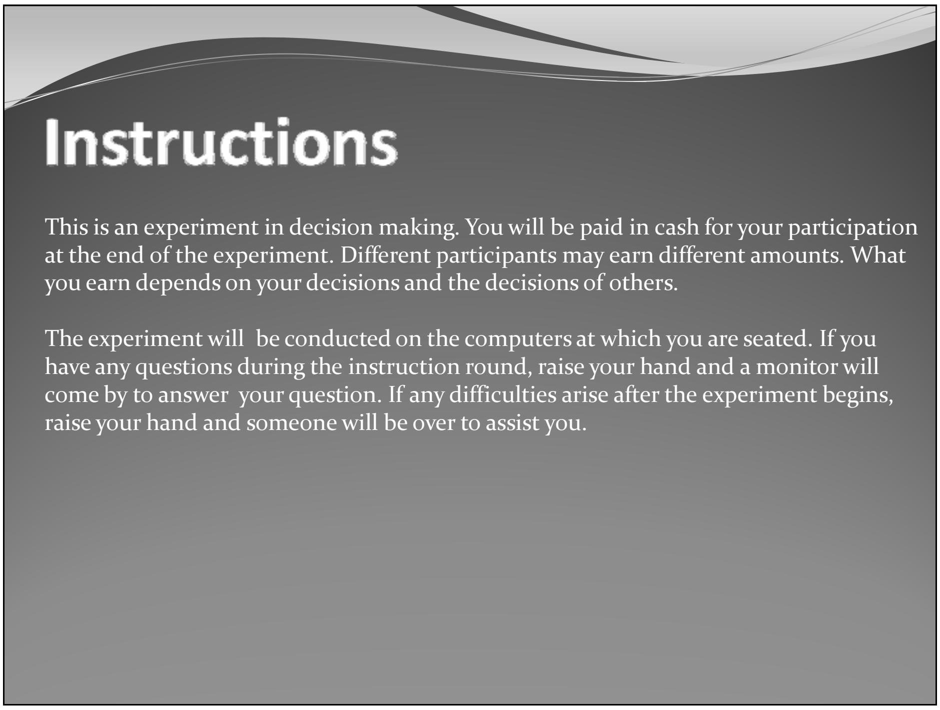
6. At the end of round 3, if the numbers 1or 2 are rolled the dividend will be the low number in the set. If the numbers 3 or 4 are rolled the dividend will be the middle number in the set. If the numbers 5 or 6 are rolled the dividend will be the high number in the set.

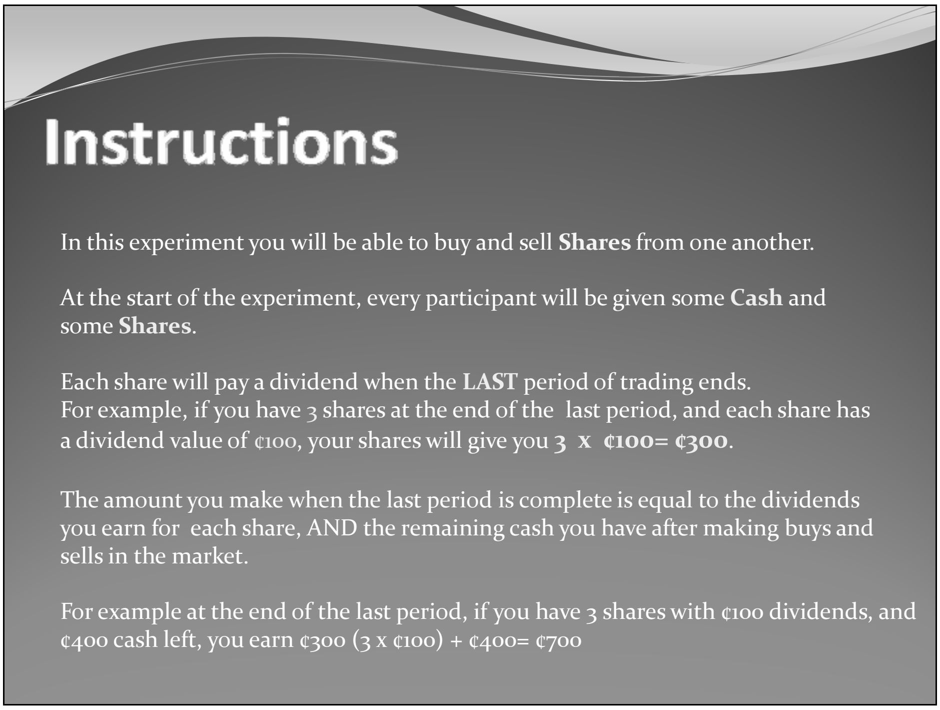
8. Your earnings will be equal to the ending cash at round 3 plus your shares at the end of round 3 times the dividend.

To go onto the review quiz, please click Next. Next

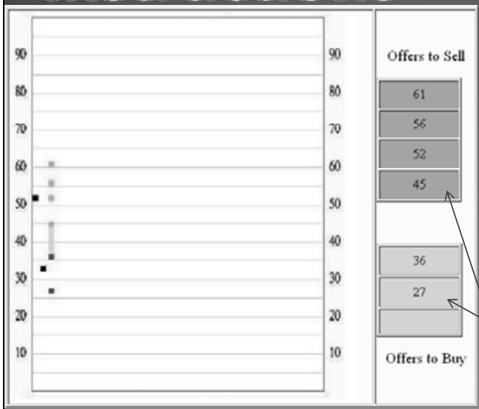
Appendix B

II. Instructions for the ambiguity treatment (full set of instructions with screenshots)





Instructions



During every round traders can buy or sell shares from one another by making offers to buy or to sell.

Every time someone makes an offer to buy a share, a GREEN dot will appear on the graph to the left.

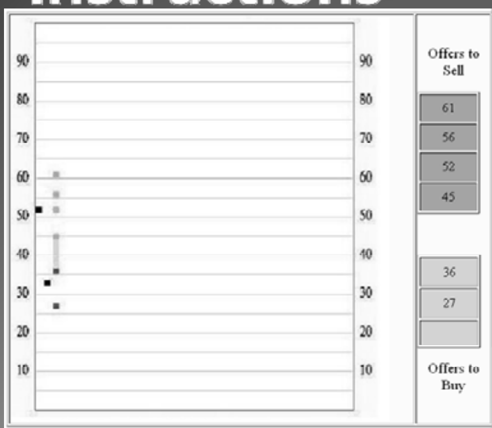
Every time someone makes an offer to sell, an ORANGE dot will appear on the graph to the left.

Offers to buy will be listed in GREEN

Offers to sell will be listed in ORANGE

Once a trade is completed, it will be shown as a BLACK dot on the graph

Instructions



Orders

Submit New Order Buy [ ] Sell [ ]

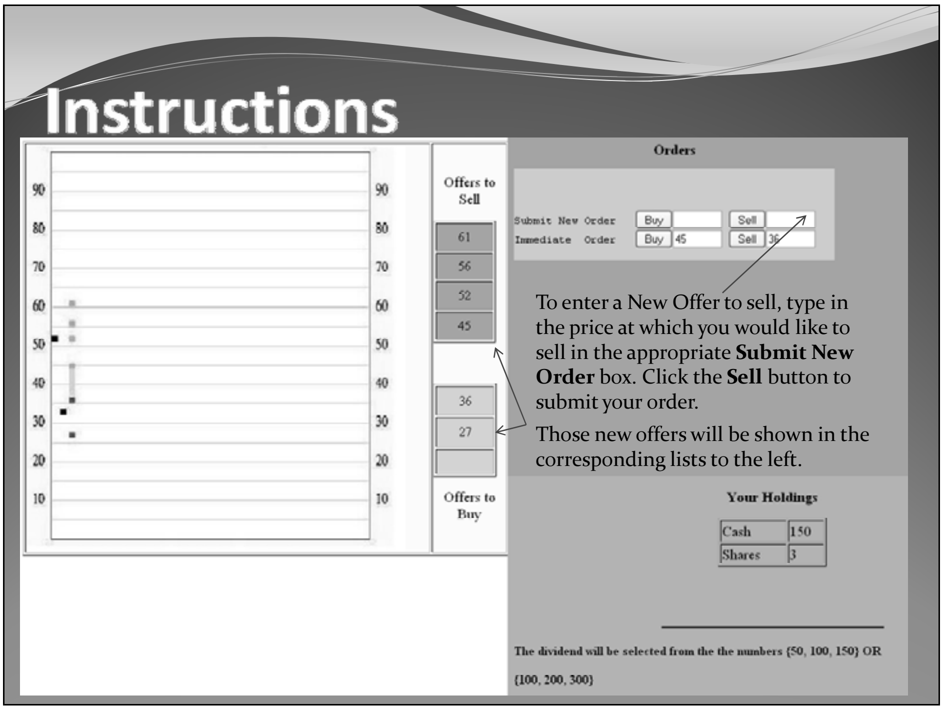
Immediate Order Buy 45 Sell 36

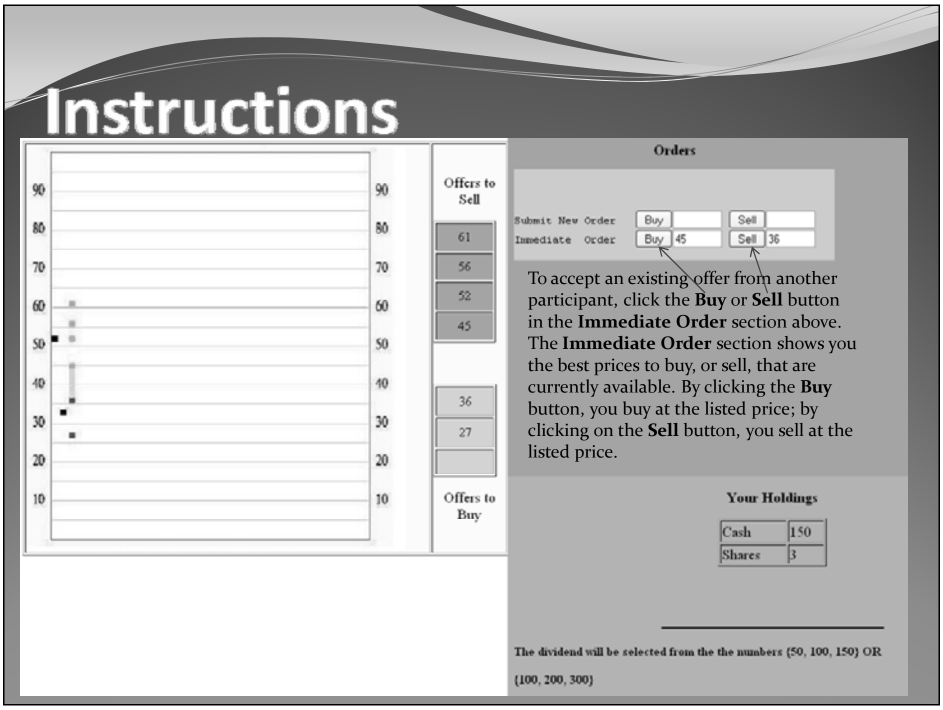
To enter a New Offer to buy, type in the price at which you would like to buy in the appropriate **Submit New Order** box. Click the **Buy** button to submit your order.

