Expectation formation in an experimental foreign exchange market

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Abstract

Participants of an experimental foreign exchange market forecast an exchange rate with an unknown price reaction function. Aggregate demand is derived from their own forecasts and random shocks. Our experimental results indicate that the expectations of the subjects tend to be coordinated on a common prediction strategy. This strategy is best described as a trend-extrapolative, destabilizing expectation formation scheme. Deviations from common expectations are mainly caused by random shocks, which can be ascribed to the similarity of the subjects' behavior within and between the different markets. The findings can be explained using insights of behavioral economics.

Key words: Foreign exchange market, experimental economics, behavioral finance, expectation formation.

1 Introduction

According to economic theory, exchange rates are basically determined by rational expectations about future fundamentals. However, the empirical support for such models is rather poor. The empirical failure of economic exchange rate models is often explained either by the irrational behavior or excessive speculative trading activities of at least some market participants. Keynes (1936) was one of the first who analyzed the impact of a speculative market environment on the individual expectation formation. He argued that, in speculative markets, in addition to fundamental considerations, non-fundamental factors become more important. In particular, the expectations of other market participants concerning the future exchange rate become relevant. According to Keynes (1936), participants in speculative markets are mostly concerned with the anticipation of the expectations of

the other market participants.[1] Keynes (1936) calls this information of the third degree. A reasonable behavior in such decision-making situations is to be geared to existing market conventions. The present study is concerned with the experimental investigation of expectation formation in the context of foreign exchange markets. In particular, we are interested in the individual behavior in a market environment that is characterized by feedback loops.

Related research on expectation formation can be classified into forecasting experiments and experimental markets. In forecasting experiments participants judgmentally predict future values of a time series based on its past realizations. The behavior of the participants is analyzed by testing hypotheses of expectation formation. In the majority of the studies, the time series are generated by linear autoregressive processes (Hey (1994)) or they are pure random walks (Dwyer et al. (1993), Beckman and Downs (1997)). For instance it was shown that subjects are able to behave rationally when forecasting random walks but fail to do so with more complex time series. In an experiment by Becker et. al (2007) subjects were given several indicators, i.e. time series with a lead of one period, for the forecast of another time series. The authors presented a heuristic that models average forecasting behavior of the subjects much better than the rational expectations hypothesis.

Only a few studies have been mentioned, but these generally have in common that they do not account for expectation feedback as the applied time series are fixed in advance.

Although there is numerous literature on experimental markets (see Sunder (1995) for a review, Williams (1987) and Smith et al. (1988)) only a few of the studies are focused on foreign exchange markets. Arifovic (1996) explored the celebrated result that the exchange nominal rate is not determined in an overlapping generations model. He found weak support for the theory in an experimental market. Noussair et al. (1997) tested a two-country model with a real side and two cash-in-advance constraints. These authors also reported mixed evidence for simple elements of exchange rate theory. Fisher and Kelly (2000) studied essentially identical assets in a non-stationary environment and showed that cross-asset asset arbitrage held, even though every asset had a significant bubble. This result was interpreted as support for simple exchange rate theories. Even though subjects did not perform backward induction, they understood that asset prices were related, and the bubbles for the different assets were almost perfectly correlated.

Although all of these experiments include a dynamic feedback component, the pure analysis of expectations hypotheses is not possible. The observed market behavior also includes other behavioral features that may be due to e.g. trading activity. In our experiment, we explicitly consider expectation

[1] Note that both reasons are closely interrelated: holding excessive speculation responsible for deviations of the exchange rate from its fundamental level implicitly assumes that speculation is not based on fundamental, and thus rational, considerations.

feedback. Individuals' expectations directly influence the actual realization of the exchange rate, i.e. the time series they forecast. This is an important feature of the experimental design in order to accurately reproduce the decision-making situation in financial markets. We focus on the expectations of subjects to exclude undesirable effects, e.g. trading decisions. There are only a few studies with similar characteristics. Gerber et al. (2002) investigate forecasting behavior in a beauty contest experiment. According to their experimental setting, participants are only able to sell and buy an asset whose price is determined by aggregated orders and a noise component. Although the framework is quite similar to our experimental setting, it is rather abstract and expectations are not explicitly analyzed. We closely relate our experimental setting to Hommes et al. (2002, 2005) and Heemeijer et al. (2004) who explore expectation formation in an asset market with expectations feedback. In their experiments, participants forecast the future price of an asset which is given as a function of the average forecasts of all subjects, a noise component and (in a few treatments) the forecasts of some fundamentalist computer traders who always forecast the fundamental value of the asset. