Forming Price Expectations in Positive and Negative Feedback Systems

by Peter Heemeijer, Cars Hommes,
Jan Tuinstra & Joep Sonnemans (June 2004)

CeNDEF
Center for Non-linear Dynamics in Economics and Finance

ABSTRACT

We analyse the results of an experiment on expectation formation carried out last year (*i.e.*, 2003) in the CREED laboratory in Amsterdam. The experiment involved 78 participants, who were asked to predict prices in artificial single-good economies, and were paid according to their accuracy in doing so. Thirteen markets, with six subjects each, were created, in two different treatments. The first treatment concerns a Cobweb-like commodity market with supply-driven expectations feedback. The second treatment concerns a speculative asset market with demand-driven expectations feedback. In the first treatment price fluctuations are relatively stable, quickly converging to the Rational Expectations fundamental value. In the second treatment prices do not converge quickly, but tend to display a slow oscillation around the fundamental price. An important factor in generating these differences is shown to be the strong coordination of price predictions among participants. This suggests a large degree of homogeneity in the expectation rules applied by the participants, which was confirmed by explicitly fitting the individual predictions to a linear adaptive autoregressive specification.

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UNIVERSITEIT VAN AMSTERDAM

*Peter Heemeijer, Assistant Researcher**
p.heemeijer@uva.nl

Jan Tuinstra, Senior Researcher
j.tuinstra@uva.nl

Cars Hommes, Professor of Economics
c.h.hommes@uva.nl

Joep Sonnemans, Senior Researcher
j.h.sonnemans@uva.nl

Center for Non-linear Dynamics in Economics and Finance, www.fee.uva.nl/cendef

* Correspondence relating to the content of this working paper may be directed at the first author.

1. Introduction

In February 2003 an experiment on expectation formation was carried out in the economics laboratory at the University of Amsterdam. In total it involved 78 participants, mostly students of economics and students coming from neighboring faculties. The participants were asked to predict prices in artificial single-good economies and were paid according to their forecasting accuracy. Thirteen such economies were created, by dividing the participants into random groups of six. Of those groups, six formed a supply-driven cobweb-like economy, characterised by a negative price expectations feedback system, and seven formed a demand-driven asset pricing-like economy, characterised by a positive expectations feedback system. Actually, the experimental models had been designed to differ only in the sign of their expectations feedback effect. All economies were run for 50 time periods, and all of them had an endogenous price development, except for a small amount of added noise. The objective of the experiment has been to study the influence of market structure on individual price expectations and on the resulting stability properties of prices, by applying two canonical models that are each representative of a large class of markets, and comparing their results.

The experiment that is the topic of this working paper has been the last of a series of experiments on expectations formation directed by the CeNDEF research group over the last few years. The results from these experiments, in which also Cars Hommes, Jan Tuinstra and Joep Sonnemans were involved, have been bundled and analysed in a PhD thesis by Henk van de Velden (2001)[1]. Much like the experiment of this paper, the main goals of Van de Velden's research were to study price expectations formation in cobweb- and asset pricing-like models, and to compare the results. As it turned out though, the second of these goals was difficult to achieve directly, since the two models, aside from having opposite expectations feedback effects, were burdened by an important asymmetry in the prediction horizon of the participants. That is, because of peculiarities in the models' design, participants in the Asset Pricing treatments were asked to predict the market price of two periods ahead, while participants in the Cobweb treatments could suffice with next period predictions (*pp.* 3-4). Qualitative differences in the results could therefore not easily be ascribed to either one of the two model asymmetries, considerably hindering any comparison. In the present setup both models have been restructured so as to preserve their essential characteristics, but, at the same time, reduce their differences to the expectations feedback sign only. Thus, the feedback sign can hereafter be held responsible for any difference in results between treatments[2].

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[1] Two parts of which, Hommes *et al.* (2004a) and Hommes *et al.* (2004b), are to be published as seperate articles.

[2] It is beyond the scope of this working paper to further treat here the literature connected to the present research. Suffice it to say that prominent related articles are Lei, Noussair & Plott (2001), Smith, Suchanek & Williams (1988) and Schmalensee (1976), while the main theoretical inspiration comes from Brock & Hommes (1997). Recently, Leitner & Schmidt (2004) have reported an

2. Stucture of the artificial economies

The participants were randomly divided into groups of six and every group was then placed in one of two artificial economic environments[3]. In both environments, participants were asked in each time period to predict the market price of the following period, while on their computer screens a graphical and numerical record was kept of past market prices and their own predictions of those prices. By assuming the demand and supply functions to be fixed in all cases, the participants' predictions in each group then generated the true market price, to which only a small random shock was dealt, preventing trivial developments. Once the new price was calculated, the records on the computer screens would be updated and, except of course in the final time period, the participants would again be asked for their predictions of the next period. It is important to keep in mind that the two models in the experiment have been designed to bear each other an almost perfect resemblance, disturbed only in the feedback sign of price expectations.

The first of the artificial economies used in the experiment was based on a Cobweb model. This model has been designed to represent markets for a non-storable consumer good or semi-good, which are driven mainly by price predictions and resulting production decisions of the suppliers, rather than by comparable predictions and decisions of consumers[4]. In the experiment a market maker version of the Cobweb model was used, meaning that equality between demand and supply in each period is not required, but that the market price is constantly adapted in the direction of the excess demand, the trade gap itself being absorbed by a hypothetical market maker. Thus, it is the difference between demand and supply that drives the price development. Increasing price predictions lead to increasing production, a decreasing excess demand and therefore lower prices, causing tendencies in expectations to produce a reverse effect in market prices. The following price adjustment formula was used:

$$p_t = p_{t-1} + \lambda\left(D(p_{t-1}) - \sum_{h=1}^{H} n_{h,t} S(p^e_{h,t}) \right) + \varepsilon_t \qquad (1)$$

Between the brackets the excess demand is depicted. D And S are the demand and supply curves respectively, while $n_{h,t}$ and H are the market shares of the producers in the economy and the number of producers respectively. They are equal to 1/6 and 6, since each producer is associated

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experiment on expectation formation in the international currency market. Their experiment is related to our Asset Pricing treatment, and yields comparable results.

[3] Actually, the experiment consisted of four sessions, performed on four seperate occasions. At the start of each of the sessions, the participants were randomly grouped. See Appendix A for details about the experimental design.

[4] The Cobweb model apparently originates from an article by Kaldor (1934). Subsequent to its discovery, it was mainly applied to markets for agricultural products such as pigs, from whence the expression "hog cycle" derived, and corn (see, *e.g.*, Ezekiel (1938) and Nerlove (1958)). Later, the application of the model was broadened, with notable applications to job market fluctuations (*e.g.* Freeman (1976)). An important new field of application for the Cobweb model might be the market for computer microchips, which seems to show many of its typical characteristics (*Economist* 1996a, 1996b, 2001).

with a single participant and the producers have equal and constant shares in the market. The market maker adjusts the market price proportionally to the excess demand, using some positive value for λ, and makes a slight error ε in the process[5]. In the Cobweb treatment, the participants act as advisors to the producers in the market, so their individual price expectations $p_{h,t}^{e}$ determine aggrgate supply. The demand and supply functions are taken to be linearly decreasing and linearly increasing respectively. A demand function of this form is compatible with micro-economic principles, while a linearly increasing supply function is implied by the assumption that the producers have quadratic production costs[6].

It is important to note here that the quantity between brackets in equation (1) is never actually realized on the market, but is rather a crude anticipation by the market maker of excess demand in time period t. This seemingly unconventional market structure is actually generated by the production lag that is characteristic of the Cobweb model. This lag forces the producers to come up with a price estimate of the next period and commence production based on it, before the actual price becomes known, in our case as a result of calculations by the market maker. Therefore, assuming that the market maker can observe either the price expectations directly together with the supply functions, or the resulting magnitudes of production, it would be only natural for him to attempt to use this information in the calculation of the next period's price. Equation (1) is actually a specific case of such a correction to the price adjustment calculation, with the supply quantities based on the predictions for time period t - 1 being entirely replaced by the quantities based on the most recent predictions[7]. Our reason for choosing this particular market structure has been to create a maximum of symmetry between the two treatments, as will become clear from the description of the positive expectations feedback model below.

The second of the artificial economies the participants were confronted with consisted of an Asset Pricing model. Usually, such a model is said to describe the price development of a financial asset, such as a stock or an option, by comparing in some way demand and supply for this good. An excess of demand would characteristically lead to an increase in the asset price, and an excess supply to the reverse. Since in the experiment demand was taken to be an increasing function of the price predictions, as would be natural in the case of a stock or an option, our Asset Pricing treatment was driven by a positive expectations feedback system, which, to a certain extent, confirmed any tendency in the participants' belief about future prices. The basic pricing formula was chosen to be the following:

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[5] Without loss of generality though, the noise term can be multiplied by $1/\lambda$ and moved to within the brackets, allowing it to be interpreted as a demand shock, which may seem more credible.

[6] The producers are assumed to behave homogeneously. The supply function is explicitly derived in the mathematical appendix.

[7] If our interpretation of equation (1) seems unrepresentative of Cobweb-like models in practice, it is important to note that the parameter choices in the experiment also make it equivalent to the more traditional equilibrium version of the Cobweb model. This equivalence is shown in the mathematical appendix.

$$p_t = p_{t-1} + \lambda \left(\sum_{h=1}^{H} n_{h,t} \frac{E_{h,t}\left(p_{h,t}^e + y_t - (1+r)p_{t-1}\right)}{a\sigma^2} - z^s \right) + \varepsilon_t \tag{2}$$

In this recursive equation prices are, as in the Cobweb model above, adapted by a market maker in proportion to the excess in demand, which is shown between brackets on the right hand side. After this adaptation, they are slightly distorted by a randomly varying amount denoted by epsilon[8]. Within the brackets, a constant supply of assets z^s is subtracted from aggregate demand, which consists of a sum of the individual demand quantities of the traders on the market. It is assumed that the participants function as advisors to these traders, informing them of their predictions $p_{h,t}^e$, which the traders then use to calculate their demand functions. In this sense, the Asset Pricing market fundamentally differs from the Cobweb market, for the latter is primarily supply-driven and therefore requires participants to submit their predictions to producers instead of buyers. Since six participants form a group in the experiment and the traders are again defined to have an equal market share, $n_{h,t}$ equals 1/6 and H equals 6. The specific shape of the demand function, in which y_t represents a stochastic dividend with variance σ^2 generated by the asset, r equals the risk-free rate of return, such as one would normally get on a savings deposit, and a equals the coefficient of risk aversion, is derived using mean-variance optimization[9].

In the experiment, the parameters in the Cobweb equation (1) have been chosen in such a way as to allow for a reasonable amount of convergence potential, to obtain symmetry in expectations feedback properties with the second model presented below, and at the same time to keep mathematics as simple as possible. To satisfy these principles, the feedback effects of both realized and expected prizes were required to have specific values, in their turn restricting parameter choice. Assuming that price expectations rules are equal among participants, feedback effects are as follows, the slopes of the demand and supply functions denoted by – d and s respectively:

$$\frac{\partial p_t}{\partial p_{t-1}} = 1 - \lambda d, \quad \frac{\partial p_t}{\partial p_t^e} = -\lambda s \tag{3}$$

Firstly, we take the market to be fundamentally well-behaved, which is to say that prices converge globally to the fundamental price under naive expectations rules. After substituting for naivety, the derivatives in (3) can be added, making the requirement for global convergence that $\lambda(d+s)$ fall between zero and two. Secondly, we remove entirely the state variable feedback, denoted by the first derivative in (3), to ease comparison between the two models and to simplify

[8] Similarly to the Cobweb model, ε can be put inside the brackets and interpreted as a supply shock, if so desired.
[9] This derivation can be found in the mathematical appendix to this working paper. In particular, it requires that the traders have a constant absolute risk aversion and that they believe the dividend proces to be normally distributed. It is again assumed here that the economic behavior of the traders is completely homogeneous.

further calculations. This requires us to set λ equal to $1/d$, at the same time equating the product above to $1+s/d$, which necessitates the slope of the supply function to be absolutely smaller than the slope of the demand function. Selecting, based on these considerations, suitable values for the remaining parameters[10], the law of motion becomes the following:

$$p_t = \frac{20}{21}\left(123 - \sum_{h=1}^{6} \frac{1}{6} p_{h,t}^e\right) + \varepsilon_t \tag{4}$$

Similarly, the first-order derivatives generated by Asset Pricing equation (2), assuming uniformity of the participants' prediction rules, are listed below:

$$\frac{\partial p_t}{\partial p_{t-1}} = 1 - \frac{\lambda(1+r)}{a\sigma^2}, \quad \frac{\partial p_t}{\partial p_t^e} = \frac{\lambda}{a\sigma^2} \tag{5}$$

To achieve symmetry between both treatments, so that they differ only in the sign of the expectations feedback, it is necessary to set the first derivative equal to zero and the second to λ. Assuming that in both models the market maker uses the same price adjustment parameter, these restrictions imply that $a\sigma^2 = 1$ and $\lambda = 1/(1+r)$. Making the remaining parameter choices in accordance with the interpretation of equation (2)[11], the actual law of motion became the one below:

$$p_t = \frac{20}{21}\left(\sum_{h=1}^{6} \frac{1}{6} p_{h,t}^e + 3\right) + \varepsilon_t \tag{6}$$

3. Inspection of the experimental data

At the end of the experiment, each of the thirteen groups had generated a series of 50 market prices along with six series of predicted prices, of the same length. Also, each of the participants had answered a set of questions regarding the experiment and themselves, and was paid a sum of money proportional to the accuracy of his predictions[12].

The results of the first six groups, assigned to the Cobweb treatment, are shown in Figure

[10] That is, s was set equal to 1, d to 21/20 and λ to 20/21. Furthermore, the intercept of the demand function was chosen to be 123 and the distribution of the noise term was taken to be normal, specifically N(0, 1/4). It will be verified in the mathematical appendix that with these parameter choices the fundamental price is equal to 60. The feedback effects in (3) imply that prices will globally converge to it in an alternating manner under naive expectations.

[11] That is, $y = 4$, $\sigma^2 = 1/4$, $a = 4$ and $z^s = 1$. $r = 1/20$ Already follows directly from the last restriction for λ. The distribution of the noise term was again defined to be N(0, 1/4). These parameter values produce a fundamental price of 60, the same as in the Cobweb model, with prices globally converging monotonically under naive expectations. See the mathematical appendix for details.

[12] The questionnaire consisted of a total of 22 questions, mostly on the participant's behavior during the experiment and on background information that might have influenced the results. The participants were paid according to a quadratic scoring rule, allowing them to earn a maximum of half a euro for a perfectly accurate prediction. See for details Appendix A.

#1[13]. The six corresponding graphs show considerable similarity. In all cases, the first few time periods demonstrate relatively large fluctuations of prices and price predictions around the fundamental price, which then peter out quickly, in most cases well before the tenth period. After this initial volatile phase has been completed, market prices and predictions remain very close to the fundamental price, except for some incidental outliers in predictions, causing a deviation in the market price, which is though never large enough to destabilize the system[14]. These rough qualitative features suggest that the Cobweb market structure generates great stability in the price development. It might even be supposed, if an entry phase of a few periods is respected and thus excluded from further analysis, that the market prices do not deviate significantly from those under the assumption of rational expectations, that is, from a purely stochastic move-ment around the fundamental price. Verification of this hypothesis would be remarkable, since the participants have been provided only with a bare minimum of information of the market, as is described in Appendix A, and, in particular, were not informed of the explicit demand and supply functions. This question, and others related to it, will be addressed in the following sections.

The results of the seven groups assigned to the Asset Pricing treatment are shown in Figure #2. Again there is much similarity between the graphs in the figure, though in a manner different from the Cobweb case. The initial phase leading to coordination among the price predictions of the participants is now much shorter, in most groups only one time period. On the other hand, the coordination of beliefs, unlike in the Cobweb setting, here does not automatically generate convergence of the market price to the fundamental price. Therefore, though the price predictions tend to be very close to each other within each of the seven groups, the market price only occasionally is very close to the fundamental price. This imperfection seems to be slowly alleviating, since most graphs apparently demonstrate a dampening oscillatory movement around the fundamental. There also seem to be exceptions to this supposition however, most notably in graphs (b) and (g), in which the market price rather seems to hover over the fundamental price, making it unclear whether long-term convergence will be achieved. An interesting difference with the Cobweb treatment lies in the occasional outliers in individual forcasts. These appear to have a much greater effect on the market price and on the other predictions, in some cases resulting in disrupting the market price development by inflating the apparent oscillatory movement[15]. In the following sections, the extent to which the Asset Pricing markets converge to the fundamental price will be investigated, and particular attention will be paid to the individual expectation rules, which, in this particular context, seem to prevent fast convergence.

Earnings by the participants were almost uniformly close to the greatest possible amount, in both the Cobweb and Asset Pricing treatments. They are depicted in Figure #3 for all 78 partici-

[13] All figures will be collected in Appendix C, all tables in Appendix D.
[14] Examples can be found around period 36 in graph (c) and around periods 21 and 41 in graph (e). All perturbations seem to be due to errors made by single participants.
[15] The clearest case of such a disruption occurs at period 7 in graph (e), while other examples are periods 15 and 25 in graph (f).

pants, categorized according to session and group number[16]. The closeness of the individual earnings within the groups and, excepting only the second group in graph (d), between groups, is an implication of the strong coordination among price predictions that groups in both treatments tend to exhibit[17]. In the Cobweb model, such coordination is feasible only when it occurs close to the fundamental price, since in other cases the participants would be making obvious large errors *en masse*. In the Asset Pricing model though, coordination among participants does not restrict the market price to an area around the fundamental, since a unanimous deviation from the fundamental price produces a similar effect in the market price, allowing it some freedom of movement, which is then restricted by the absence of rational bubble solutions and the stability of the model under naive expectations[18]. Given the fact though, that, during the experiment, participants were unable to observe any of the other group members' price predictions, it is quite remarkable that the qualitative features from the group results in general seem to comply with the above analysis. The only way in which this apparent synchronization of price prediction movements can be explained is by the absence of any significant ideosyncracies in the procedure through which individuals form expectations. Thus, it seems there is a surprising amount of coordination in the participants' behavior, both in the Cobweb and the Asset Pricing treatment. In the following sections, an attempt will be made to formally describe this general type of expectation formation.

An interesting question with regard to the earnings of the participants is whether the limited amount of variance that is present among them can be explained to some extent by group membership or by personal characteristics. Table #1 in Appendix D shows the results from a least squares regression of the earnings on a selection of personal information, derived from the questionnaire, and group membership dummies. Surprisingly, nearly all of the variance can be explained by the variables that remain after restricting the significance level to 5%. Both personal information and group membership appear relevant in explaining the differences in earnings between participants.

Regarding the questionnaire variables, easily intelligible results are the positive coefficient signs with the variables "maximize income" and "made effort", indicating roughly that participants who described themselves as being profit maximizing, highly motivated individuals derived from this attitude a positive income effect. More difficult to interpret are the negative coefficient signs with the variables "age" and "study unknown". They are probably due though to the participation

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[16] In the first pair of sessions the Cobweb treatment was performed and in the second pair the Asset Pricing Treatment. All sessions were made up by three groups of participants, except for the last one, made up of four groups. For details, see Appendix A.

[17] Looking at graph (e) of Figure #2, it is easy to understand why this group's members have been by far the worst performing in the Asset Pricing treatment. Still, when the market price reenters the graph after the enormous shock at time period 7, all but one of the predictions already follow nicely in its path, suggesting that is is not a general lack of coordination, but rather an incidental desastrous error, that makes the group earn so poorly.

[18] The non-existence of explosive movements in the market price under rational expectations is shown in the mathematical appendix. For the global stability of both models under naive expectations, see Section 2.

of several older students and non-students in the experiment, who seemed to be less accurate than the younger student-participants.

The entries for the binary group variables clearly indicate the relatively large between group variance in earnings, since all but four of them, of which one is the reference variable, are highly significant. The coefficients show that the Cobweb groups as a whole earn less than groups #1, #3, #4 and #7 of the Asset Pricing treatment, but also that it cannot simply be said that Cobweb groups generally do worse than Asset Pricing groups, since Asset Pricing groups #5 and #6 also show considerable negative coefficients. This ambiguity in ordering the treatments according to earnings of their participants may be caused by the earlier observations that, on the one hand, the volatile entry phase takes longer to complete in the Cobweb treatment, but, on the other hand, the market price development in the Asset Pricing treatment is less trivial and more sensitive to prediction shocks. On the whole, the results from Table #1 show that in most cases group membership has a greater influence on earnings than individual characteristics have, which is consistent with the conjecture that the amount of heterogeneity in participants' prediction rules is small, and, in particular, that prominent individual characteristics like gender, type of education and cultural background do not significantly influence earnings.

4. Phase of Entry and Convergence

In the first period of the experiment, participants provided their estimates for that period's market price without having any information about prior market developments. Since they had read only a brief introduction about the general characteristics of the artificial market, in this first period they could do little more than give an arbitrary number between 0 and 100. In the periods following the beginning, this information shortage naturally alleviated, though the quality of predictions would indirectly still be impaired by the deliberately impulsive birth of the markets and the subsequent volatility in realized prices[19]. The testing of unambiguous hypotheses regarding the experimental data requires, though, that an assumption of stationarity can reasonably be made. Therefore, it is necessary to discard a certain number of time periods at the beginning of each of the data series, which approximately contains all the excess volatility due to market initialization. Between the treatments, the amount and the duration of this volatility varies greatly, so the amount of periods discarded will be seen to differ as well.

Figure #4 reproduces the results from the first groups of the Cobweb and Asset Pricing treatments. These groups are taken to be fairly representative for their treatments as a whole, so they will be used for expository purposes in this section. In both graphs of the Figure, dashed vertical lines have been drawn intersecting early time periods. At $t = 1$, represented by the y-axis

[19] The reason for not informing the participants of all the market characteristics explicitly was to keep the fundamental price from acting like a focal point, as could, for example, easily occur if the participants were shown a figure with the Marshallian cross associated with their treatment prior to the experiment. In such a case, pseudo-rational behavior would ensue that would have no practical relevance.

in both graphs, price predictions are more or less arbitrary, generating, as one would expect, a market price above the fundamental in the Cobweb group and one below it in the Asset Pricing group. At $t = 2$, the participants are aware of last period's market price and their own prediction of it, so they have a limited amount of data on which to base their second prediction. Since they only know one realized market price though, they cannot yet form an image of the way in which the price develops, so in both graphs we see a high proportion of naive expectations of the second market price.

It is at this point that an important difference arises between the two treatments. In the Cobweb group, because of the negative expectations feedback, the market price sinks below the fundamental price, denying most of the participants any earnings this period. In the Asset Pricing group, the situation is radically different, with the market price keeping at the same side of the fundamental, allowing some participants to already achieve near-maximum earnings, though the market price itself is quite far away from the fundamental. Obviously, after the second time period has been completed, participants start to think very differently between both treatments. In the Cobweb group, they are strongly motivated to avoid naive expectations in the coming period, while in the Asset Pricing group it probably seems a good idea not to deviate much from naivety.

At $t = 3$, we see indeed that naive predictions are largely avoided in the Cobweb group. Since the information set of participants now contains two market prices and their predictions of them, obvious alternatives are a linear extrapolation of the realized prices or some average of these prices and the predictions of the last period. Looking at graph (a) at the second dashed line, it seems that most group members have opted for the latter, resulting in a market price that is much closer to the fundamental value, though many predictions are still not very nearby. Looking at the same time period in graph (b), we see a much better performance. As was expected, participants have largely retained their naivety, pushing the market price slightly towards the fundamental, as is required by the global stability of the market under such expectations.

When the way in which the participants of the Asset Pricing group form their expectations in the third time period is compared to the way they do so the rest of the experiment, it cannot be said, at least after just a quick glance at the data, that there are major differences. It seems that the main reason for this behavioral consistence is the observation that the general characteristics of the market price development as a whole are already incorporated largely in its first two realizations. That is, a participant who simply predicts a linear extrapolation of the last two market prices, maybe adjusting slightly towards his last prediction or the last realized price, would do very well in the experiment, while he might have invented such a rule in the third period. Therefore, in the Asset Pricing treatment, the minimum amount of time periods that should be discarded to allow an assumption of stationarity to be made, is two.

In the Cobweb groups, the first time periods tend to be less coordinated than in the Asset Pricing case, so it is natural to suppose that more than two time periods should be discarded for further analysis. Indeed, in graph (a) at $t = 3$, it is clear that the participants cannot be expected to foresee the alternating behavior that the market price is about to display. One period ahead, though, they have witnessed the absence of monotinicity that is characteristic of all negative feedback systems under naive expectations, which does put them in a position to find an expectation rule befitting the structure of the market they participate in. The minimum number of time periods to be discarded in the Cobweb treatment should therefore equal three.

Inspecting graph (a) of Figure #4 at $t = 4$, it becomes clear immediately that the earliest moment when participants might theoretically adopt a succesful expectation rule is not necessarily equal to the moment in which the majority actually does so. At $t = 4$, the accuracy of the group as a whole is actually worse than the period before, though afterwards it improves strongly within a few time periods. Therefore, it seems wise to allow the participants a short learning period in addition to the few initial periods already discussed above, so as to be sure that the volatile beginning of the markets has no meaningful effect on the data series that will hereafter be analysed. A reasonable criterium to determine the end of such a learning phase would be, for each of the treatments separately, to set it equal to the first time period in which a majority within each group, that is at least four participants per group, first succeeds in submitting a prediction that comes very close to the realized price. If this criterium is fulfilled, it is very likely that stationarity of the prediction rules can be assumed, since even groups with strongly erratic beginnings by then show a certain amount of coordination on the market price, while the equality of market shares, as demonstrated in equations (1) and (2), ensures that accurate participants now dominate price determination everywhere.

Define the above criterium as the Majority Criterium and define the set of time periods preceding the period for which the Criterium is fulfilled as the Phase of Entry. Both concepts are dependent on what "coming very close to the realized price" is said to mean. Taking into account the noise that is, in each period, added to the market price, "very close" will here be interpreted as deviating no more than five percent from the market price of the same time period[20]. The length of the Phases of Entry, for the Cobweb and the Asset Pricing treatments respectively, is shown in Figure #5. Graphs (a) and (b) show the number of participants predicting close enough to the market price, per group and on average. Both graphs initially show a monotonous increase in the number of sufficiently accurate participants, covering virtually the whole range between zero and six. Once these average numbers reach the top they stay near it, only decreasing a little when prediction mistakes are made in specific groups. From the graphs the duration of the Phases of Entry can easily be derived. In the Asset Pricing treatment, the Majority Criterium is satisfied at $t = 4$, giving the Phase a length of three, and in the Cobweb treatment, in which the increase of the

[20] This level of accuracy implies that, if the market price will be equal to the fundamental price of 60, participants are "very close" to it if their prediction lies between 57 and 63. In other words, the distance should be less than six standard deviations of noise. Since rational players would almost always come to within two standard deviations, participants are required to have roughly one-third of the best-attainable accuracy. These demands become less strict if the market price will be higher than the fundamental, and stricter if it will be lower, reflecting the fact that the interval of possible prices below the fundamental is much shorter than the interval above it.

average number of accurate participants is less steep, it is satisfied at $t = 8$, implying a duration of seven[21]. In the rest of this working paper, market prices and price predictions dated before the end of the relevant Phase of Entry shall be excluded from the analysis.

It was already mentioned that, at least for the Asset Pricing treatment, coordination of price predictions does not by itself imply convergence of the market price to the fundamental value. This conjecture can be further refined by drawing a pair of graphs resembling the accuracy graphs of Figure #5, but counting rather the number of predictions that are sufficiently accurate relative to the fundamental price. These graphs are contained in Figure #6. Graph (a) strongly resembles its equivalent in Figure #5, which is logical, since after the Phase of Entry market prices in the Cobweb groups were, on the whole, very close to the fundamental value. Comparing Graphs (b) of Figures #5 and #6, on the other hand, reveals no similarity whatsoever. In the Asset Pricing groups, market prices are in general not very close to the fundamental value, though in most groups the market price passes several times through the fundamental, and, as was already hypothesised, there seems to be a tendency towards long-term convergence. These three observations are all reflected in graph (b) of Figure #6. Firstly, the graph shows average values that are much lower than comparable values of the accuracy graphs before it. Secondly, it shows upward and downward spikes in average values at time periods when many groups happen to cross, respectively not to cross, the fundamental price[22]. And thirdly, the evident tendency of the accentuated line to rise over the fifty period range suggests that general convergence can indeed be achieved if the experiment were repeated and run over a greater number of time periods[23].

5. Coordination and Overreaction

Both graphs of Figure #5 show that, when the Phase of Entry is complete, virtually all participants succeed in keeping their predictions very close to the market price. However, graphs (a) and (b) of Figure #4 demonstrate at the same time that predictive accuracy is not a sufficient condition for convergence of the market price to the fundamental value. That is, graph (a) does demonstrate such convergence approximately, while graph (b) does only slightly, at least within 50 time periods. It seems therefore, that, at least in the Asset Pricing treatment, despite of the

[21] In Figure #4, dashed lines have been drawn along these time periods following the end of the Phases of Entry. These are then followed only by a pair of lines lying three periods ahead, at $t = 11$ and $t = 7$ respectively, which marks the lower boundaries of the sample range that will be used in Section 6, when a specification with three price lags will be estimated on the data to identify individual expectation rules.

[22] As can be checked by comparing with Figure #2. For example, between time periods 10 and 20 all but the last of the Asset Pricing groups pass through the fundamental, producing three spikes in graph (b). Between periods 35 and 40, only groups #2 and #5 do not get close to the fundamental, resulting in two more spikes. Just after 40, all market prices are above the fundamental price, producing a long downward spike.

[23] Assuming that all Asset Pricing groups would have shown convergence to the fundamental price if they would have been allowed to continue for a longer time, the aggregate qualitative features of the results in the Asset Pricing treatment can be appropriately summarized with the phrases "fast coordination" and "slow convergence". The analogous phrases for the Cobweb treamtment would then be "slow coordination" and "fast convergence".

general accuracy, there exists a tendency towards a specific collective bias that prevents the market price from converging easily, as it would do for example under naive expectations. Such a tendency would be equivalent to the tendency towards blind coordination of price predictions identified in Section 3.

An easy way of quantifying expectation coordination in the sense of the above is suggested by the following error decomposition:

$$\begin{aligned}\sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(p_{h,t}^{e}-p_t\right)^2 &= \sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(p_{h,t}^{e}-\bar{p}_t^{e}+\bar{p}_t^{e}-p_t\right)^2\\ &= \sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(p_{h,t}^{e}-\bar{p}_t^{e}\right)^2+\sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(\bar{p}_t^{e}-p_t\right)^2+2\left(\bar{p}_t^{e}-p_t\right)\sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(p_{h,t}^{e}-\bar{p}_t^{e}\right)\\ &= \sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(p_{h,t}^{e}-\bar{p}_t^{e}\right)^2+\sum_{t=t^*}^{50}\sum_{h=1}^{6}\left(\bar{p}_t^{e}-p_t\right)^2\end{aligned} \tag{7}$$

Obviously, the decomposition applies to the results of a single group, in which t^* denotes the time period when its treatment as a whole fulfills the Majority Criterium and the superscript bar indicates an average of predictions. The first summation of terms on the right hand side can be named the Dispersion Error and the second the Common Error, since they measure the total quadratic deviation from the mean prediction of the group and the total quadratic deviation of this group mean to the market price respectively. Theoretically, it seems reasonable to suppose that the Common Error will be very small compared to the Dispersion Error. If there would be a sufficient amount of a priori heterogeneity among the group's participants, this would be a logical implication of the fact that individuals cannot observe each others' predictions. That is, when making the rather strong assumption that the distributions of the participants' predictions through time are roughtly centered around the actual market price[24].

Figure #7 shows the shares of the Common Error and the Dispersion Error in the total sum of squared errors, for each of the thirteen groups. Before calculating these shares, in each group those time periods were excluded that showed market or prediction price irregularities clearly due to incidental outliers in price predictions[25]. Including all time periods would have disproportionately increased the share of the Dispersion Error, since any prediction mistake adds much more to the dispersion of price predictions than to the displacement of the prediction mean, on

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[24] As such, this assumption is identical to Muth's original definition of the Rational Expectations Hypothesis (Muth, 1961, *p*. 316). In this working paper the Rational Expectations Hypothesis will be said to mean that participants can unerringly foresee market price development, excluding only the noise interference, as soon as the Phases of Entry have ended. As is demonstrated in the mathematical appendix, in the experiment rational individuals would always predict the fundamental price, resulting in a Common Error of zero and a Dispersion Error equal to the sum of squared noise terms.

[25] The sets of excluded time periods are as follows. For the six Cobweb groups: {44}, {8, ..., 12}, {36, 45, ..., 50}, Ø, {21, 41} and {8, ..., 15, 22} respectively. For the seven Asset Pricing groups: Ø, Ø, Ø, {39}, {7, ..., 16, 28, 34, 45}, {15, 25, 35} and Ø respectively. Figures #1 and #2 can be used to confirm that these periods indeed demonstrate abnormalities.

which it has only limited influence. Furthermore, the prediction mistakes in both treatments can indeed be regarded as accidents, because during most of the expriment all participants are quite able to submit fairly accurate predictions, eliminating the rationale for wild experimentation[26].

On the whole, Figure #7 shows surprisingly large shares for the Common Error, averaging in both treatments over 60% and reaching almost 80% in the Cobweb treatment. The smaller average and larger standard deviation of the Common Error shares in the Asset Pricing groups seem to be mainly caused by the relatively large Dispersion Error in the third through sixth groups of that treatment. Since Asset Pricing groups 5 and 6 were also the ones in the experiment suffering most from prediction mistakes and, on the other hand, the untroubled groups 1, 2 and 7 show results in Figure #7 that are entirely comparable with those of the Cobweb groups, it is quite possible that, despite the exclusion of atypical time periods beforehand, there is still some residual influence of the prediction mistakes biasing downward the average share of the Common Error in the Asset Pricing treatment. Therefore, aside from the general conclusion that the Common Error's share in the total prediction error is significant for both treatments, supporting the existence of blind coordination among participants that was already observed in the last section, it can be said that the degree of coordination is very high in both treatments, equalling at least 60% on average but being more likely to approach 80%, as long as prediction mistakes do not occur[27].

The significance of the Common Error in both treatments implies the existence of inter-subject coordination, but, more specifically, it also suggests the presence of certain regularities in the way participants tend to pick up changes in the market price. That is to say, a structural tendency to either over or underestimate short-term trends in the market price development could in theory result in the sort of error decomposition magnitudes witnessed in Figure #7. A simple way of gaining some intuition into the kind of prediction rules the participants coordinate on is to inspect the degree of overreaction their predictions tend to exhibit relative to market price fluctuations. Defining this kind of overreaction as the extent to which the average change, from one period to the next, in a participant's expectations is greater than the average change in realized prices on that participant's market, Figure #8 shows the degrees of overreaction for all 78 participants divided over the six Cobweb and zeven Asset Pricing groups.

Graph (a) gives an indication of the degrees of overreaction based on absolute changes in price predictions and market prices. Indeed it shows clear regularities whithin the treatments. The group averages of the mean absolute prediction changes, as represented by the grey bars, are below the mean absolute market price changes, represented by the black bars, for five out of six

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[26] In the answers to the questionnaire after the experiment, several participants actually admitted to having made prediction mistakes, mostly as a result of typing errors. See Appendix A for details.

[27] If the turbulent periods were not excluded, these averages would fall to 45% for the Asset Pricing treatment and 55% for the Cobweb treatment, the Asset Pricing treatment's Common Error being no longer significantly positive at reasonable significance levels. This dramatic drop confirms the statistic's sensitivity to prediction outliers.

Cobweb groups, while they are above them for all seven Asset Pricing groups[28]. This result suggests that participants in the Asset Pricing treatment have a tendency to overreact to changes in the market price, while Cobweb treatment participants instead show a tendency to underreact. These conjectures are further supported by the observations that never more than two participants overreact in any of the six Cobweb groups, that the one case of average overreaction in the Cobweb treatment, at group three, is clearly due to an outlier, and that only two participants in the entire Asset Pricing treatment underreact, excluding the possibility that the tendency to overreact in the Asset Pricing treatment is primarily caused by several outlying overreactions.

It must be noted here that the observed tendencies towards overreaction and underreaction in the Asset Pricing and Cobweb treatment respectively are consistent with the notion, which after a casual inspection of Figures #1 and #2 seems credible, that participants in the Asset Pricing groups generally use simple linear trend-extrapolative prediction rules, while their counterparts in the Cobweb groups rather seem to use some form of adaptive expectations rules. To these hypotheses, which will be further investigated in sections 6 and 7 of this working paper, Graph (b) of Figure #8 adds an interesting refinement.

The Graph is identical to Graph (a), except for the fact that it is based on nominal instead of absolute changes in price predictions and market prices. A first observation is the closeness of the grey and black bars, except for the third Cobweb group which is again disturbed by its confused fifth participant, indicating that the underreactions and overreactions occurring in Graph (a) are more or less symmetrical with respect to the sign of the change in market prices. The market prices themselves, though, do not everywhere follow a balanced movement in the time periods considered, as is demonstrated by all but the last of the Asset Pricing groups, again ignoring the third Cobweb group. Apparently, market prices and predictions thereof in the Asset Pricing treatment generally have a stronger tendency to rise than to fall and they do so in tandem.

There are two possible explanations for this phenomenon. Firstly, that the specific conception of the experimental markets, which for the Asset Pricing groups resulted in an initial market price of well below the fundamental value, together with the limited total amount of time periods produced, for many groups in the Asset Pricing treatment, unrepresentative segments of oscillatory price developments that may well have been, if they would have been complete, perfectly balanced in their increasing and decreasing parts. Secondly, that there is a specific asymmetry in the prediction rules used in the six Asset Pricing groups under consideration that makes participants respond differently to market price decreases and increases, in such a way that the increases tend to be reinforced more strongly than the decreases, while a discrepancy of any significance between the aggregate prediction changes and market price changes is avoided. Unfortunately, this working paper lacks the space to further explore these explanations, so they will be left as untested hypotheses for future research.

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[28] The fifth Asset Pricing group's grey bar floating at 64.56 and its black bar at 36.67, both falling beyond the range of the graph.

6. Testing the Rational Expectations Hypothesis

If all the participants of the experiment would have consistently used rational expectations, which is to say that all of them in each time period would have predicted correctly the deterministic part of the market price, then, as will be verified in the mathematical appendix, all price predictions would equal the fundamental value, leaving only noise as a source of inequality between the treatments. However, the experimental results, as shown in the Figures #1 and #2, clearly reveal major differences in both price predictions and market prices, suggesting that the above hypothesis of universal rationality does not hold. On the other hand, if we restrict attention to the groups of the Cobweb treatment only, and delete the Phase of Entry that has been devised in the last section, it would be very difficult to discern with the naked eye whether or not certain groups fulfill this rationality hypothesis.

In this section the Rational Expectations Hypothesis (REH) will be tested using several statistics comprised of realised prices[29]. The hypothesis itself can be simply formulated as follows:

$$H_0: \quad p_t \sim N\left(p^*, \sigma^2\right), \quad \forall t \in \left\{t^*, \ldots, 50\right\} \tag{8}$$

As usual, p^* denotes the fundamental price of 60, σ^2 the noise variance of 1/4 and t^* the period following termination of the Phase of Entry, equal to 8 in the Cobweb treatment and 4 in the Asset Pricing treatment. This probability distribution of the market price will be used to derive the distribution of several widely used statistics below. For each group, the realized value of these statistics will be confronted with their distributions under the null hypothesis, in order to investigate the extent to which the above Hypothesis can be considered to hold for this experiment.

The first statistics to be tested for consistence with the Rational Expectations Hypothesis are, of course, the mean and variance. Both of the statistics will be tested for each of the thirteen groups, but also the sample range will be varied in each case, to obtain a measure of the robustness of each end result. In total, dozens of tests will be performed on these first two sample moments, using the following explicit formulas, derived from the null hypothesis[30]:

$$\begin{aligned} \hat{p}_{t^{**}} &= \frac{1}{t^{**} - (t^* - 1)}\left(p_{t^*} + \ldots + p_{t^{**}}\right) \quad \sim N\left(p^*, \frac{\sigma^2}{t^{**} - (t^* - 1)}\right) \\ \Leftrightarrow \quad & \frac{\sqrt{t^{**} - (t^* - 1)}}{\sigma}\left(\hat{p}_{t^{**}} - p^*\right) \quad \sim N\left(0,1\right) \end{aligned} \tag{9}$$

[29] The REH, which might seem to have no practical significance to begin with, could be expected not to provide a reasonable explanation of market price behavior. However, it has been found that in both treatments in some sense the market price converges to the fundamental, allowing for the possibility that the REH would perform quite well as a long-term price description.

[30] The statistical derivations in this section are well-known and shall not be expounded here. See for example Bain & Engelhardt (1987 / 1992) and Enders (1995) for more information.

$$\hat{\sigma}^2 = \frac{1}{t^{**}-t^*}\left[\left(p_{t^*}-p^*\right)^2+\ldots+\left(p_{t^{**}}-p^*\right)^2\right] \sim \frac{\sigma^2}{t^{**}-t^*}\chi\left(t^{**}-t^*\right)$$
$$\Leftrightarrow \frac{t^{**}-t^*}{\sigma^2}\hat{\sigma}^2 \sim \chi\left(t^{**}-t^*\right) \qquad (10)$$

In these distributions, *t*** represents the upper boundary of the sample range over which the statistics are calculated, and *t**, as usual, represents the lower boundary. For each group, *t** is kept constant at the time period for which the Majority Criterium holds, while *t*** assumes all values between *t** and 50 for which the relevant statistic is defined[31].

Figure #9 shows the qualitative results for all tests on the group mean and variance. The significance level was set at 5%. Both graphs show a considerable difference between the two treatments, with the seven Asset Pricing groups showing a much higher rejection rate than the six Cobweb groups. This was to be expected, since already from Figure #2 it becomes clear that market price development in the Asset Pricing treatment is something quite different from a white noise process around the fundamental value. Also between the graphs there is some difference, since the Cobweb groups are more in accordance with the null hypothesis when tested for their mean than for their variance. This is also consistent with the graphs from Figure #1, since they show a development closely around the fundamental, but with occasional outliers and subsequent volatility that would inflate any statistic measuring the second moment of this development. On the whole, for the Asset Pricing treatment, 98.5% and 98.2% of all 329 tests were rejected in graphs (a) and (b) respectively, showing clearly the incapability of the Rational Expectations Hypothesis to describe the first two moments of the market price in this treatment[32]. For the Cobweb treatment the numbers are much better, though very different, 7.0% and 61.6% of all 258 tests being rejected in graphs (a) and (b) respectively. The REH seems therefore to be a rather good explanation of the first moment of price development in the Cobweb model, but not such a good one of the second moment[33].

Another implication of the Rational Expectations Hypothesis is the absence of any auto-

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[31] Ordering the sample ranges in such a way allows for a better evaluation of the validity of the null hypothesis, since it is basically being tested at every possible time period, ensuring that rejections or non-rejections that are unrepresentative of the group results as a whole do not obtain a false prominence.
[32] An interesting result is the non-rejection at $t^{**} = 50$ for group 8 in graph (a). If tests would only be done for full sample ranges, then it would appear that this group has an average market price that is not significantly different from the value predicted by the REH, while for all other ranges considered here the reverse statement holds.
[33] Another way of testing for the REH mean and variance is by fixing the upper boundary of the sample range and varying the lower boundary. This approach though yields rejection rates that are not qualitatively different from the ones above, with 97.9% and 88.2% respectively for the Asset Pricing groups, and 19.8% and 44.0% respectively for the Cobweb groups. For completeness, tests were also done over the full sample ranges, but excluding the turbulent time periods of footnote 25. The results were almost identical to those of the last columns in Figure #9, with only the variance test of the sixth Cobweb group being accepted instead of rejected, giving no reason to assume that prediction outliers are responsible for the REH's poor relevance.

correlation in market prices. That is, autocorrelation of the k-th order should, under the null hypothesis (9), have the following characteristics:

$$\hat{r}_k = \frac{\sum_{t=t^*+k}^{50} (p_t - \hat{p}_{50})(p_{t-k} - \hat{p}_{50}) \Big/ \left(50-(t^*+k-1)\right)}{\sum_{t=t^*}^{50} (p_t - \hat{p}_{50})^2 \Big/ \left(50-(t^*-1)\right)} \tag{11}$$

$$\Rightarrow \quad P\left(|\hat{r}_k| > 2 \Big/ \sqrt{50-(t^*-1)} \right) \approx 0.05$$

The implication describes a way in which the null hypothesis can be tested through the autocorrelation, at a significance level of 5%. The value of the r statistic in (11) has been calculated for each group and for each k up to five. The results are displayed in Figure #10. Again, the difference between both treatments is large, with the market prices in the Cobweb groups showing much less significance in the autocorrelation statistic than in the Asset Pricing groups. Also, each treatment suffers from autocorrelation in the realized prices with a specific sign only, the Asset Pricing groups showing only positive and the Cobweb groups only negative autocorrelation. These results are generally in line with the group results in Figures #1 and #2, since the Asset Pricing groups there revealed a long-term oscillatory movement around the fundamental value, suggesting positive autocorrelation with several lags at least, and the Cobweb groups showed a strong alternating convergence to the fundamental, suggesting negative autocorrelation with a single lag only[34]. The sixth column in Figure #10 shows that only two groups in the Cobweb treatment, one-third of the total number, is free entirely of market autocorrelation, while none of the Asset Pricing groups satisfy this criterium[35].

If the results of graphs (a) and (b) of Figure #9 and Figure #10 are compared, it can be seen that none of the groups in either of the two treatments convincingly statisfies the requirements of the Rational Expectations Hypothesis. In Figure #9, only groups 1 and 4 of the Cobweb treatment were candidates, but they were found to have a significant amount of autocorrelation, though in both cases the null hypothesis was rejected only marginally for a single order[36]. On the other hand, the Cobweb groups showed a much greater compliance with the REH than the Asset

[34] Moreover, the signs in Figure #10 neatly reproduce the signs of the corresponding feedback effects of the market structures, suggesting that participants tend to stick close to the last observed market price, so that the market price adaptation has the same sign as the feedback effect, ultimately equalizing the signs of the autocorrelation and the feedback.
[35] In more realistic models of asset markets, the Efficient Market Hypothesis would of course dispose of any easily predictable linear structure in market prices. Because of the chronological rigidity of our Asset Pricing model and the non-strategic risk-averseness of the traders though, the Hypothesis cannot be expected to hold here.
[36] It must be said though that comparing results in this sense effectively increases the significance level, so a joint non-rejection would indeed require "convincing satisfaction".

Pricing groups, especially through the mean, but in a smaller fraction of cases also through the variance and the autocorrelation.

7. Estimation of the individual prediction rules

The limitations of human cognition aside, it is impossible for the participants in the experiment to explicitly use the Rational Expectations strategy, since they are not given enough information beforehand to completely understand the structure of the market. Given this lack of information, it is all the more interesting that the market prices do show some compliance with the Rational Expectations Hypothesis, to an extent that cannot be entirely due to chance. On the other hand, on the basis of the tests employed in the last section, in the Asset Pricing treatment the REH is convincingly rejected. Therefore, to be able to understand the true development of the market price in both treatments, it is necessary to construct an alternative hypothesis that better incorporates the actual behavior of the participants.

Instead of assuming that the participants have a sound theoretical understanding of the market in which they are active, it is hereafter supposed that they use simple prediction rules, based on information of the recent past, for which they need neither theoretical insight nor computational skill. The information each individual has, consists of the series of market prices of his group up to the last time period, and the series of his past predictions of these prices. Assuming that participants can incorporate only a small amount of information in their prediction rules, the following specification might offer a reasonable description of these rules:

$$p_{h,t}^{\,e} = c + o_1 p_{t-1} + o_2 p_{t-2} + o_3 p_{t-3} + s_1 p^e_{h,t-1} + s_2 p^e_{h,t-2} + s_3 p^e_{h,t-3} + \varepsilon_t \qquad (12)$$

In its most general form, the specification uses three former market prices and three predictions of them, further containing only a constant c and a noise term ε. The market prices can be seen as objective variables and the predictions as subjective ones, which explains the names given to the six coefficients. As a whole, the linear specification in (12) will be designated the AdAR(3,3) prediction rule, AdAR standing for Adaptive Autoregressive, referring to the subjective and the objective parts of the specifation respectively, and the parameters indicate the greatest lag of the objective and subjective variables respectively that has been included as an explanatory variable.

Standard econometric techniques can be used to estimate the coefficients in (12), for all 78 participants. Ordinary Least Squares yields the results in Tables #2 and #3, for the Cobweb and the Asset Pricing treatment respectively. These results have also been depicted in Figure #11. In Tables #2 and #3 an encouraging result is that the amount of prediction rules for which autocorrelation has remained in the residuals is small, that is 7 out of 78, of which 3 originate from the fifth Asset Pricing group, which was subject to a wildly destabilizing prediction error. With more than 90% of all prediction developments described adequately by the AdAR specification, there is little reason to make it more complicated by introducing non-linearity or adding explanatory variables. Tables #2 and #3 show also that the R-squared statistic tends to be much larger in the

Asset Pricing treatment, though in the Cobweb treatment it already seems to achieve reasonably high values, given the rather unvolatile price developments in most of its groups[37]. Moreover, in the Asset Pricing treatment, the constant tends to have a much lower value than in the Cobweb treatment, the first lag of the market price tends to have absolutely a higher value, and more terms tend to have a coefficient that significantly differs from zero. These results all reflect the slow oscillating movement of the market price in the Asset Pricing treatment as opposed to the almost stable movement in the Cobweb treatment, in the sense that, in the Asset Pricing groups, participants cannot base their prediction rules on a single absolute value, but they can assign a high predictive value to the last market price, and in general they will need a more complicated rule to capture market price development than their colleagues in the Cobweb groups.

Figure 11 consists of a graphical representation of the objective and subjective coefficients of specification (12). The parameter vectors o and s have been plotted in seperate three-dimensional spaces. Additionally, in the so-called objective coefficient space, the results have been plotted of an application of (12) to the market prices of the thirteen groups, which amounted to an ordinary AR(3) estimation, since the subjective terms were irrelevant in this case[38]. The position of the open and closed diamonds representing the AR(3) coefficients give an indication how well the participants have picked up the statistical regularities in the market price developments. Note that the spaces differ in scale, suggesting immediately the asymmetry between objective and subjective variables in the participants' prediction rules.

The distribution of the dots within graphs (a) and (b) demonstrates several interesting features. Firstly, it seems as though, in both spaces, a large part of the dots lie on the two-dimensional level plane, and even stronger, in the subjective space, a majority is confined to one of the axis in the plane. It is impossible to verify this hypothesis from Figure #11 alone, but the extent to which it is true can easily be inferred by reading Tables #2 and #3. Secondly, in the objective coefficient space there are clear signs of clustering among coefficient vectors belonging to the same treatment, and between the group diamonds and vectors of the same treatment. In the subjective space clustering among coefficient vectors from the same treatment hardly seems to be present though. Thirdly, in the objective coefficient space, the vectors of the Cobweb treatment have a strong tendency to remain close to the origin, and the great majority of them appears to be very close to the positive unit square in the two-dimensional plane. At the same time, the coefficient vectors of the Asset Pricing treatment tend to be a bit farther from the origin, and almost all of them appear to lie in the unit square that roughly forms an "8" shape with the positive unit square. These conjectures taken together suggest that there might be a simple way to describe many of the estimated prediction rules, possibly even of both treatments simultaneously. An attempt at such a description will be made in the next section.

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[37] The fact that zero values for the R-squared are associated with prediction rules that cannot be distinguished from Rational Expectations and therefore should be excluded if the R-squared is to be interpreted as a measure of the quality of estimation, makes this statement even more true.
[38] A numerical version of these results has been contained in Table #4.

The success of the AdAR(3,3) specification in capturing the great majority of the participants' prediction rules demonstrates, whatever the true mechanism is generating these rules, that the human capacity for expectation formation is severely limited both in memory usage and in the construction of an appropriate specification. By far the most of the prediction series in the experiment can be statistically described by an additively linear composition of the available price information, with a lag depth of at most three. A more exact way to describe the extent to which human expectation formation is limited, is to count for each participant with an AdAR rule the number of explanatory variables comprising it, using these numbers to calculate averages over both treatments. The number of significant variables in a participant's prediction rule is here defined to be its Complexity.

The average Complexities for both of the treatments are depicted in Figure #12. The first pair of bars shows that the average Complexity of the Asset Pricing AdAR rules is almost twice as high as the average Complexity of the Cobweb AdAR rules. This result seems to reflect the relatively non-trivial nature of the market price developments in the Asset Pricing treatment, which the predictions tend to follow closely. A more surprising result is obtained by comparing the second and third pair of bars with the first. In both pairs the height of the second bar is, like in the first pair, approximately twice as large as the height of the first bar. This implies that the number of variables participants use in their prediction rules is, on average, distributed over the objective and subjective parts of the AdAR specification with proportions that are approximately identical for both the Cobweb and the Asset Pricing treatments. Comparing the second and the third pair of bars yields a ratio of, again, approximately two to one, in favor of the objective variables.

Figure #12 produces yet another universal result. If the average Complexities of the market price developments, which can be calculated by applying an AdAR(3,0) or AR(3) specification to them, are deducted from the average Complexities of the participants' prediction rules, in each treatment seperately, then in both cases almost one significant term remains. It can be said, therefore, that participants on average overestimate the market price development by a single variable, regardless of the treatment they are in. This result has an ironic quality, since with all their boundedness and imperfection, participants of both treatments on average behave in a way that is clearly more sophisticated than the market as a whole does.

8. Shifting Trend Expectations

The AdAR specification in equation (12), with its six-dimensional parameter space, in principle captures a multitude of prediction rules. Since the degree of heterogeneity among the participants is probably quite small though, as was hypothesised in Section 3 regarding the blind coordination among price predictions, it might be possible to put a number of restrictions on the AdAR coefficients, resulting in a more specific description of individual expectation formation, while keeping the number of rules failing to satisfy these restrictions to a minimum.

Obvious candidates for restrictions on the AdAR coefficients are the ones that eliminate the higher lags from the specification in (12). In the last section it was already shown that the third lag of the market prices is relatively little used across both treatments, while participants at the same time tend to use only one of the first two lags of their price predictions, mostly ignoring the third prediction lag. These statements can be clarified by classifying the estimated prediction rules according to their highest lags in objective and subjective variables, counting the number of rules in each category and then putting them in decreasing order.

Figure #13 shows the results of such a procedure. The first two bars show the great applicability of the AdAR specification to real world prediction rules. The twelve bars to the right of the first pair show lag depth for all 71 estimated prediction rules, resulting in the exclusion of the combinations (0, 1) and (0, 2), since they never occurred. Reading the Figure from left to right, the sum of the lag depths tends to increase, showing that the complexity of a prediction rule is roughly inversely related to its popularity among participants. Also, the Figure confirms that prediction rules with a high subjective lag depth have little weight in both treatments. This becomes clear especially when inspecting the third through seventh bars, ending with (2, 1). Only one of these four bars has a positive subjective lag depth, which is no greater than one, while the four of them account for roughly 62% of all prediction rules. Lastly, the domination of Cobweb prediction rules in low lag depths like (1, 0) and (0, 0), and the domination of Asset Pricing rules in higher ones like (2, 1), (3, 0), and (1, 3) reflects the asymmetry between the treatments, the Asset Pricing participants having in general more complex prediction rules than the Cobweb participants.

If it's mainly prediction rules with short lag depths that participants choose to use, favoring past market prices over their own past predictions, then there are several well-known rules that might describe a large proportion of the participants' rules, while being themselves specific forms of the AdAR specification in (12). Figure #14 shows the results of the application of five canonical prediction rules to the 71 succesful AdAR estimations[39]. The third through seventh bar indicate their weight in the population of participants, divided into the two treatments[40]. All of the canonical rules have some support in both treatments, but none of them seems particularly representative, the most succesful one being AR(2), describing almost 17% of the estimated rules. To improve on this result, it is necessary to construct a new prediction rule that captures much more of the participants' behavior, while still offering a more specific explanation of individual expectation formation than the general AdAR specification does.

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[39] The exact way in which the prediction rules of Figure #17 are distributed over the seperate groups is listed in Table #5.

[40] To make sure the labels are well understood, "AR(1)" and "AR(2)" denote autoregressive rules of the order one and two exactly, that is, they are here considered to be mutually exclusive; "Naive" denotes the first-order autoregressive rule with a coefficient of one, "Fundamental" the constant prediction rule at 60 and "Adaptive" an average between the first lag of the market price and the first lag of the price prediction. The autoregressive rules have been tested by simply checking the entries in Tables #2 and #3 for the required pattern, while the other ones were verified by appropriate joint Wald parameter restrictions tests, at 5% significance level (see Greene, 1997 / 1993, *pp*. 162-165).

The last bar in Figure #14 shows that such a rule exists. The so-called Shifting Trend rule accurately describes 40 of the AdAR estimations, which is over 56%, or approximately 51% of all 78 participants. Moreover, its representation is divided almost equally over both treatments, suggesting that it has some robustness to changes in market structure. The success of the Shifting Trend rule undoubtedly is partly due to the fact that it can be seen as a specific composition of the five canonical rules in Figure #14. Enough restrictions apply to this composition though to make it a close description of the actual thought process of a majority of participants.

An individual is said to have Shifting Trend Expectations if his price predictions satisfy the following specification:

$$p^e_{h,t} = \alpha_1 p_{t-1} + \alpha_2 p^e_{h,t-1} + \left(1 - \alpha_1 - \alpha_2\right) p^* + \beta\left(p_{t-1} - p_{t-2}\right) + \varepsilon_t \tag{13}$$

In this recursive equation, as usual, p^* denotes the fundamental price of 60 and ε is a series of identically and independently distributed random numbers with an average of zero. The equation has four coefficients and three parameters, so can be described as STE(α_1, α_2, β). For the main part, it consists of an average over three variables that are in general most likely to approximate the market price of the next time period, under the assumption that participants consider only simple variables as predictors and ignore candidates that were manifested more than one period ago[41]. Since this choice restriction necessarily produces crude price estimates, it is further assumed that participants compensate for short-term fluctuations, again in a most simple way, by adding a market price difference term to their prediction rule with a certain weight, which might very well be negative. The rule as a whole is given its name, since it requires the addition of the estimated trend in the market price development and a longer term estimate of the market price level, thereby constantly shifting the base from which an imaginary trend line, which itself will be rotating from period to period, is extended.

Figure #15 depicts the 40 confirmed Shifting Trend Expectations rules in an intuitive geometric form[42]. The parameter choices granted by the first three variables in the Shifting Trend specification are represented by the simplex in the two-dimensional plane and the weight attached to the first-order estimate of the market price trend is incorporated by extending the simplex into the third dimension. The geometric shape resulting is that of a prism, which in the Figure has been cut off by the hyperplanes at an absolute height of one. In its level plane, the prism contains a mixture of the three most obvious price predictions of the zeroth order, while any parameter vector either above or below the level plane is associated with a Shifting Trend rule that uses a first-order estimate of the market price trend. The prism as a whole can therefore

[41] What is left implicit in this equation, is the way in which participants derive the fundamental price, in the case they assign a positive coefficient to it. In principle they could use a complicated function of former prices and predictions to estimate it, but it will be seen that only the Cobweb participants generally use the fundamental value in their STE rules, and in none of the Cobweb groups long memory or heavy computation is required to infer the fundamental value.

[42] The exact values of the parameters describing these rules are listed in Table #6, along with the group membership and participant number of the individuals found to use these rules.

be referred to as the Prism of First-Order Heuristics.

Within the Prism, the estimated parameter vectors clearly show clustering among vectors coming from the same treatment. The 19 Cobweb vectors, often lying so close together that they cannot be distinguished, are mostly positioned along the α_1-axis, implying that most of the participants having a Shifting Trend rule in the Cobweb treatment use only an average of the last market price and the fundamental value to predict future prices. Composing the labels in Figure #15, these individuals can be designated as "naive fundamentalists"[43], though it must be said that some of them have parameter vectors so close to, or even on, the vertices of the simplex that they might as well have been described as "naive" or "fundamentalist"[44].

The 21 Asset Pricing vectors also tend to be positioned in a specific part of the Prism's boundary, only this part seems to consist of two seperate areas, namely the ones surrounding the vertical lines connecting the points (1, 0, 0) and (1, 0, 1), and (1/2, 1/2, 0) and (1/2, 1/2, 1) respectively[45]. The majority of the parameter vectors is concentrated above (1, 0, 0), which means their owners use last period's market price as a base for constructing their predictions, extending from this base a trend line with a positive fraction of the angle following from the two last market prices. These individuals can therefore roughly be designated as "naive trend followers". The remaining Asset Pricing parameter vectors, hovering approximately over (1/2, 1/2, 0), are associated with prediction rules that are slightly more complicated, since they use an average of the last period's market price and their prediction of it as a base for calculating predictions, instead of just the market price. These individuals as a whole have the most sophisticated Shifting Trend rules in the experiment, and can be labelled as "adaptive trend followers".

To what extent the estimated Shifting Trend Expectations rules, which, as reported above, describe 56% of the succesfully estimated AdAR rules or 51% of all individual expectations series, are representative for the way in which individuals form expectations in general can be roughly inferred from the ability of the estimated rules to recreate market price developments similar to those obtained from the experiment. For this purpose, two artificial groups of expectations rules were created, consisting, respectively, of the 19 STE rules derived from participants of the Cobweb treatment and the 21 STE rules from Asset Pricing treatment participants. Using

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[43] In the Figure, "obstinacy" refers to the prediction rule that consists only of the last price prediction, while "trend following" and "trend reversing" refer to all prediction rules that assign a weight of 1 and -1 respectively to the difference term β in the specification (13). The other labels are explained in footnote 40.

[44] Based on the appropriate Wald parameter restrictions tests at 5% significance level, 14 out of 19 Cobweb coefficient vectors can be said not to deviate significantly from the α_1-axis, while 9 out of these 14 are close to the origin and 5 to (1, 0, 0). Four vectors though are "close" to both the origin and the opposing vertex, reflecting the small difference in general between the fundamental value and the market price in the Cobweb treatment groups. The exact results are shown in Table #6.

[45] Again applying appropriate Wald parameter restrictions tests at 5% significance level, 10 out of 21 Asset Pricing coefficient vectors are found not to deviate significantly from the vertical line through (1, 0, 0) and 8 from the vertical line through (1/2, 1/2, 0). In two cases, a vector is "close" to both these lines. See Table #6 for details.

different values for the average initial price prediction and assuming that all artificial members of both groups naively predict the market price in the second period, series of market prices with a length of 50 have been generated that can be compared with those of the experiment. Moreover, to investigate the way in which participants in the experiment had adapted their prediction rules to the treatment they were in, the two groups of STE rules were also applied to the model opposite to the one they were originally derived from.

Figure #16 shows the results of the four constructed cases. In Graphs (a) and (b), the STE rules have been applied to their original feedback systems, that is, the Cobweb model and the Asset Pricing model respectively. The market price developments shown, of which the one with the intermediate initial value deserves the most attention, are in important respects similar to the experimental ones, as shown in Figures #1 and #2. Like in the experiment, the market prices in the Cobweb model are very volatile for a few periods, but then quickly and permanently converge to the fundamental value. Likewise, market prices in the Asset Pricing model show much less initial volatility, but also take a much longer time to converge, which they do so less convincingly than in the Cobweb model. Actually, aside from the greater smoothness of the market price series in Graphs (a) and (b), which is likely to be due to the absence of prediction anomalies and the greater number of artificial group members, the only qualitative difference with the experimental data seems to be the absence of oscillatory movement around the fundamental price in the Asset Pricing model. However, this discrepancy can probably also for a large part be ascribed to the absence of prediction mistakes, which are well-known to influence price development in the Asset Pricing model much more than in the Cobweb model, creating the possibility of transforming exponential convergence into dampening oscillation[46]. Lastly, it must be noted that, if indeed the simulated price series are representative for the experimental developments stripped of prediction outliers, they lend strong support for the hypothesis that market prices in both models will, in the long term, converge to the fundamental value, as required by the Rational Expectations Hypothesis.

The fact that participants in the two treatments have been found to use in general quite different prediction rules, as is reflected in the within treatment clustering inside the Prism of Figure #15, shows that individuals choose the prediction rule they apply to match in some way the environment they are in. To be able to judge in what way the expectation formation of the individual adapts itself to the two treatments of the experiment, it might be insightful to subject the groups of STE rules to the treatments opposite to their original ones. The results are shown in Graph (c), generated by the Asset Pricing rules in the Cobweb model, and in Graph (d), generated by the Cobweb rules in the Asset Pricing model. The simulated market price series in Graph (c) are all strongly divergent, as was to be expected, since among the STE rules from the Asset Pricing treatment are many trend-following ones that by themselves cause alternating price

[46] Clear examples of such a transformation occur in Graph (f) of Figure #2 at time periods 15 and 25, as well as in Graph (d) at time period 39.

movements of increasing amplitude when applied to a negative feedback system such as the Cobweb model. Therefore, it may be said that the participants in the Cobweb treatment, again assuming that the 19 STE rules are a sufficient representation, have adapted to their environment, in the sense that their "naive fundamentalist" rules clearly perform far superior to the trend-following alternative.

More surprising are the price series of Graph (d). They are slightly similar to the series of Graph (b), only show a much faster and closer convergence to the fundamental price. Undoubtedly, this paradoxical succes can be explained by the fact that many of the STE rules from the Cobweb treatment contain a large component equal to the fundamental price, which the participants in the Cobweb groups had plenty of opportunity to learn in the course of the experiment. The value of such knowledge is clearly illustrated by comparison of Graphs (b) and (d) and it would be unfair to conclude that the participants of the Asset Pricing treatment have poorly chosen their prediction rules, since they could have only reasonably learned the fundamental price some time into the experiment.

9. Conclusion

When individuals are placed in artificial economies that are purely expectations-driven, in the sense that supply and demand functions are fixed and trade is therefore automatic, major differences can arise in the development of market prices, even when traditional economic theory would predict there to be no difference whatsoever. This anomaly implies that humans, instead of being fully rational, use some kind of bounded rationality to form price expectations, which, as is evident in the experimental results, they may vary according to the economic environment they are confronted with. However, the ability of individuals to choose an appropriate form of bounded rationality is likely to be limited, since in the experiment it is shown that most participants, whatever the shape of their economy, choose their prediction rule from a highly restricted and simple set of rules.

The two treatments of the experiment have produced series of market prices with clear qualitative differences. In the Cobweb groups, prices tend to go through an initial phase of high volatility, neatly converging afterwards to the fundamental price, only to be disturbed occasionally by the impact of a mistake by one of the group members. In the Asset Pricing groups, volatility in the beginning lasts for a much shorter period, but also is not followed by a quick convergence to the fundamental price. Rather, most groups demonstrate a slow oscillatory movement around the fundamental value, which seems to come very close to it only in the long run. A short and general way of describing the market price development in the Cobweb treatment is therefore "slow coordination and fast convergence", and in the Asset Pricing treatment "fast coordination and slow convergence". These labels are at odds with the Rational Expectations Hypothesis in this context, which requires market prices to be a white noise process around the fundamental value. In the long run, though, it might be expected that prices in both treatments would be sufficiently close to the fundamental value to resemble the REH process, though some excess volatility would undoubtedly remain.

A surprising characteristic of the price predictions, from participants of both treatments, is their closeness to each other, resulting in small differences in earnings within groups, as compared to significant deviations in aggregate earnings between them. This coordination of price predictions is surprising, since participants were not able to observe each others' predictions during the experiment, making the coordination itself "blind", or so to speak. In accordance with this phenomenon, it was found that participants in the Asset Pricing treatment tended to overreact in their predictions to market price changes, while Cobweb treatment participants tended to underreact. The only way to explain the blind coordination is by assuming a high degree of homogeneity in human expectation formation within the economic contexts simulated by the experiment. In general, expectation formation might therefore be conjectured to consist of the selection of prediction rules, appropriate to certain environments, from a set of previously embedded rules that is both limited in complexity and virtually ubiquitous as a component of human bounded rationality.

Perhaps the most important objective of the experiment has been to derive explicitly the prediction rules actually used by the participants in both treatments. For the great majority of them, a mathematical description has indeed been found, by using the linear Adaptive Autoregressive specification. These descriptions then point towards yet another specification, simpler and more easily interpretable than the family of AdAR rules. This is the Shifting Trend Expectations rule, composed of several of the most basic prediction rules already known. A majority of AdAR rules, almost equally distributed among both treatments, has proven to be statistically equivalent to an STE rule with suitable parameters. By depicting these parameters in a geometric figure shaped as a prism, a general way of distinguishing between participants from different treatments immediately suggested itself. Cobweb treatment participants were best described as "naive fundamentalists", while Asset Pricing treatment participants could be called either "naive trend followers" of "adaptive trend followers". To verify the extent to which the STE rules are representative for all the participants' predictions, they were grouped by treatment and used in a simulation attempting to recreate qualitatively the experimental results. For both treatments there appears to be a close similarity between theory and practice. Surprisingly, an application of the Cobweb STE rules in the Asset Pricing model improved the speed and the extent of the convergence to the fundamental value, indicating the importance of information on fundamentals for the stability properties of positive feedback systems, *e.g.* markets for financial assets.

Finally, looking back at Henk van de Velden's thesis (2001), which directly precedes the present research as mentioned in the introduction, an important difference should be noted concerning the existence of bubble-like developments in the market price. In Van de Velden's so-called *NoRobot* Asset Pricing treatment, which is the equivalent of the present Asset Pricing treatment, realized prices exhibited explosive movements in five out of six groups, which were restricted only by imposing an artificial price ceiling (*pp.* 127-9). In none of our seven Asset Pricing groups, though, a sustained inflating movement in the market prices has been witnessed (see Figure #2). Van de Velden's explanation for his "*endogenously speculative bubbles*" was that "*participants try to extrapolate trends*" (*p.* 132), that is, trends in realized prices[47].

This statement suggests the existence of an interesting limitation in human prediction capabilities. Apparently, participants in a single-market economy that has positive expectations feedback and is stable under naive expectations tend to produce a slowly converging oscillatory movement in the relevant price when they predict one period ahead, while increasing the prediction horizon with a single time period generally results in diverging price developments that do not seem to end themselves endogenously. This sensitivity of the qualitative results for small changes in prediction horizon implies that the participants' prediction rules are mainly useful in the extremely short term and quickly become counter-productive in the absence of relevant information directly preceding the price to be forecasted. Specifically, this sensitivity undermines the explanatory value of the Rational Expectations Hypothesis, which does not allow for any change in market price development due to shifts in prediction horizon.

References

- Bain, L.J. & Engelhardt, M. (1987 / 1992) "*Introduction to Probability and Mathematical Statistics*", Duxbury Press.
- Botazzi, G. & Devetag, G. (2003) "Expectations Structure in Asset Pricing Experiments", Working Paper, Sant'Anna School of Advanced Studies, Italy.
- Brock, W.A. & Hommes, C.H. (1997) "A Rational Route to Randomness", *Econometrica* 65, *pp.* 1129-60.
- *Economist* (1996a) "That Astonishing Microchip", Leader, Vol. 338, Issue 7958, 23rd March.
- *Economist* (1996b) "When the Chips are Down", Section Semiconductors, Vol. 338, Issue 7958, 23rd March.
- *Economist* (2001) "The Great Chip Glut", Section Business, Vol. 360, Issue 8234, 11th August.
- Enders, W. (1995) "*Applied Econometric Time Series*", John Wiley & Sons.
- Ezekiel, M. (1938) "The Cobweb Theorem", *The Quarterly Journal of Economics* 52, *pp.* 255-80.
- Freeman, R.B. (1976) "A Cobweb Study of the Supply and Starting Salary of New Engineers", Industrial & Labor Relations Review 29-2, *pp.* 236-48.
- Greene, W.H. (1997 / 1993) "*Econometric Analysis*", Prentice-Hall, Inc.
- Hommes, C.H. & Sonnemans, J.H. & Tuinstra, J. & Van de Velden, H. (2004a) "The Instability

[47] Interestingly, a recent experiment by Bottazzi & Devetag (2003) recreates Van de Velden's equilibrium version of the Asset Pricing model, but finds little evidence for speculative bubble developments. As the authors suggest (*p.* 9), this seems to be mainly due to the requirement that participants submit not only a prediction of the market price, but also a confidence interval of that prediction, introducing a specific form of non-linearity in the pricing equation that makes it hard for the participants to coordinate on a common prediction rule.

of a Heterogeneous Cobweb Economy: A Strategy Experiment on Expectation Formation", forthcoming in the *Journal of Economic Behavior & Organization*.

- Hommes, C.H. & Sonnemans, J.H. & Tuinstra, J. & Van de Velden, H. (2004b) "Coordination of Expectations in Asset Pricing Experiments", Working Paper, University of Amsterdam, The Netherlands.
- Kaldor, N. (1934) "A Classificatory Note on the Determinateness of Equilibrium", *Review of Economic Studies* 1-2, *pp.* 122-36.
- Lei, V. & Noussair, C.N. & Plott, C.R. (2001) "Nonspeculative Bubbles in Experimental Asset Markets: Lack of Common Knowledge of Rationality vs. Actual Irrationality", *Econometrica* 69, *pp.* 831-59.
- Leitner, J. & Schmidt, R. (2004) "Expectation Formation in an Experimental Foreign Exchange Market — Evidence for Coordinated, Trend-Extrapolative Expectations", Working Paper, Karl-Franzens-University of Graz, Austria.
- Muth, J.F. (1961) "Rational Expectations and the Theory of Price Movements", *Econometrica* 29-3, *pp.* 315-35.
- Nerlove, M. (1958) "Adaptive Expectations and Cobweb Phenomena", *Quarterly Journal of Economics* 72-2, *pp.* 227-40.
- Schmalensee, R. (1976) "An Experimental Study of Expectation Formation", *Econometrica* 44, *pp.* 17-41.
- Smith, V.L. & Suchanek, G.L. & Williams, A.W. (1988) "Bubbles, Crashes and Endogenous Expectations in Experimental Spot Asset Markets", *Econometrica* 56, *pp.* 1119-51.
- Velden, H. van de (2001) "*An Experimental Approach to Expectation Formation in Dynamic Economic Systems*", PhD thesis, University of Amsterdam, The Netherlands.
- Whittaker, E.T. & Watson, G.N. (1902 / 2003) "*A Course of Modern Analysis*", Cambridge University Press.

Appendix A: Experimental Protocol

The experiment was carried out on tuesday the 18th and wednesday the 19th of February 2003, at the CREED laboratory inside the economics faculty of the University of Amsterdam[1]. The organizers of the experiment, Peter Heemeijer (MSc), Joep Sonnemans (PhD), Jan Tuinstra (PhD) and Cars Hommes (PhD), are all members of the CeNDEF research insitute, while Joep Sonnemans is also a member of CREED[2]. On the 18th of February Sessions #1 and #2 were successively performed, each with 18 participants, making up the Cobweb treatment of the experiment. On the 19th of February Sessions #3 and #4 were successively performed, the first with 18 participants and the second with 24, making up the Asset Pricing treatment. At the beginning of each session, excess participants were given 5 euros as a show-up reward and excluded from the experiment. These participants were selected first on a voluntary basis and then at random.

During each of the sessions, when the excess participants had left, a short welcoming message was read aloud from paper, after which the participants were randomly assigned to a cubicle in the computer lab. In each cubicle there was a computer, some experimental instructions on paper and some blank paper with a pen. The two treatments had different instructions. When all the participants were seated, they were asked to read the instructions on their desks. After a few minutes, they were given the opportunity to ask questions regarding the instructions, after which the experiment started. When the 50 time periods were completed, the participants were asked to remain seated and fill in the questionnaire, which was subsequently handed out to them. After a reasonable amount of time, the participants were called to the ante-room one by one to hand in the questionnaire and receive their earnings, in cash. The participants left the computer lab after receiving their earnings.

The experimental instructions the participants read in their cubicles consisted of three parts, totalling five pages. The first part contained general information about the market the experiment was about to simulate, which was of course treatment-specific. The second part contained an explanation of the computer program used during the experiment. The third part displayed a table relating the absolute prediction error made in any single period to the amount of credits earned in that period. The conversion rate between credits and euros, being 2600 credits to 1 euro, was made public by announcement, since it was not listed with the table. The questionnaire after the experiment contained 19 questions, the first 10 of which could be answered only by the integers 1 through 5. The experimental instructions and the questionnaire are attached to this appendix and will be translated respectively below.

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[1] CREED Is an abbreviation for Center for Research in Experimental Economics and political Decision-making. The economics faculty of the University of Amsterdam is located at Roetersstraat 11, the computer lab is in room B515.

[2] CeNDEF Meaning Center for Non-linear Dynamics in Economics and Finance. It is part of the department of Quantitative Economics and Cars Hommes is its director.

- **Translation of *"CW, Experimentele instructies"***

CW [short for Cobweb treatment]

Experimental instructions

The shape of the artificial market used by the experiment, and the role you will have in it, will be explained in the text below. Read these instructions carefully. They continue on the backside of this sheet of paper.

General information

You are an advisor of an importer who is active on a market for a certain product. In each time period the importer needs a good prediction of the price of the product. Furthermore, the price should be predicted one period ahead, since importing the good takes some time. As the advisor of the importer you will predict the price P(t) of the product during 50 successive time periods. Your earnings during the experiment will depend on the accuracy of your predictions. The smaller your prediction errors, the greater your earnings.

About the market

The price of the product will be determined by the law of supply and demand. The size of demand is dependent on the price. If the price goes up, demand will go down. The supply on the market is determined by the importers of the product. Higher price predictions make an importer import a higher quantity, increasing supply. There are several large importers active on this market and each of them is advised by a participant of this experiment. Total supply is largely determined by the sum of the individual supplies of these importers. Besides the large importers, a number of small importers is active on the market, creating small fluctuations in total supply.

About the price

The price is determined as follows. If total demand is larger than total supply, the price will rise. Conversely, if total supply is larger than total demand, the price will fall.

About predicting the price

The only task of the advisors in this experiment is to predict the market price P(t) in each time period as accurately as possible. The price (and your prediction) can never become negative and lies always between 0 and 100 euros in the first period. The price and the prediction in period 2 through 50 is only required to be positive. The price will be predicted one period ahead. At the beginning of the experiment you are asked to give a prediction for period 1, V(1). When all participants have submitted their predictions for the first period, the market price P(1) for this period will be made public. Based on the prediction error in period 1, P(1) - V(1), your earnings in the first period will be calculated. Subsequently, you are asked to enter your prediction for period 2, V(2). When all participants have submitted their prediction for the second period, the market price for that period, P(2), will be made public and your earnings will be calculated, and so on, for 50 consecutive periods. The information you have to form a prediction at period t consists of: All market prices up to time period t - 1: {P(t - 1), P(t - 2), ..., P(1)}; All your predictions up until time period t-1: {V(t - 1), V(t - 2), ..., V(1)}; Your total earnings at time period t - 1.

About the earnings

Your earnings depend only on the accuracy of your predictions. The better you predict the price in each period, the higher will be your total earnings. The attached table lists all possible earnings.

When you are done reading the experimental instructions, you may continue reading the computer instructions, which have been placed on your desk as well.

- **Translation of *"AP, Experimentele instructies"***

AP [short for Asset Pricing treatment]

Experimental instructions

The shape of the artificial market used by the experiment, and the role you will have in it, will be explained in the text below. Read these instructions carefully. They continue on the backside of this sheet of paper.

General information

You are an advisor of a trader who is active on a market for a certain product. In each time period the trader needs to decide how many units of the product he will buy, intending to sell them again the next period. To take an optimal decision, the trader requires a good prediction of the market price in the next time period. As the advisor of the trader you will predict the price P(t) of the product during 50 successive time periods. Your earnings during the experiment will depend on the accuracy of your predictions. The smaller your prediction errors, the greater your earnings.

About the market

The price of the product will be determined by the law of supply and demand. Supply and demand on the market are determined by the traders of the product. Higher price predictions make a trader demand a higher quantity. A high price prediction makes the trader willing to buy the product, a low price prediction makes him willing to sell it. There are several large traders active on this market and each of them is advised by a participant of this experiment. Total supply is largely determined by the sum of the individual supplies and demands of these traders. Besides the large traders, a number of small traders is active on the market, creating small fluctuations in total supply and demand.

About the price

The price is determined as follows. If total demand is larger than total supply, the price will rise. Conversely, of total supply is larger than total demand, the price will fall.

About predicting the price

The only task of the advisors in this experiment is to predict the market price P(t) in each time period as accurately as possible. The price (and your prediction) can never become negative and lies always between 0 and 100 euros in the first period. The price and the prediction in period 2 through 50 is only required to be positive. The price will be predicted one period ahead. At the beginning of the experiment you are asked to give a prediction for period 1, V(1). When all participants have submitted their predictions for the first period, the market price P(1) for this period will be made public. Based on the prediction error in period 1, P(1) - V(1), your earnings in the first period will be calculated. Subsequently, you are asked to enter your prediction for period 2, V(2). When all participants have submitted their prediction for the second period, the market price for that period, P(2), will be made public and your earnings will be calculated, and so on, for 50 consecutive periods. The information you have to form a prediction at period t consists of: All market prices up to time period t - 1: {P(t - 1), P(t - 2), ..., P(1)}; All your predictions up until time period t - 1: {V(t - 1), V(t - 2), ..., V(1)}; Your total earnings at time period t - 1.

About the earnings

Your earnings depend only on the accuracy of your predictions. The better you predict the price in each period, the higher will be your total earnings. The attached table lists all possible earnings.

When you are done reading the experimental instructions, you may continue reading the computer instructions, which have been placed on your desk as well.

▪ Translation of *"Computerinstructies"*

Computer instructions

The way the computer program works that will be used in the experiment, is explained in the text below. Read these instructions carefully. They continue on the backside of this sheet of paper.

The mouse does not work in this program.

Your earnings in the experiment depend on the accuracy of your predictions. A smaller prediction error in each period will result in higher earnings.

To enter your prediction you can use the numbers, the point and, if necessary, the backspace key on the keyboard.

Your prediction can have two decimal numbers, for example 30.75. Pay attention not to enter a comma instead of a point. Never use the comma. Press enter if you have made your choice.

The better your prediction, the more credits you will earn. On your desk is a table listing your earnings for all possible prediction errors.

For example, your prediction was 13.42. The true market price turned out to be 12.13. This means that the prediction error is: 13.42 – 12.13 ≈ 1.30. The table then says your earnings are 1255 credits (as listed in the third column [this is a typing error, it should be second column]).

The available information for predicting the price of the product in period t consists of: All product prices from the past up to period t - 1; Your predictions up to period t - 1; Your earnings until then.

[the caption of the figure] The computer screen. The instructions below refer to this figure.

In the upper left corner a graph will be displayed consisting of your predictions and of the true prices in each period. This graph will be updated at the end of each period.

In the rectangle in the middle left you will see information about the number of credits you have earned in the last period and the number you have earned in total. The time period is also displayed here, possibly along with other relevant information.

On the right hand side of the screen the experimental results will be displayed, that is, your predictions and the true prices for at most the last 20 periods.

At the moment of submitting your price prediction, the rectangle in the lower left side of the figure will appear. When all participants have subsequently submitted their predictions, the results for the next period will be calculated.

When everyone is ready reading the instructions, we will begin the experiment. If you have questions now or during the experiment, raise your hand. Someone will come to you for assistance.

▪ Translation of *"Uitbetalingstabel"*

Earnings table

[title of the first, third and fifth columns] error

[title of the second, fourth and sixth columns] credits

[at the bottom of the sixth column] For a prediction error of 7 or larger no credits are earned.

▪ Translation of *"Vragenlijst over het experiment"*

Questionnaire about the experiment

Before you collect your earnings, we would like to ask you a few qustions regarding the experiment. Answering the questionnaire will take several minutes. The answers will be treated completely anonymously.

1. Multiple choice questions

Below mark only one of the possible answers. The answer "1" means "I totally disapprove", the answer "5" means "I totally approve" and the other answers fit in naturally between these two extremes.

1. "My objective during the experiment was to earn as much money as possible."
2. "I think I have earned well."
3. "I constantly have thought for some time about the predictions I submitted."
4. "Often I could predict accurately what the price would be."
5. "As time passed during the experiment, I started to understand the market better."
6. "It was interesting to take part in this experiment."
7. "The instructions prior to the experiment were clear to me."
8. "The computer program was suitable for this experiment."
9. "During the experiment, I had a good idea about the kind of market that was being simulated."

10. "I have used insights of economic theory to form my predictions."

2. Open questions

Write your answers to the following questions out in full.

1. "During the experiment, have you consciously used a specific prediction rule? If so, which one was it?"

2. "If you would take part in the experiment once again, would you take different decisions? If so, how?"

3. "When forming your prediction, did you primarily look at the graph, at the left of the screen, or at the table, at the right? Why?"

4. "Do you have suggestions for improving this kind of experiments?"

3. Questions about yourself

The following questions will be, as the rest of the questions, treated completely anonymously.

1. "What is your age and gender?"

2. "What are you studying and in what year are you?"

3. "Are you religious, and if so, what is your religion?"

4. "What is your cultural background?"

5. Have you participated in a CREED experiment before, and if so, how many times approximately?"

Experimentele instructies

Hieronder wordt uitgelegd wat de vorm is van de kunstmatige markt waarbinnen het experiment zich afspeelt en welke rol u hierin zal hebben. Lees de instructies aandachtig. Ze gaan door op de achterzijde van het document.

Algemene Informatie

U bent adviseur voor een importeur die actief is op de markt voor een zeker goed. In elke periode heeft de importeur een goede voorspelling van de goederenprijs nodig. Bovendien moet, omdat het invoeren van het goed enige tijd duurt, de prijs één periode vooruit voorspeld worden. Als adviseur van de importeur moet u de prijs $P(t)$ van het goed voorspellen, gedurende 50 opeenvolgende perioden. Uw verdiensten tijdens het experiment hangen af van de nauwkeurigheid van uw voorspellingen. Hoe kleiner uw voorspelfouten, des te groter uw verdiensten.

Over de markt

De prijs van het goed wordt bepaald door de wet van vraag en aanbod. De vraag is afhankelijk van de prijs. Als de prijs omhoog gaat, zal de vraag dalen. Het aanbod op de markt wordt bepaald door de importeurs van het goed. Voor een importeur geldt dat een *hogere prijsvoorspelling* ertoe leidt dat hij *meer zal importeren*, zodat het *aanbod toeneemt*. Er zijn een aantal grote importeurs actief op deze markt en elke importeur wordt door een deelnemer aan dit experiment geadviseerd. Het totale aanbod wordt voor het grootste gedeelte bepaald door de som van het aanbod van deze importeurs. Daarnaast is er een aantal kleinere importeurs actief die voor kleine schommelingen in het totale aanbod kunnen zorgen.

Over de prijs

De prijs komt als volgt tot stand. Als de vraag groter is dan het totale aanbod zal de prijs stijgen. Omgekeerd, als het totale aanbod groter is dan de vraag zal de prijs dalen.

Over het voorspellen

De enige taak van de afviseurs in dit experiment is het zo nauwkeurig mogelijk voorspellen van de marktprijs $P(t)$ in iedere periode. De prijs (en uw voorspelling) kan nooit negatief worden en ligt in periode 1 altijd tussen 0 en 100 euro. Voor de

prijs en de voorspelling in periode 2, 3 tot en met periode 50 geldt alleen dat deze positief moet zijn. De prijs moet één periode vooruit voorspeld worden. Aan het begin van het experiment moet u uw prijsvoorspelling voor periode 1, $V(1)$, geven. Als alle deelnemers hun voorspelling voor periode 1 gedaan hebben, wordt de marktprijs $P(1)$ voor periode 1 bekend worden gemaakt. Gebaseerd op de voorspelfout in periode 1, $P(1) - V(1)$, worden uw verdiensten voor periode 1 berekend. Daarna moet u uw voorspelling voor periode 2, $V(2)$, geven. Als alle deelnemers hun voorspelling voor periode 2 gedaan hebben, wordt de marktprijs voor periode 2, $P(2)$, bekendgemaakt en worden uw verdiensten voor periode 2 berekend, en zo verder, voor 50 opeenvolgende perioden. De informatie die u heeft om een voorspelling op tijdstip t te doen bestaat uit:

- *Alle prijzen* tot tijdstip t-1: $\{P(t-1), P(t-2), ..., P(1)\}$;
- Al uw *eigen voorspellingen* tot tijdstip t-1: $\{V(t-1), V(t-2), ..., V(1)\}$;
- Uw totale verdiensten tot tijdstip t-1.

Over de verdiensten

De verdiensten hangen alleen af van de nauwkeurigheid van de voorspellingen. Hoe beter u de prijs voorspelt in elke periode, des te hoger uw totale verdiensten. De bijgevoegde tabel geeft de mogelijke verdiensten weer.

Als u klaar bent met het lezen van de experimentele instructies, kunt u doorgaan met het lezen van de computerinstructies, die ook op uw bureau liggen.

Experimentele instructies

Hieronder wordt uitgelegd wat de vorm is van de kunstmatige markt waarbinnen het experiment zich afspeelt en welke rol u hierin zal hebben. Lees de instructies aandachtig. Ze gaan door op de achterzijde van het document.

Algemene Informatie

U bent adviseur voor een handelaar die actief is op de markt voor een zeker goed. In elke periode moet de handelaar beslissen hoeveel eenheden van het goed hij zal kopen, met het doel om deze een periode later weer te verkopen. Om een optimale beslissing te nemen moet de handelaar een goede voorspelling van de prijs in de volgende periode hebben. Als adviseur van de handelaar moet u de prijs $P(t)$ van het goed voorspellen, gedurende 50 opeenvolgende perioden. Uw verdiensten tijdens het experiment hangen af van de nauwkeurigheid van uw voorspellingen. Hoe kleiner uw voorspelfouten, des te groter uw verdiensten.

Over de markt

De prijs van het goed wordt bepaald door de wet van vraag en aanbod. Vraag en aanbod op de markt worden bepaald door de handelaren. Voor een handelaar geldt dat een *hogere prijsvoorspelling* ertoe leidt dat hij *meer van het goed* zal vragen. Een hoge voorspelling leidt ertoe dat de handelaar het goed wil kopen, een lage voorspelling leidt ertoe dat de handelaar het goed wil verkopen. Er zijn een aantal grote handelaren actief op deze markt en elke handelaar wordt door een deelnemer aan dit experiment geadviseerd. Vraag en aanbod van het goed worden voor het grootste gedeelte bepaald door de som van vraag en aanbod van deze handelaren. Daarnaast is er nog een aantal kleinere handelaren actief die voor kleine schommelingen in vraag en aanbod kunnen zorgen.

Over de prijs

De prijs komt als volgt tot stand. Als de totale vraag groter is dan het aanbod zal de prijs stijgen. Omgekeerd, als het aanbod groter is dan de totale vraag zal de prijs dalen.

Over het voorspellen

De enige taak van de adviseurs in dit experiment is het zo nauwkeurig mogelijk

voorspellen van de marktprijs $P(t)$ in iedere periode. De prijs (en uw voorspelling) kan nooit negatief worden en ligt in periode 1 altijd tussen 0 en 100 euro. Voor de prijs en voorspelling in periode 2, 3 tot en met periode 50 geldt alleen dat deze positief moet zijn. De prijs moet één periode vooruit voorspeld worden. Aan het begin van het experiment moet u uw prijsvoorspelling voor periode 1, $V(1)$, geven. Als alle deelnemers hun voorspelling voor periode 1 gedaan hebben, wordt de marktprijs $P(1)$ voor periode 1 bekend gemaakt. Gebaseerd op de voorspelfout in periode 1, $P(1) - V(1)$, worden uw verdiensten voor periode 1 berekend. Daarna moet u uw voorspelling voor periode 2, $V(2)$, geven. Als alle deelnemers hun voorspelling voor periode 2 gedaan hebben, wordt de marktprijs voor periode 2, $P(2)$, bekendgemaakt en worden uw verdiensten voor periode 2 berekend, en zo verder voor 50 opeenvolgende perioden. De informatie die u heeft om een voorspelling op tijdstip t te doen bestaat uit:

- *Alle prijzen* tot tijdstip t-1: $\{P(t-1), P(t-2), ..., P(1)\}$;
- Al uw *eigen voorspellingen* tot tijdstip t-1: $\{V(t-1), V(t-2), ..., V(1)\}$;
- Uw totale verdiensten tot tijdstip t-1.

Over de verdiensten

De verdiensten hangen alleen af van de nauwkeurigheid van de voorspellingen. Hoe beter u de prijs voorspelt in elke periode, des te hoger uw totale verdiensten. De bijgevoegde tabel geeft de mogelijke verdiensten weer.

Als u klaar bent met het lezen van de experimentele instructies, kunt u doorgaan met het lezen van de computerinstructies, die ook op uw bureau liggen.

Computerinstructies

Hieronder wordt uitgelegd hoe het computerprogramma werkt dat voor het aanstaande experiment gebruikt wordt. Lees de instructies aandachtig. Ze gaan door op de achterzijde van dit document.

De muis werkt niet in dit programma.

Uw verdiensten tijdens het experiment hangen af van de nauwkeurigheid van uw voorspellingen. Een kleinere voorspelfout in elke periode levert hogere verdiensten op.

Om uw voorspelling in te toetsen maakt u gebruik van de cijfers, de punt en, zonodig, de backspace-toets op het toetsenbord.

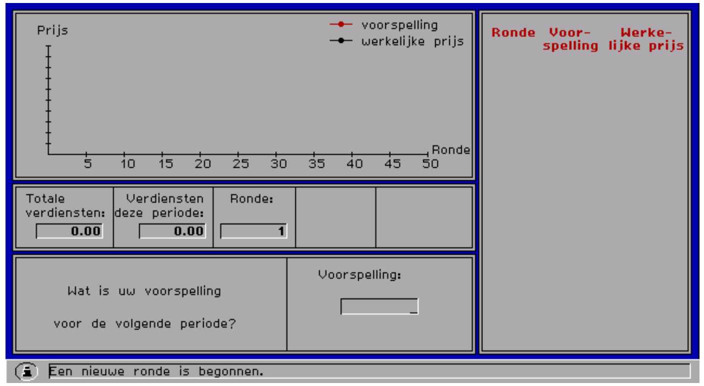
Uw voorspelling mag twee decimalen achter de punt hebben, dus bijvoorbeeld 30.75. Let u er vooral op dat u geen komma in plaats van een punt intoetst. De komma wordt niet door de computer herkend. Gebruik dus nooit de komma. Nadat u een keuze heeft gemaakt drukt u op de enter-toets.

Hoe beter uw voorspelling is, hoe meer punten u verdient. Op uw tafel ligt een tabel waarin u uw verdiensten af kunt lezen voor iedere fout.

Bijvoorbeeld, uw voorspelling was 13.42. De werkelijke prijs bleek 12.13 te zijn. Dit betekent dat uw fout is: 13.42 - 12.13 is $1.29 \approx 1.30$. In de tabel kunt u dan aflezen dat u 1255 punten heeft verdiend (derde kolom in uw tabel).

De aanwezige informatie voor het voorspellen van de goederenprijs in periode t bestaat uit:

- Alle goederenprijzen uit het verleden tot en met periode t-1;
- Uw voorspellingen tot en met periode t-1;
- Uw totale verdiensten tot dusver.



Het computerscherm. De onderstaande instructies hebben betrekking op deze figuur.

In de linker bovenhoek krijgt u een grafiek te zien van uw voorspellingen en van de werkelijke prijzen per periode. Deze grafiek wordt aan het eind van elke periode bijgewerkt.

In het blok links in het midden ziet u informatie over hoeveel punten u in de vorige periode heeft verdiend en hoeveel punten in totaal. Ook worden het nummer van de huidige ronde en eventuele extra informatie hier weergegeven.

Aan de rechterkant van het scherm krijgt u de resultaten, dat wil zeggen uw voorspelling en de werkelijke prijs, van ten meeste de laatste 20 perioden te zien.

Op het moment dat u uw voorspelling op kunt geven verschijnt links onder in uw scherm het hierboven zichtbare blok. Als alle deelnemers vervolgens hun voorspelling hebben ingevoerd, zullen de resultaten van de ronde worden berekend.

Als iedereen klaar is met het lezen van de instructies zullen we het experiment starten. Als u nu of gedurende het experiment een vraag heeft, steek dan uw hand in de lucht. Iemand komt dan naar u toe om u te helpen.

UITBETALINGSTABEL

fout	*punten*	*fout*	*punten*	*fout*	*punten*
0.10	1300	2.60	1121	**5.00**	**637**
0.15	1299	2.65	1114	5.05	623
0.20	1299	2.70	1107	5.10	610
0.25	1298	2.75	1099	5.15	596
0.30	1298	2.80	1092	5.20	583
0.35	1297	2.85	1085	5.25	569
0.40	1296	2.90	1077	5.30	555
0.45	1295	2.95	1069	5.35	541
0.50	1293	**3.00**	**1061**	5.40	526
0.55	1292	3.05	1053	5.45	512
0.60	1290	3.10	1045	5.50	497
0.65	1289	3.15	1037	5.55	483
0.70	1287	3.20	1028	5.60	468
0.75	1285	3.25	1020	5.65	453
0.80	1283	3.30	1011	5.70	438
0.85	1281	3.35	1002	5.75	423
0.90	1279	3.40	993	5.80	408
0.95	1276	3.45	984	5.85	392
1.00	**1273**	3.50	975	5.90	376
1.05	1271	3.55	966	5.95	361
1.10	1268	3.60	956	**6.00**	**345**
1.15	1265	3.65	947	6.05	329
1.20	1262	3.70	937	6.10	313
1.25	1259	3.75	927	6.15	297
1.30	1255	3.80	917	6.20	280
1.35	1252	3.85	907	6.25	264
1.40	1248	3.90	896	6.30	247
1.45	1244	3.95	886	6.35	230
1.50	1240	**4.00**	**876**	6.40	213
1.55	1236	4.05	865	6.45	196
1.60	1232	4.10	854	6.50	179
1.65	1228	4.15	843	6.55	162
1.70	1223	4.20	832	6.60	144
1.75	1219	4.25	821	6.65	127
1.80	1214	4.30	809	6.70	109
1.85	1209	4.35	798	6.75	91
1.90	1204	4.40	786	6.80	73
1.95	1199	4.45	775	6.85	55
2.00	**1194**	4.50	763	6.90	37
2.05	1189	4.55	751	6.95	19
2.10	1183	4.60	739	**7.00**	**0**
2.15	1177	4.65	726		
2.20	1172	4.70	714	*Bij een voor-spelfout van groter dan 7 worden geen punten meer verdiend.*	
2.25	1166	4.75	701		
2.30	1160	4.80	689		
2.35	1153	4.85	676		
2.40	1147	4.90	663		
2.45	1141	4.95	650		

Vragenlijst over het experiment

Voordat u uw verdiensten gaat ophalen, willen we u graag nog een paar vragen stellen over het experiment. Het invullen van de vragenlijst duurt enkele minuten. De antwoorden zullen volstrekt anoniem behandeld worden.

I Meerkeuzevragen

Kruis steeds één van de mogelijke antwoorden aan. Het antwoord "1" duidt aan "geheel niet mee eens", het antwoord "5" "geheel mee eens" en de overige antwoorden liggen daar op natuurlijke wijze tussenin.

	1	*2*	*3*	*4*	*5*
1. "Mijn doel tijdens het experiment was om zoveel mogelijk geld te verdienen."					
2. "Ik denk dat ik goed verdiend heb."					
3. "Over de voorspellingen die ik heb gedaan, heb ik steeds goed nagedacht."					
4. "Ik kon vaak goed voorspellen wat de echte prijs zou worden."					
5. "Naar mate het experiment vorderde, begon ik de markt beter te begrijpen."					
6. "Het was boeiend om aan dit experiment mee te doen."					
7. "De instructies voorafgaand aan het experiment waren duidelijk."					
8. "Het gebruikte computerprogramma was geschikt voor dit experiment."					
9. "Ik kon me tijdens het experiment goed voorstellen in welk soort markt het experiment zich afspeelde."					
10. "Ik heb economische inzichten gebruikt bij het bepalen van mijn voorspellingen."					

II Open vragen

Schrijf uw antwoorden op de volgende vragen uit.

1. Heeft u tijdens het experiment gebruik gemaakt van een bewuste voorspelregel? Zoja, welke was dat?

2. Als u het experiment nogmaals kon doen, zou u dan andere beslissingen nemen? Zoja, hoe dan?

3. Keek u bij het bedenken van uw voorspelling voornamelijk naar de grafiek, op de linkerkant van het scherm, of voornamelijk naar de tabel, aan de rechterkant? Waarom?

4. Heeft u suggesties voor verbetering van dit soort experimenten?

III Vragen over uzelf

De volgende vragen zullen, zoals alle andere, volstrekt anoniem behandeld worden.

1. Wat zijn uw leeftijd en geslacht?

2. Wat zijn uw studierichting en studiejaar?

3. Bent u gelovig, en zoja, welk geloof is dat?

4. Wat is uw culturele achtergrond?

5. Heeft u al eens eerder meegedaan aan een CREED-experiment, en zoja, hoeveel keer ongeveer?

Appendix B: Mathematical Statements

Several technical results used in the analysis of the experiment will be explicitly stated and proved below. Subjects will be treated according to their order of appearance in the main text, starting the paragraph headings with their first place of reference in it.

▪ Section 2, page 3: The linearity of the supply function in the Cobweb model

The expected profit of a producer in the Cobweb model on an amount of products q that he will sell at period t is, based on the price prediction $p_{h,t}^e$ that he has obtained from participant h, equal to $p_{h,t}^e\, q - c(q)$, with the costs of production equalling $c(q)$. Profit maximization by the producer would then require the produced amount to satisfy the first-order condition:

$$p_{h,t}^e = \frac{\partial}{\partial q} c(q) \quad \Leftrightarrow \quad q = \left(\frac{\partial}{\partial q} c \right)^{-1} (p_{h,t}^e) \qquad \text{(B1)}$$

Suppose now that the producers have identical quadratic production costs, meaning $c(q) = a q^2$ with a positive constant a. Then the derivative of the production cost function simply equals $2aq$, and the inverse of the derivative evaluated at the price prediction becomes $p_{h,t}^e / 2a$. This is a linearly increasing function in the price prediction. It is also the supply function, since for quadratic production costs the expected profit function has only one optimum, which is a maximum, so the first-order condition generates only profit maximizing quantities.

▪ Section 2, page 3: The equivalence of the Cobweb model with the traditional equilibrium version

The equilibrium version of the Cobweb model derives its name from the straightforward price generating formula. Ignoring the noise term, its most general form is:

$$D(p_t) = \sum_{h=1}^{H} S(p_{h,t}^e) \quad \Leftrightarrow \quad p_t = D^{-1}\left(\sum_{h=1}^{H} S(p_{h,t}^e) \right) \qquad \text{(B2)}$$

Equation (3) in the main text can be seen to be a specific case of this formula, with specific choices for the demand and supply function. This becomes clear immediately after rewriting it slightly, again ignoring the noise term:

$$p_t = \frac{20}{21}\left(123 - \sum_{h=1}^{6} \frac{1}{6} p_{h,t}^e \right) \quad \Leftrightarrow \quad 129\frac{3}{20} - p_t = \sum_{h=1}^{6} \frac{10}{63} p_{h,t}^e \qquad \text{(B3)}$$

The left part of the equation is a linearly decreasing function of the current price, suitable as a demand function in the Cobweb model, while the right part consists of a sum of linearly increasing functions of predictions of the current price, suitable as the sum of supply functions.

Thus, the market maker version of the Cobweb model used in the experiment is actually equivalent to a specific form of the equilibrium version, using slightly different demand and supply functions.

▪ Section 2, page 4: Derivation of the demand function in the Asset Pricing model using mean-variance optimization

Suppose that traders in the Asset Pricing model divide their total wealth W between two kinds of financial assets, one with a risk-free rate of return of r and the other with a variable price p_t and dividend y_t. Trader h needs a prediction $p_{h,t+1}^{e}$ of the risky asset's price in the next period to be able to determine the amount $z_{h,t}$ he should buy to maximize his future wealth $W_{h,t+1}$. The rest of his current wealth he invests in the risk-free asset, giving the following wealth development:

$$W_{h,t+1} = (1+r)W_{h,t} + \left(p_{h,t+1}^{e} + y_{t+1} - (1+r)p_t\right)z_{h,t} \tag{B6}$$

Assuming that the prediction $p_{h,t+1}^{e}$ is provided by an advisor of the trader, the part played by the participants in the experiment, and that the current price of the risky asset is known when the traders decide on their demand quantities, the only source of uncertainty in tomorrow's wealth is the size of the dividend y_{t+1}. To determine the optimal quantities traders will choose in each period, assumptions are required about their subjective beliefs on the probability distribution of the dividend, and on their attitudes towards risk. Common choices in this respect are to suppose that all traders believe the dividend to be normally distributed with a positive mean and variance σ^2, while at the same time all of them share a constant absolute risk aversion with intensity parameter a towards the size of their own wealth, that is, $U(W) = -e^{-aW}$. Accepting these choices and, furthermore, assuming the Expected Utility Hypothesis to hold, the optimization problem of the traders can be described as follows:

$$\begin{aligned} &\frac{\partial}{\partial z_{h,t}} U\left(W_{h,t+1}\right) = 0 \\ \Leftrightarrow \quad &\frac{\partial}{\partial z_{h,t}} E\left(-e^{-a(1+r)W_{h,t} - az_{h,t}\left(p_{h,t+1}{}^{e} + y_{t+1} - (1+r)p_t\right)}\right) = 0 \end{aligned} \tag{B7}$$

Defining the excess returns, the quantity between brackets being multiplied by $-az_{h,t}$, to be equal to X_{t+1}, and recognizing that the first term in the exponent of the second equality does not contain the variable to be calculated and therefore is redundant, the optimization is continued in the following way:

$$\begin{aligned} &\frac{\partial}{\partial z_{h,t}} E\left(-e^{-az_{h,t}X_{t+1}}\right) = 0 \\ \Leftrightarrow \quad &\frac{\partial}{\partial z_{h,t}} \int_{X_{t+1}=-\infty}^{\infty} -e^{-az_{h,t}X_{t+1}} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(X_{t+1}-\mu)^2}{2\sigma^2}} dX_{t+1} = 0 \end{aligned} \tag{B8}$$

$$\Leftrightarrow \quad \int_{X_{t+1}=-\infty}^{\infty} \frac{\partial}{\partial z_{h,t}} \frac{-1}{\sqrt{2\pi\sigma^2}} e^{-az_{h,t}X_{t+1}-\frac{(X_{t+1}-\mu)^2}{2\sigma^2}} dX_{t+1} = 0 \tag{B8}$$

The exchange of the integral and derivative signs in the last equivalence is not trivial, but rather a consequence of the continuity of the integrand in the second equation of (B8) in both X_{t+1} and $z_{h,t}$ and the convergence of the integrand to zero for diverging values of X_{t+1}[1]. It is now possible to actually take the derivative and solve for the optimal demand quantity of trader *h*:

$$\begin{aligned} & a \int_{X_{t+1}=-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} X_{t+1} e^{-az_{h,t}X_{t+1}-\frac{(X_{t+1}-\mu)^2}{2\sigma^2}} dX_{t+1} = 0 \\ \Leftrightarrow \quad & z_{h,t} = \frac{\mu}{a\sigma^2} = \frac{E_{ht}\left(p^e_{h,t} + y_t - (1+r)p_{t-1}\right)}{a\sigma^2} \end{aligned} \tag{B9}$$

The optimal quantity is chosen is such a way to make the left part of the first equation have the form of a constant times the expectation of a normally distributed random number with a mean of zero, thus equalling it to zero as required.

▪ Section 2, page 5: Derivation of the fundamental price in the Cobweb model and the Asset Pricing model

Assuming that participants are able to perfectly predict the non-stochastic component of the market price, as required by the Rational Expectations Hypothesis applied to the behavior of the individual, the predicted price satisfies the identity $p_{h,t}^{e} = E_{t-1}(p_t)$, that is, equals the expectation of the market price lacking knowledge only of the size of the noise term at time *t*. Substituting in this way for the predictions of all participants, which is possible due to the homogeneity of individual behavior under the REH, it becomes clear what series of market prices, in both treatments, can be designated as "fundamental".

Fortunately, the nullification of the state variable feedback in both treatments simplifies calculations. In the Cobweb model, as described in its most explicit form by equation (3) in the main text, substituting for rational predictions and taking expectations yields the unique solution:

$$\begin{aligned} & p_t = \frac{20}{21}\left(123 - E_{t-1}(p_t)\right) + \varepsilon_t \\ \Rightarrow \quad & E_{t-1}(p_t) = \frac{20}{21}\left(123 - E_{t-1}(p_t)\right) \\ \Leftrightarrow \quad & p^e_{h,t} = E_{t-1}(p_t) = \frac{41}{21}\frac{20}{21}123 = 60 \end{aligned} \tag{B4}$$

A similar procedure can be applied to equation (6) for the Asset Pricing model:

---

[1] To see this, apply Theorem 4.2 in Whittaker & Watson (1902 / 2003, *p.* 67) repetitively, with diverging integration bounds.

$$
\begin{aligned}
& p_t = \frac{20}{21}\left(E_{t-1}(p_t)+3\right)+\varepsilon_t \\
\Rightarrow \quad & E_{t-1}(p_t) = \frac{20}{21}\left(E_{t-1}(p_t)+3\right) \\
\Leftrightarrow \quad & p^e_{h,t} = E_{t-1}(p_t) = 21\frac{20}{21}3 = 60
\end{aligned}
\tag{B5}
$$

If all participants in an experimental group would have behaved in accordance with the REH, they would have constantly predicted a price of 60 and the true price would have described a white noise process around this price, irrespective of the treatment the group was a part of. Moreover, in the experiment rational participants could not have acted differently, for example following a speculative bubble development in the Asset Pricing treatment. It will be shown below that the absence of non-constant fundamental price developments is actually a peculiarity arising from the specific choice of the model parameters in the experiment.

- **Section 3, page 7: The absence of fundamental bubble solutions in the Asset Pricing model**

Rewriting the Asset Pricing model's pricing formula, equation (4) in the main text, gives:

$$
p_t = \left(1-\frac{\lambda(1+r)}{a\sigma^2}\right)p_{t-1} + \lambda\sum_{h=1}^{H}\frac{n_{h,t}}{a\sigma^2}p^e_{h,t} + \lambda\frac{y-a\sigma^2 z^s}{a\sigma^2} + \varepsilon_t \tag{B10}
$$

Suppose now that the H advisors of the traders in the market are rational, in the sense that they are able to foresee the exact deterministic part of the following market price, and that their prediction rule consists only of a constant b_0 and the last known market price multiplied by a factor b_1. Substituting for these assumptions in the above equation, the following parameter restiction is generated:

$$
\begin{aligned}
& b_0 + b_1 p_{t-1} = \left(1-\frac{\lambda(1+r)}{a\sigma^2}\right)p_{t-1} + \frac{\lambda}{a\sigma^2}\left(b_0 + b_1 p_{t-1}\right) + \lambda\frac{y-a\sigma^2 z^s}{a\sigma^2} \\
\Leftrightarrow \quad & b_0 + b_1 p_{t-1} = \left(\frac{\lambda}{a\sigma^2}b_0 + \lambda\frac{y-a\sigma^2 z^s}{a\sigma^2}\right) + \left(1-\frac{\lambda(1+r)}{a\sigma^2}+\frac{\lambda}{a\sigma^2}b_1\right)p_{t-1}
\end{aligned}
\tag{B11}
$$

b_0 And b_1 are assumed to be constants, so the above equation implies a pair of expressions for these coefficients in terms of the model parameters:

$$
\begin{aligned}
& \frac{a\sigma^2-\lambda}{a\sigma^2}b_0 = \lambda\frac{y-a\sigma^2 z^s}{a\sigma^2} \quad \Leftrightarrow \quad b_0 = \lambda\frac{y-a\sigma^2 z^s}{a\sigma^2-\lambda} \\
& \frac{a\sigma^2-\lambda}{a\sigma^2}b_1 = \frac{a\sigma^2-\lambda(1+r)}{a\sigma^2} \quad \Leftrightarrow \quad b_1 = \frac{a\sigma^2-\lambda(1+r)}{a\sigma^2-\lambda}
\end{aligned}
\tag{B12}
$$

The uniqueness in the experiment of the fundamental value as a series of fundamental prices can now easily be explained. Calculating b_0 and b_1 using the experimental parameters gives 60 and 0 respectively, consistent with the derivation of the fundamental price in the Asset Pricing model earlier in this appendix. When a variation of the market maker's adjustment speed λ is considered though, it becomes clear that a constant fundamental price is a rather singular phenomenon relative to a substantive area of the parameter space.

When the adjustment speed is decreased to a smaller positive quantity than given by the ratio $a\sigma^2/(1+r)$, b_0 decreases to 0 and b_1 rises to 1. Therefore, in this open interval of cases with $\lambda = 0$ as its left-hand limit, since b_1 lies between 0 and 1, the fundamental market price converges in expectation but is in general not constant. Since it converges in expectation, its non-stochastic parts do not change anymore in the limit, creating equivalence, again in expectation, with the situation of the calculation (B5) above. Therefore, all positive lambdas smaller than $a\sigma^2/(1+r)$, *ceteris paribus*, in general generate a stochastic fluctuation around the fundamental value as a fundamental price series only in the long term.

Three intervals of λ values are interesting to consider here, in a similar way as the one above, since they each produce different qualitative features in fundamental price development. In each case it is the value of b_1 that determines the convergence properties of the fundamental series. For λ between $a\sigma^2/(1+r)$ and $2a\sigma^2/(2+r)$, b_0 is greater than 60 and b_1 lies between 0 and 1. The fundamental price therefore alternatingly converges in expectation to the fundamental value. For λ between $2a\sigma^2/(2+r)$ and $a\sigma^2$, b_0 is far greater than 60 and b_1 is smaller than –1. The fundamental price therefore alternatingly diverges in expectation from the fundamental value. That is, as far as possible, since the price of course cannot become negative. Finally, for λ greater than $a\sigma^2$, b_0 is negative and b_1 is greater than 1. The fundamental price therefore monotonically diverges in expectation, creating a speculative bubble solution if the initial price is larger than 60.

An interesting question for further research would be whether the absence of speculative bubbles in the experiment is caused by the absence of a fundamental bubble solution, or by an irrational bias in the participants' prediction behavior towards a relatively stable development around equilibrium. This question could be answered by repeating the experiment with a λ value for which a fundamental bubble solution would exist and observing whether the participants would still refrain from following it. A convenient value for λ for example would be $2a\sigma^2 = 2$, implying values for b_0 and b_1 of $-2(y - a\sigma^2 z^s) = -6$ and $1 + 2r = 1.10$ respectively. It is important to note that setting a different λ would also resurrect the state variable feedback, necessitating an initial condition for the market price and a slight complication in the probability distribution of the fundamental price, which will include a noise term from the last period.

Appendix C: Figures

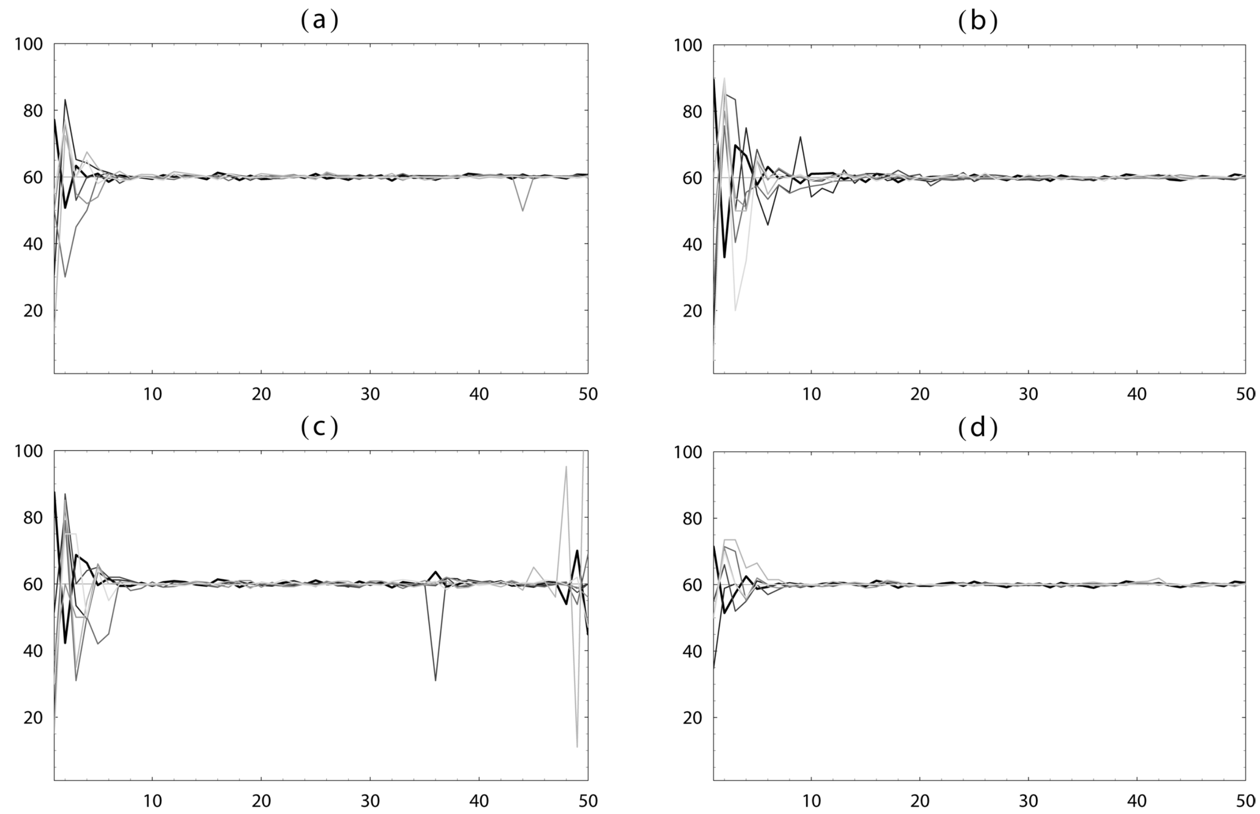


Figure #1 (part 1 of 2): Market prices, price predictions and the fundamental price for four of the six Cobweb groups. The market prices are connected by the thick black lines, the predictions by the thinner ones in shades of grey and the fundamental price is the horizontal line at 60. *(continued on the next page)*

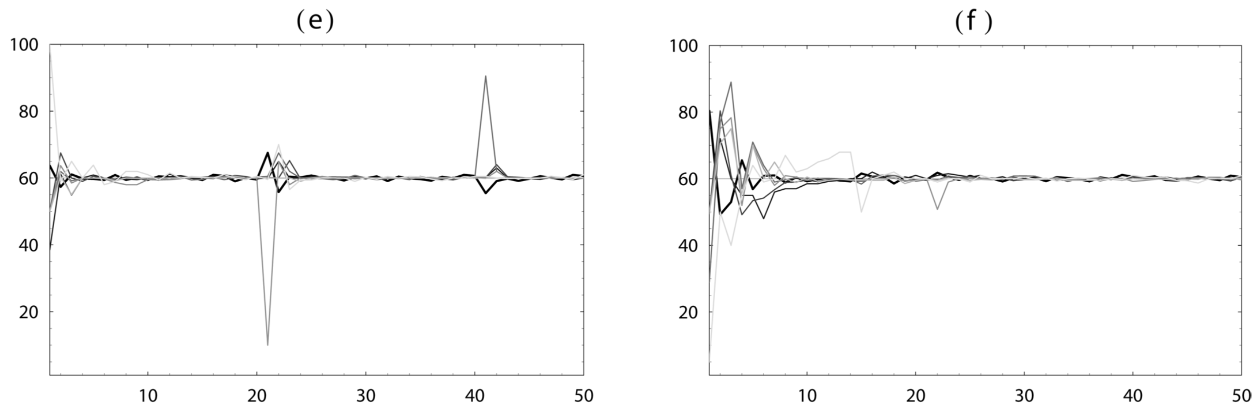


Figure #1 (part 2 of 2): Market prices, price predictions and the fundamental price for the last two of the six Cobweb groups. The market prices are connected by the thick black lines, the predictions by the thinner ones in shades of grey and the fundamental price is the horizontal line at 60.

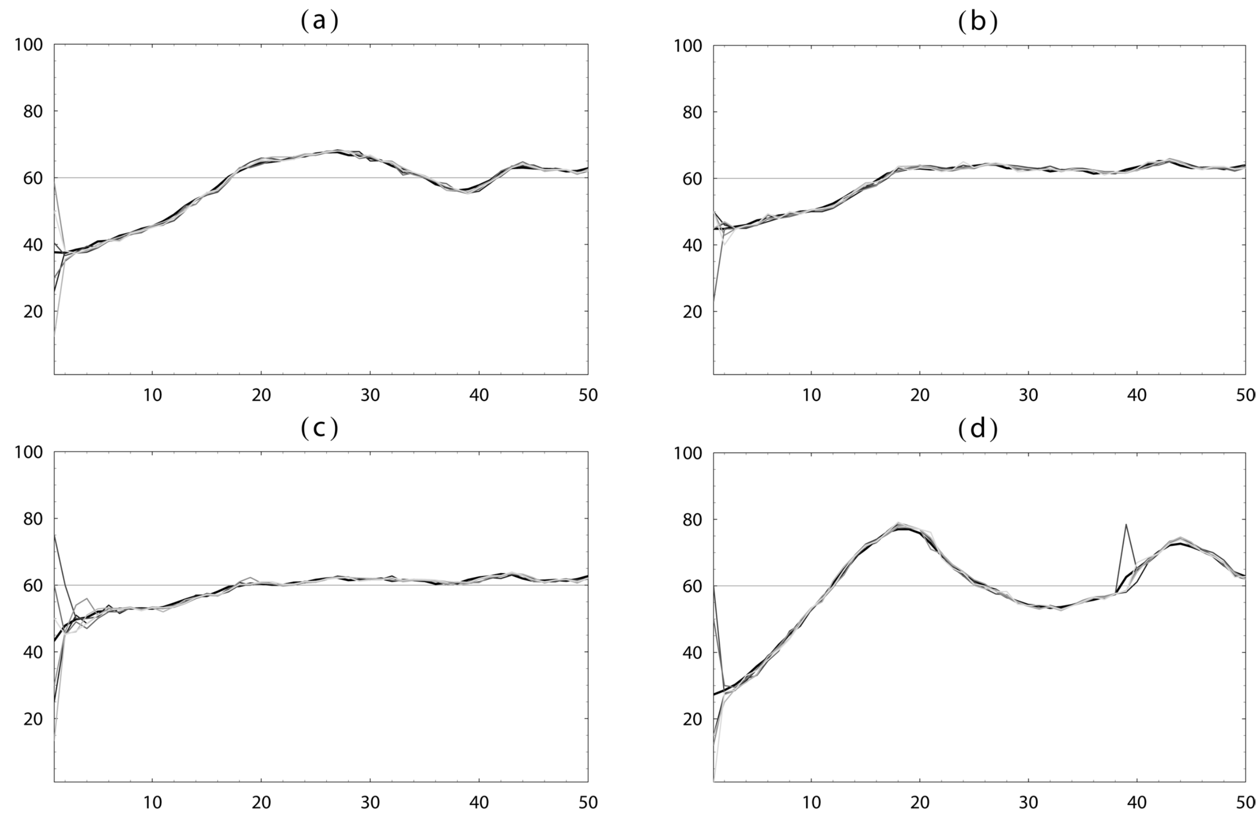


Figure #2 (part 1 of 2): Market prices, price predictions and the fundamental price for four of the seven Asset Pricing groups. The market prices are connected by the thick black lines, the predictions by the thinner ones in shades of grey and the fundamental price is the horizontal line at 60.

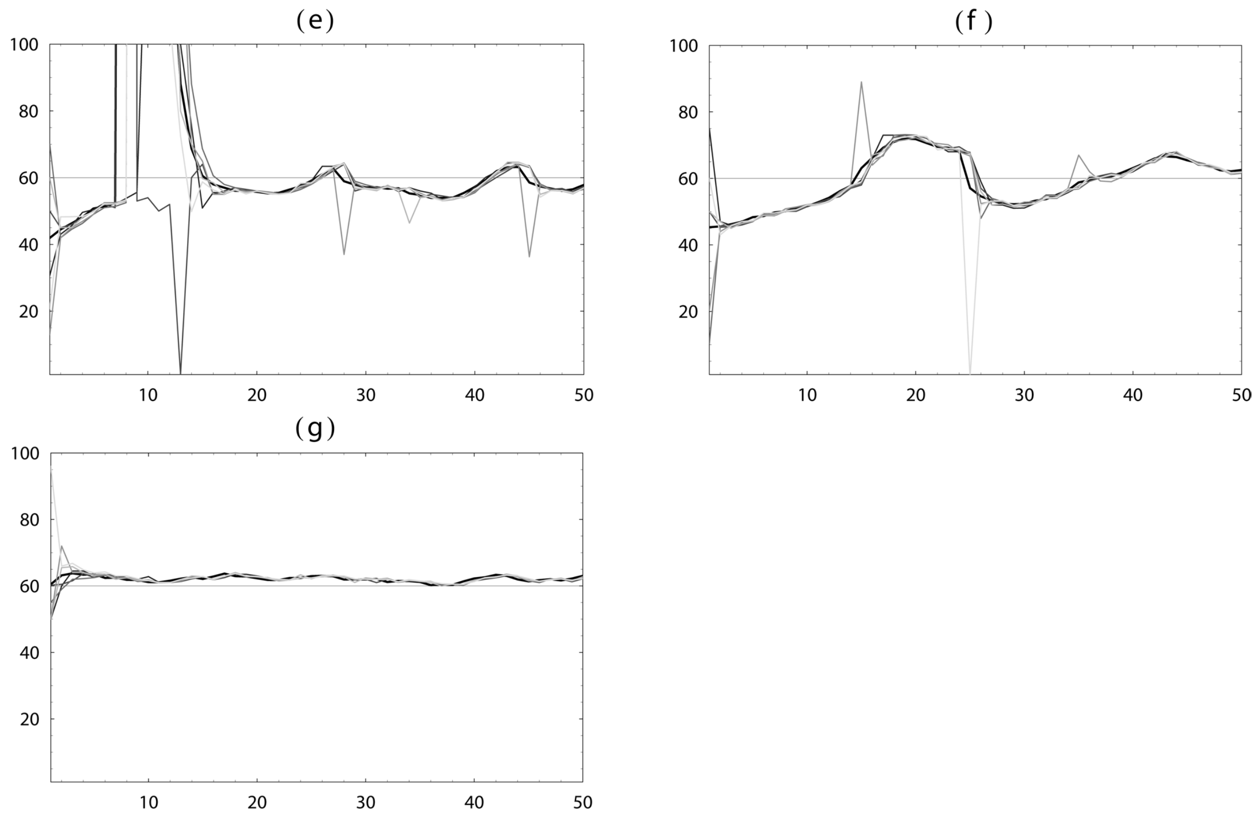


Figure #2 (part 2 of 2): Market prices, price predictions and the fundamental price for the last three of the seven Asset Pricing groups. The market prices are connected by the thick black lines, the predictions by the thinner ones in shades of grey and the fundamental price is the horizontal line at 60.

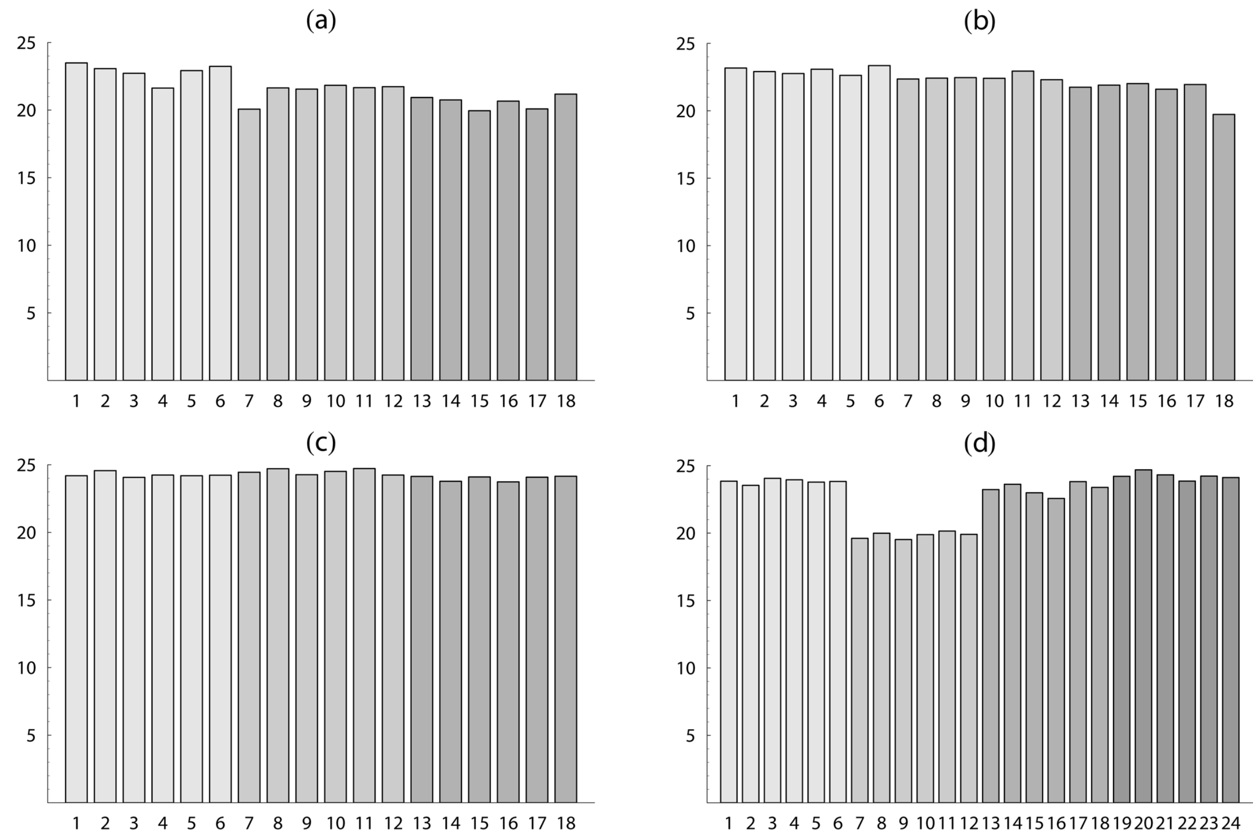


Figure #3: Earnings of all 78 participants, in euros. The four graphs divide the participants up according to session number. Different shades of grey indicate group compositions. The first row shows the six Cobweb groups and the second the seven Asset Pricing groups.

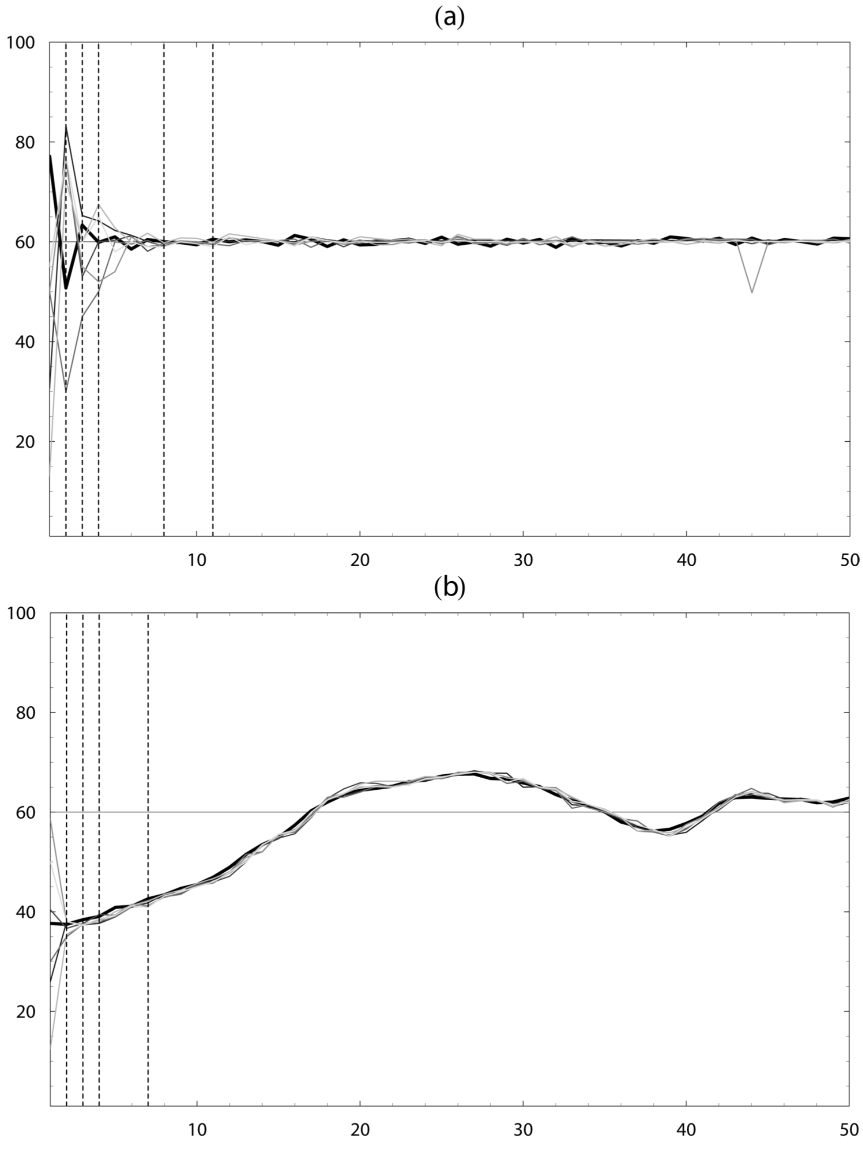


Figure #4: Decomposition of the Phases of Entry for both treatments. Graph (a) and (b) show the first of the Cobweb groups and the Asset Pricing groups respectively, enlargements of graphs (a) of Figures #1 and #2 respectively.

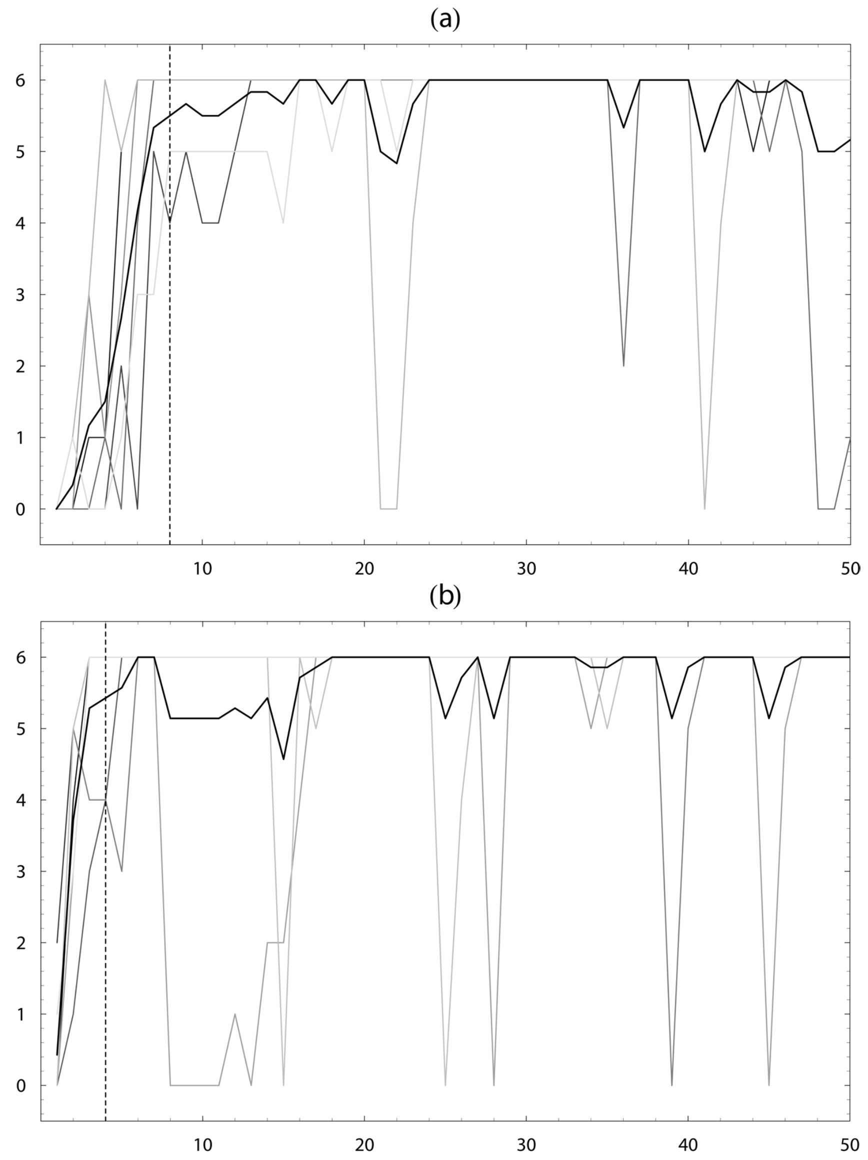


Figure #5: Calculating the length of the Phases of Entry, for the Cobweb treatment in graph (a) and the Asset Pricing treatment in graph (b). The graphs show the number of participants with a prediction error of less than five percent of the market price. Thin lines in shades of grey denote the results for individual groups and thick lines connect the average numbers per treatment. The Majority Criterium is reached at the dashed lines.

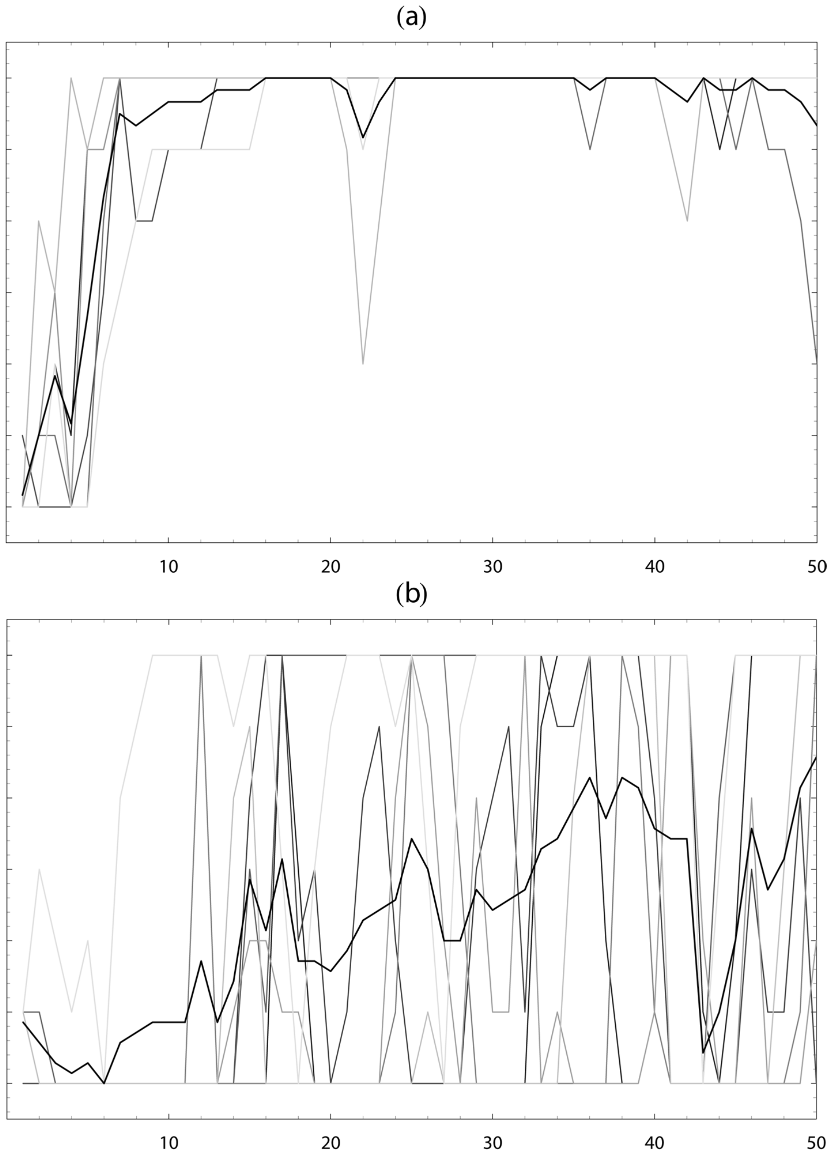


Figure #6: Number of participants with a prediction deviating less than five percent from the fundamental price. Graph (a) represents the Cobweb treatment and graph (b) the Asset Pricing treatment. Thin lines in shades of grey denote the results for individual groups and thick lines connect the average numbers.

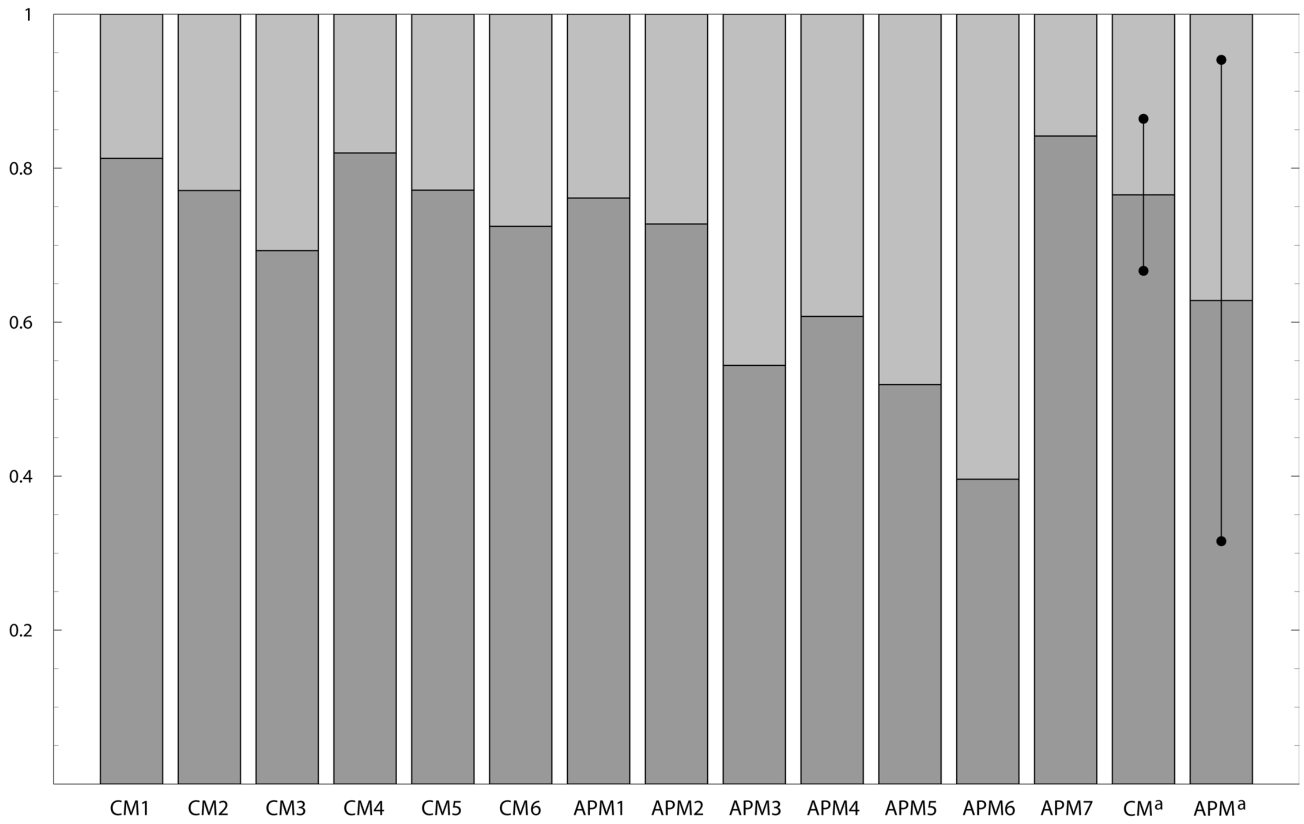


Figure #7: Decomposition of the prediction error, for each group and for both treatment as a whole. The lower parts of the bars represent the total Common Error and the upper parts the Dispersion Error. "CM", "APM" and "a" are abbreviations of "Cobweb Model", "Asset Pricing Model" and "average" respectively, while the numbers on the horizontal axis are group numbers. The two bars to the far-right side show the average over the groups in their treatments, the vertical lines measuring two unbiased standard deviations in either direction from the mean. In all groups, time periods that demonstrated atypical prices due to large prediction mistakes, as listed in footnote 25, had been excluded when constructing the above Figure.

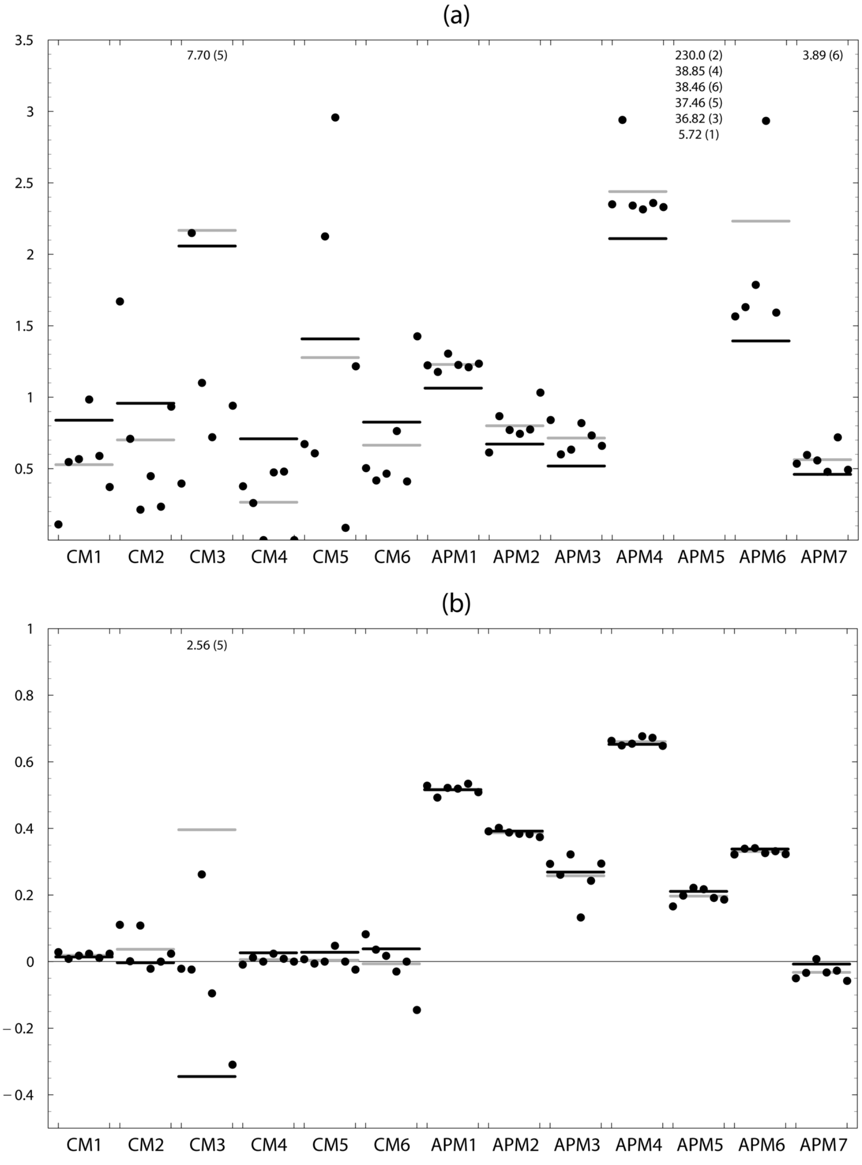


Figure #8: Degrees of overreaction, for each participant and for each group as a whole. Graph (a) is based on mean absolute changes in price predictions and market prices, while Graph (b) is based on mean nominal changes. Dots represent mean changes in predictions for individual participants, grey bars the group averages over the individual results and black bars the mean changes in market prices. The numbers below the ceiling of the Graphs give the location of outlying dots, with the group number of the associated participant between brackets. "CM" and "APM" stand for Cobweb Model and Asset Pricing Model.

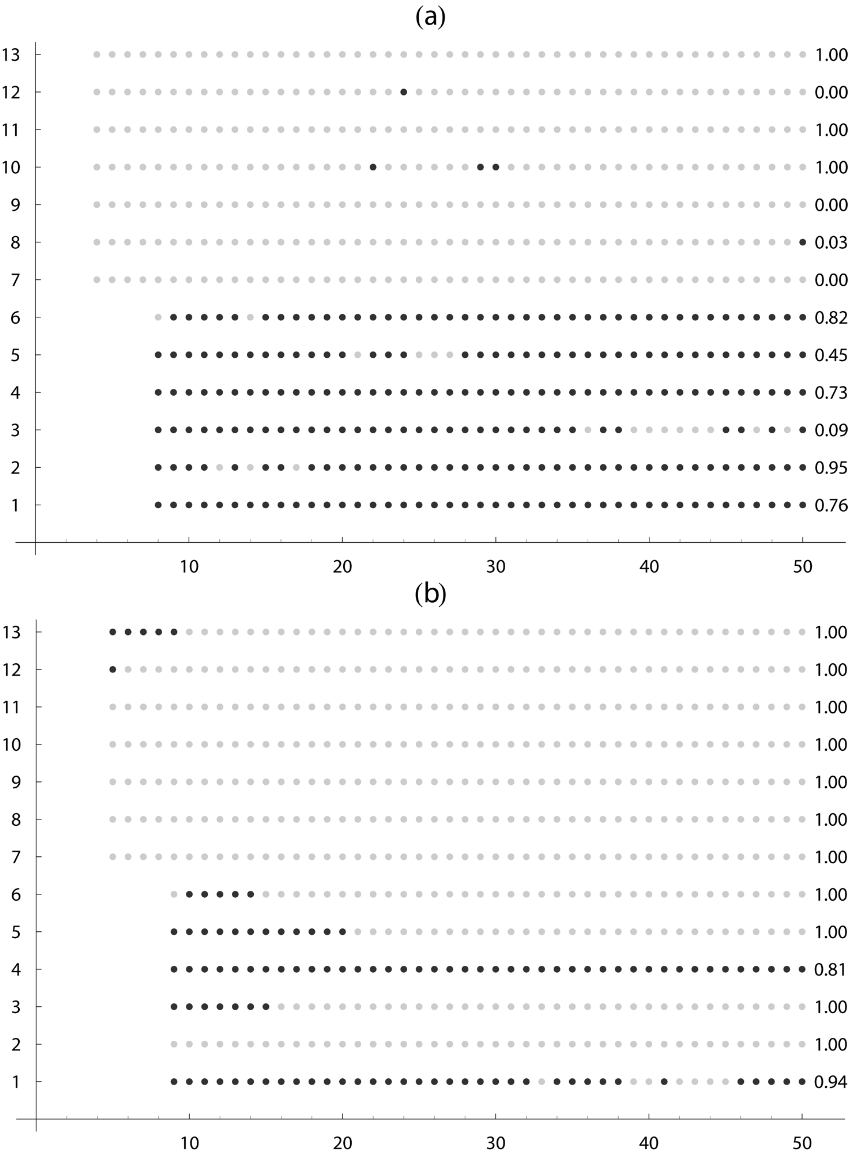


Figure #9: Testing the Rational Expectations Hypothesis for the group mean and variance of the market prices. On the vertical axes are the thirteen groups, starting with the six Cobweb groups. On the horizontal axes the end of the test sample is indicated, starting right after the Phases of Entry. Graph (a) shows the tests for the mean and graph (b) tests for the variance. A dark spot denotes non-rejection of the Rational Expectations Hypothesis in this case, while a light spot denotes rejection, at 5% significance level. The columns of numbers at the right end of the graphs indicate the values of the relevant probability distribution functions evaluated at the statistics corresponding to the last column of dots.

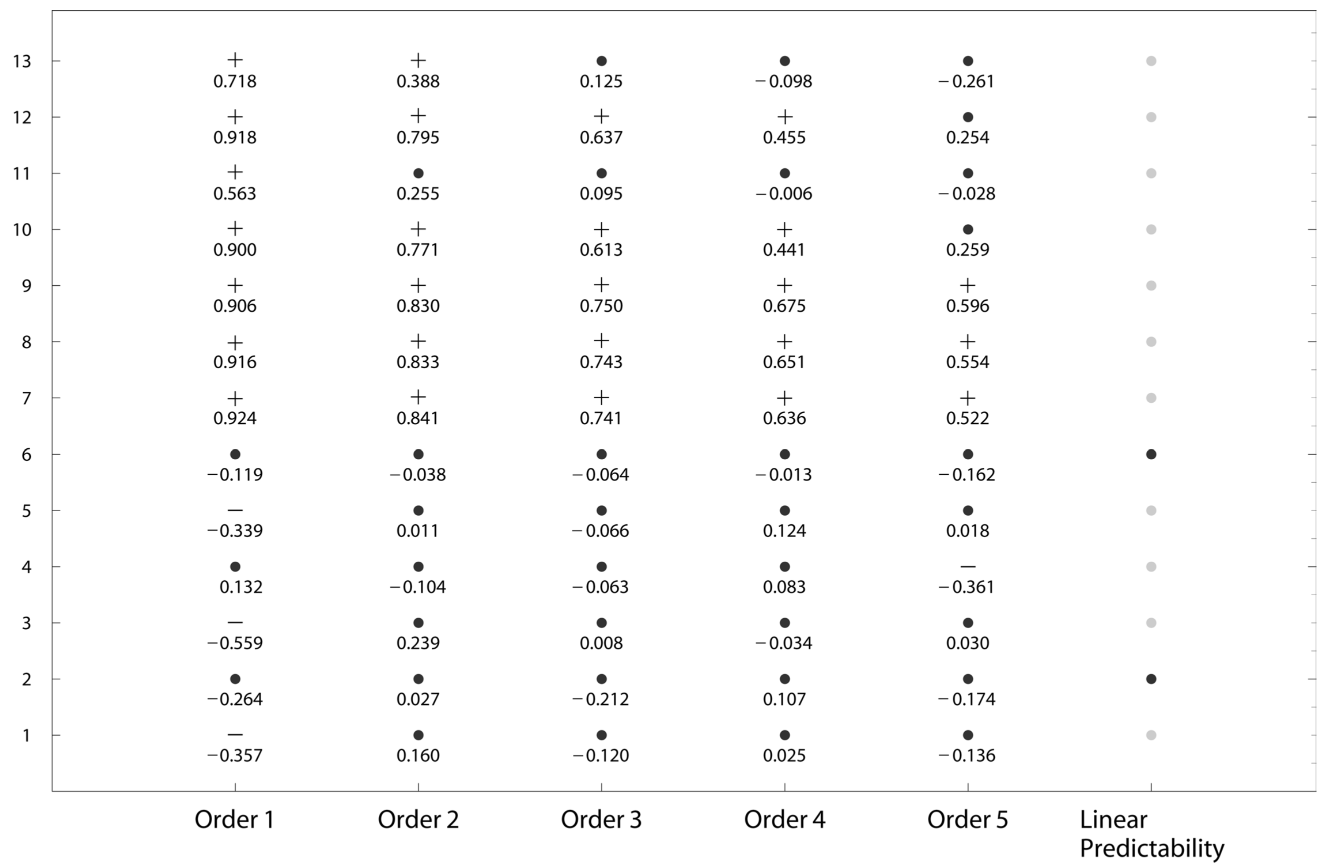


Figure #10: Testing the Rational Expectations Hypothesis for the group autocorrelations of the market prices. On the vertical axis are the thirteen groups, starting with the Cobweb groups. On the horizontal axis, five orders of autocorrelation are indicated. The sixth column summarizes whether markets contain any autocorrelation. Plus and minus signs indicate significant positive and negative autocorrelation respectively, at a significance level of 5%, while dark and light spots indicate the absence and presence of any autocorrelation. The numbers in the graph represent the r statistics (see equation (11) in the main text), with a critical value of 0.305 for the Cobweb treatment and 0.292 for the Asset Pricing treatment.

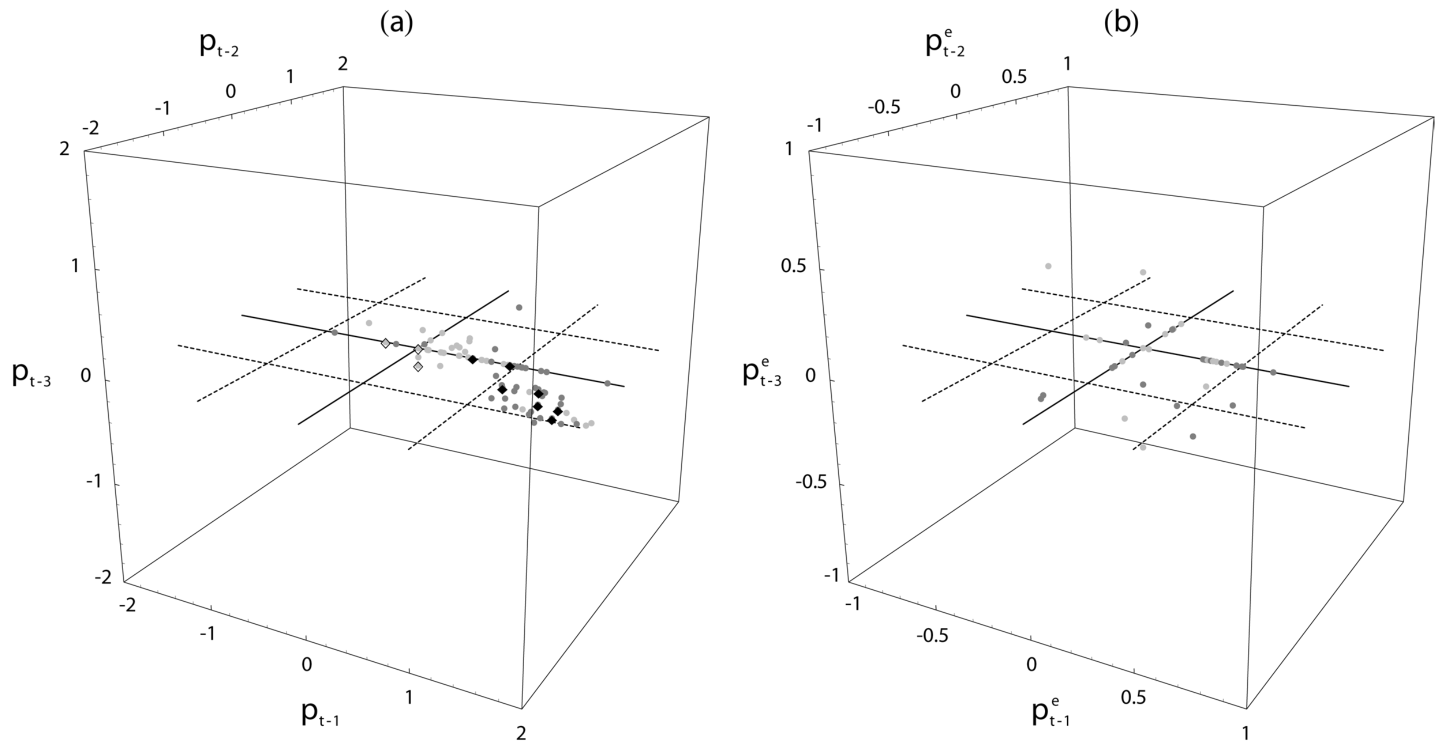


Figure #11: Objective and subjective coefficient spaces. Graph (a) shows the objective coefficients of the AdAR(3,3) specification (see equation (12) in the main text), and graph (b) shows the subjective coefficients. Light dots belong to participants of the Cobweb treatment and dark dots to participants of the Asset Pricing treatment. In graph (a), the filled diamonds depict the coefficients of an AR(3) estimation of market prices in Asset Pricing groups, and open diamonds depict such results for Cobweb groups.

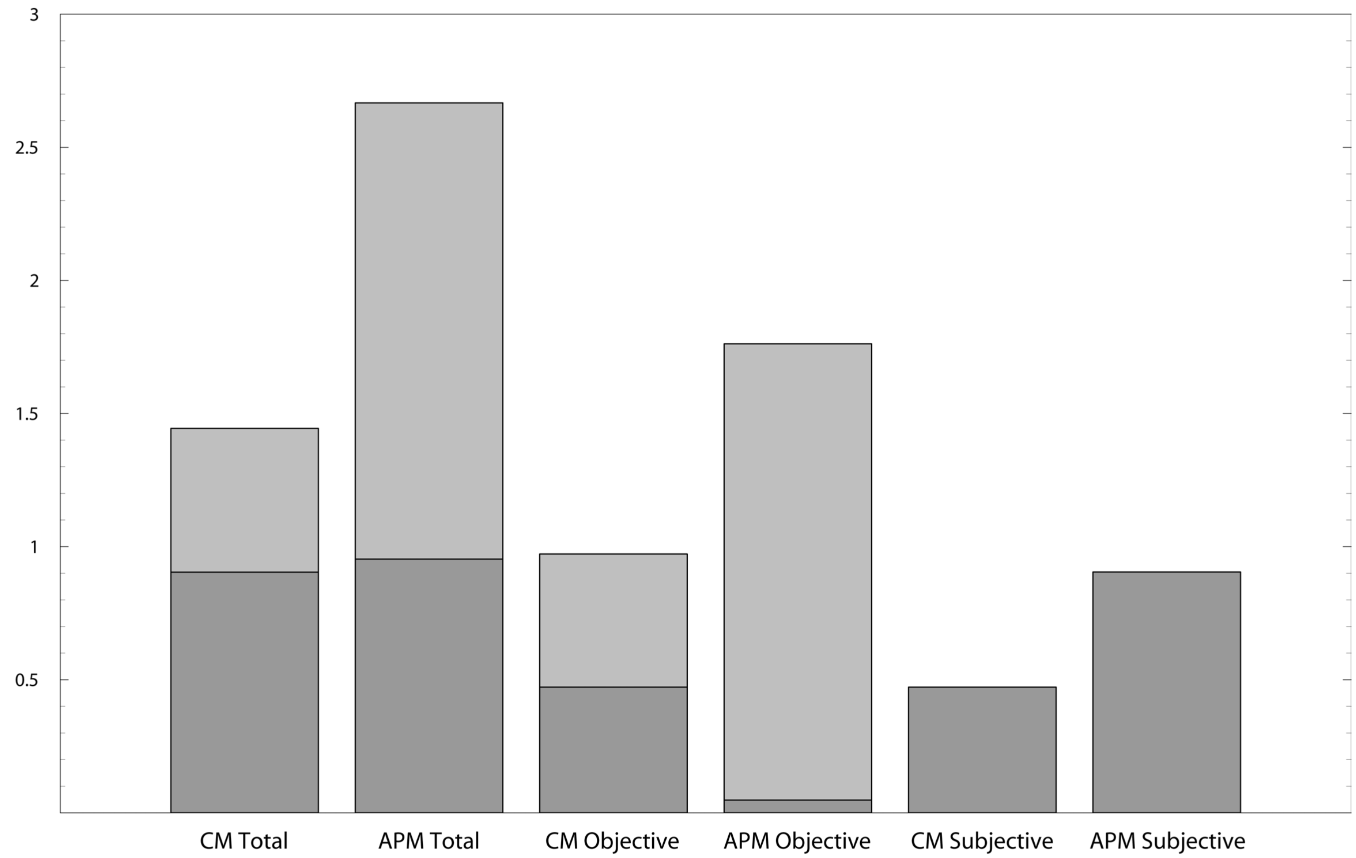


Figure #12: Average Complexities of the AdAR prediction rules (see equation (12) in the main text). The vertical axis shows the average number of significant explanatory variables. "CM" And "APM" are abbreviations for "Cobweb Model" and "Asset Pricing Model" respectively. The first pair of bars shows the results for the treatments as a whole, while the second and third pair of bars restrict attention to the objective and subjective variables respectively. The light shade of grey represents the average Complexity of market price developments.

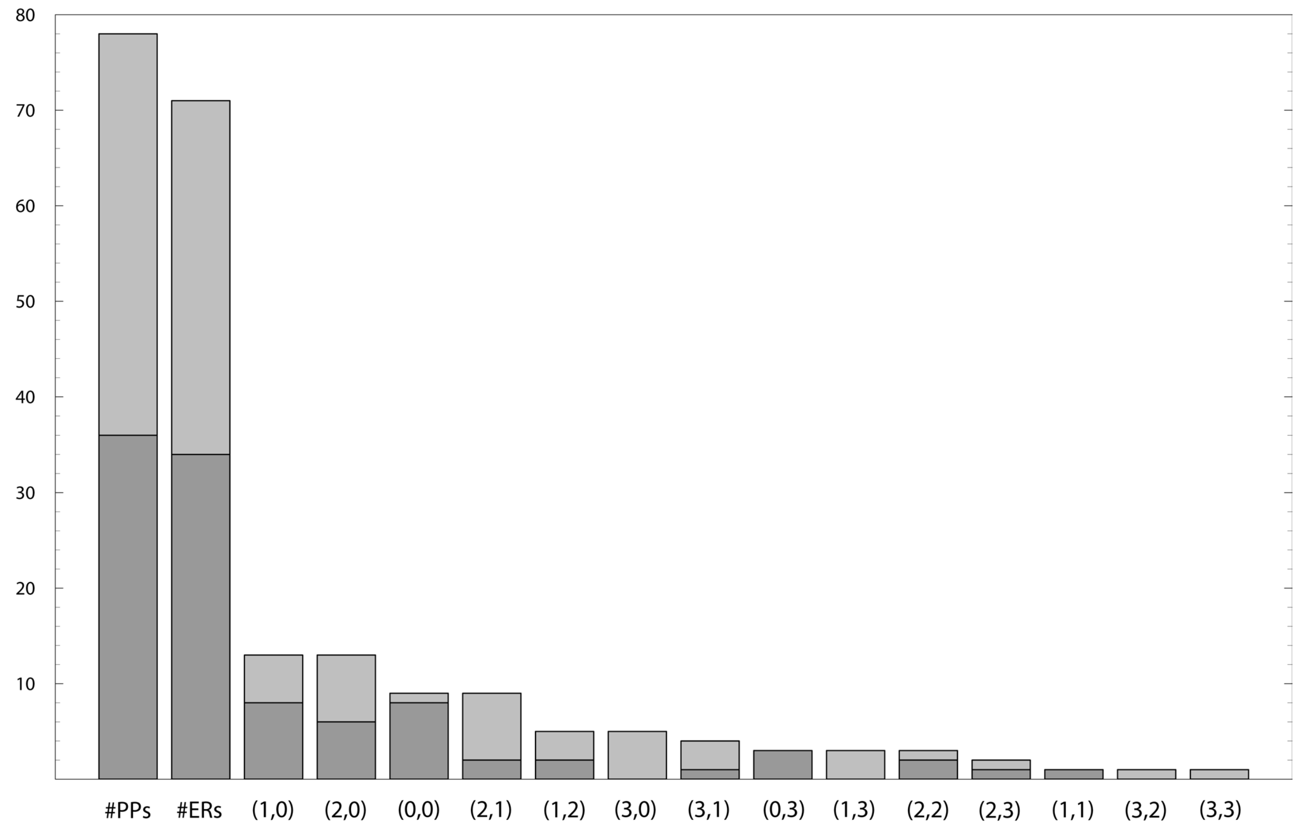


Figure #13: Lag depth of estimated Adaptive Autoregressive (AdAR) prediction rules (see equation (12) in the main text), for both treatments. "#PPs" And "#ERs" are abbreviations for number of participants and number of succesfully estimated AdAR rules respectively. The two-dimensional vectors contain the highest lag of the market prices and the price predictions respectively that was significant in the AdAR specification, to a maximum of three. The dark shade of grey is produced by prediction rules from the Cobweb treatment and the light shade by rules from the Asset Pricing treatment.

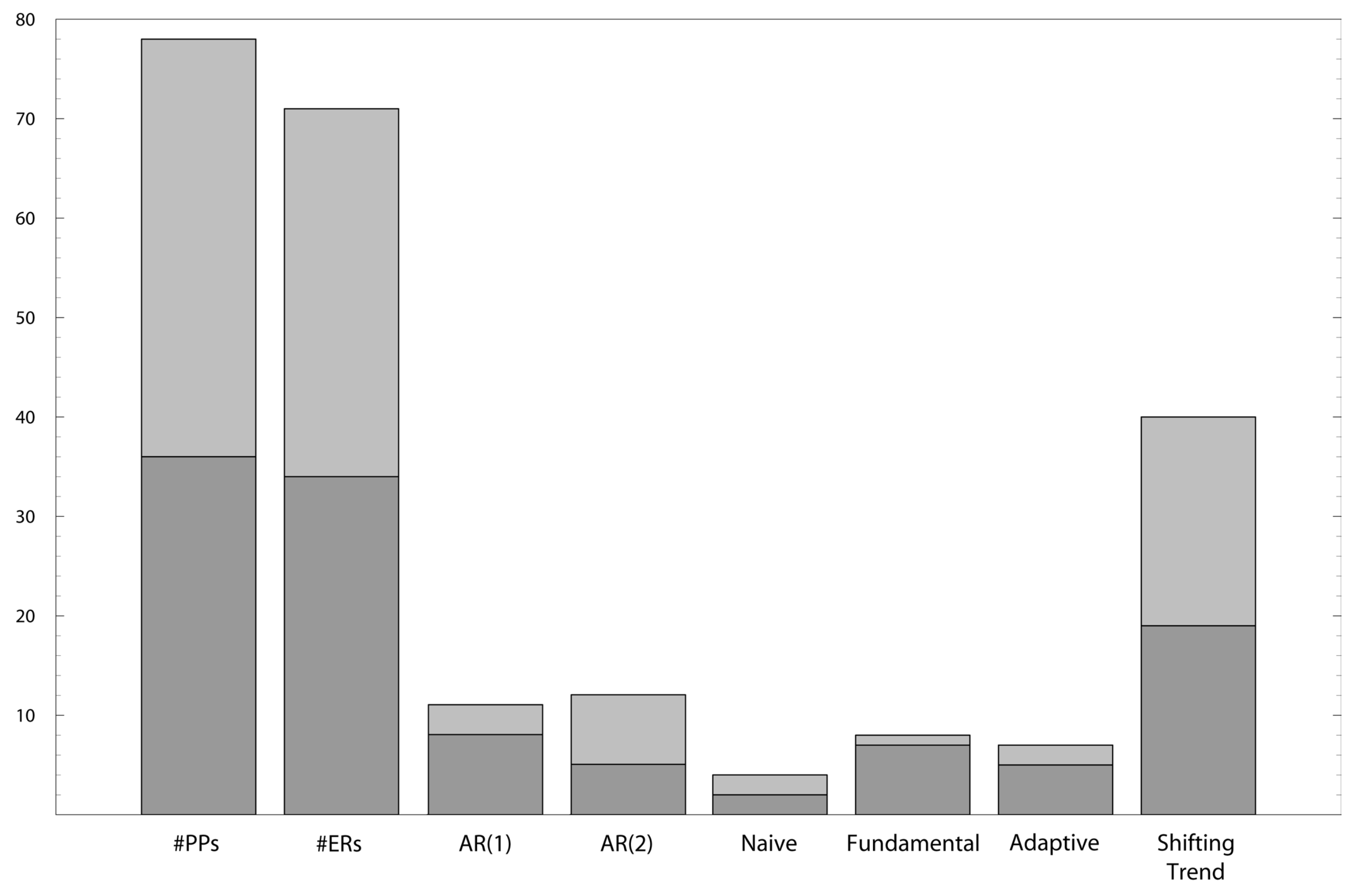


Figure #14: Classification of the estimated prediction rules into several kinds of expectation formation. "#PPs" And "#ERs" are abbreviations for number of participants and number of succesfully` estimated AdAR rules (see equation (12) in the main text) respectively. The dark shade of grey is produced by prediction rules from the Cobweb treatment and the light shade by rules from the Asset Pricing treatment. Wald restriction tests at 5% significance level were used to arrive at the results.

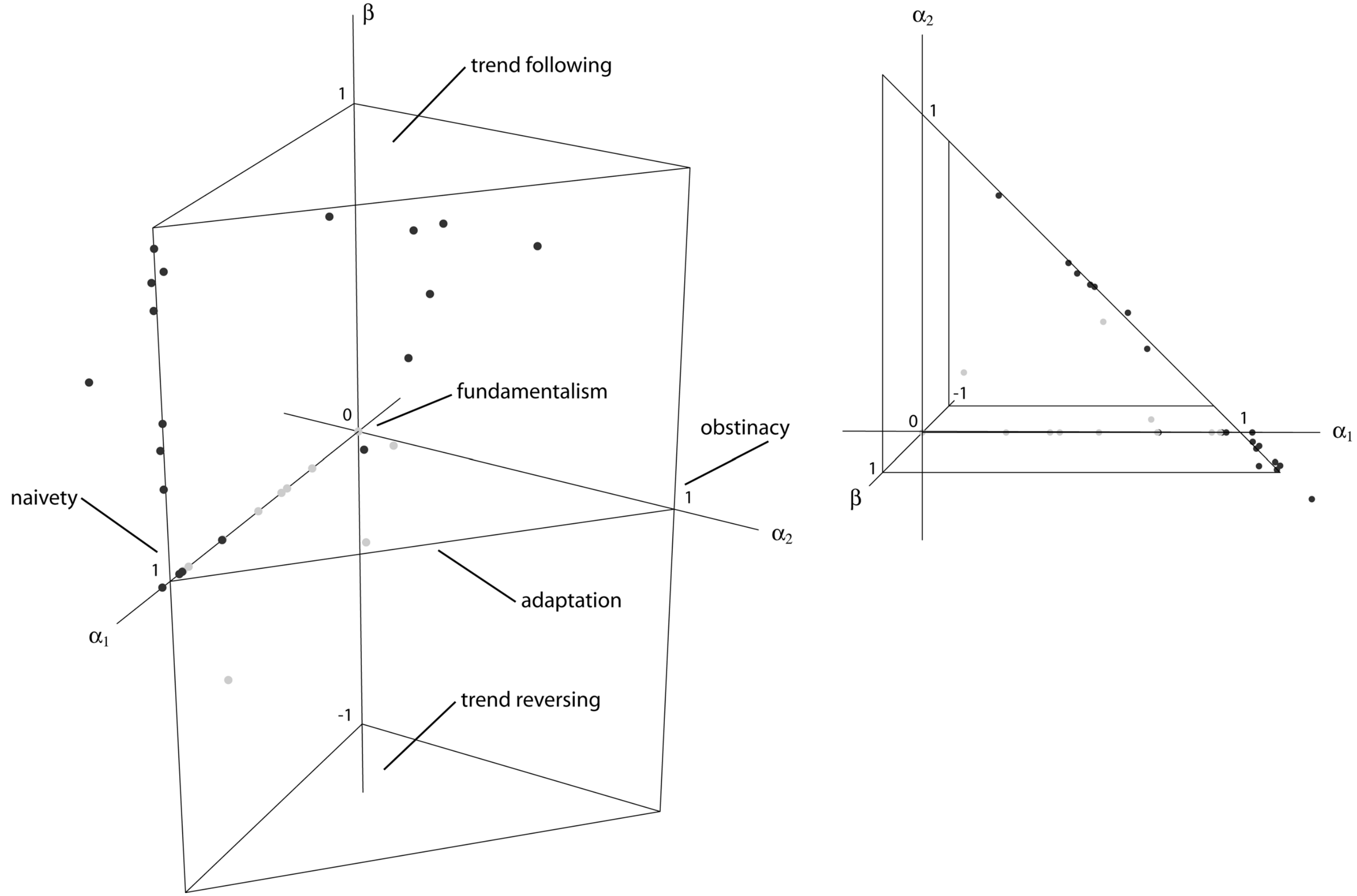
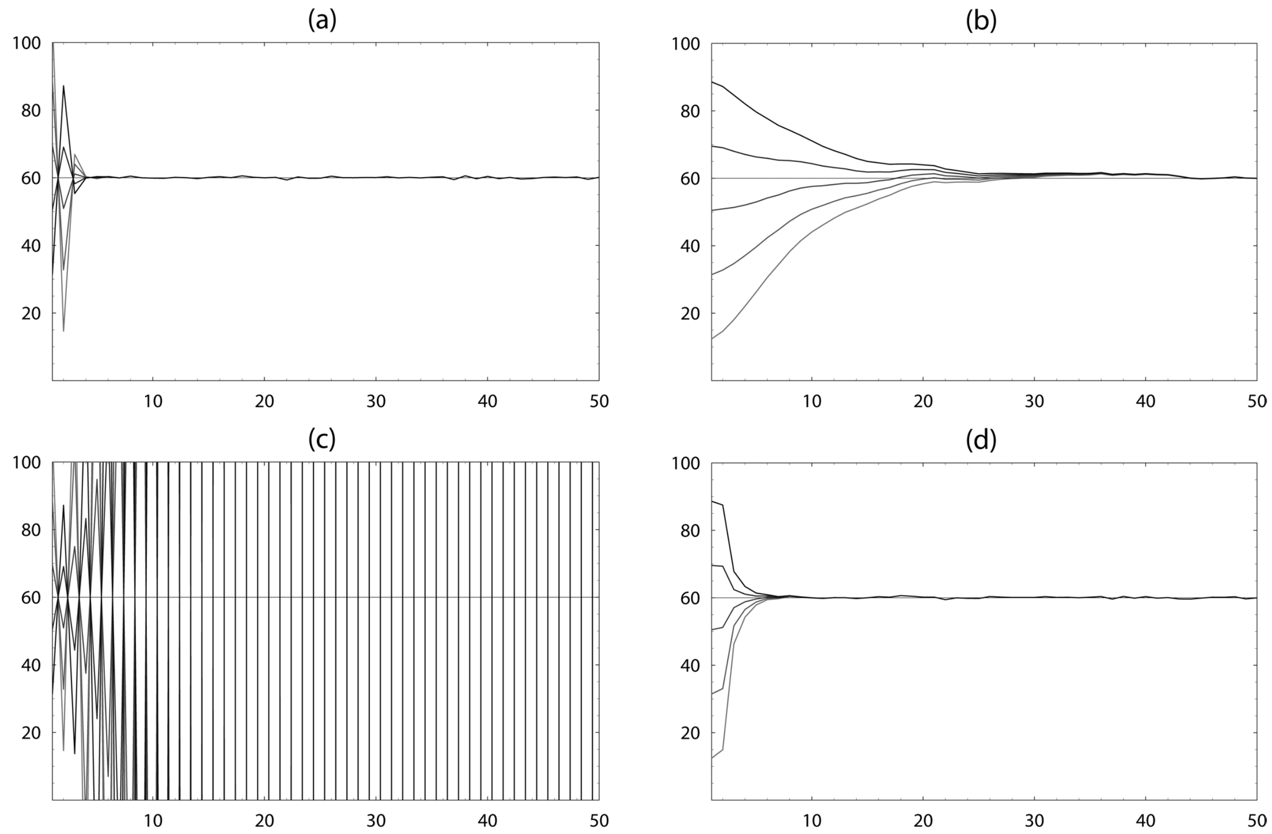


Figure #15: Prism of First-Order Heuristics containing the parameter vectors of the Shifting Trend prediction rules (see equation (13) in the main text). The smaller graph on the right is a top-down view of the Prism. Light dots depict prediction rules from participants in the Cobweb treatment and dark dots rules from participants in the Asset Pricing treatment.



Figuur #16: Market price simulations based on the estimated Shifting Trend rules (see equation (13) in the main text), grouped by treatment. Each graph shows market price developments based on average initial price predictions of 10, 30, 50, 70 and 90 respectively. In Graph (a) the Cobweb STE rules are applied to the Cobweb model; in Graph (b) the Asset Pricing STE rules to the Asset Pricing model; in Graph (c) the Asset Pricing STE rules to the Cobweb model; in Graph (d) the Cobweb STE rules to the Asset Pricing model. All simulations make us of a single series of disturbances.

Appendix D: Tables

Variable	*Estimate*	*St. Deviation*	*t Value*	*p Value*
constant	23.19	0.4137	56.05	0.0000
maximize income (Q1)	0.2387	0.0503	4.746	0.0000
made effort (Q3)	0.1449	0.0479	3.025	0.0036
age (Q16)	-0.0376	0.0113	-3.302	0.0016
study unknown (Q18)	-1.100	0.2739	-4.017	0.0002
group Cobweb #1	-0.9779	0.1635	-5.981	0.0000
group Cobweb #2	-2.501	0.1515	-16.51	0.0000
group Cobweb #3	-3.352	0.1512	-22.18	0.0000
group Cobweb #4	-1.004	0.1502	-6.685	0.0000
group Cobweb #5	-1.559	0.1583	-9.849	0.0000
group Cobweb #6	-2.561	0.1501	-17.05	0.0000
group Asset Pricing #2	0.481	0.1541	3.119	0.0027
group Asset Pricing #5	-4.252	0.1517	-28.03	0.0000
group Asset Pricing #6	-0.7154	0.1503	-4.762	0.0000
Number of Observations	78			
R Squared (Adjusted)	0.9607 (0.9527)			
F Statistic (P Value)	120.4 (0.0000)			
Minimal P Value of Q Statistics 1 through 32 (at lag)	0.601 (30)			

Table #1: Ordinary least squares regression of the participants' earnings on the quantifiable part of the answers to the questionnaire (see Appendix A) and the group membership dummies. Numbers following "Q" between parentheses refer to questions of the same number. The significance level has been set to 1%, to compensate for the possibility of overestimation due to the relatively large number of explanatory variables. Variables have been eliminated by iteratively deleting the one with the greatest *p* value.

Part.no.	*c*	p_{-1}	p_{-2}	p_{-3}	p^e_{-1}	p^e_{-2}	p^e_{-3}	R^2	*AC*
1	53.67	0.1080	0	0	0	0	0	0.2013	No
2	29.75	0.7002	0	0	0	-0.1957	0	0.8795	No
3	25.47	0	0.2431	0	0	0	0	0.0983	No
4	23.30*	0.4213	0	0	0	0	0	0.1385	No
5	32.90*	0.3919	-0.3136	0	0.3750	0	0	0.3077	No
6	39.48	0.3255	0.2009	0	-0.5089	0	0.3240	0.6504	No
7	87.60	0	0	0	0	-0.1772	-0.2876	0.3478	No
8	10.26*	0.0111	0	0	0.0306	0	0	0.1912	No
9	32.15	0.0953	0	0	0	0	0.3662	0.7756	Yes
10	29.38	0.2818	0.2317	0	0	0	0	0.2821	No
11	16.13	0.2697	0.1532	0	0	0.3088	0	0.4381	No
12	20.81	0.6534	0	0	0	0	0	0.5102	No
13	-0.489*	0.3003	0.4690	0	0	0.2218	0	0.7600	No
14	59.15	0	0	0	0	0	0	0.0000	No
15	7.433	0.8692	0	0	0	0	0	0.9412	No
16	31.26	0	0.4799	0	0	0	0	0.4220	No
17	-170.6	0	0	0	-1.356	1.538	3.671	0.9670	No
18	82.00	-0.7656	0.3995	0	0	0	0	0.7943	No
19	34.40	0.4264	0	0	0	0	0	0.5653	No
20	45.60	0.2423	0	0	0	0	0	0.3077	No
21	60.00	0	0	0	0	0	0	0.0000	No
22	20.97	0.6489	0	0	0	0	0	0.7385	Yes
23	16.56	0.3326	0.3946	0	0	0	0	0.2316	No
24	60.00	0	0	0	0	0	0	0.0000	No
25	44.31	0.2653	0	0	0	0	0	0.2074	No
26	23.03	-0.2041	0.4658	0	0.3586	0	0	0.6671	No
27	60.98	0	0	0	0	0	0	0.0000	No
28	58.89	0	0	0	0	0	0	0.0000	No
29	45.38	0	0	-0.0898	0	0	0	0.5408	No
30	5.533*	0.9115	0	0	0	0	0	0.7367	No
31	5.767*	0.5157	0	0	0	0.3906	0	0.7284	No
32	27.21	0.4251	0.1179	0	0	0	0	0.6324	No
33	90.46	0	0	0	0	0	-0.5047	0.2533	No
34	59.66	0	0	0	0	0	0	0.0000	No
35	45.71	0.2338	0	0	0	0	0	0.2004	No
36	60.48	0	0	0	0	0	0	0.0000	No

Table #2: Estimated AdAR prediction rules for the 36 participants of the Cobweb treatment. The first column shows the participant's number, clustered according to group. The second through eighth column show the estimations of the AdAR parameters, including the constant. The last two columns show the R-squared statistic and the report on the presence of autocorrelation in the residuals up to the twentieth order. Insignificant explanatory variables have been eliminated one at a time, the one with the largest p value first, until all values were below 5%. An asterisk in the second column indicates that the constant is insignificant.

Part.no.	*c*	p_{-1}	p_{-2}	p_{-3}	p^e_{-1}	p^e_{-2}	p^e_{-3}	R^2	*AC*
1	-0.790*	1.675	0	-0.4329	-0.2324	0	0	0.9965	No
2	-0.682*	1.340	-0.5007	0	0.4642	-0.2914	0	0.9980	No
3	-1.176*	1.724	0	-0.3995	-0.3069	0	0	0.9932	No
4	-1.121	1.893	-0.8748	0	0	0	0	0.9971	No
5	0.417*	1.443	-0.8745	0	0.4264	0	0	0.9975	No
6	-0.817*	1.787	-0.7724	0	0	0	0	0.9982	No
7	0.742*	1.184	0	-0.1698	0	0	0	0.9964	Yes
8	-0.179*	1.463	-0.4552	0	0	0	0	0.9938	No
9	0.657*	1.220	-0.7315	0	0.5006	0	0	0.9969	No
10	0.339*	1.285	0	0	0	-0.2887	0	0.9969	No
11	0.693*	1.368	-0.8523	0	0.4743	0	0	0.9948	No
12	0.223*	1.851	0	0	-0.3270	-0.3533	-0.1723	0.9926	No
13	0.040*	1.450	-0.4504	0	0	0	0	0.9870	No
14	0.164*	1.069	-0.4708	0	0.4000	0	0	0.9943	No
15	-0.251*	1.275	-0.2989	-0.2706	0	0.2984	0	0.9981	No
16	2.170*	1.232	0	0	0	-0.2662	0	0.9780	No
17	-0.985*	1.251	0	-0.2345	0	0	0	0.9900	No
18	-0.1026	1.219	-0.5430	0	0.4372	0	0	0.9942	No
19	2.411	1.084	0	0	0.2635	0	-0.3910	0.9940	No
20	1.956*	-0.9115	0	0	0	0	0	0.8975	No
21	1.382	1.641	-0.9729	0	0.3084	0	0	0.9978	No
22	2.687	1.6274	-0.4900	0	0	0	-0.1816	0.9934	No
23	1.475	1.441	0	-0.4659	0	0	0	0.9948	No
24	0.062*	1.943	-0.9439	0	0	0	0	0.9953	No
25	34.27	0	0.1203	0	0.3421	0.2670	-0.3179	0.9892	Yes
26	173.7*	0	0	0	0	0	0	0.0000	No
27	2.601	1.000	0	-0.1972	-0.0384	0.1215	0.0682	1.0000	Yes
28	4.160	1.005	0	0	0	-0.1025	0	0.9981	No
29	15.71	1.004	0	0.5544	-0.2446	-0.4973	-0.1217	0.9981	Yes
30	13.52	1.062	-0.5319	0.3410	0.2280	-0.0978	-0.2084	0.9995	No
31	2.295*	0.8857	0	-0.4284	0.5064	0	0	0.9866	No
32	0.7813*	1.117	-0.7796	0	0.6513	0	0	0.9927	No
33	-0.946*	1.767	-0.8572	0.1052	0	0	0	0.9937	No
34	8.501*	1.130	0	-0.4372	0	0	0	0.6584	No
35	1.851	1.182	0	-0.5068	0	0.2952	0	0.9931	Yes
36	14.01*	0.7478	0	0	0	0	0	0.2058	No
37	-3.020*	1.0498	0	0	0	0	0	0.9363	No
38	1.560	0.9728	0	0	0	0	0	0.9316	No
39	6.501	1.1315	-0.2359	0	0	0	0	0.9656	No
40	2.584*	1.043	0	0	0	-0.1619	0.0780	0.9719	No
41	1.739*	1.383	-0.4099	0	0	0	0	0.9443	No
42	1.113*	0.9327	-0.2968	0	0.3471	0	0	0.9569	No

Table #3: Estimated AdAR prediction rules for the 42 participants of the Asset Pricing treatment. See for more information the caption with Table #2.

Gr.no.	*c*	p_{-1}	p_{-2}	p_{-3}	p^e_{-1}	p^e_{-2}	p^e_{-3}	R^2	*AC*
CM1	80.92	-0.3476	0	0	0	0	0	0.1371	No
CM2	70.91	0	0	-0.1719	0	0	0	0.1063	No
CM3	59.89	0	0	0	0	0	0	0.0000	No
CM4	60.05	0	0	0	0	0	0	0.0000	No
CM5	80.80	-0.3466	0	0	0	0	0	0.1201	No
CM6	60.09	0	0	0	0	0	0	0.0000	No
APM1	2.600	1.699	-0.7409	0	0	0	0	0.9920	No
APM2	3.392	1.408	-0.4608	0	0	0	0	0.9841	No
APM3	4.322	0.9315	0	0	0	0	0	0.9676	No
APM4	4.475	1.352	0	-0.4301	0	0	0	0.9900	No
APM5	44.20	0.5617	0	0	0	0	0	0.3160	No
APM6	6.876	1.213	0	-0.4356	0	0	0	0.9311	No
APM7	22.75	0.8634	0	-0.2297	0	0	0	0.5981	No

Table #4: Autoregressive estimations of the market prices of the 13 groups. The first column shows the group treatment and number, "CM" and "APM" being abbreviations for "Cobweb Model" and "Asset Pricing Model" respectively. See for more information the caption of Table #2.

Gr.no.	*#ERs*	*AR(1)*	*AR(2)*	*Naive*	*Fundam.*	*Adaptive*	*Sh. Trend*
CM1	6	2	0	1	0	2	4
CM2	5	1	1	0	0	1	2
CM3	6	1	2	0	1	0	3
CM4	5	2	1	0	2	0	3
CM5	6	1	0	1	2	1	4
CM6	6	1	1	0	2	1	3
APM1	6	0	2	0	0	0	4
APM2	5	0	1	0	0	0	2
APM3	6	0	1	1	0	1	3
APM4	6	0	1	0	0	0	4
APM5	3	0	0	0	1	0	1
APM6	5	1	0	1	0	1	3
APM7	6	2	2	0	0	0	4
CM	34	8	5	2	7	5	19
APM	37	3	7	2	1	2	21
Total	71	11	12	4	8	7	40

Table #5: Classification of the prediction rules, for each group seperately. The first column shows the group treatment and number, "CM" and "APM" being abbreviations for "Cobweb Model" and "Asset Pricing Model" respectively. The three bottom rows show totals of the treatments and of the experiment as a whole. "*Fundam.*" And "*Sh. Trend*" are abbreviations for "Fundamentalist" and "Shifting Trend". For the meaning of the labels, see footnote 40 and equation 13 in the main text.

ST part.no.	α_1	α_2	β	*Orig. part.no.*	*Orig. gr.no.*	*Label*
1	0.7389	0	0	2	CM1	Naive Fundamentalist
2	0	0	0	3	CM1	None
3	0.9362	0	0	4	CM1	Naive & Fundamentalist
4	0.1350	0.1923	0.0605	5	CM1	Fundamentalist
5	0.5689	0.3480	0	8	CM2	None
6	0.5553	0	0	12	CM2	Naive Fundamentalist
7	0.7391	0	-0.4444	13	CM3	None
8	0	0	0	14	CM3	Naive & Fundamentalist
9	-0.3770	0	-0.3762	18	CM3	Naive Fundamentalist
10	0.4016	0	0	19	CM4	Naive Fundamentalist
11	0	0	0	21	CM4	Fundamentalist
12	0	0	0	24	CM4	Fundamentalist
13	0.2633	0	0	25	CM5	Fundamentalist
14	0	0	0	27	CM5	Naive & Fundamentalist
15	0	0	0	28	CM5	Naive & Fundamentalist
16	0.9101	0	0	30	CM5	Naive
17	0	0	0	34	CM6	Fundamentalist
18	0.4321	0	0	35	CM6	None
19	0	0	0	36	CM6	None
20	1.5096	-0.5238	0	3	APM1	Naive Trend Follower
21	1.0177	0	0.8591	4	APM1	Naive Trend Follower
22	0.5227	0.4711	0.9118	5	APM1	Adaptive Trend Follower
23	1.0142	0	0.7818	6	APM1	None
24	0.4888	0.5000	0.7290	9	APM2	Adaptive Trend Follower
25	0.4670	0.5269	0.9210	11	APM2	Adaptive Trend Follower
26	0.9994	0	0.4609	13	APM3	Naive Trend Follower
27	0.5369	0.4627	0.5587	14	APM3	Adaptive Trend Follower
28	1.0090	0	0.2765	15	APM3	Naive Trend Follower
29	0.9557	0	0	20	APM4	Naive Trend Follower
30	0.6669	0.3089	0.9696	21	APM4	None
31	0.9616	0	0.8678	22	APM4	None
32	0.9989	0	0.9437	24	APM4	Naive & Adaptive Tr.Foll.
33	0	0	0	26	APM5	Naive & Adaptive Tr.Foll.
34	0.2831	0.7045	0.8266	32	APM6	Adaptive Trend Follower
35	1.1366	-0.1226	0.6077	33	APM6	Naive Trend Follower
36	0.7428	0	0	36	APM6	Naive Trend Follower
37	1.0376	0	0	37	APM7	None
38	0.9419	0	0	38	APM7	None
39	1.0155	0	0.2907	41	APM7	Naive Trend Follower
40	0.6370	0.3842	0.3182	42	APM7	Adaptive Trend Follower

Table #6: Estimated Shifting Trend prediction rules for both treatments. The 1st column shows the participant's number, clustered according to treatment. The 2nd, 3rd and 4th column show the estimated STE parameters, calculated by iterative OLS estimation, eliminating the least significant variable until all p values were below 5%. This procedure was applied only to the AdAR rules that were found to be equivalent to an STE rule, which was determined by using the appropriate Wald restriction test at 5% level. The 5th and 6th columns show the original number and group of the participants, while the 7th shows a classification of the STE estimations (see footnotes 44 and 45).