Cognitive Bubbles*

Ciril Bosch-Rosa†
Thomas Meissner‡
Antoni Bosch-Domènech§

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Abstract

Smith et al. (1988) reported large bubbles and crashes in experimental asset markets, a result that has been replicated by a large literature. Here we test whether the occurrence of bubbles depends on the experimental subjects' cognitive sophistication. In a two-part experiment, we first run a battery of tests to assess the subjects' cognitive sophistication and classify them into low or high levels of cognitive sophistication. We then invite them separately to two asset market experiments populated only by subjects with either low or high cognitive sophistication. We observe classic bubble- crash patterns in the sessions populated by subjects with low levels of cognitive sophistication. Yet, no bubbles or crashes are observed with our sophisticated subjects. This result lends strong support to the view that the usual bubbles and crashes in experimental asset markets are caused by subjects' confusion and, therefore, raises some doubts about the external validity of this type of experiments.

Keywords Asset Market Experiment · Bubbles · Cognitive Sophistication

JEL Classification C91 · D12 · D84 · G11

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†Berlin University of Technology
‡Berlin University of Technology
§Universitat Pompeu Fabra and Barcelona GSE

1 Introduction

In 1988, *Econometrica* published a seminal paper by Vernon Smith, Gerry Suchanek and Arlington Williams (SSW) (Smith et al. (1988)) reporting the results of experiments on the efficiency of asset markets. In the simple market they had designed, SSW observed large bubbles and crashes. To the surprise of most, these bubbles turned out to be extremely resilient to replications under different treatments.[1,2]

Thus, the results became canonical to the extent that seldom a paper in the economic experimental literature has spawned such a large industry of replications and follow-ups. Steven Palan in a recent survey (Palan (2013)) documents the main findings based on the results from 41 published papers, 3 book chapters and 20 working papers, describing them under 32 observations. Palan concludes with an optimistic appraisal: "Hundreds of SSW markets have been run, yielding valuable insights into the behavior of economic actors and the factors governing bubbles"(p. 570).

We are not so sure about that. We show below that the bubbles and crashes observed in experimental asset markets disappear when the participants have a sufficient level of cognitive sophistication. This being so, it is problematic to sustain that these experiments yield valuable insights into the behavior of economic actors or into the factors governing bubbles, as their external validity becomes questionable. If we are right, bubbles and crashes stop being intrinsic to experimental asset markets, and become dependent on the cognitive profile of the experimental subjects.

The idea that the observed bubbles and crashes in the SSW-type experiments may be due to some lack of understanding by the participants in the experiments is not entirely new. Huber and Kirchler (2012) and Kirchler et al. (2012) have managed to reduce bubbles in their experiments by either offering a more thorough rendering of the market

[1] E.g.: Porter and Smith (1995), Caginalp et al. (1998), Caginalp et al. (2000), Smith et al. (2000), Dufwenberg et al. (2005), Noussair and Tucker (2006), Haruvy and Noussair (2006), Haruvy et al. (2007), Hussam et al. (2008), Williams (2008).

[2] In a recent interview Vernon Smith reminisced about his earlier experiments and declared that the design of his SSW experiment was transparent and, consequently, he could not understand why subjects would not trade at the fundamental value: "We then turned to asset markets in the 1980s, and we started with a very transparent market, an asset that could be re-traded but there was a yield, a dividend on it that was common information. And we thought that would be very simple. It would be transparent and people would trade at fundamental value. Well, wrong [...] These markets are very subject to bubbles in the lab. And people get caught up in self-reinforcing expectations of rising prices. We don't know where that comes from. It's incredible, but they do." http://www.econtalk.org/archives/2014/11/vernon_smith_on_2.html. November 17 2014.

(using graphs and describing what the fundamental values for the asset are in each period) or describung the asset as a "stock from a depletable gold mine". According to them, an easier understanding of the market diminishes the bubbles. However, this interpretation has been challenged. Baghestanian and Walker (2014) argue that particular features of the experimental design by Kirchler et al. (2012) generate asset prices equal to the fundamental value through increased focalism or anchoring, and not because agents are less confused.

In this paper we test whether the occurrence of bubbles in SSW-type experiments depends on the subjects' cognitive sophistication, as we conjecture that some degree of confusion may be the main driver behind the bubbles. If this is right, then we should expect participants who are more cognitively sophisticated to generate fewer bubbles compared to less sophisticated ones. To test this hypothesis we design a two-part experiment: In the first part we invite subjects to participate in a battery of tasks that, we reasonably believe, allow us to approximate their "cognitive sophistication". In part two, which is scheduled for a later date, we invite subjects that score low (high) in our tasks of cognitive sophistication to participate in an asset market experiment populated only by low (high) sophistication subjects. The results of the experiment verify our expectations. Bubbles and crashes persist when the experimental subjects are selected because of their lower cognitive scores, but vanish when we run the experiment with the more sophisticated subjects.

2 The Cognitive Tasks

A total of 352 subjects participated in our cognitive tasks. Sessions were run at the Experimental Economics Laboratory of the Berlin University of Technology. Most of our subjects were undergraduates in the fields of engineering or economics, who were asked to participate in a number of time-constrained tasks to evaluate their cognitive abilities. They began with a "Cognitive Reflection Test" (CRT)(Frederick (2005), followed by playing a "Guessing Game" (Nagel (1995)) against other subjects, then a "Guessing Game Against Oneself", and finally 12 rounds of "Race to 60".[3] There was no feedback to the participants during or in-between tasks.

[3] The instructions for the cognitive tasks are presented in Appendix A.

The CRT is a three-item task of an algebraic nature, designed to measure the ability to override an intuitive response that is incorrect and to engage in further *reflection* that leads to the correct response. It has been shown that the test results are highly correlated with IQ level, with compliance to expected utility theory, as well as with lower discount rates (higher patience) for short horizons and lower levels of risk aversion (see e. g. Frederick (2005) and Oechssler et al. (2009)). With respect to experimental asset markets, Corgnet et al. (2014) and Noussair et al. (2014) find that CRT scores correlate positively with earnings. In the Guessing Game (against others), participants were asked to guess a number between 0 and 100 and were paid based on how close their choice was to 2/3 of the average of all the guesses within their session. The guess gives an indication of the participant's capacity to perform iterative reasoning in a strategic environment. A simpler way (because devoid of any strategic concerns) of testing the basic capacity for *iterative reasoning* is the Guessing Game Against Oneself, where a participant has to pick two numbers between 0 and 100, and each number is paid independently, according to how close it is to 2/3 of the average of the two chosen numbers.[4] Finally, participants played Race to 60, a variant of the race game (Gneezy et al. (2010), Levitt et al. (2011)), for 12 rounds against a computer. In this game, the participants and the computer sequentially choose numbers between 0 and 10, which are added up. Whoever is first to push the sum to or above 60 wins the game. The game is solvable by *backward induction*, and the first mover can always win. Subjects always move first and therefore, independently of the computer sophistication, they can always win the game by applying backward induction.

We finally computed an index of cognitive sophistication, S_i, as a weighted average of the results obtained by each subject (i) in the four tasks described above. This index has a value between zero and one, and we use it to rank our subjects. A subject is classified as having Low (High) cognitive sophistication if she is in the lower (upper) 30% of the distribution of S_i.[5] We counted 84 subjects with low sophistication and 83 with high sophistication.[6]

[4]To our knowledge, this is the first experiment in which a guessing game against oneself is played. Petersen and Winn (2014) have a similar setup in which subjects compete against themselves in a monopolistic competition environment.

[5]See Appendix B for detailed results of each task, the construction of the Cognitive Sophistication measure S_i, as well as its final distribution.

[6]After the first batch of sessions, and in order to run three additional High sessions (see 4.2 below for an explanation), we invited more subjects to be tested at a later time. We classified these subjects as

3 The Experiment

All sessions of the asset market experiment followed the design of Haruvy et al. (2007), except that our subjects participated in groups of seven (instead of nine), we did not allow for practice runs, and had three (instead of four) repetitions of the market. Subjects were endowed with a bundle composed of Talers (our experimental currency) and a number of assets. Three subjects received 1 asset and 472 Taler, one subject received 2 assets and 292 Taler, and three subjects received 3 assets and 112 Taler.[7] Each session consisted of three repetitions (that are called rounds) and each round lasted 15 periods. In each period subjects were able to trade units of the asset (called "shares" in the instructions) in a call market with other subjects.[8] At the end of every period, each share paid a stochastic dividend of either 0, 4, 14 or 30 Taler with equal probability (expected dividend, 12 Taler). Shares had no buy back value at the end of the 15 periods. Before any trade took place, subjects were asked to predict the price of the asset for all upcoming periods. So, in period 1 subjects were asked to predict 15 prices, in period 2 they were asked to predict 14, and so on. Subjects were incentivized to give accurate predictions: They were paid 5 extra Taler if a price prediction was within 5% of the actual price, 2 Taler if a prediction was within 25%, 1 Taler if a prediction was within 50% of the price, and nothing otherwise.[9] At the end of each period, subjects were told the price at which the asset was traded, the dividend they collected, their profits, their share and cash holdings, and

being of High Sophistication if they were above the boundaries of our first batch of tested subjects. In total we ended up inviting 92 subjects with high scores. Participants who were not classified as having either Low or High cognitive sophistication, i. e. the remaining 40%, were not subjects in the asset market experiment.

[7]Subjects knew about their private endowment and were told that participants could have different endowments.

[8]The SSW-type of asset market experiment has been run in the literature with different institutional arrangements, basically either a continuous double auction or a call market. A call market, as in Haruvy et al. (2007), allows only one price per period, as opposed to the possibility of multiple prices in the continuous double auction, thus yielding a crisp description of the price dynamics. It also helps participants to better understand the price prediction process, and mitigates the possibility of subjects trying to manipulate prices to improve their prediction scores. Importantly, these advantages come at no cost, as call markets and continuous double auction markets do not differ in their results. See Palan (2013) (in particular his Observation 27: "A two-sided sealed-bid call auction does not significantly attenuate the bubble") for a detailed discussion on the matter and references to experiments comparing both institutions.

[9]Notice that subjects were paid independently for all predictions they made of the price for a certain period. For example, for the price in period 2 subjects were paid twice; once for the prediction they made in period 1, and once again for the prediction they made in period 2.

their accumulated profits from their price predictions. Each session (which, as mentioned above, is composed of three rounds) was programmed to last for two and a half hours, but a few sessions went somewhat beyond.[10]

Before turning to the results, recall that our experiment had two different treatments:

- Low Sophistication treatment: all subjects that took part in this treatment were from the lower 30% of the distribution for S_i
- High Sophistication treatment: all subjects that took part in this treatment were from the upper 30% of the distribution for S_i,

and that the main purpose of the experiment was to compare the asset price dynamics in the two treatments.

4 Results

4.1 Low Sophistication Treatment

We ran six sessions of the experiment under the Low Sophistication treatment. The results in all six sessions are the usual ones reported in the literature. The diagram on the left of Figure 1 shows the price dynamics for the first round of each of the six sessions. Prices begin below the fundamental value of the asset, climbing in the following periods well above and beyond it, to finally crash near the last period. In summary, when the experimental subjects belong to the lower end of the distribution of Cognitive Sophistication, we observe the classic price dynamics of bubbles and crashes.[11] As in previous experiments reported in the literature, bubbles tend to diminish somewhat in the second and third round of a session with the same subjects and endowments.[12]

[10]The instructions for the experiment can be found in Appendix C.

[11]It is worth mentioning that while subjects that participated in the Low treatment performed relatively poorly in the cognitive tests, the population tested was made of students from one of the top engineering schools in Germany. There is no reason to suspect that their cognitive sophistication was below that of the average undergraduate participating in the usual asset market experiments. The results observed in the three rounds of the sessions add credence to this assumption.

[12]The second and third rounds of each session are not the focus of this paper. Therefore, they are not reported in its main body. See Appendix D for the results from rounds two and three.

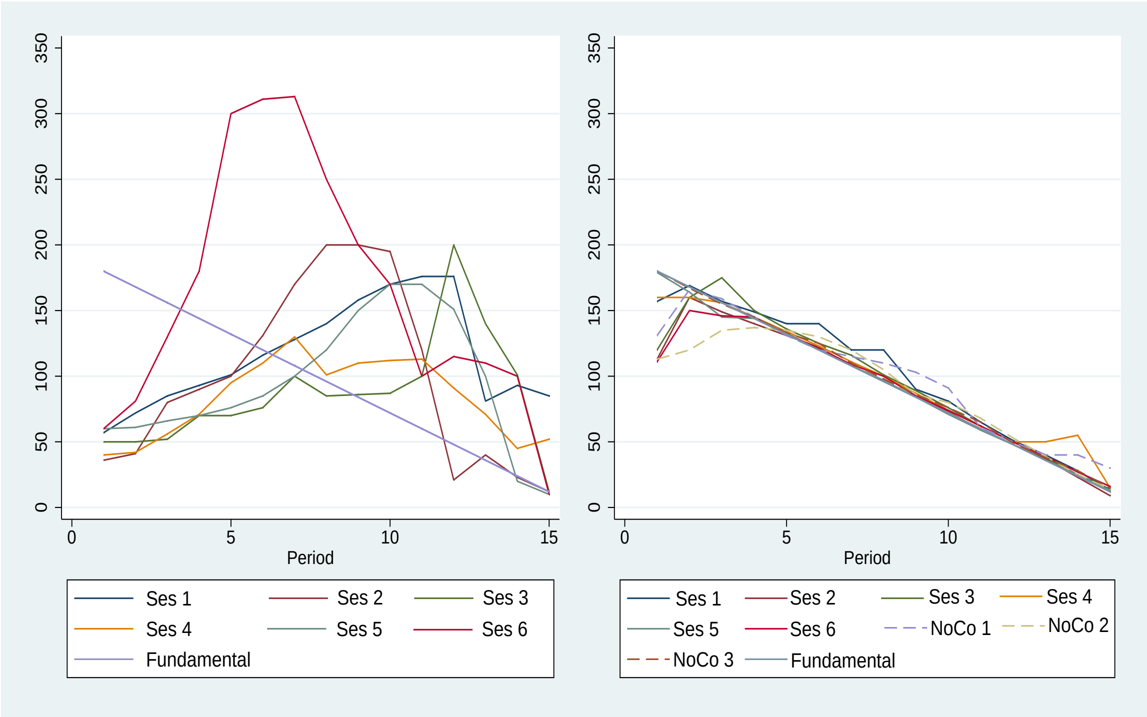

Figure 1: Asset prices in the first rounds of the two treatments: Six sessions in the Low Sophistication treatment (on the left) and nine sessions in the High Sophistication treatment (on the right). The diagonal line corresponds to the asset fundamental value.

4.2 High Sophistication Treatment

Under the High Sophistication treatment we ran a total of nine sessions where all subjects were chosen from to the upper 30% of the distribution of S_i. In six of these sessions subjects were told that everyone in the session had "scored above average" in the cognitive tasks. The results for these six High Sophistication sessions are striking by how markedly they differ from the standard results of bubbles and crashes. In all six sessions, asset prices track the fundamental value (almost) perfectly, as shown in the diagram on the right of Figure 1 with the labels Sessions 1 to 6. While in both treatments, Low and High, prices start below the fundamental value (as one would expect if subjects are risk averse and begin the experiment by testing the market), in the High Sophistication treatment prices reach the fundamental value sooner and hover close to it for the remaining periods. Because we were in doubt whether the disappearance of the bubbles was due to the high cognitive scores of the experimental subjects or to their shared knowledge of it, we ran three additional sessions. These sessions were populated by High Sophistication subjects who were *not told* that they had been selected because of their high scores (dashed lines in Figure 1 with labels NoCo1 to 3). Again, we observe that prices approach the fundamental value of the asset from below and stay close to it for the remaining periods. In essence, as before, bubbles and crashes vanish. Since we do not observe any differences whether subjects share or not a knowledge for their common sophistication, we pool the nine sessions together in the graph to the right of Figure 1, to facilitate the comparison with the Low Sophistication treatment on the left of it. In the second and third round of the High Sophistication treatment we observe basically the same price dynamics.[13]

5 Discussion

In order to formally compare the asset price dynamics in our two treatments, we make use of the two standard bubble measures by (Stöckl et al. (2010)). These measures are relative absolute deviation (RAD) and relative deviation (RD). We also use a measure of our own, which we call positive deviation (PD). This last measure is analogous to RD except that it only takes into account positive deviations from the fundamental value, i.e. overvaluations of the asset. These measures are defined as follows:

$$\text{RAD} = \frac{1}{N}\sum_{t=1}^{N} |P_t - FV_t|/\overline{FV} \tag{1}$$

$$\text{RD} = \frac{1}{N}\sum_{t=1}^{N} (P_t - FV_t)/\overline{FV} \tag{2}$$

$$\text{PD} = \frac{1}{N_{pos}}\sum_{t=1}^{N_{pos}} \max\{0, (P_t - FV_t)/\overline{FV}\}, \tag{3}$$

where P_t and FV_t denote the observed price and the fundamental value in period t respectively. The number of total periods is $N = 15$, and N_{pos} denotes the number of rounds in which the deviations from the fundamental have a positive sign. In Figure 2 we show the values of all three measures (RAD, RD and PD) for the first round across all sessions: dots correspond to the six Low Sophistication sessions and triangles to the nine High Sophistication sessions. The values of the three measures for the High Sophistication sessions have a low variance and are grouped together close to zero (the means are 0.077,

[13] In two of the nine sessions in this treatment, prices tend to rise somewhat towards the end of the third round. We do not attribute any significance to this pattern, which might well be due to simple boredom from the previous uneventful rounds. See Appendix D for additional comments.

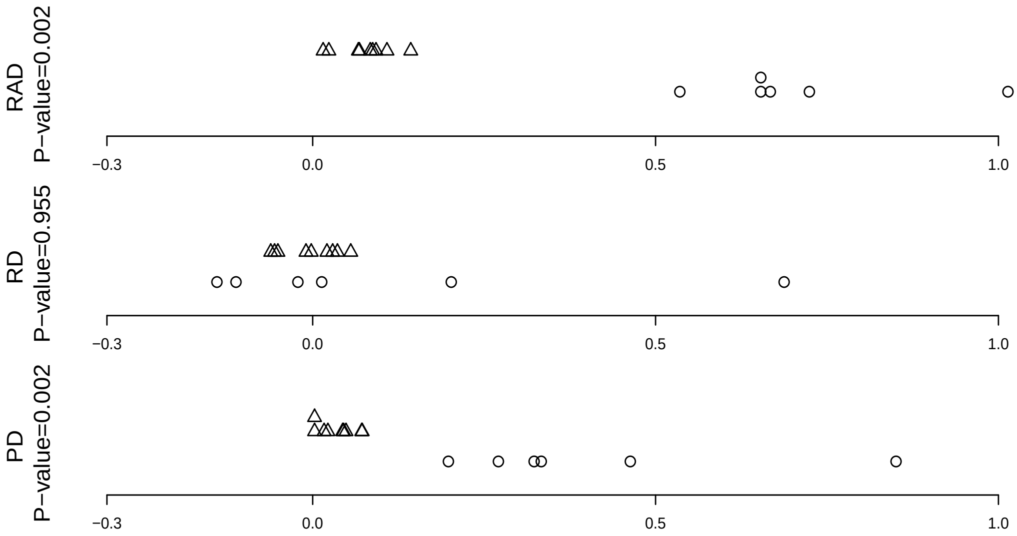

Figure 2: Bubble measures RAD, RD, and PD in the first rounds for all sessions. Dots and triangles represent Low Sophistication and High Sophistication respectively. P-values were calculated by use of Mann-Whitney U-tests.

-0.004, and 0.036, for RAD, RD, and PD, respectively), confirming that in this treatment asset prices stay close to the fundamental value. In contrast, the values of the three measures for the Low Sophistication sessions are dispersed with means above zero (means are 0.70, 0.10, and 0.33 for RAD, RD and PD, respectively)[14]. A Mann-Whitney U-test (p-values for RAD, RD and PD are 0.002, 0.955 and 0.002, respectively), indicates that we can safely reject the hypothesis that RAD and PD values come from the same distribution in the two treatments.

As mentioned above, in every period subjects were asked to predict asset prices for the actual and the remaining periods of the round before posting a bid or ask. These predictions were incentivized to nudge subjects to give their best guess of present and future prices. Figure 3 shows the average predictions (over the first rounds of all sessions) for the Low (left) and High (right) treatments respectively. One axis indicates the period in which the prediction was elicited (t), while the other shows the predictions for all remaining periods ($16 - t$). The coloring of the bars indicates their height, with lighter colors representing higher price predictions and darker colors representing lower price

[14]While RAD aggregates the absolute distances of the prices to the fundamental values, and therefore, the larger the deviations above and below, the larger is the value it takes, RD can give a result close to zero even if the distances from below and from above are large, provided they are similar in absolute value.

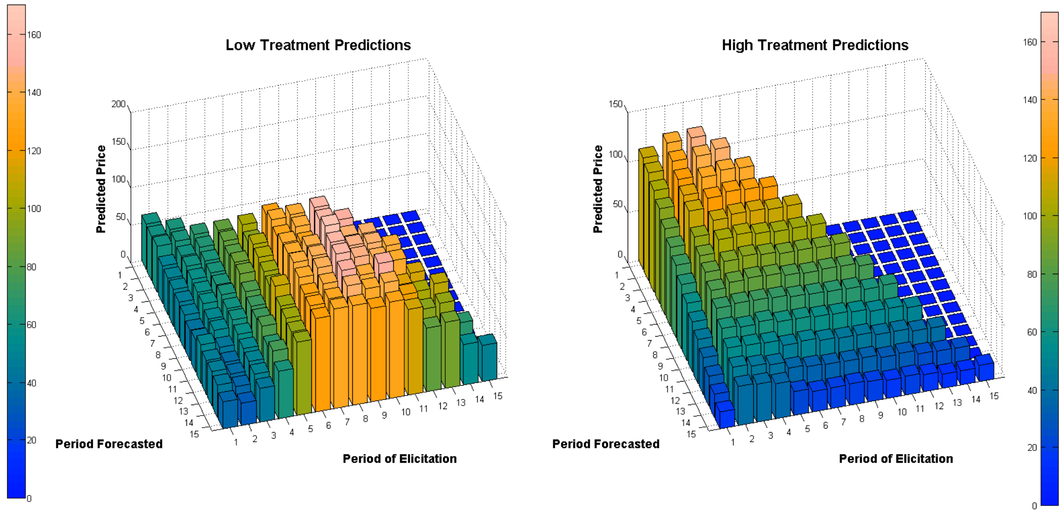

Figure 3: Average price predictions in the Low Treatment (left) and High Treatment (right). "Period of Elicitation" indicates the period in which the price predictions are made. "Period Forecasted" indicates the periods for which the predictions are made. The colors of the bars code for the average prices predicted, from beige for high prices to dark blue for low ones.

predictions.[15]

In the Low Treatment, we observe the color pattern running perpendicular to the x-axis as subjects, in each period of elicitation, do not anticipate the price changes across the remaining periods. In contrast, in the High Treatment, bar colors remain unaltered along the x-axis, indicating that subjects on average predicted the same price for each period independently of the period in which prices were elicited. In other words, they anticipated from the beginning of the experiment what was bound to happen and, therefore, did not have to change their predictions as the experiment proceeded. For a different view of the predictions, in Figure 4 we present a rotation of Figure 3 that offers a frontal perspective of the axis describing the period of elicitation. This view shows the price predictions stacking on top of each other, with the highest prediction for each period topping the column. In addition, to facilitate the comparison, we plot a line, representing the observed (average) prices at each period.

In a nutshell, Figures 3 and 4 show that in the Low Treatment subjects keep adjusting their predictions to the current price, such that there is little difference between the

[15]While we included the numerical values on the z-axis, it is easier to read the levels of the price predictions from their color coding, as the perspective distorts the vertical view.

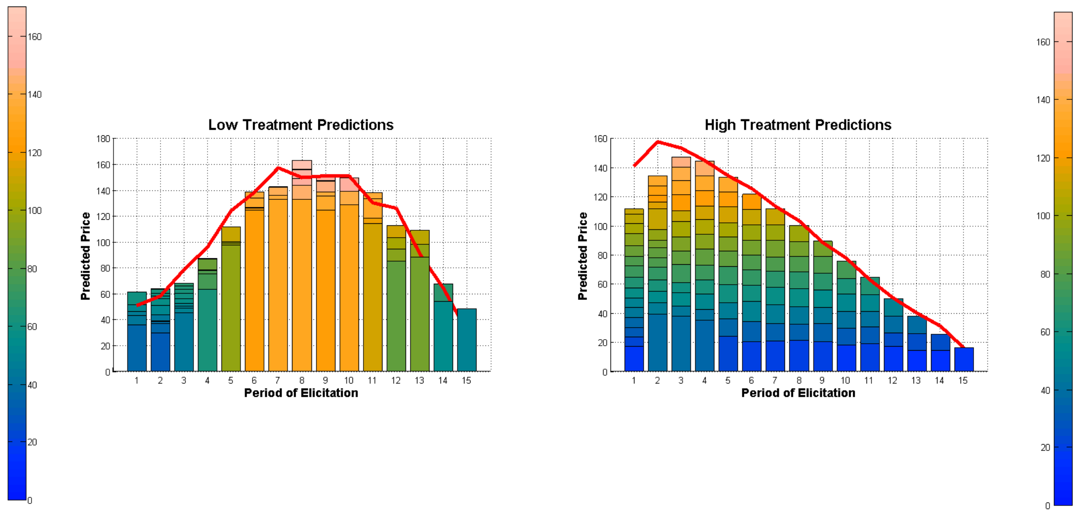

Figure 4: Average price predictions in the Low treatment (left) and High treatment (right). The (red) line plots the observed average price at each period

current price and their next-price prediction. Instead, in the High Treatment, the price predictions stay very close to the fundamental values, and so do the actual prices. Such different patterns of price expectations between Low Sophistication and High Sophistication participants bring further support to the hypothesis that subjects' confusion is at the root of the bubbles and crashes typically observed in the asset experimental markets. Low Sophistication subjects are apparently lost, their incentivized price predictions merely mimicking the current observed price, unable to anticipate what is coming next. High Sophistication subjects, on the contrary, appear to understand what the experiment is all about. They predict well, and bubbles basically vanish in their sessions.

6 Conclusion

Our goal was to test the hypothesis that bubbles and crashes observed in experimental asset markets are due to the subjects' lack of cognitive sophistication. We use a battery of cognitive tests to separate our pool of subjects into two groups (High and Low Sophistication) and run separate experiments with each group. The results are striking. While the asset markets populated by Low Sophistication subjects show the usual pattern of bubbles and crashes, these vanish when the experimental subjects belong to the High Sophistication group. Such results lend strong support to the hypothesis that the bubbles and crashes observed in experimental asset markets are caused by subjects' confusion with the experiment and consequently, raise some questions about the external validity of this type of experiments. Incidentally, if subjects are confused by the relatively simple design of the asset market described in the paper, then the results of more complex experiments should be taken with the proverbial grain of salt.

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A Instructions

The instructions below are translated from the original German instructions. The instructions were read aloud to the participants.

Overview This is the first part of a two-part experiment. The second part will take place this coming Friday, November 7th, 2014. Depending on your decisions in this experiment you may be invited to the second part of the experiment. However, not all participants of this experiment will be invited to the second part. The experiment today is made up of several games and questionnaires. After each game/questionnaire, you will receive new instructions for the next game/questionnaire. In total, the experiment will take approx. one hour. For your participation you will receive a minimum payment of 5 Euro. Depending on your actions during the experiment you can earn more than that. After all questionnaires and games are done, your payoff will be shown on your monitor. You will then be handed a receipt in which you enter your earned payoff as well as your name and address. Please go then to the adjoining room to receive your payment.

Quiz In this quiz, we ask you to answer three questions of differing difficulty. Please try to answer as many of them as possible. You have 5 minutes of time, and you will receive one Euro for each question answered correctly.

Game 1 In this game you choose a number between 0 and 100 (both included). The other participants also choose a number between 0 and 100. Your payoff depends on how far away your number is from 2/3 of the average of all chosen numbers (yours included). The closer your number to 2/3 of the average, the higher your payoff. Your payoff is calculated as follows:

$$\text{Payoff (in Euro)} = 1 - 0.05 * |\text{your number} - 2/3 * \text{average}|$$

In words: your payoff (in Euro) is calculated as 1 minus 0.05 times the absolute difference between your number and two thirds of the average of all chosen numbers. Since the absolute difference (as indicated by the absolute value bars "|") is used, it does not matter whether your number is above or below two thirds of the average. Only the absolute distance is used to calculate your payoff. The smaller the difference, i.e. the distance of your number to two thirds of the average of the chosen numbers, the higher your payoff. Please note that your payoff cannot be negative. If your payoff, as calculated with the above formula, turns out to be negative, then you will receive 0 Euro. Since the payoff for the other participants is calculated in the same way, they too have an incentive to choose a number that is as close as possible to 2/3 of the average. You are playing this game with all other participants that are presently in the room. You have 90 seconds to enter your number.

Game 2 This game is very similar to the game played before. Again, it is your goal to choose numbers that are as close as possible to 2/3 of the average. This time, however, you will be playing against yourself. You are playing the same game as before, only this time the only player with whom you play, is yourself. This time you will be asked to enter two numbers between 0 and 100 (both included), and your payoff will depend on how close your numbers are to two thirds of the average of the two numbers that you chose. Since you play against yourself, the average number equals your first chosen number plus your second chosen number, divided by two. This time you will be paid twice, once for each number you choose. The payoff for your first chosen number is calculated as:

$$\text{Payoff (in Euro)} = 0.5 - 0.05|\text{Number1} - 2/3 * [((\text{Number1} + \text{Number2}))/2]|,$$

where Number1 is the first chosen number, and Number2 is the second chosen number. Your payoff for your second chosen number is calculated as:

$$\text{Payoff (in Euro)} = 0.5 - 0.05|\text{Number2} - 2/3 * [((\text{Number1} + \text{Number2}))/2]|,$$

You have 90 seconds to enter both numbers.

Game 3 (Race to 60) In this game, you play several repetitions of the game "Race to 60". Your goal is to win this game as often as possible against the computer. In this game you and the computer alternately choose numbers between 1 and 10. The numbers are added up, and whoever chooses the number that pushes the sum of numbers to or above 60 wins the game. In detail, the game works as follows: You start the game against the computer, by choosing a number between 1 and 10 (both included). Then the game follows these steps: The computer enters a number between 1 and 10. This number is added to your number. The sum of all chosen numbers so far is shown on the screen. If the sum is smaller than 60, you again enter a number between 1 and 10, which in turn will be added to all numbers chosen so far by you and the computer. This sequence is repeated until the sum of all numbers is above or equal to 60. Whoever (i.e. you or the computer) chooses the number that adds up to a sum equal or above 60 wins the game. You will be playing this game 12 times against the computer. For each of these games you have 90 seconds of time. For each game won, you receive 0,5 Euro.

B Index of Cognitive Sophistication

The index S_i used to rank participants is constructed according to the following weighted average:

$$S_i = 1/3 * \text{CRTn}_i + 1/3 * (0.5 * \text{DistanceOSn}_i + 0.5 * \text{Selfn}_i) + 1/3 * (0.5 * \text{Racen}_i + 0.5 * \text{MeanBIn}_i)$$

CRTn: CRTn is the normalized result of the number of correct answers for the CRT questions (if all three answers are correct, CRTn=1, if only two are correct, CRTn=2/3, if only one, CRTn=1/3, and CRTn=0 if no correct answers.

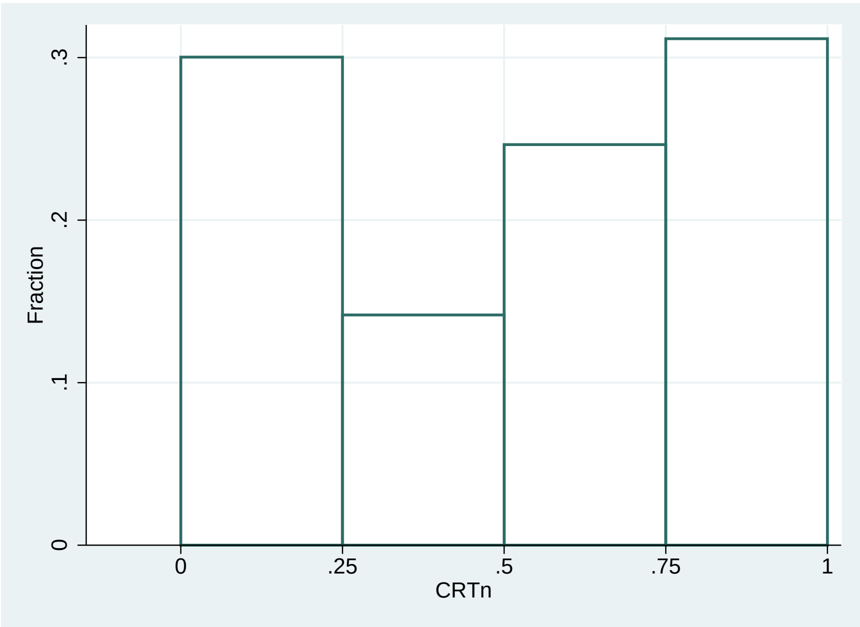

Figure 5: CRTn Distribution

DistanceOSn: The variable DistanceOSn is our measure of how well a subject performed in the guessing game. To construct it we take the following steps. First, we separate the choices of all subjects (ChoiceOS_i) into two groups: those that played a dominated strategy (i.e. ChoiceOS $>$ 66) and the rest. Those in the former group are assigned a score of zero for their DistanceOSn. We then define our "objective" value, which is 2/3 of the average of choices all chosen numbers in the guessing game across all

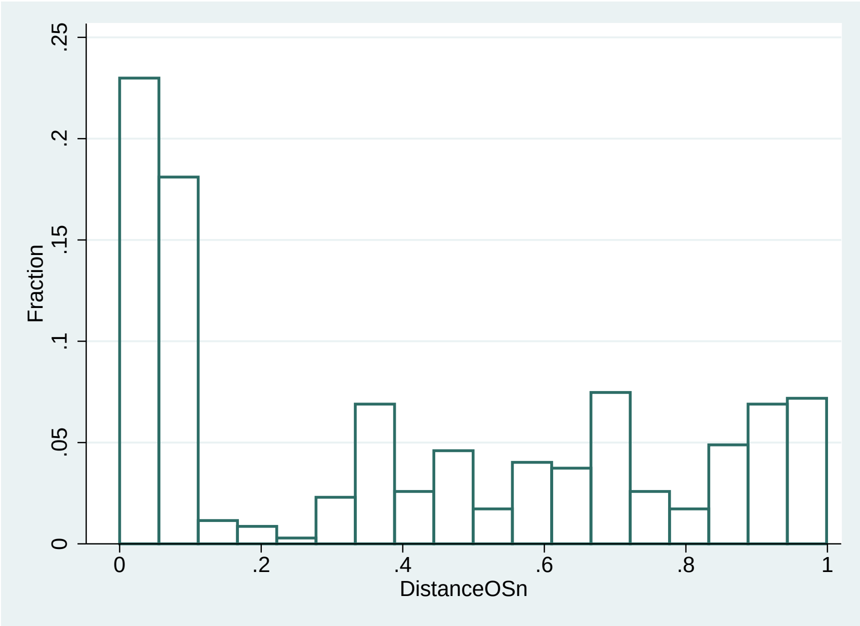

Figure 6: DistanceOSn Distribution

sessions , which is 25.587. With this, we create a measure called Distance_i as follows:

$$\text{Distance}_i = |(25.587 - \text{ChoiceOS}_i)/(66 - 25.587)|,$$

if $\text{ChoiceOS}_i \leq 66$. This allows us to rank all subjects in a range between zero and one, with zero being assigned to those players that played exactly the objective value and one to those subjects that played above 66. In addition, we posit that choosing a number below the objective value indicates a better understanding of the game than choosing a number above it. Accordingly, in our measure of cognitive sophistication for the guessing game we add an extra 50% to the "distance" for any choice above the objective value. This translates into the following equation:

$$\text{DistanceOSn}_i = \max\{0, \begin{cases} 1 - \text{Distance}_i * 1.5 & \text{if ChoiceOS}_i > 25.587 \\ 1 - \text{Distance}_i & \text{if ChoiceOS}_i < 25.587 \end{cases}\}$$

Selfn: The measure Selfn, for cognitive sophistication in the "playing against self" game, is again a two-step procedure. We posit that the game has two dimensions of understanding: the first dimension is realizing that the numbers picked should always be close together (in fact they should be the same); the second dimension is realizing that there is a unique correct answer (zero for both choices). In order to evaluate both dimensions we first measure the distance of each choice (ProximitySelf^1 and ProximitySelf^2) to 2/3 of the average (AvgSelf) of both:

$$\text{ProximitySelf}_i^1 = |\text{Self}_i^1 - 2/3\text{AvgSelf}|$$

$$\text{ProximitySelf}_i^2 = |\text{Self}_i^2 - 2/3\text{AvgSelf}|$$

,

where Self_i^1 is the first number chosen and Self_i^2 is the second number chosen by subject i. We then create a normalized measure for the proximity of both values:

$$\text{NormalizedSelf}_i^a = 1 - (\text{ProximitySelf}_i^1 + \text{ProximitySelf}_i 2)/100$$

Next we compute the second measure:

$$\text{Normalizedself}_i^b = 1 - (\text{Self}_i^1 + \text{Self}_i^2)/200,$$

which penalizes subjects for picking numbers away from the solution of the game. Using both NormalizedSelf^a and NormalizedSelf^b we create the final measure:

$$\text{Selfn}_i = (\text{NormalizedSelf}_i^a + \text{NormalizedSelf}_i b)/2$$

Racen: This measure is the normalization of the number of rounds won by each subject in the Race to 60 game (Won_i):

$$\text{Racen}_i = \text{Won}_i/12$$

MeanBIn This measure is the average number of backward induction steps (MeanBIn) that a subject made during the 12 Rounds of Race to 60. Race to 60 has a correct path [5, 16, 27, 38, 49, 60] that allows the first mover to always win the game. The number of backward induction steps is dependent on when a subject enters this optimal path and stays on it. If a subject starts out with a 5, and then stays on the correct path, we say that she has 6 backward induction steps. In this case she has solved the game

