

Implied Volatility and Investor Beliefs in Experimental Asset Markets

Lucy F. Ackert
Department of Economics and Finance
Michael J. Coles College of Business
Kennesaw State University
Atlanta, Georgia 30144
(470) 578 6111
lackert@kennesaw.edu

Brian D. Kluger
Department of Finance
Carl H. Lindner College of Business
University of Cincinnati
Cincinnati, Ohio 45221-0195
(513) 556 1688
brian.kluger@uc.edu

Li Qi
Department of Economics
Agnes Scott College
141 E. College Avenue
Decatur, Georgia 30030
(404) 471-5182
lqi@agnesscott.edu

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Abstract

This paper examines whether investor beliefs are related to the volatility implied by traded option prices. Our experimental markets feature a stock and a call option written on the stock. The stock has two possible outcomes and the distance between the outcomes is our measure of volatility. The outcome range is sometimes announced, and other times not. Regardless of whether the range is announced and despite observed mispricing of the two assets, knowledge of the range implied by trading prices informs observers about subjects' beliefs concerning volatility.

Keywords: VIX, implied volatility, option market, investor beliefs

JEL codes: C90, G10

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“Bull-markets are born on pessimism, grow on skepticism, mature on optimism and die on euphoria.”

Sir John Templeton

1. Introduction

Prominent investor Sir John Templeton argued that markets are driven by investors' positive and negative expectations of the future. Because markets move with investor expectations, it is important to be able to gauge the investing public's beliefs (Barberis, Shleifer, and Vishny (1998)). One measure of forward-looking expectations is the Chicago Board Options Exchange's (CBOE) volatility index (VIX) index, commonly referred to as the “investor fear gauge.” The VIX reflects investors' expectations of future market volatility as expressed through trade (Whaley (2000), (2009)). This paper examines how investors' views are related to implied volatility using an experimental method.

Market volatility is of great concern to policymakers, academics, and practitioners alike. Volatility implied by traded option prices has become a standard measure of expectations of future uncertainty. Since the introduction of VIX in 1993, researchers have examined how implied volatilities have changed over time and whether or not the fear gauge is informative about the future (e.g., Schwert (2011), Völkert (2014)). Yet, at times skepticism surrounding the information content of the VIX is expressed. For example, a recent *Wall Street Journal* article warns investors not to “read too much into the fear gauge” (Jakab (2014)). We examine whether investor beliefs are related to implied volatility in experimental asset markets. To accomplish this we design an

experiment in which subjects simultaneously trade in markets for the asset and a call option written on the asset.

The experimental market is simple, with only two possible outcomes in any period. We vary the range, that is, the distance between the possible outcomes. We consider two treatments. In the first treatment we induce investor beliefs about the range, by publicly announcing the value. In the second treatment, we allow investors to form their own beliefs about the range. We do not provide either the value or the distribution of the range. In this treatment, we elicit subjects' opinions concerning the unannounced spread parameter. Our experiments then test to see whether the implied range, calculated from the stock and call option prices revealed through trade, is related to the publicly announced range, and, when the range is unspecified, whether the implied range is related to subjects' beliefs about the spread. In both cases, we find that the implied range is informative. The magnitude of the implied range informs an observer about market participants' beliefs concerning volatility.

The remainder of our paper is structured as follows. Section 2 provides a brief review of the literature. Section 3 describes the experimental method. Section 4 provides a discussion of the results and Section 5 contains a summary and concluding remarks.

2. Background and research questions

The VIX is designed to measure traders' expectations for the future. Using call and put options for a wide range of strike prices, Black-Scholes-Merton (Black and Scholes (1973), Merton (1973)) option pricing formulas are used by the CBOE to back-out the volatility implied by current option prices. This so-called "fear gauge" is taken to

be a barometer of investors' expectations. Some research has studied the properties of the VIX using data from naturally occurring markets and, though there have been a few asset market experiments featuring options, to our knowledge, no prior research has examined implied volatility using an experimental methodology. Next we briefly discuss research on the VIX and experimental option markets, in turn.

A. Studies using the VIX

The VIX is widely regarded as a measure of market uncertainty by practitioners, and is a component of CNN's Index of Fear and Greed, a popular sentiment measure.¹ Academics use the VIX as an empirical measure of uncertainty and the market's expectation of volatility (e.g., Barinov (2013)). Empirical evidence supports the use of the VIX as proxy for expectations. For example, Völkert (2014) provides evidence that the VIX is informative about changes in future volatility. In addition, Schwert (2011) examines market behavior surrounding the 2008 financial crisis and concludes that volatility expectations measured by the VIX were accurate. Furthermore, researchers report that expected equity returns respond to changes in investors' expectations of future uncertainty as measured by VIX. For example, Durand, Lim, and Zumwalt (2011) report that an increase in the VIX leads to flights to quality and higher required equity returns. In addition to pricing effects, uncertainty as measured by the VIX is shown to impact market quality, including liquidity (Chung and Chuwonganant (2013)).

A growing body of evidence supports the view that the VIX is informative about future stock market levels and volatility (e.g., Fleming, Ostdiek, and Whaley (1995),

¹ The VIX index was originally calculated using implied volatilities from S&P 100 options. Later, the basis for calculation shifted to S&P 500 options as trading volume moved to these options. For details, see the Chicago Board Options Exchange publication (CBOE (2014)). On CNN's index see <http://money.cnn.com/data/fear-and-greed/> (accessed January 28, 2015).

Hibbert, Daigler, and Dupoyet (2008), Chung, Tsai, Wang, and Weng (2011)). Implied volatilities are correlated with future market volatility and uncertainty measures based on the VIX exhibit return predictability (Dreschler and Yaron (2011)). If investors' beliefs are on average correct, these results can be interpreted as demonstrating that the implied volatility is capturing their beliefs. We study this proposition directly, using experimental methods. In the laboratory, we can specify the volatility of our experimental asset, and we can survey participants regarding their beliefs. Also, our experimental tests do not require investor beliefs to be correct on average.

B. Options in experimental asset markets

Only a handful of experimental studies feature options. Abbink and Rockenbach (2006) design a simple experiment in order to test whether options are priced according to the Binomial Option Pricing Model or BOPM (Cox, Ross and Rubinstein (1979)). Their experimental subjects did not interact in a market but instead made consecutive investment decisions across rounds. Subjects were given the opportunity to invest in two risky assets, an underlying and its call option, where two possible states of the world were possible each round. While their laboratory setting is stark, it allows for clear tests of the BOPM and provides a starting point for subsequent research. With student participants experimental prices diverged significantly from theoretical predictions. Interestingly, when the experiment was conducted again with professional traders, performance further deteriorated.

Other experiments focus on how option introduction affects the market for the underlying security. Both Kluger and Wyatt (1995) and de Jong, Koedijk and Schnitzlein (2006) study the market quality of the underlying asset in the presence of asymmetric

information. Kluger and Wyatt use a double auction market institution and report faster information aggregation in the presence of an option market. de Jong, Koedijk and Schnitzlein employ dealer markets with informed and liquidity traders. Unlike Kluger and Wyatt, de Jong, Koedijk and Schnitzlein's option and asset markets are open simultaneously, allowing for feedback between the markets. Nonetheless, the conclusions are similar. Both studies report that the introduction of an option can speed information dissemination and improve the efficiency of the market for the underlying security.

While we build upon this literature, our experiment is distinguished from previous work because we seek to shed light on the relationship between the volatility implied by traded option prices and investors' beliefs. While a byproduct of our study, assessing an option-pricing model is not our main focus. As we detail subsequently, our experimental market prices do not strongly conform to the values predicted by the BOPM (consistent with the results of Abbink and Rockenbach). However, testing an option pricing model is a byproduct of our examination, it is not our focus. Our experiment addresses a distinct question not tackled by previous research. Does the volatility implied by traded asset and option prices inform observers about traders' beliefs concerning volatility?

3. Experimental design

During each experimental session, subjects participated in a series of experimental asset markets. The markets were conducted using a customized program written with the Fischbacher (2007) z-Tree (Zurich Toolbox for Readymade Economic Experiments) programming package. Each session consists of ten three-minute trading

periods, where eight subjects traded two assets using a computerized double auction institution.