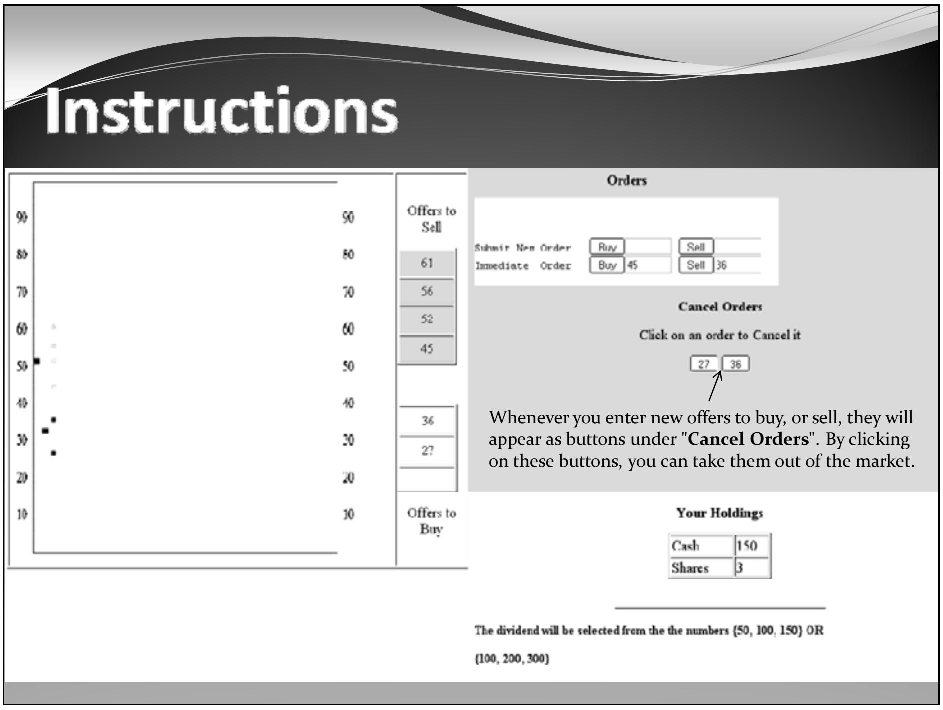
Your Holdings

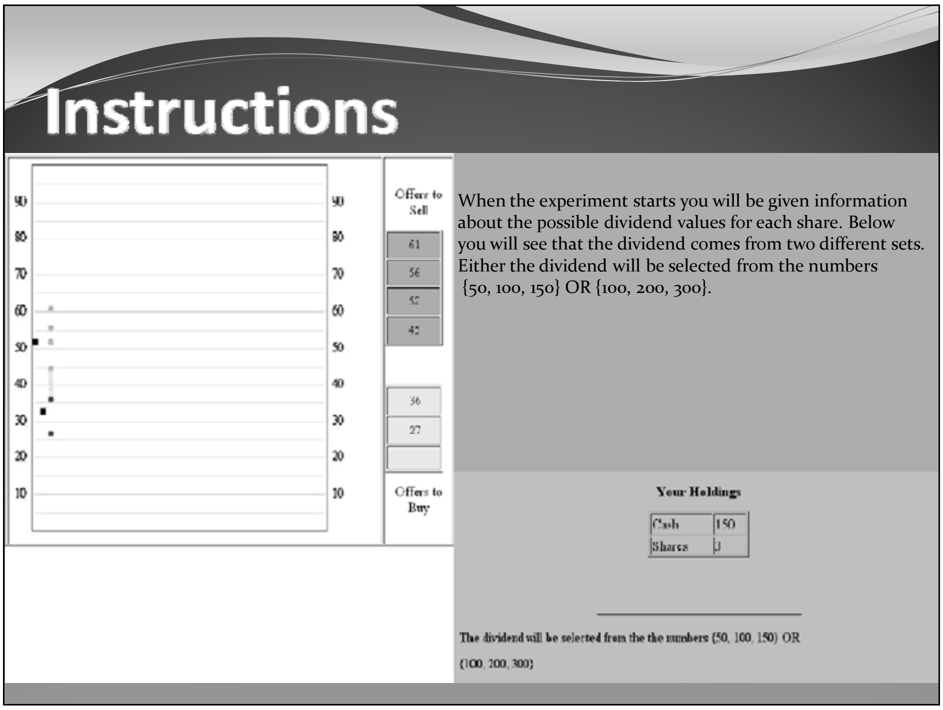
Cash	150
Shares	3

The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}

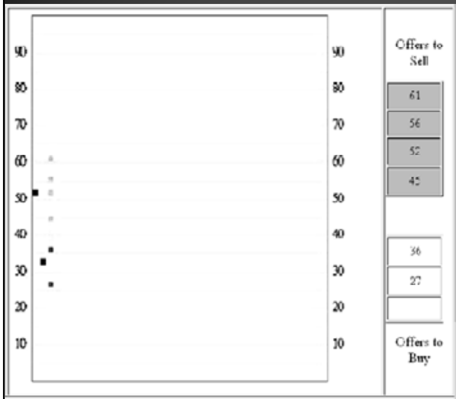

Instructions
Orders
Offers to Sell
Submit New Order Buy Sell
Immediate Order Buy 45 Sell 36
61
56
52
45
36
27
Offers to Buy
To enter a New Offer to sell, type in the price at which you would like to sell in the appropriate **Submit New Order** box. Click the **Sell** button to submit your order.
Those new offers will be shown in the corresponding lists to the left.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Orders
Offers to Sell
Submit New Order Buy Sell
Immediate Order Buy 45 Sell 36
61
56
52
45
36
27
Offers to Buy
To accept an existing offer from another participant, click the **Buy** or **Sell** button in the **Immediate Order** section above. The **Immediate Order** section shows you the best prices to buy, or sell, that are currently available. By clicking the **Buy** button, you buy at the listed price; by clicking on the **Sell** button, you sell at the listed price.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Orders
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Submit New Order
Immediate Order
Buy
Sell
Buy 45
Sell 36
Cancel Orders
Click on an order to Cancel it
27
36
Whenever you enter new offers to buy, or sell, they will appear as buttons under "Cancel Orders". By clicking on these buttons, you can take them out of the market.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Offers to Sell