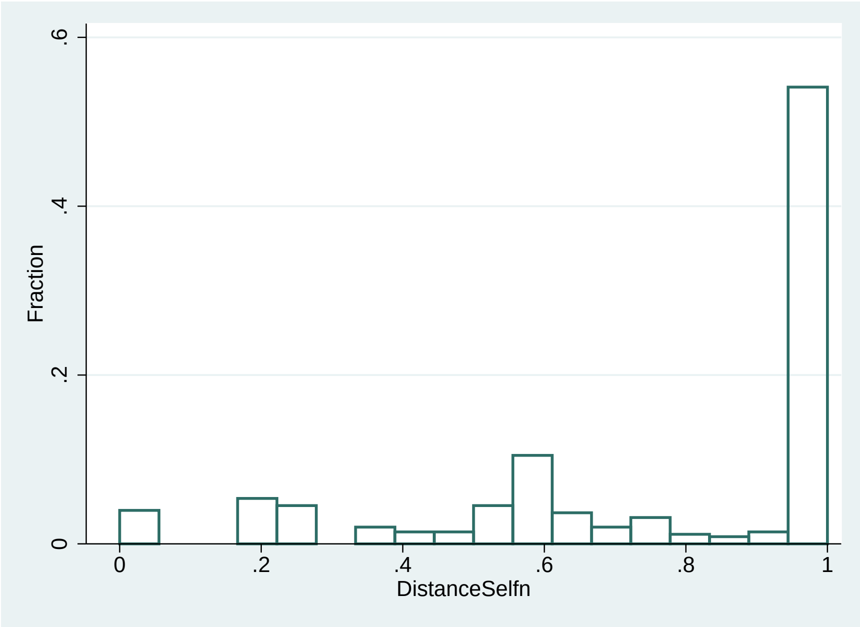

Figure 7: Selfn Distribution

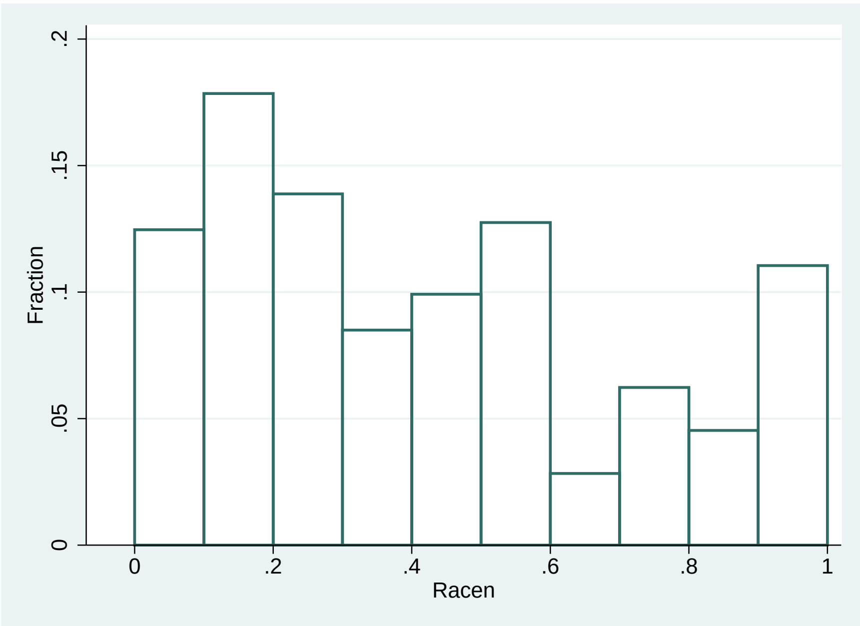

Figure 8: Racen Distribution

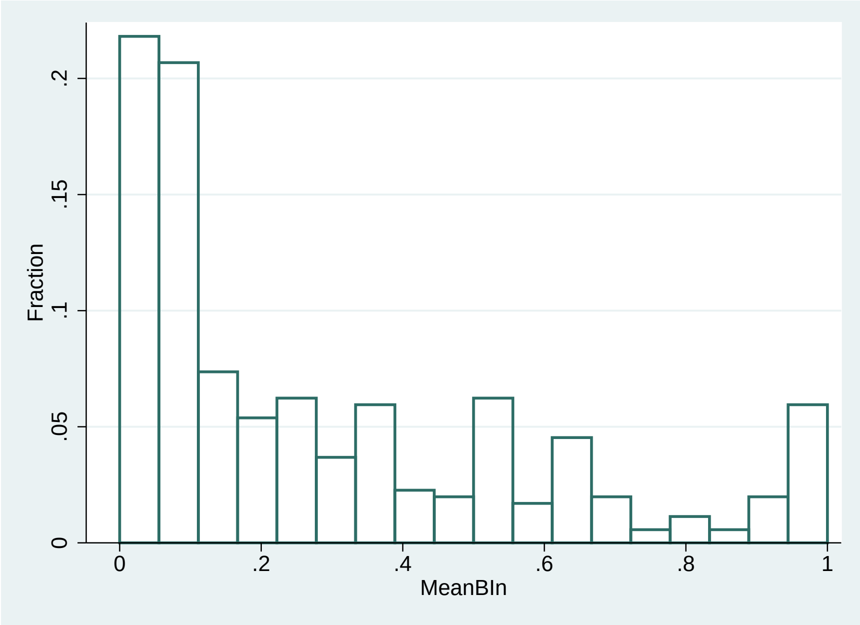

Figure 9: MeanBIn Distribution

completely. Consequently, if a subject enters the correct path at, say, 38 she thinks three steps ahead. We then create the measure $MeanBIn$ which is the normalized mean of backward induction steps that a subject has taken across all 12 rounds.

$$\text{MeanBI}_i = \sum_{r=1}^{12} \frac{\text{BIsteps}_{ir}}{12}$$

It is important to notice that we are able to extract this measure because we varied the number of backward induction steps the computer made. If our computer had 6 steps of backward induction, we would not know if a subject is able to make 4 or 3 or 2 backward induction steps, since the computer will enter the optimal path earlier than a subject with less than 6 backward induction steps. Our subjects played two rounds against a computer with one backward induction steps, two rounds against a computer with two backward induction steps, and so on.

Distribution of S_i Finally we present the distribution of S_i in Figure 10. Any subject with a score $S_i > 0.678$ ($S_i < 0.28$) was considered to be of High (Low) Sophistication.

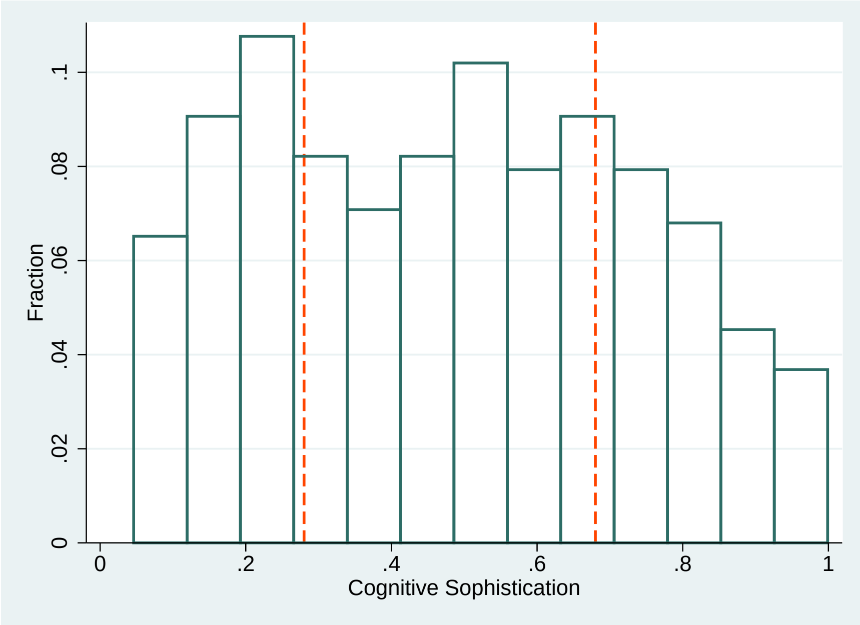

Figure 10: Cognitive Sophistication Measure (S_i) Distribution. The red dashed lines mark the separation for Low and High Sophistication subjects

C Asset Market Experiment Instructions

This is the second part of the experiment. [Based on your answers to the questionnaires and your actions in the games of the first part of the experiment, we have calculated a "performance score", that reflects the quality of your decisions. You have been invited to this experiment today because your score was above average.] [The last two sentences were only included in the instructions for the "shared-knowledge" High Sophistication treatment]

Overview This is an economic experiment on decisions in markets. In this experiment we generate a market, in which you trade units of a fictitious asset with the other participants of the experiment. The instructions are not complicated, and if you follow them closely and make appropriate decisions, you can earn a considerable amount of money. The money that you earn during the experiment will be paid in cash at the end of the experiment. The experiment consists of 3 rounds. Each round consists of 15 periods (in the following also named trading periods) in which you have the opportunity to trade in the market, i.e. to buy and sell. The currency in which you trade is called "Taler". All transactions in the market will be denoted in this currency. The payoff that you receive will be paid in Euro. You will receive one Euro for every 90 Taler.