A. Experimental assets

Each experimental period has two possible states, high and low. The payoffs for each asset depend on the state, and the liquidating dividends are paid as shown in Figure 1.

Insert Figure 1

The payoffs for Asset 2 correspond to a call option with a strike price of \$100 written on Asset 1. For exposition purposes, here we refer to Asset 1 as the “stock,” and Asset 2 as the “call.” However, both in the instructions and during the experiment, the assets are always referred to as Asset 1 and Asset 2 (see Appendix A). Typically, subjects did not realize that the experiment pertains to options.

Two parameters varied across periods within a session. The probability parameter, p , represents the probability that the state is high, and took three levels, 0.25, 0.50, and 0.75. The level is determined randomly, with 0.50 having a 50% chance of selection, and 0.25 and 0.75 each having a 25% chance of selection. The probability level was posted on the initial screen presented to subjects at the beginning of each period. Thus, the probability of the state being high and low for the period was common knowledge to all subjects.

The second parameter, k , determines the range of payoff for the underlying asset and is, thus, our measure of asset volatility. Subjects were informed that k is an integer between 0 and 100, but were given no information concerning the likelihoods associated

with each outcome. The probability distribution used to select k each period was actually uniform, but this was never disclosed to subjects.

We have two within subject treatments related to the k parameter. In the first treatment (periods 1, 2, 5, 6 and 9) the value of k is announced to all subjects. In the second (periods 3, 4, 7, 8 and 10) no announcement is made concerning k . For the first treatment, we induce subjects' beliefs about k to be correct by simply telling them the correct value. There is uncertainty about whether the high or low state will occur, but no uncertainty or disagreement among subjects concerning the value of k .

In the second treatment, we no longer induce beliefs, but allow subjects to form their own beliefs about k . Subjects cannot use the moments of the distribution of k to form beliefs since they do not have the necessary information about the distribution. We do not try to explain subject beliefs here. Beliefs may be based on hunches, biases, decision errors, or confusion. In the second treatment, we retain the uncertainty about whether the high or low state will occur, but add the additional "risk" stemming from the feature that the value of k is vague.²

B. Experimental markets

At the beginning of each trading period, subjects were awarded an initial cash balance of \$1,600 trading dollars.³ However, half of this balance was a zero-interest loan and, at the end of the period, \$800 was subtracted from each subject's cash balance. All subjects were also endowed with five shares of the stock. Half of the subjects were given

² In this treatment, our subjects are facing a situation analogous to ambiguity. In addition to possibly being risk-averse, subjects may also prefer to avoid choices featuring parameters with unknown probability distributions. See Bossaerts, Ghirardato, Guarneschelli and Zame (2010) for an explanation of the effects of ambiguity on prices and allocations in an experimental asset market.

³ Prior to the trading periods, subjects answered a questionnaire containing instruments to measure both optimism and overconfidence. As we did not find any relation between these measures and implied volatility, we do not include these results in the paper. However, description of the instruments, and the analysis using these measures is presented in Appendix B.

three call options (that is, they are long shares of Asset 2) and the other half start with three written call options (that is, they are short shares of Asset 2). The subjects with long and short positions were varied across periods so that over the entire session, all subjects started long in calls half of the periods, and short in calls the other half of the periods.

During a trading period, each trader could post and/or accept offers for one share of either security. Traders were free to post multiple orders for either asset and were able to cancel outstanding orders at any time. Throughout each period, all outstanding offers were displayed. As trades occur, they were immediately displayed in a chronological list. However, the identity of traders posting or accepting offers was not shown on the trading screen.

While subjects start each period with \$1,600 trading dollars, half of which was a zero-interest loan, they were not allowed to borrow additional funds during the experiment. Subjects were allowed to short sell, but only to a balance of negative ten shares of each asset. These constraints allowed subjects to make purchases and sales as desired, but at the same time limited the losses they could suffer in a single period. If a subject lost money in a period, that loss is reflected in total earnings. However, regardless of performance, the total payout to a subject was guaranteed to be at least six U.S. dollars.

After each trading period, z-Tree displays one or more additional screens. In periods where the k parameter is not specified, subjects were asked to guess the value of k for the period. The guessed value of k , which for ease of exposition we refer to as “guess,” is our elicited measure of subjects’ expectations of range. Next, the earnings summary screen was shown. Each subject’s screen displayed the values for the

parameters, final state of the economy, payoffs for each of the assets, share and cash balances, and subject's earnings for the period. At the end of each trading period, all shares of the experimental assets were liquidated. Then, the next period commenced until the final or 10th trading period.

Recall that in our design, the call option has a strike price of 100 so that the possible payoffs are k in the high state and zero in the low. The BOPM can be used to compute an implied k , or inferred range of payoffs. Using the standard BOPM formula applied to the asset and option payoffs in our experiment we can compute the implied range in payoffs or volatility as:

$$k = 100 + (1+r_f)(2C-S), \quad (1)$$

where r_f is the risk-free interest rate, C is the market price of the call option, and S is the market price of the stock or underlying asset. Using market data from the experiments, we compute the implied k and compare it with subjects' beliefs about the range in possible payoffs. When the actual range is induced, comparison of the implied range (implied k) to the actual range (k) is a test of the BOPM. When the actual range is unspecified, we examine whether the implied range is related to subjective beliefs about the range as reflected in subjects' guesses.

Each session lasted approximately two-and-a-half hours, including both a software demonstration and a practice period. Participants were recruited from the student population of the University of Cincinnati. During the experiment, all prices and balances were denominated in "trading dollars" which were converted to dollars at the end of the session.

4. Results

Our results are drawn from twelve sessions, each containing ten three-minute markets.⁴ There were eight subjects per session, with 96 subjects in total. Subjects received a fixed fee of \$6 U.S. dollars for participating, and typical total payouts ranged between \$30 and \$45 per subject.

A. Informational efficiency

Prices and volumes by period are presented in Tables 1 and 2.

Insert Table 1

Insert Table 2

Table 1 reports median prices and volumes for the periods when k is announced, and Table 2 contains the data for the periods when k is unknown. Prices varied considerably across periods.⁵ Some of this variability may have to do with risk-aversion and/or differences across sessions, but high variability in both stock and call prices is observed even within the same session. Volumes also fluctuate, with stocks trading more frequently in some periods, and calls trading more frequently in other periods. For periods where the range parameter is announced, expected values as well as the absolute differences between median prices and expected values are presented.

We first note that our markets sometimes displayed irrational pricing. The asterisks in Table 1 denote irrational pricing in the corresponding periods. These cases represent prices that are either above the maximum possible payout, or below the

⁴ There was a technical problem in one session where all the computers in the lab simultaneously shut down. As a result, session 5 has only 6 periods.

⁵ Using averages instead of medians produce comparable results. Similarly, using the average of the periods' last five transactions for each asset does not greatly change the conclusions.

minimum possible payout. The maximum and minimums are easily calculated since k is announced in this treatment.

As our experiment is more complex than many experimental asset market designs, and our subjects are inexperienced, perhaps the irrational prices are due to subject confusion and/or errors. Lei, Noussair and Plott (2001) study bubble formation, and attribute irrationality at the start of their asset market experiments to subject confusion pertaining to the task and the structure of their experimental asset. As their experiments progress, some subjects recognize that other subjects are prone to irrationality, and may speculate, causing a bubble. However, after more experience, decision errors decline. As subjects become rational and come to realize that the other subjects are rational, the market crashes. Although our asset market design differs from theirs, our subjects may well be confused, particularly at the start of the session. For the underlying asset, we observe two unambiguous violations of rationality, and both occurred in the first periods. For the call, we report fourteen violations, with five in the first periods of their session.

Table 1 also contains the expected value of each asset. For the underlying asset, median price varies considerably, sometimes being above the expected value and sometimes below. The null hypothesis that the price of the underlying asset is equal to the expected value cannot be rejected using either a paired t-test ($p = .23$, two-tailed) or a Wilcoxon Signed Rank test ($p = .39$, two-tailed). However, corresponding hypothesis tests comparing the call median price to its expected value do reject the null using both the paired t ($p < .0001$, two-tailed) and the Wilcoxon ($p < .0001$, two-tailed). Averaging over all markets in the treatment where k is announced, the median call price was greater than the expected value by 7.18.