61
56
52
45
36
27
Offers to Buy
When the experiment starts you will be given information about the possible dividend values for each share. Below you will see that the dividend comes from two different sets. Either the dividend will be selected from the numbers {50, 100, 150} OR {100, 200, 300}.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}

Instructions



The experiment will have three rounds of trading. In round 1, you can trade shares without knowing which of the two sets the dividend will be selected from.

Before round two begins, we will draw a marble from a bag of 2 colors (LIGHT and DARK blue) to determine which set of values will be used. The number of marbles of each color is left unknown.

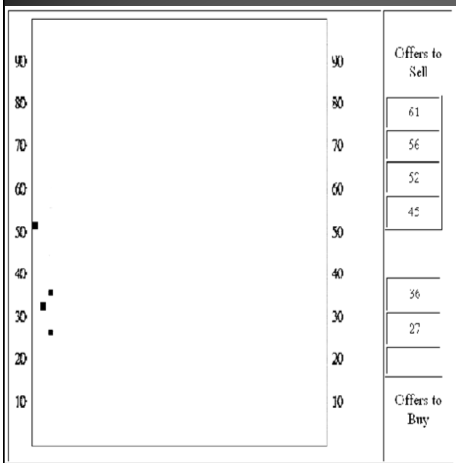
You will then be able to trade shares in round 2.

Your Holdings

Cash	150
Shares	3

The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}

Instructions



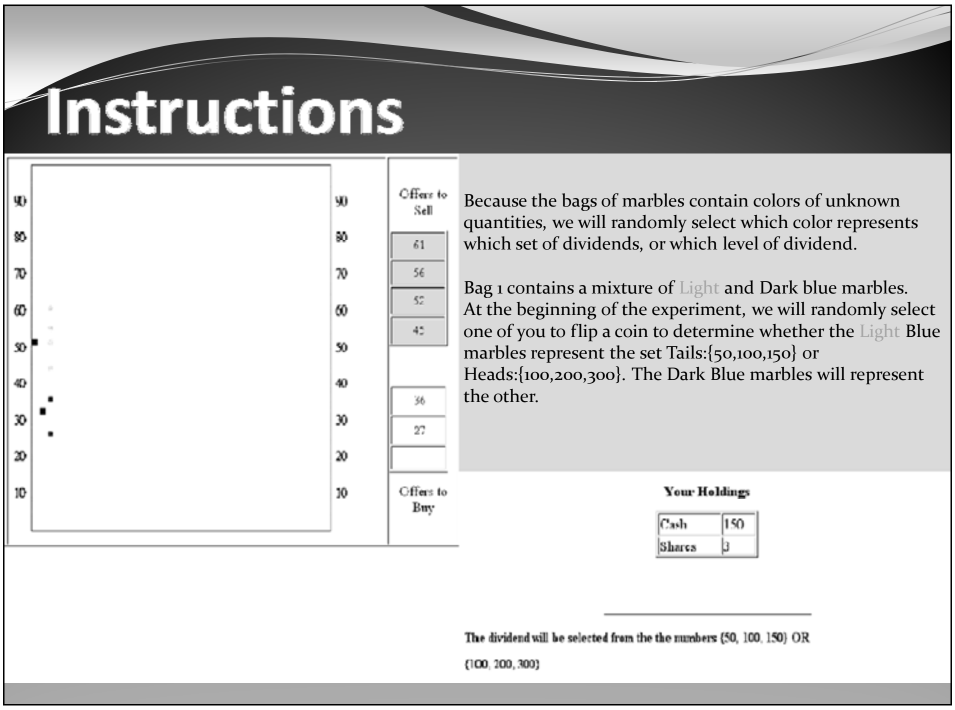
At the end of round 2, we will announce which of the three dividends will NOT be selected by drawing a marble from a bag containing 3 different colors. Again, the number of marbles of each color is left unknown.

You will then be able to trade in round 3. When round 3 ends we draw a marble from a third and final bag to determine whether the HIGH or the LOW dividend from the two remaining dividends will be used to calculate your profits.

Your Holdings

Cash	150
Shares	3

The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
90
80
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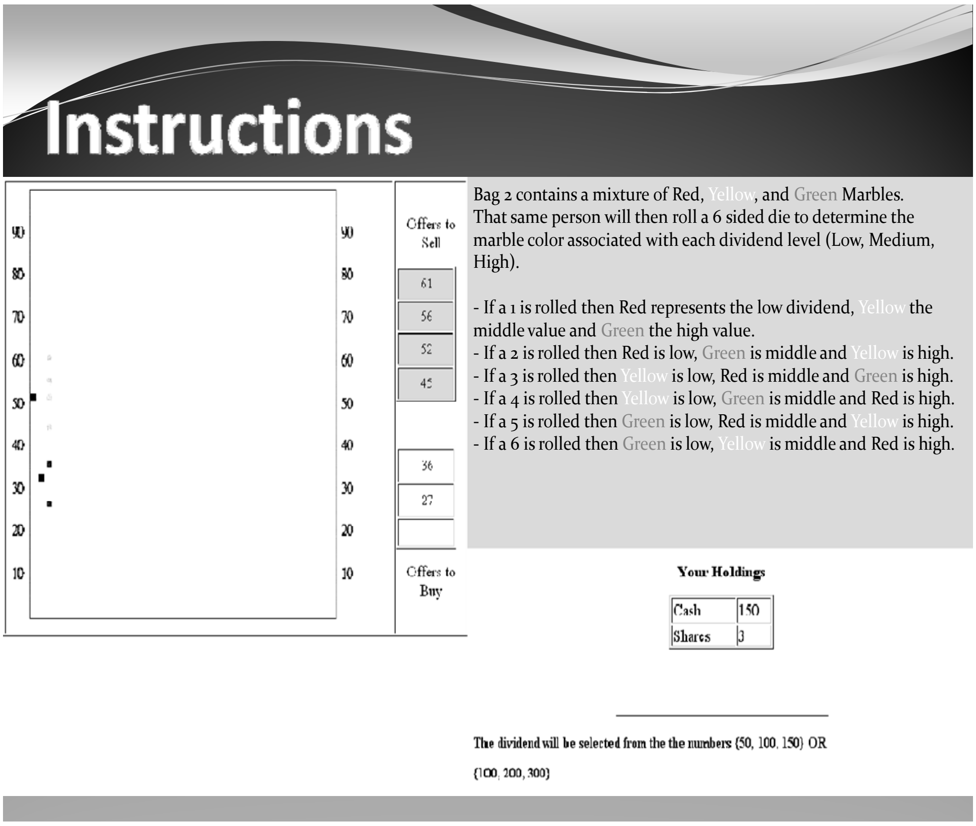
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Because the bags of marbles contain colors of unknown quantities, we will randomly select which color represents which set of dividends, or which level of dividend.
Bag 1 contains a mixture of Light and Dark blue marbles.
At the beginning of the experiment, we will randomly select one of you to flip a coin to determine whether the Light Blue marbles represent the set Tails:{50,100,150} or Heads:{100,200,300}. The Dark Blue marbles will represent the other.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
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80
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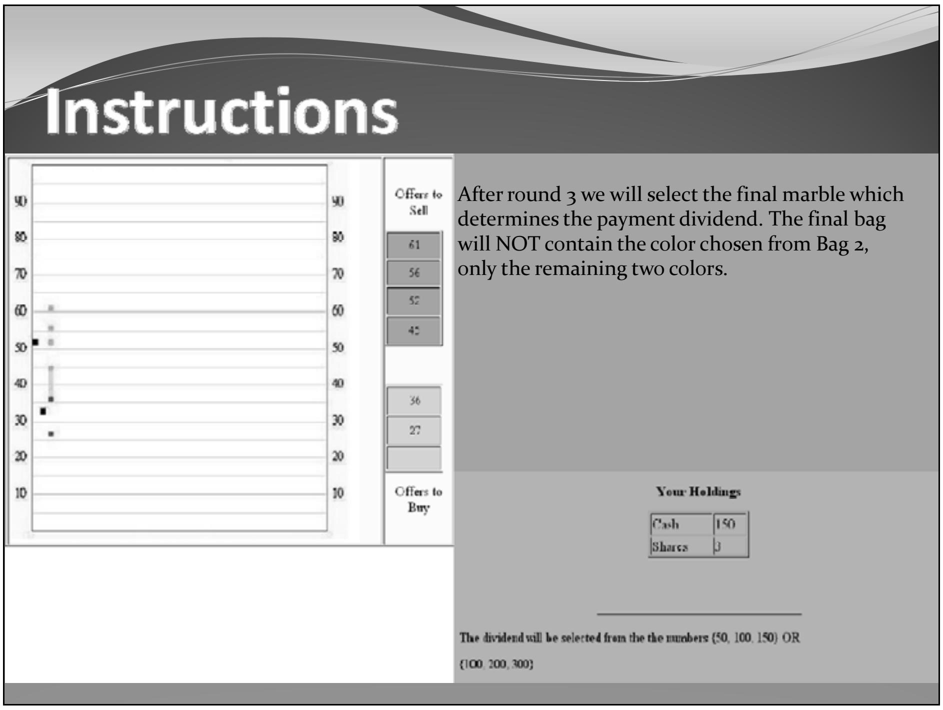
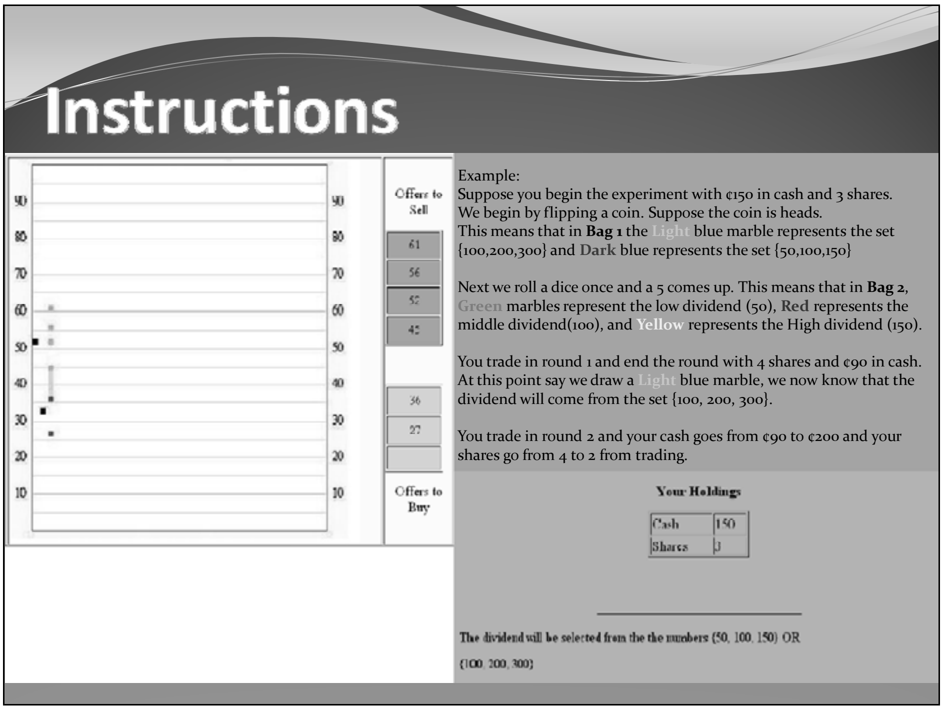
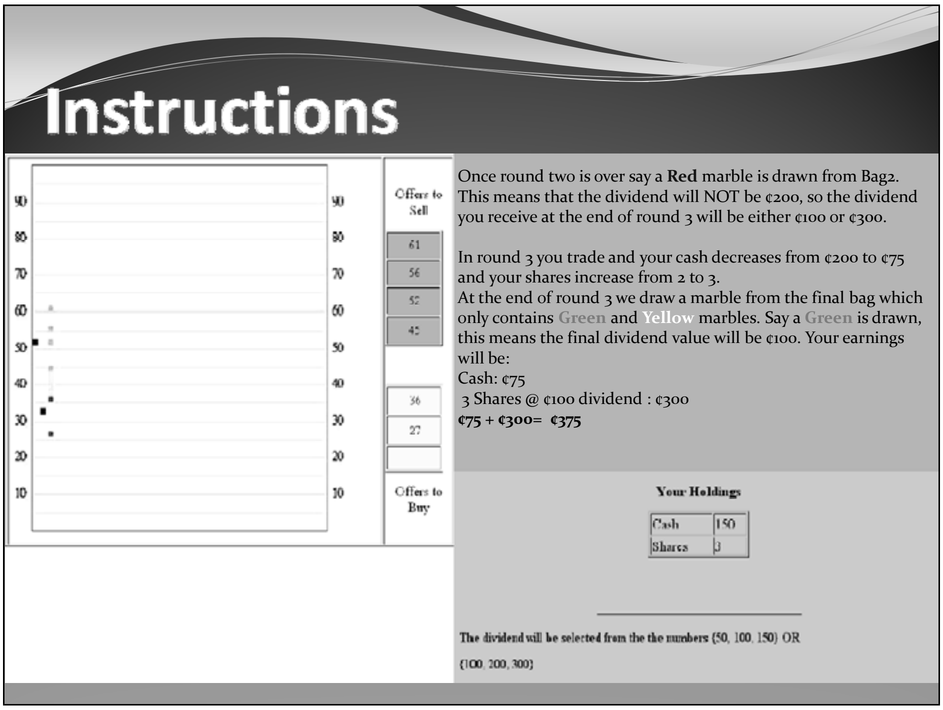
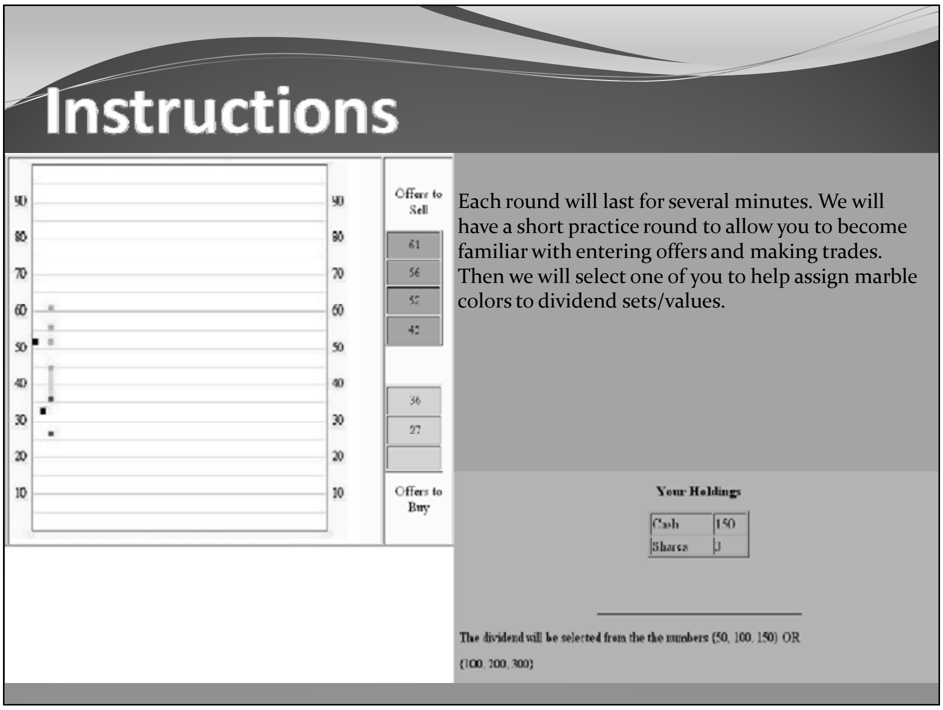
20
10
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Bag 2 contains a mixture of Red, Yellow, and Green Marbles.
That same person will then roll a 6 sided die to determine the marble color associated with each dividend level (Low, Medium, High).
- If a 1 is rolled then Red represents the low dividend, Yellow the middle value and Green the high value.
- If a 2 is rolled then Red is low, Green is middle and Yellow is high.
- If a 3 is rolled then Yellow is low, Red is middle and Green is high.
- If a 4 is rolled then Yellow is low, Green is middle and Red is high.
- If a 5 is rolled then Green is low, Red is middle and Yellow is high.
- If a 6 is rolled then Green is low, Yellow is middle and Red is high.