Experiment Software and Market You will be trading in one of two markets, each of which consists of 7 participants. Both markets are identical in their functionality and are independent of each other. Your assignment to one of these markets is random, and you will stay in this market for the duration of the experiment. You can make your decisions in the market through the experiment software. A screenshot of this software can be found on the next page. In every trading period you can buy and sell units of an asset (called "share" from now on). In the top left corner of the screen you can see how many Taler and shares you have at every moment (see screenshot). In case you want to buy shares, you can issue a buy order. A buy order contains the number of shares that you want to buy and the highest price that you are willing to pay per share. In case you want to sell shares, you can issue a sell order. Similar to the buy order, a sell order contains the number of shares that you want to sell as well as the lowest price that you are willing to accept for each share. The price at which you want to buy shares has to be lower than the price at which you want to sell shares. All prices refer to prices of a single share.

The experiment software combines the buy and sell orders of all participants and determines the trading price, at which shares are bought and sold. This price is determined so that the number of shares with sell order prices at or below this price is equal to the number of shares with buy order prices at or above this price. All participants who submit buy orders above the trading price will buy shares, and those that have sell orders below the trading price will sell shares. Example of how the market works: Suppose there are four traders in the market and:

- Trader 1 submits a buy order for one share at the price of 60 Taler.
- Trader 2 submits a buy order for one share at the price of 20 Taler.
- Trader 3 submits a sell order for one share at the price of 10 Taler.
- Trader 4 submits a sell order for one share at the price of 40 Taler.

At any price above 40, there are more units offered for sale than units for purchase. At any price below 20, there are more units offered for purchase than for sale. At any price between 21 and 39, there is an equal number of units offered for purchase and sale. The trading price is the lowest price at which there is an equal number of units offered for purchase and sale. In this case, the trading price is 21 Taler. Trader 1 buys one share from Trader 3 at the price of 21 Taler. Trader 2 buys no shares, because her buy order price is below the trading price. Trader 4 does not sell any shares, because her sell order price is above the trading price.

Specific Instructions for this Experiment This experiment consist of 3 independent rounds, each consisting of 15 trading periods. In every period you can trade in the market, according to the rules stated above. At the start of each round, you receive an endowment of Taler and shares. This endowment does not have to be the same for every participant. As mentioned, you can see the amount of shares and Taler that you own on the top left corner of your screen. Shares have a life of 15 periods. The shares that you have purchased in one period are at your disposal at the next period. If you happen to own 5 shares at the end of period 1, you own the same 5 shares at the beginning of period 2. For every share you own, you receive a dividend at the end of each of the 15 periods. At the end of each period, including period 15, each share pays a dividend of either 0, 4, 14, or 30 Taler, with equal probability. This means that the average dividend is 12 Taler. The dividend is added automatically to your Taler account at the end of each period. After the dividend of period 15 has been paid, the market closes and you will not receive any further dividends for the shares that you own. After this round is finished, a new round of 15 period starts, in which you can buy and sell shares. Since all rounds are independent, shares and Taler from the previous period are not at your disposal anymore. Instead, you receive the same endowment of shares and Taler that you had at the beginning of round one. The experiment consists of 3 rounds with 15 periods each.

Average Holding Value The table "Average Holding Value", which is attached to these instructions, is meant to facilitate your choices. The table shows how much dividend a share pays on average, if you hold it from the current period until the last period, i.e. period 15 of this round. The first column indicates the current period. The second column gives the average earnings of a share if it is held from this period until the end of the round. These earnings are calculated as the average dividend, 12, multiplied by the number of remaining periods, including the current period.

Accuracy	Your Earnings
Within 10% of actual price	5 Taler
Within 25% of actual price	2 Taler
Within 50% of actual price	1 Taler

Predictions In addition to the money you earn by trading shares, you can earn additional money by predicting the trading prices. In every period, before you can trade shares, you will be asked to predict the trading prices in all future periods. You will indicate your forecasts in a screen that looks exactly like the screen in front of you. The cells correspond to the periods for which you have to make a forecast. Each cell is labeled with the period for which you are asked to make a forecast. The amount of Taler you can earn with your forecasts is calculated as follows.

You can earn money on each and every forecast. The accuracy is calculated separately for each forecast. For example, in period 2, your forecast from period 1 and your forecast from period 2 are evaluated separately. If both forecast are within 10% of the actual price, you earn 2*5=10 Taler. If one is within 10% of the actual price and one is within 25% of the actual price, but not within 10%, you earn 5 Taler + 2 Taler = 7 Taler.

Your Payoff For your participation you receive a fixed payment of 5 Euro and a payment that depends on your actions. The latter part of the payment is calculated for each round, as the amount of Taler that you have at the end of period 15, after the last dividend has been paid, plus the amount of Taler you receive for your forecasts. Your payoff for each round is calculated as:

The amount of Taler you have at the beginning of period 1
+ the dividends you receive
+ Taler that you receive from selling shares
– Taler that you spend on shares
+ Taler that you earn with your forecasts.

The total payment that you receive in Euro consists of the sum of Taler you earn in all three rounds, multiplied by 1/90, plus the fixed payment of 5 Euro.

Period	Average Holding Value
1	180
2	168
3	156
4	144
5	132
6	120
7	108
8	96
9	84
10	72
11	60
12	48
13	36
14	24
15	12

D Second and Third Round Results

In this section we report the results for the second and third round of our market sessions, both for High and Low treatments.

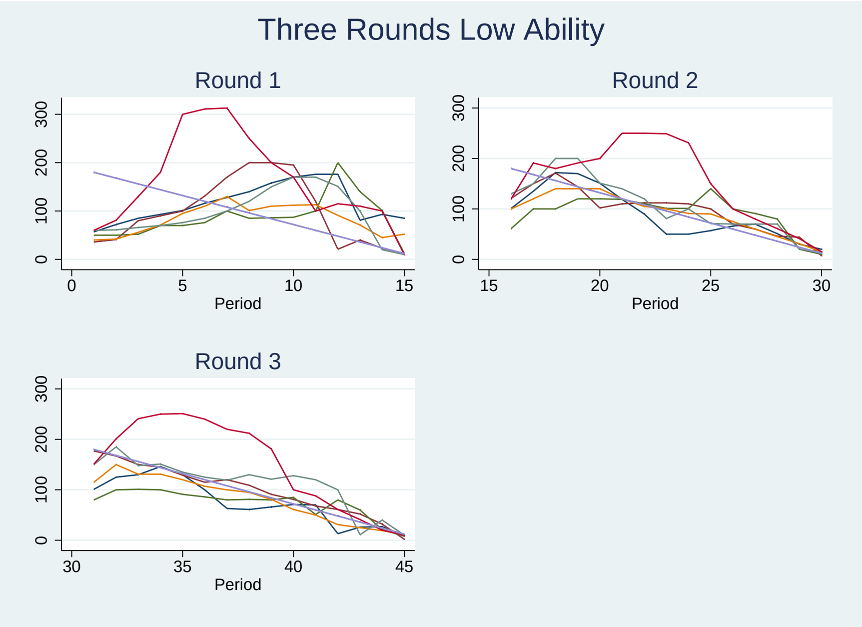

Figure 11: All Rounds Low Markets

In Figure 11 we present the evolution of prices in the Low Sophistication sessions. As usually found in the literature, prices appear to converge (slowly) to the fundamental value. We present standard bubble measures for all rounds in Table 1. Indeed, all bubble measures appear to decrease over rounds, indicating convergence to the fundamental value. The price dynamics for the High Sophistication treatment are presented in Figure 12. There seems to be a slight increase in deviations from the fundamental value in the last round, according to the bubble measures in Table 1 This deviation appears to be concentrated in the late periods of two of the nine sessions, which might very well indicate, as we mentioned in footnote 13, that some subjects were becoming bored from the third repetition of an uneventful market.