B. Implied k: when k is announced

In half of the periods, k is publicly announced. Subjects' beliefs about the value of k are therefore induced to be the correct values. For these periods we study the relation between the implied k and the announced k . Each period, the implied k is calculated from the median transaction prices during the double auctions.

Insert Table 3

Panel A of Table 3 presents tests of the null hypothesis that implied k equals announced k . The test is conducted for the periods within each probability treatment, and again for all periods. The tests are conducted using all periods, and again excluding the first period of each session.⁶ The null is strongly rejected in each case, except for probability of 75%. Implied k does not equal the announced k in the experiment. Consistent with the results reported by Abbink and Rockenbach (2006), our experimental markets' options prices are not consistent with the BOPM.

But, OLS regressions in Panel B suggest that the implied and announced k are positively correlated. The coefficient on the implied k is strongly significant in all four regressions, and the variables controlling for the probability treatment are not significant. The result stands both when the first period is included and when it is not. We conclude that, although implied k and announced k are not equal, a market observer can infer useful information about investors' beliefs about k from the implied k . The observer

⁶Excluding the first period might reduce the effect of confusion on our results, as it seems plausible that confusion is more likely at the beginning of the experiment. We do notice that in each instance, probabilities associated with both tests decline when the first period is excluded. It is certainly possible that subject confusion was present.

does not need to know the parameter values available to the subjects. Simply tracking the implied range provides a measure of subjects' beliefs.

C. Implied k , when k is not announced

In half of the periods, subjects are not told the value of k , the volatility parameter. Information about k is unspecified, as subjects only know the maximum and minimum possible values. While subjects knew that k was an integer between zero and one hundred, they had no information about the probability distribution governing k . Subjects were also told that no other subject has any additional information about k . Therefore, there was no information available to help a subject infer the value of k . Instead of inducing beliefs about k , we allow subjects to form their own beliefs.

In the periods where k was unannounced, we collected subjects' guesses as to the value of k .⁷ Information about these guesses is presented in Table 4.

Insert Table 4

If a subject has diffuse priors about k , then he or she should guess 50. Table 4 shows that only nine subjects guessed k at 50 every period. The majority of subjects varied their guesses from period to period. Further, most subjects' average guess does not equal 50. Subjects' beliefs concerning k may be affected by confusion, decision biases and/or probability judgment errors. However, our purpose is not to explain how subjects' beliefs are formed. Our focus here is to see whether investors' beliefs are captured by implied volatilities.

Insert Table 5

⁷ These guesses were not incentivized in that subjects' responses did not directly affect their payoffs.

Table 5 compares the implied k , calculated for each period using the median trading prices of the stock and the call, to the average of the subjects' guesses for k for the same period. Panel A presents tests of the null hypothesis that implied k equals the average guess. The tests are performed using all the data, and again excluding the third period. The third period was the first market subjects faced in the treatment where k was not announced. The null hypothesis is rejected at the standard significance level of 5% in all but one case. When the probability parameter is 25% and the third period was excluded, the p-value was slightly higher at 0.055.

Although we reject the hypothesis that the implied k equals the guesses of k , we still find a significant relationship between them. Panel B of Table 5 presents several OLS models predicting guesses with the implied k as an explanatory variable. In all the models the coefficient of implied k is positive and strongly statistically significant. Similar results are presented excluding the third period in Panel C. Observing the implied volatility provides information about subjects' beliefs about the value of k , even when the sources of those beliefs are not based on rational factors. When k is not announced, we do not really know why subjects are varying their guesses. Guesses may be affected by confusion, decision biases or hunches. Our design does not allow us to determine how subjects' beliefs are formed, and this is not the purpose of our experiment. We are interested in whether the implied k measures subjects' beliefs regardless of the belief formation process. In our experiments, the implied range is correlated with subjects' beliefs as reflected by their guesses.

5. Summary

Implied volatility is used to measure investors' expectations by both academics and practitioners. This paper directly studies the relationship between implied volatility and investor beliefs in simplified experimental asset markets. The range, or distance between possible outcomes, is our measure of dispersion or volatility. Our design includes two treatments.

In the first treatment, we induce investor beliefs about k by publicly announcing the range parameter. We find that the implied volatility does not equal the actual range. This result suggests that the BOPM does not describe pricing in our markets, and mirrors the findings of Abbink and Rockenbach (2006). They observe that executing a sequence of trades to take advantage of an arbitrage opportunity is not easy, which also applies to our markets. Detecting mispricing during the experimental double auctions may also be cognitively difficult. And even if mispricing is spotted, arbitrage is challenging because it is difficult to simultaneously execute trades for both assets.

We further find some evidence of subject confusion in the form of asset prices that are either higher than the maximum or lower than the minimum possible payouts when k is announced. Our participants were inexperienced in that this was the first time they had faced this particular market design. Subject confusion may be an important factor in explaining why the BOPM does not describe prices in our markets. With more experience, it is certainly possible that the BOPM predictions may be more descriptive despite the obstacles pointed out by Abbink and Rockenbach.

Despite the finding that BOPM does not hold, we do find a statistically significant positive relationship between the implied and actual volatility. A market observer can

learn something about actual volatility from seeing the implied value. Thus, implied volatility is informative even though the prices do not follow the binomial option-pricing model. This finding is important in that it demonstrates that implied volatility can be informative regardless of the presence of subject confusion and/or other possible impediments to rational option pricing.

When the actual range is not announced, we are not able to test the BOPM because the actual volatility is left ambiguous. Instead, this treatment allows us to test whether observation of the market is informative about traders' beliefs. Individual subjects are asked to guess the range, and these guesses are compared to the implied range. We find a statistically significant link between the average of subjects' guesses as to the value of the range, and the implied range. As in the first treatment, a market observer can learn something about participants' beliefs regarding volatility by observing the implied range. Importantly, an observer can use the implied range to gauge investor beliefs about the range even when the observer does not know the range, its probability distribution, or even the probabilities associated with the high and low states.

Finally, the implied range is informative even when subjects' beliefs are likely not based on fundamental information about asset values. The implied range is useful as a measure of investor beliefs even though, during some trading periods, we observe prices that are perceptibly different from fundamental values.

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Figure 1
Asset liquidation values

The liquidation value of each asset depends on the state, revealed at the end of the period. The probability that the state is high can be 0.25, 0.50, or 0.75. Each period, the probability is announced, prior to trading. The realized state is announced at the end of the period, after trading is finished. The parameter, k , ranges from zero to 100. In trading periods 1, 2, 5, 6 and 9, k was announced prior to trade. In the other periods, no information was given concerning k and both the value and the underlying distribution of k was unspecified.

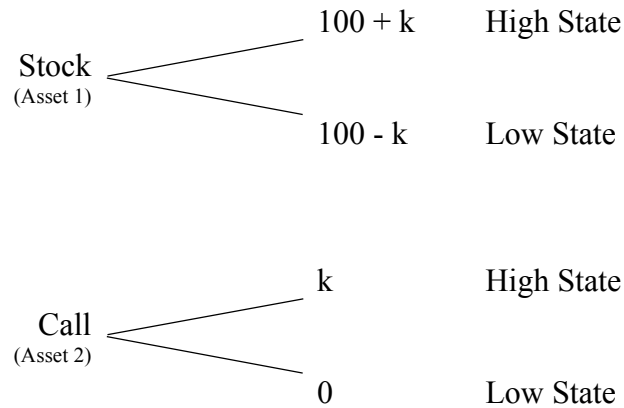


Table 1
Asset prices and volumes when k is announced

Asset prices and volumes are presented by period, for the treatments where k is announced. Med S is the median price of the stock and Q_S is the number of shares traded for that period. Med C and Q_C are the call prices and volumes. E is the expected value: $E_s = 100 - k(1-2(\text{prob}))$ and $E_c = (\text{prob})k$.

Session	Period	k	Med S	Q_S	E_s	Med C	Q_C	E_c
1	1	76	145	18	138	50	31	57
1	2	18	101	12	100	12	27	9
1	5	74	65	22	63	20	21	18.5
1	6	58	110	21	100	30	23	29
1	9	56	75	15	72	25	20	14
2	1	79	110	12	100	80*	20	39.5
2	2	95	75	21	52.5	34	12	23.75
2	5	82	117.5	16	141	72.5	16	61.5
2	6	33	95	12	100	50*	16	16.5
2	9	48	62	20	76	14	15	12
3	1	21	113	9	110.5	20.5	14	15.75
3	2	44	120	20	100	38.5	14	22
3	5	44	129	18	122	45.5*	33	33
3	6	7	96	24	96.5	7.98*	26	1.75
3	9	97	165	22	148.5	60	21	72.75
4	1	3	99	16	101.5	17*	15	2.25
4	2	12	100	19	100	10	18	6
4	5	55	135	14	127.5	30	24	41.25
4	6	83	163	19	141.5	45	29	62.25
4	9	56	122.5	24	100	32.5	14	28
5	1	5	64*	18	100	30*	13	2.5
5	2	67	132	6	133.5	27	24	50.25
5	5	66	87.5	8	100	35	11	33
5	6	33	95	14	100	20	8	16.5
6	1	39	65	14	80.5	12	16	9.75
6	2	55	112.5	8	100	35	24	27.5
6	5	40	95	33	100	30	24	20
6	6	18	95	22	100	15	7	9
6	9	18	105	25	100	12	14	9
7	1	95	145	14	147.5	90	14	71.25
7	2	55	50	15	72.5	18.5	14	13.75
7	5	5	97	11	100	6*	13	2.5
7	6	21	90	11	100	10	9	10.5
7	9	15	105	19	100	15	12	7.5
8	1	1	20*	32	100.5	20*	33	0.75
8	2	74	44	31	100	45	18	37
8	5	91	80	28	100	30	21	45.5
8	6	9	98.5	30	104.5	10.5*	14	6.75
8	9	73	40	21	63.5	25	30	18.25
9	1	69	110	25	134.5	35	19	51.75
9	2	25	80	29	87.5	10	26	6.25
9	5	61	95	44	100	35	32	30.5
9	6	18	90	43	100	15	37	9
9	9	52	100	49	126	40	40	39
10	1	20	110	19	110	20	23	15
10	2	34	105	17	100	16	7	17
10	5	84	140	18	142	75	17	63
10	6	30	105	18	115	45*	29	22.5
10	9	71	100	23	100	35	29	35.5
11	1	40	130	17	100	33	18	20
11	2	35	100	19	82.5	30	25	8.75
11	5	41	140	19	120.5	52*	16	30.75
11	6	66	95	36	67	40	21	16.5
11	9	22	110	21	100	15	17	11
12	1	11	99	13	100	13*	39	5.5
12	2	70	100	17	135	48	15	52.5
12	5	36	88	32	100	52.5*	50	18
12	6	21	100	21	110.5	39*	20	15.75
12	9	60	95	43	70	35	19	15

Table 2**Asset prices and volumes when k is not announced**

Asset prices and volumes are presented by period, for the treatments where k is not announced. Med S is the median price of the stock and Q_s is the number of shares traded for that period. Med C is the median price of the call and Q_c is the number of calls traded for that period. Prob is the probability parameter.

Session	Period	k	Prob	Med S	Q_s	Med C	Q_c
1	3	11	0.25	90	30	17	9
1	4	6	0.75	130	26	40	19
1	7	85	0.50	105	25	40	18
1	8	93	0.25	87	19	17	17
1	10	31	0.50	102	23	35	20
2	3	52	0.25	70	17	44.5	24
2	4	18	0.50	92.5	12	52.5	14
2	7	45	0.75	115	19	49.5	12
2	8	86	0.25	69	19	19.5	14
2	10	171	0.75	127	21	50	17
3	3	65	0.25	100	15	26	15
3	4	18	0.50	109	27	29	14
3	7	70	0.50	105	15	30.5	18
3	8	76	0.50	120	39	29	11
3	10	19	0.50	119	23	32	23
4	3	89	0.25	91	18	11	17
4	4	62	0.25	96	14	12	24
4	7	29	0.75	140	21	40	11
4	8	48	0.50	132	20	30	23
4	10	68	0.75	140	20	50	20
5	3	65	0.25	112.5	8	26	13
5	4	20	0.75	125	7	50	21
6	3	62	0.25	90	32	20	21
6	4	30	0.25	70	31	15	19
6	7	62	0.50	100	28	27.5	10
6	8	71	0.75	125	36	27	15
6	10	31	0.25	94	26	15	26
7	3	16	0.50	100	4	25	5
7	4	45	0.75	140	14	40	7
7	7	24	0.50	134	18	31.5	20
7	8	76	0.75	110	13	50	9
7	10	91	0.50	90	21	19	13
8	3	20	0.50	45	19	49.5	16
8	4	77	0.25	23	50	32	23
8	7	18	0.25	45	35	30	15
8	8	91	0.50	49	26	26	30
8	10	35	0.50	55	21	27	11
9	3	3	0.25	70	32	25	36
9	4	83	0.75	87.5	20	40	30
9	7	15	0.75	100	34	42.5	44
9	8	70	0.5	100	45	37	38
9	10	21	0.5	120	51	32.5	20
10	3	19	0.25	100	18	19	11
10	4	52	0.50	105	17	27.5	28
10	7	43	0.50	100	18	30	22
10	8	6	0.50	100	21	30	21
10	10	49	0.50	100	19	40	27
11	3	54	0.75	120	17	42.5	14
11	4	88	0.50	122.5	26	42	16
11	7	76	0.50	140	15	50	17
11	8	46	0.50	120	21	40	19
11	10	59	0.25	110	32	20	22
12	3	90	0.50	127	8	50	34
12	4	88	0.25	84	60	30	22
12	7	35	0.25	90	67	20	24
12	8	44	0.50	105	21	54	14
12	10	86	0.50	100	36	45	23

Table 3
Implied k and announced k

For each period where the k parameter is announced, the implied k is calculated using median prices of the two assets. In Panel A, Wilcoxon Signed Rank and Paired t tests comparing the implied k to the announced value are then performed. The tests are conducted for the periods within each probability treatment, and again for all periods. Panel B presents OLS regressions predicting announced k, using implied k as an explanatory variable. The parameters p25 and p75 are dummy variables representing the observations where the probability treatment is 25% and 75% respectively. p-values are shown below parameter estimates. Hypothesis tests are conducted both excluding and including data from the first period of each session.

Panel A: Does the Implied k Equal the Announced k?

Ho: Implied k = Announced k Ha: Implied k ≠ Announced k	Implied k – Announced k	n	t	p	SR	p
Periods where p = .25	17.7	12	5.54	.0002	37.0	.002
Excluding 1 st period	17.5	11	5.01	.0003	31.0	.003
Periods where p = .50	19.3	27	3.34	.003	135.0	.0004
Excluding 1 st period	15.1	23	2.81	.01	93.0	.002
Periods where p = .75	14.9	20	1.61	.12	39.0	.15
Excluding 1 st period	9.2	13	0.85	.41	9.5	.53
All periods	17.5	59	4.26	<.0001	585.0	<.0001
Excluding 1 st period	14.0	47	3.50	<.0001	345.0	<.0001

Panel B: Is the Implied k Informative?

Model (n=59)	α	β	γ	δ
$k = \beta(\text{Implied } k) + e$	-	0.65 <.0001	-	-
$k = \alpha + \beta(\text{Implied } k) + e$	20.28 .002	0.40 <.0001	-	-
$k = \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	-	0.58 <.0001	0.18 0.15	0.07 0.53
$k = \alpha + \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	20.03 .003	0.34 .001	0.16 0.15	0.08 0.43

Panel C: Is the Implied k Informative? Excluding 1st Period.

Model (n=47)	α	β	γ	δ
$k = \beta(\text{Implied } k) + e$	-	0.70 <.0001	-	-
$k = \alpha + \beta(\text{Implied } k) + e$	19.65 .004	0.45 <.0001	-	-
$k = \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	-	0.65 <.0001	0.12 0.31	0.07 0.52
$k = \alpha + \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	20.17 .004	0.38 .002	0.14 0.22	0.10 0.36

Table 4
Guesses of k

For each period in which k was not announced, subjects were asked to provide an estimate or guess of k. The guess was made after the double auction was completed, just before the liquidation values were revealed. Avg k, Min k and Max k are the average, the minimum and the maximum guesses by the each subject.

Session	Subject	Avg k	Min k	Max k
1	1	50	50	50
1	2	38	11	99
1	3	50	50	50
1	4	54	20	70
1	5	39	21	60
1	6	57	25	100
1	7	22	10	35
1	8	50	50	50
2	1	50	50	50
2	2	57	35	87
2	3	51	30	70
2	4	45	2	90
2	5	30	20	40
2	6	49	30	70
2	7	39	30	50
2	8	56	50	80
3	1	35	25	50
3	2	50	50	50
3	3	61	30	80
3	4	27	15	40
3	5	39	15	52
3	6	100	100	100
3	7	30	30	30
3	8	26	4	50
4	1	24	15	30
4	2	25	15	45
4	3	38	25	50
4	4	52	45	65
4	5	21	10	60
4	6	28	8	46
4	7	26	20	35
4	8	34	15	60
5	1	35	25	45
5	2	30	20	40
5	3	11	1	20
5	4	30	25	35
5	5	50	50	50
5	6	55	45	65
5	7	60	45	75
5	8	50	50	50
6	1	35	25	75
6	2	39	30	50
6	3	66	50	80
6	4	22	10	25
6	5	32	20	50
6	6	25	25	25
6	7	46	30	50
6	8	20	10	35

Session	Subject	Avg k	Min k	Max k
7	1	45	25	60
7	2	33	20	50
7	3	20	20	20
7	4	36	10	50
7	5	28	20	35
7	6	50	25	85
7	7	50	25	75
7	8	37	15	50
8	1	39	20	50
8	2	45	25	75
8	3	40	30	50
8	4	50	35	60
8	5	66	50	80
8	6	47	35	50
8	7	33	20	50
8	8	45	20	80
9	1	24	10	30
9	2	32	10	75
9	3	50	50	50
9	4	50	50	50
9	5	40	30	45
9	6	40	25	50
9	7	52	30	60
9	8	33	1	80
10	1	65	30	99
10	2	34	20	40
10	3	58	45	80
10	4	31	5	50
10	5	24	2	50
10	6	36	20	70
10	7	50	50	50
10	8	28	20	40
11	1	48	30	60
11	2	39	20	50
11	3	17	0	30
11	4	43	25	60
11	5	27	5	50
11	6	50	50	50
11	7	58	15	100
11	8	30	10	50
12	1	37	20	55
12	2	73	0	100
12	3	50	20	95
12	4	49	25	85
12	5	51	50	55
12	6	36	30	50
12	7	48	40	50
12	8	41	25	85

Table 5
Implied and guessed k

For each period in which k is not announced, subjects provided an estimate or guess of k. Guesses are averaged, and compared to the implied k, which is calculated using average trading prices for the call and stock. In Panel A, Wilcoxon Signed Rank and Paired t tests comparing the implied k parameter to the average guess are then performed. The tests are performed for all periods, and separately for periods according to the probability parameter. Panel B presents OLS regressions predicting guessed k, using implied k as an explanatory variable. The parameters p25 and p75 are dummy variables representing the observations where the probability treatment is 25% and 75% respectively. p-values are shown underneath the parameter estimates.

Panel A: Does the Implied k Equal the Average Guess of k?

Ho: Implied k = Guess Ha: Implied k ≠ Guess	Implied k – Guess	n	t	p	SR	p
Periods where p = .25	22.44	17	3.04	.007	68.5	.002
Excluding 3 rd Period	24.80	10	2.20	.055	23.5	.014
Periods where p = .50	25.28	27	5.07	<.0001	175.0	<.0001
Excluding 3 rd Period	22.10	24	5.28	<.0001	136.0	<.0001
Periods where p = .75	22.54	12	3.85	.003	33.0	.007
Excluding 3 rd Period	22.31	11	3.48	.006	27.0	.013
All periods	23.80	57	6.83	<.0001	719.0	<.0001
Excluding 3 rd Period	22.75	45	6.32	<.0001	445.5	<.0001

Panel B: Is the Implied k Informative?

Model (n=57)	α	β	γ	δ
Guess = $\beta(\text{Implied } k) + e$	-	0.55 <.0001	-	-
Guess = $\alpha + \beta(\text{Implied } k) + e$	34.70 <.0001	0.10 .003	-	-
Guess = $\beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	-	0.55 <.0001	-0.04 0.58	0.05 0.51
Guess = $\alpha + \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	34.57 <.0001	0.11 <.002	-0.04 0.18	0.01 0.81

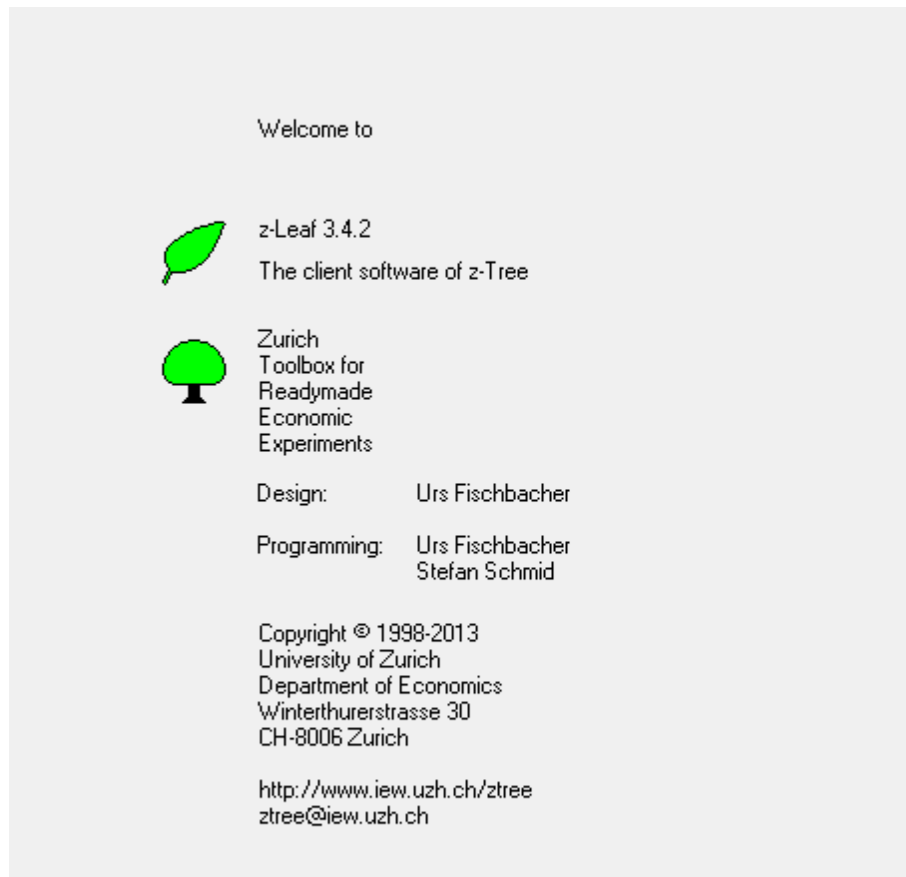
Panel C: Is the Implied k Informative? Excluding 3rd Period.

Model (n=57)	α	β	γ	δ
Guess = $\beta(\text{Implied } k) + e$	-	0.58 <.0001	-	-
Guess = $\alpha + \beta(\text{Implied } k) + e$	34.65 <.0001	0.12 .006	-	-
Guess = $\beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	-	0.60 <.0001	-0.11 0.16	0.00 0.99
Guess = $\alpha + \beta(\text{Implied } k) + \gamma(p25*\text{Implied } k) + \delta(p75*\text{Implied } k) + e$	34.09 <.0001	0.13 <.004	-0.04 0.24	0.00 0.97

Appendix A Instructions

We are about to begin an asset market in which you can trade two assets using experimental currency. The experiment is conducted in a computerized electronic market. We will describe how this market works and your interface with it.

Please raise your hand and let the experimenter know if you don't see the following screen on your computer:



Please free to ask questions at any time. We will practice trading on the computer before the actual market begins.