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
After round 3 we will select the final marble which determines the payment dividend. The final bag will NOT contain the color chosen from Bag 2, only the remaining two colors.
Offers to Sell
61
56
52
42
36
27
Offers to Buy
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Example:
Suppose you begin the experiment with ¢150 in cash and 3 shares.
We begin by flipping a coin. Suppose the coin is heads.
This means that in Bag 1 the Light blue marble represents the set {100,200,300} and Dark blue represents the set {50,100,150}
Next we roll a dice once and a 5 comes up. This means that in Bag 2, Green marbles represent the low dividend (50), Red represents the middle dividend(100), and Yellow represents the High dividend (150).
You trade in round 1 and end the round with 4 shares and ¢90 in cash. At this point say we draw a Light blue marble, we now know that the dividend will come from the set {100, 200, 300}.
You trade in round 2 and your cash goes from ¢90 to ¢200 and your shares go from 4 to 2 from trading.
Offers to Sell
61
56
52
42
36
27
Offers to Buy
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Once round two is over say a Red marble is drawn from Bag2. This means that the dividend will NOT be ¢200, so the dividend you receive at the end of round 3 will be either ¢100 or ¢300.
In round 3 you trade and your cash decreases from ¢200 to ¢75 and your shares increase from 2 to 3.
At the end of round 3 we draw a marble from the final bag which only contains Green and Yellow marbles. Say a Green is drawn, this means the final dividend value will be ¢100. Your earnings will be:
Cash: ¢75
3 Shares @ ¢100 dividend : ¢300
¢75 + ¢300= ¢375
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}


Instructions
Each round will last for several minutes. We will have a short practice round to allow you to become familiar with entering offers and making trades. Then we will select one of you to help assign marble colors to dividend sets/values.
Offers to Sell
61
56
52
45
36
27
Offers to Buy
Your Holdings
Cash 150
Shares 3
The dividend will be selected from the the numbers {50, 100, 150} OR {100, 200, 300}

Summary

1. You will be given an initial amount of Cash and Shares.

2. Every share generates a dividend from the set {50, 100, 150} or {100, 200, 300}.

3. Before round 1, we will flip a coin to determine which blue marble represent either the set of dividends {50, 100, 150} or {100, 200, 300}. We will also roll a dice to determine whether the colors Red, Yellow and Green represent the low, the middle or the high dividend value.

3. You can submit offers to BUY shares and offers to SELL shares.

4. You make trades by buying at the current lowest offer to sell or selling at the current highest offer to buy.

5. The experiment will have three trading rounds. At the beginning of round 2 a marble will be drawn from Bag1, and we will announce which set of dividends will be used.

Summary

6. At the beginning of round 3 a marble will be drawn from Bag2 (containing Green, Yellow, and Red marbles), and we will announce which dividend of the set will NOT be used.

7. At the end of round 3 a marble will be drawn from the final bag, which only contains the colors not drawn previously. This marble will determine the actual dividend.

8. Your earnings will be equal to the ending cash at round 3 plus your shares at the end of round 3 times the dividend.

To go onto the review quiz, please click Next.