In this appendix, we also document the price predictions of our two treatments in rounds 2 and 3. (Figure 13 and 14). Two things are noteworthy in the Low Sophistication treatment; first, subjects in the second round predict a bubble and crash pattern, which is akin to what Haruvy et al. (2007) observe in their experiment. Second, in the third round subjects seem to have improved their understanding of the asset price dynamics and

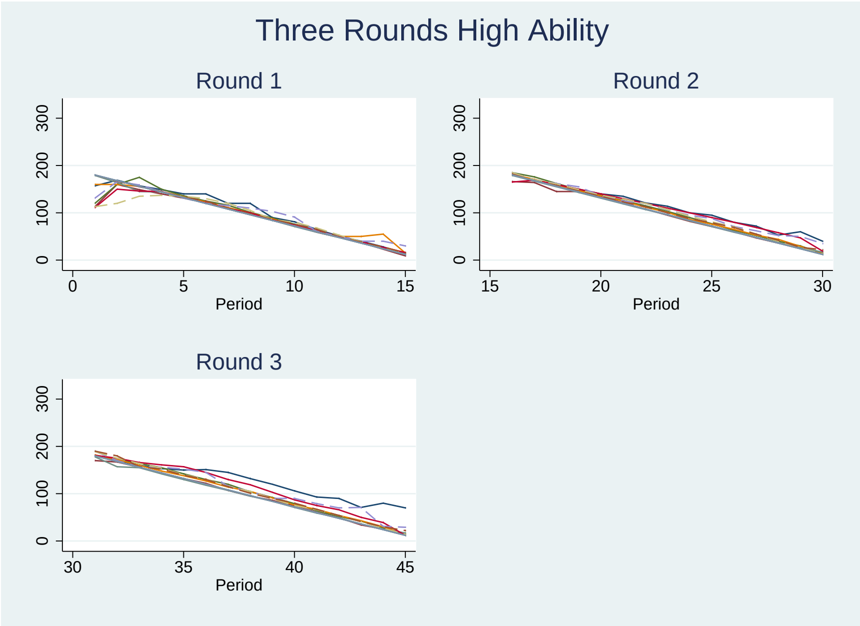

Figure 12: All Rounds High Markets

predict a falling trajectory of prices instead of the perennial inverted-U shape of round 1 and 2. As in round 1, the price predictions in the High Sophistication treatment track the fundamental value almost perfectly.

Measure	Treatment	Round 1	Round 2	Round 3	Total
mean RAD	high	0.077	0.074	0.101	0.084
mean RAD	low	0.708	0.308	0.277	0.431
pvalue		0.002	0	0.018	0
mean RD	high	-0.004	0.065	0.095	0.052
mean RD	low	0.105	0.092	0.031	0.148
pvalue		0.955	0.272	0.388	0.529
mean PD	high	0.036	0.069	0.098	0.068
mean PD	low	0.406	0.2	0.154	0.253
pvalue		0	0.066	0.955	0.008

Table 1: Bubble Measures. P-values are calculated using the Mann-Whitney U-test, the null hypothesis being that the distributions of the measures in the treatments high and low are identical.

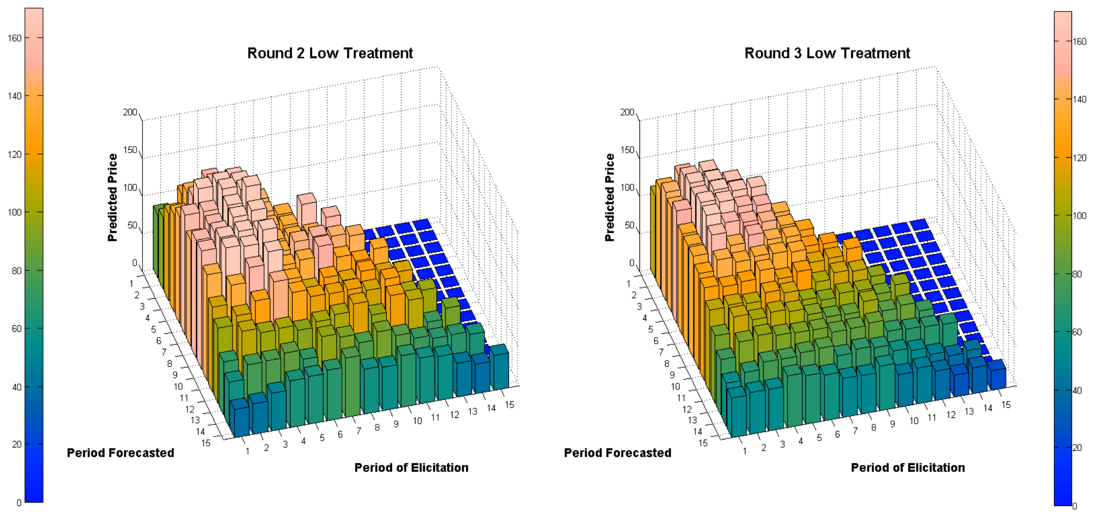

Figure 13: Price Predictions for Round 2 and 3 of the Low Treatment

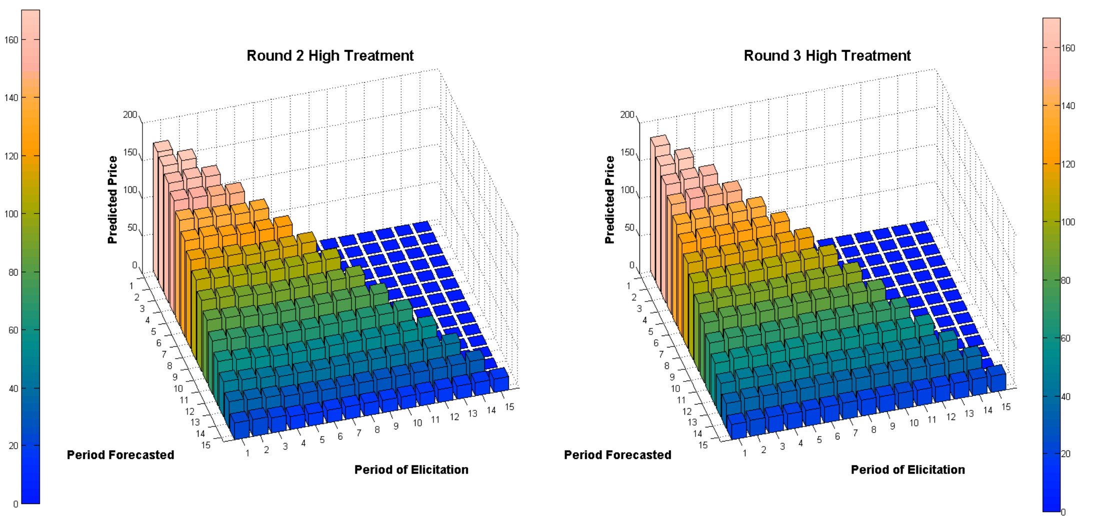

Figure 14: Price Predictions for Round 2 and 3 of the High Treatment