There are two assets in today's experiment. Asset 1 (A1) is traded in market A1 and asset 2 (A2) is traded in market A2. All traders are permitted to transact in both markets. Trading activity in both markets will be visible on the trading screen.

At the beginning of each period you will see a screen that indicates the possible payoffs for each asset. There are two possible states, High and Low. A random draw determines the state and there is one random draw per period, which determines the state for both markets. In other words, the state is the same for both markets in any given period.

IF THE STATE IS HIGH THEN A1 PAYS:	125
IF THE STATE IS HIGH THEN A2 PAYS:	25
IF THE STATE IS LOW THEN A1 PAYS:	75
IF THE STATE IS LOW THEN A2 PAYS:	0
THIS PERIOD THE PROBABILITY THAT THE STATE IS HIGH IS:	0.50
THIS PERIOD THE PROBABILITY THAT THE STATE IS LOW IS:	0.50

You see in the screen above that asset A1 pays 125 in the High state and 75 in the Low state, whereas asset A2 pays 25 in the High state and nothing in the Low state. Also, note that, in this example, the probability or likelihood that the High state will occur is 50% and the probability that the low state will occur is 50%. That is, the High state and the Low state are equally likely to occur. However, in some instances, the probability of the High state occurring may be specified at a different value.

In some periods, the possible payoffs will not be shown to you until trading for the period is finished. Payoffs will be based on an unknown parameter, K , which will always be a number between 0 and 100. However, you will not know the precise value of K for that period. In each period where K is unknown, K can have a different value.

If K is unknown, the initial screen will show that the High state and Low state payoffs for A1 are $100 + K$, and $100 - K$ respectively. The corresponding values for A2 are K if the state is High, and zero if the state is Low.

In some periods, the probability that the state will be High may be unknown. If so, the text on the bottom of the screen will say: “THIS PERIOD THE PROBABILITY THAT THE STATE IS HIGH IS UNKNOWN” and “THIS PERIOD THE PROBABILITY THAT THE STATE IS LOW IS UNKNOWN.” In these periods, you will not know the probabilities for High and Low outcomes.

Trading Screen:

Most of our time will be spent using the trading screen. Here, you will be able to purchase and sell shares of both A1 and A2. An enlarged screenshot of the trading screen is shown on the following page.

At the start of each period you will be given some shares of A1 and A2. The starting number of shares is shown on the left-most boxes the trading screen. As you buy and/or sell shares, your number of shares will change accordingly.

In this experiment, you will always start with a positive number of shares of A1. However, the starting number of shares of A2 may be either positive or negative. A negative number signifies that you are in a *short* position. This simply means that instead of receiving the payoff for the shares at the end of the period, you will have to pay that amount. For example, if you have -2 shares of A2, and the end-of-period payoff for A2 is 25, then your position would be $-2(25)$ or -50, meaning that 50 would be deducted from your earnings.

At the start of each period, you will also be given 800 francs. In addition, you will receive a loan for an additional 800 francs, so you will see a starting balance of 1600 francs on the trading screen. At the end of the period you will repay the loan. There is no interest charge and the 800 francs will be automatically subtracted from your cash balance.

The left upper corner of the screen shows you the current trading period and the total number of trading periods in the market today. The right upper corner shows the remaining *seconds* of the *current* trading period. In today’s experiment, each trading period is 2 minutes.

The bottom of the screen displays your trader ID and the money you have in your portfolio. The rest of the screen is divided into two horizontal boxes, one for each market (A2 and A1).

On the left of each horizontal box, you will see the number of units of each asset in your portfolio. The above window indicates that you have 1 unit of Asset 2 in your portfolio. In the next column you can submit offers to sell A2; right next to it is the column of existing offers submitted to the market to sell A2. The middle column shows you the prices at which A2 has traded. The next column on the right shows existing offers

Period		2 of 2			Remaining Time [sec]: 13	
A2 Quantity -2	Offer To Sell A2 <input type="text" value="100"/>	OffersTo Sell Asset 2 102.00 100.00	Trading Price for A2	Offers to Buy A2 101.00	Offer To Buy A2 <input type="text" value="101"/>	
	<input type="button" value="Offer To Sell A2"/> <input type="button" value="Cancel"/>	<input type="button" value="BUY A2 at highlighted P"/>		<input type="button" value="SELL A2 at highlighted P"/>	<input type="button" value="Offer to Buy A2"/> <input type="button" value="Cancel"/>	
A1 Quantity 2	Offer To Sell A1 <input type="text" value="31"/>	Offer To Sell A1 35.00 34.00 34.00 31.00	Trading Price for A1	Offers to Buy A1 28.00	Offer To Buy A1 <input type="text" value="28"/>	
	<input type="button" value="Offer To Sell A1"/> <input type="button" value="Cancel"/>	<input type="button" value="BUY A1 at highlighted P"/>		<input type="button" value="SELL A1 at highlighted P"/>	<input type="button" value="Offer to Buy A1"/> <input type="button" value="Cancel"/>	
		Trader ID 2		Trading Currency 1000.00		

submitted in to buy A2. The last column on the very right of the screen is where you can submit offers to buy A2. The boxes for A1 follow the same design.

To Sell or Buy an Asset:

To place an offer to sell an asset, type the price you want to sell it for in the cell under the label “Offer to Sell” A2 or A1. You can only trade *one unit at a time*, therefore there is no need to specify the quantity you wish to trade. Click the button “Offer to Sell” to send your offer. Your offer will be posted in the column of “Offers to Sell” A2 or A1, which is to the right of the column where you submitted your offer. If after you submit an offer to buy or sell, *you can cancel your offer by clicking the “Cancel” button.*

Follow the same steps to place an offer to buy an asset. The column to submit buying offers and the column showing the current submitted buying offers are laid symmetrically to the right of the box for each market. The offers are displayed in descending order using submitted prices.

Accepting an offer results in a trade. If you would like to accept any of the offers (either to buy or sell a asset) submitted to the market, click the red “BUY (or SELL) A2 (or A1) at highlighted P” button.

Note that accepting an offer from the column of “Offers to Sell A2” means that you are buying that asset from the trader who submitted the offer, while accepting an offer from the column of “Offers to Buy A2” means that you are selling that asset to the trader who submitted the offer at the specified price. After the transaction, the corresponding units of the asset you traded and the money left in your portfolio will be updated and the trading price will be posted in the middle column of “Trading Price for A2 (or A1).” Meanwhile, the offer will be eliminated from the column of existing offers.

Notice that there are 2 ways to sell an asset. First, an offer to sell that you have submitted may be accepted by another trader. Second, you can accept another trader’s offer to buy.

Similarly, there are 2 ways to buy an asset. First, an offer to buy that you have submitted may be accepted by another trader. Second, you can accept another trader’s offer to sell.

There are a few restrictions regarding submitting and accepting offers when trading. They are summarized as follows:

First, you are also not allowed to trade with yourself, meaning that you cannot accept offers that you submitted. If you do so, an error message will appear.

Second, short selling is allowed, which means that if you don’t have a unit of an asset, you can still send out an offer to sell that asset. However, your ability to short sell is limited. You will not be able to short more than 10 shares of each asset.

Guessing Screen:

In periods where you are not told the precise values of the potential payoffs, you will be asked to estimate or guess the value of the parameter K . Recall that K is a number between 0 and 100, and the asset payoffs for A1 is $100+K$ if the state is High, and $100-K$ if the state is Low. Similarly A2 will pay K if the state is High, or 0 if the state is Low.

In periods where you are not told the probability that the state is High or Low, you will be asked to estimate or guess this probability. If prompted, enter your estimates and press OK to continue to the results screen.

Results Screen:

The final screen for the period is the result screen, summarizing your activities for the period.

You are now told whether the state for the period is High or Low, and are shown the payoffs for both A1 and A2.

The screen summarizes your transactions, showing the number of shares of A1 and A2 purchased and/or sold, and your earnings for the period.

Trader ID	2
This trading period the state is: HIGH	
Money in your portfolio after loan is paid	957
Payoff for each unit of A1 in this trading period	148
Units of A1 in your portfolio	11
Total payoff earned from A1 in this period	1628
Payoff for each unit of A2 in this trading period	48
Units of A2 in your portfolio	-6
Total payoff earned from A2 in this period	-288
Ending value of your portfolio for this trading period	2297

When you are done looking at the summary screen, press OK to commence the next period.