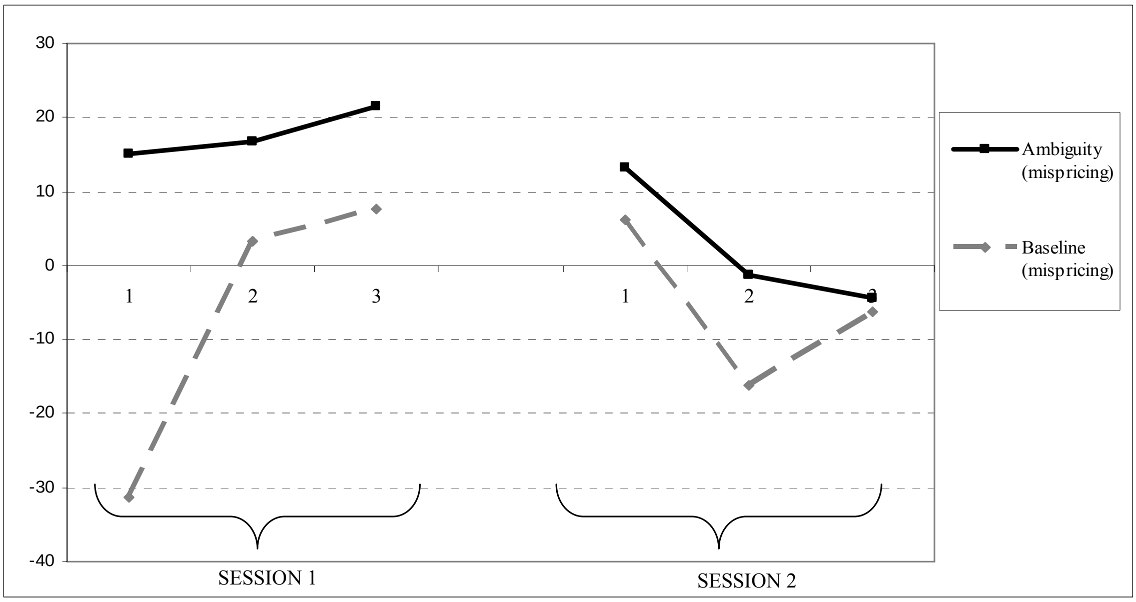
Appendix C

I. Mispricing analysis

Mispricing is defined as the difference between average price and fundamental value (the expected value of the future stream of dividends). Average mispricing in the baseline treatment is -31.3. Given that the fundamental value of the asset in the baseline treatment is 150 in period 1, this suggests that subjects trade below t he fundamental value. The results for the ambiguity treatment go in the opposite direction. Subjects trade above the fundamental value in the presence of ambiguity. The magnitude of mispricing is 15.2 for the ambiguity treatment. The extent of the deviation from the fundamental value is nearly 50% less than the baseline treatment. Our results suggest that information cognition with less information differs among subjects relative to the baseline treatment where information is clearer. It may be the case that subjects pay more attention to the problem at hand under ambiguity. This may suggest better information cognition under ambiguity. This difference is, however, not maintained when subjects are experienced. This result suggests that experts are less affected by ambiguity.

We illustrate the patterns of average mispricing for sessions with inexperienced and experienced subjects in Figure C.1. One sees that the patterns of mispricing are significantly different between the ambiguity and the baseline treatment for inexperienced subjects. For experienced sessions both treatments are characterized by prices above fundamental value in the first session. With experience, an opposite reaction is found.

Figure C.1: Average mispricing per period for the baseline and the ambiguity treatment with inexperienced (session 1) subjects and experienced subjects (session 2)



II. Additional statistical analysis

Table C:1 P-values for two-sided proportion tests of consistent price changes: Inexperienced [experienced] traders (by treatments and periods)			
	Period 2	**Period 3**	**Total**
Baseline vs. Ambiguity	p-value= 1.000 [1.000]	p-value= 1.000 [0.386]	p-value = 0.910 [0.571]
Inexperienced vs. experienced	p-value = 1.000	p-value = 0.521	

Table C.2: P-values for two-sided proportion tests of correct individual responses to news: Inexperienced [experienced] traders (by treatments and periods)			
	Period 2	**Period 3**	**Total**
Baseline vs. Ambiguity	p-value= 0.57 [0.74]	p-value= 0.00*** [0.02**]	p-value= 0.00*** [0.06*]

Table C.3: Probit estimates for inexperienced [experienced] traders: Dependent variables: correct trading responses (CPR_i), n=89 [n=78]				
Coefficients (P-values)	**$CPR_{i,2}$**		**$CPR_{i,1}$**	
	Inexperienced	Experienced	Inexperienced	Experienced
Intercept	0.71***	1.56***	0.06	1.20***
Treatment	0.41	-0.18	1.87***	-1.23**
News in period 2	0.69***	-0.21	0.74***	0.09
News in period 3	-	-	-	-
R squared	0.16	0.02	0.42	0.16

Table C.4: P-values for two-sided tests comparing the proportion of price changes classified as under-reaction and over-reaction in the case of inexperienced [experienced] traders	
	Under-reaction & Over-reaction
Baseline	p-value = 1.00 [0.343]
Ambiguity	p-value = 1.000 [1.000]
Aggregate (Baseline & Ambiguity)	p-value = 1.000 [0.494]

Table C.5: Correlation matrix for the four individual measures of trading behavior				
Correlations	Basic inconsistency	Average inconsistency	Extreme pricing	Individual mispricing behavior
Basic inconsistency	1.00	-	-	-
Average inconsistency	0.63***	1.00	-	-
Extreme pricing	0.33***	0.47***	1.00	-
Individual mispricing behavior	0.19*	0.32***	0.38***	1.00

Table C.6: P-values for two-sided Wilcoxon Rank Sum tests comparing different measures of individual trading behaviour between treatments and for inexperienced [experienced] traders

	Basic inconsistency	**Average inconsistency**	**Extreme pricing**	**Individual mispricing behavior**
Baseline vs. Ambiguity	p= 0.030 [0.402]	p = 0.012 [0.588]	p = 0.000 [0.340]	p = 0.000 [0.522]
Experienced vs. Inexperienced	p = 0.213	p = 0.679	p = 0.059	p = 0.640