How Do You Earn Your Payoff?

*Remember that your cash payoff is determined by the payoffs on assets **and** the money in your portfolio at the end of each trading period.* After each period, your profits for that period will be added to your profits in all earlier periods to obtain your cumulative earnings. During the experiment, your earnings are calculated in our experimental currency, francs. At the end of the experiment your cumulative earnings will be converted to US dollars. You will receive 1 US dollar per 400 francs.

Frequently asked questions.

Frequently Asked Questions:

Q: Is this some kind of psychology experiment with an agenda you haven't told us?

A: No. It is a finance experiment. If we do anything deceptive, or don't pay you cash as described, then you can complain to the campus Human Subjects Committee and we will be in serious trouble. These instructions are on the level and our interest is in seeing how people make decisions in certain situations.

Q: Is it possible to lose money in this experiment? Will I have to pay you?

A: No, you cannot lose money. It is possible (but unlikely) for you to make NO money.

Q: I am trying to short sell a share. I have plenty of cash, so I should be allowed to short sell. Why won't the program allow me to sell?

A: The software considers all of your existing sell offers in determining whether to allow you to short sell. Let's say you currently have zero shares, and you have 5 offers to sell posted. The computer will "reserve" 500 dollars as collateral for those offers, making your available balance for other transactions lower. To free up the money, just press the "Cancel" button in the offers to sell section of the trading screen.

Let's start a practice trading period.

Appendix B

We now report on some additional analysis from our experiments. In an effort to explain belief formation, we examine whether the implied range is correlated with two aspects of individual psychology that are commonly believed to impact financial decision-making: optimism and overconfidence. As the results are inconclusive, we have elected to include them in this Appendix.

Prior to the market section of the experiment, subjects completed questionnaires designed to measure both overconfidence and optimism. Both behaviors have the potential to explain individual expectations that are at odds with fundamental valuations (e.g., Ko and Huang (2007), Puri and Robinson (2007)). Investor sentiment is thought to reflect beliefs about the future that are not justified by current information (Baker and Wurgler (2007)), and evidence suggests that sentiment affects pricing in markets (Brown and Cliff (2005)).

A. Measuring optimism and overconfidence

Psychologists define individual optimism or pessimism based on expectations for the future. A positive view of the future is linked with better mental health as it supports coping skills (Scheier and Carver (1992)). When life throws roadblocks at an optimist, the challenges are met with greater confidence. Thus, individual optimism and confidence are correlated constructs.

Insert Figure B1

To measure optimism we follow Carver, Scheier and Segerstrom (2010) and adopt the revised Life Orientation Test (LOT-R). This ten-question survey, shown in Figure B1 is designed to measure individual subjects' overall level of optimism and

pessimism. To see how the LOT-R works, consider one of the questions on the test: “If something can go wrong for me, it will.” Subjects respond on a five-choice scale with “I agree a lot,” “I agree a little,” “I neither agree nor disagree,” “I disagree a little,” and “I disagree a lot” as choices. The response is given numerical values with +2 corresponding to the most optimistic, and -2 to the least optimistic. The scores are then added across questions for each subject, so that high scores indicate optimistic and low scores indicate pessimism.

Insert Figure B2

To measure overconfidence (more precisely miscalibration) we use the procedure presented in Michailova and Katter (2014). Subjects answer twenty multiple-choice trivia questions, and receive 25¢ for each question answered correctly. In addition, for each question, subjects are asked to estimate the likelihood that their answer is correct. Since there are three choices per question, they are told to enter 33.33% if they have no idea which answer is correct, 100% if they are sure that their answer is correct, or a number between 33.33% and 100% depending on their confidence in their answer. The actual percentage of correctly answered questions is subtracted from the average (over the twenty trivia questions) of the probability estimates to obtain the miscalibration estimate for each subject.

B. Results

Table B1 reports the distribution of observed optimism/pessimism and miscalibration among experimental participants. The overall optimism score for an individual is obtained by adding the scores for six questions from the LOT-R

questionnaire. Therefore, +12 is the most optimistic overall score, 0 is neutral, and -12 is the least optimistic score.

Insert Table B1

On average, our subjects are optimistic with a mean optimism measure of +4.48. As Panel B of Table B1 indicates, the distribution is right skewed with few subjects exhibiting pessimism, while some are highly optimistic.

The miscalibration estimate (OVC) for each subject is computed taking the average (over the twenty trivia questions) of the probability estimates minus the actual percentage of correctly answered questions. Thus, a higher score indicates greater miscalibration or overconfidence. Panel A of Table B1 shows that miscalibration measures range from -0.25 to 0.384. Most of our subjects are overconfident in that the average of the miscalibration measure is +0.06, and the distribution is again, right skewed.

Although our subjects tended to be both optimistic and overconfident, the correlation between the two measures is only +0.04, and is not significantly different from zero. Further, recall the subjects provided a guess of k in periods where k was not announced. A subject's average guess of k is not significantly correlated with either their LOT-R or their OVC measure. The correlation between guess and LOT-R is +0.07 ($p = 0.48$), and the correlation between guess and OVC is -0.04 ($p = 0.68$). Neither rejects the null hypothesis of zero correlation.

Insert Table B2

We now look at correlations between the psychology measures and the implied volatility from the market portion of the experiments. Table B2 examines whether

differences between the implied k and the announced k are correlated with optimism (LOT-R) or overconfidence (OVC). For each session, the absolute difference between the implied and announced k is averaged across the periods in the session. Table B2 compares this measure to LOT-R and OVC questionnaire data for the corresponding sessions. Correlations between the absolute differences and the questionnaire data are all not statistically different from zero. Optimism/Pessimism and overconfidence, to the extent that these features are captured by the LOT-R and OVC, appear to be unrelated to the implied k , when the actual k is announced.

We present analogous results for periods in which k is not announced. Implied k is computed with median call and stock prices and then the implied range is averaged across periods to obtain session averages. These session averages are presented along with the optimism and overconfidence data in Table B3.

Insert Table B3

Several methods for combining the questionnaire data to get a session average are presented. Tests of the null hypothesis of zero correlation between the implied volatility and LOT-R or OVC cannot be rejected for any paired comparison. As in the treatment where k is announced, none of the optimism or overconfidence measures are significantly correlated with implied k .

In summary, we searched for, but failed to find a link between optimism and/or overconfidence and the implied range in either of the treatments. Implied range was not explained either by the LOT-R, a psychology-based measure of optimism, or by miscalibration, a widely used measure of overconfidence. Because both of these measures provide an overall assessment and do not vary for a subject over the course of

the experiment, they may not capture optimism and overconfidence precisely enough to observe a link with the implied range. Or, perhaps general levels of optimism or overconfidence do not affect subjects' beliefs concerning the experimental parameters. Future research could delve deeper into these questions.

C. References

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Figure B1
The LOT-R questionnaire

We adopt the approach of Carver, Scheier and Segerstrom (2010)) to measure optimism/pessimism. Subjects are given a 10-question survey and are asked to choose among the following responses:

- A. I agree a lot.
- B. I agree a little.
- C. I neither agree nor disagree.
- D. I DISagree a little.
- E. I DISagree a lot.

The questions and the directions given to subjects are shown below.

Please indicate your response by circling the letter of your choice for each question. Please be as honest and accurate as you can throughout. Try not to let your response to one statement influence your responses to other statements. There are no "correct" or "incorrect" answers. Answer according to your own feelings, rather than how you think "most people" would answer.

- 1. In uncertain times, I usually expect the best.*
- 2. It's easy for me to relax.*
- 3. If something can go wrong for me, it will.*
- 4. I'm always optimistic about my future.*
- 5. I enjoy my friends a lot.*
- 6. It's important for me to keep busy.*
- 7. I hardly ever expect things to go my way.*
- 8. I don't get upset too easily.*
- 9. I rarely count on good things happening to me.*
- 10. Overall, I expect more good things to happen to me than bad.*

To measure the level of optimism questions 2, 5, 6 and 8 are not used and the remaining six questions are scored on a five-point scale with +2 for the most optimistic response to -2 for the least optimistic response. For questions 1, 4, and 10 response A is most optimistic and scored as +2, whereas for questions 3, 7 and 9, the scale is reversed and E is the most optimistic response. The overall score is obtained by adding the scores for the six questions. Therefore +12 is the most optimistic overall score, 0 is neutral, and -12 is the least optimistic score.

Figure B2
The miscalibration questionnaire

We use the procedure suggested by Michailova and Katter (2013) to measure overconfidence. Students completed a twenty-item questionnaire, two of which are shown below for illustration. To minimize the possibility of the questions being leaked from past participants to future participants, we used two sets of questions. The full set of questions is available from the authors upon request.

The questions and the directions given to subjects are shown below.

Below you will be presented with some general knowledge questions. Imagine that you are taking part in a game, like “Trivial Pursuit” or “Who wants to be a Millionaire?,” and you have to choose the correct answer from the three given alternatives. Please indicate your response by circling the letter of your choice for each question. You will earn 25¢ for each correct answer. There is no penalty for guessing.

1) Please circle ONLY ONE of three given answers. Only one of them is correct.

2) When you have made your choice and have circled your answer, we would like to know how sure/confident you are that your answer is correct. Since there are three alternative answers and only one of them is correct you have a 33% chance of giving a correct answer. Therefore 33% means that you are guessing and do not know the correct answer, and 100% corresponds to absolute certainty.

You can use any number between 33% and 100% to indicate your confidence that your answer is correct. Enter your confidence for every answer in the gap in the question after every test item: How confident are you that your answer is correct? _____ %

Please answer all questions. Even if you have to guess on every question, you would expect to answer 33% correct by chance. You are not allowed to consult anyone else, or copy the answers from another.

NOTE: Please answer all questions, one after another in the order in which they are presented in the questionnaire. Guess any answers you do not know. Do not jump around the questions, and do not return to already-answered questions to change your answers; we are interested in your first answer.

<i>1. What actress provided the voice of Shenzi the hyena in Disney’s movie: “The Lion King”? (circle one)</i>		
<i>A. Whoopi Goldberg</i>	<i>B. Demi Moore</i>	<i>C. Rhoda Williams</i>
<i>How confident are you that your answer is correct? _____ %</i>		

<i>2. The Amur tiger is also known as the _____ ? (circle one)</i>		
<i>A. Bengal Tiger</i>	<i>B. Siberian Tiger</i>	<i>C. Sumatran Tiger</i>
<i>How confident are you that your answer is correct? _____ %</i>		

Table B1
Optimism, pessimism and overconfidence

The Revised Life Orientation Test (LOT-R) asks six questions designed to elicit the degree of optimism. Each question is coded from -2 to +2, with +2 being most optimistic, and -2 being most pessimistic. The LOT-R scores therefore vary from -12 to +12. The overconfidence score (OVC) is based on a subject's responses to twenty multiple-choice trivia questions, and elicited estimates of the likelihood that each answer is correct. The OVC score is the difference between the average likelihood elicited and the actual percentage of questions answered correctly.

Panel A: Descriptive Statistics

	LOT-R	OVC
Average	4.48	0.06
Minimum	-5	-0.25
Maximum	+12	+0.384
Standard Deviation	3.54	0.12
Correlation(LOT-R, OVC) = +0.04, p = 0.74		

Panel B: Histograms

LOT-R	frequency	OVC	frequency
+12	2	.35 to .40	1
+11	3	.30 to .35	2
+10	3	.25 to .30	2
+9	8	.20 to .25	5
+8	6	.15 to .20	10
+7	7	.10 to .15	17
+6	5	.05 to .10	9
+5	8	0 to .05	18
+4	16	-.05 to 0	11
+3	6	-.10 to -.05	6
+2	14	-.15 to -.10	0
+1	7	-.20 to -.15	5
0	5	-.25 to -.20	2
-1	2	-.30 to -.25	0
-2	3	All	88*
-3	0		
-4	0		
-5	1		
-6	0		
-7	0		
-8	0		
-9	0		
-10	0		
-11	0		
-12	0		
All	96		

*The miscalibration measure was not administered in one of the sessions, so there are a total of 88 subjects in the OVC histogram.

Table B2**Optimism, overconfidence and implied range when k is announced**

For each period in which k is announced, the implied k is calculated using median prices of the two assets. The absolute difference, $|\text{implied } k - \text{announced } k|$ is averaged across the periods within each session. The column labeled Excluding 1 omits the first period of each session. LOT-R is the Revised Life Orientation Test score averaged over the subjects in the corresponding session. LOT-R can range between -12 and +12. $|\text{LOT-R}|$ is the absolute value of the LOT-R averaged over the subjects in the corresponding session. Number $|\text{LOTR}| > 4$ counts the number of subjects in the corresponding session with LOT-R scores greater than 4 or less than -4. OVC reports the average miscalibration score for the session. Number $\text{OVC} > 0$ and Number $\text{OVC} > 10\%$, are the numbers of subjects in the corresponding session with miscalibration scores greater than zero and ten percent, respectively.

Panel A: LOTR and Implied Range

Session	Absolute Difference	Absolute Difference Excluding 1	LOT-R	$ \text{LOT-R} $	Number $ \text{LOTR} > 4$
1	10.80	8.25	2.38	3.38	1
2	41.70	34.38	3.75	3.75	3
3	18.59	21.49	6.75	6.75	6
4	27.90	26.88	5.63	5.63	6
5	41.13	24.50	3.13	3.13	1
6	13.10	11.38	5.63	5.63	3
7	20.20	15.25	4.00	4.00	2
8	50.50	33.38	4.63	4.63	4
9	17.60	19.75	5.38	5.38	3
10	19.80	22.25	3.75	4.50	5
11	14.60	17.25	3.50	5.00	4
12	39.0	44.75	5.25	5.25	5

Panel B: OVC and Implied Range

Session	Absolute Difference	Absolute Difference Excluding 1	OVC	Number $\text{OVC} > 0$	Number $\text{OVC} > 10\%$
1	10.80	8.25	-0.014	5	1
2*	41.70	34.38			
3	18.59	21.49	-0.024	3	2
4	27.90	26.88	0.076	7	3
5	41.13	24.50	0.113	7	2
6	13.10	11.38	0.011	6	2
7	20.20	15.25	-0.001	4	3
8	50.50	33.38	0.074	6	3
9	17.60	19.75	0.114	7	5
10	19.80	22.25	0.098	7	3
11	14.60	17.25	0.141	7	6
12	39.0	44.75	0.090	5	3

*OVC was not measured in Session 2.

Table B3**Optimism, overconfidence and implied volatility when k is not announced**

For each period in which k is not announced, the implied k is calculated using the median prices of the two assets. Then the implied k is averaged across the periods within each session. LOT-R is the Revised Life Orientation Test score averaged over the subjects within a session. LOT-R can range between -12 and +12. |LOT-R| is the absolute value of the LOT-R averaged over the subjects in a session. Number |LOT-R| > 4 counts the number of subjects in the session with LOT-R scores greater than 4 or less than -4. OVC is the average miscalibration score for the session. Number OVC > 0 and Number OVC > 10%, are the numbers of subjects in the corresponding session with miscalibration scores greater than zero and ten percent, respectively.

Panel A:

Session	Implied k	LOT-R	LOT-R	Number LOT-R > 4
1	56.80	2.38	3.38	1
2	91.70	3.75	3.75	3
3	48.00	6.75	6.75	6
4	37.40	5.63	5.63	6
5	57.25	3.13	3.13	1
6	46.00	5.63	5.63	3
7	51.40	4.00	4.00	2
8	122.40	4.63	4.63	4
9	75.30	5.38	5.38	3
10	57.60	3.75	4.50	5
11	55.30	3.50	5.00	4
12	78.40	5.25	5.25	5

Panel B:

Session	Implied k	OVC	Number OVC > 0	Number OVC > 10%
1	45.00	-0.014	5	1
2	47.18			
3	46.00	-0.024	3	2
4	31.03	0.076	7	3
5	40.07	0.113	7	2
6	35.63	0.011	6	2
7	37.38	-0.001	4	3
8	45.63	0.074	6	3
9	40.18	0.114	7	5
10	40.75	0.098	7	3
11	38.88	0.141	7	6
12	48.10	0.090	5	3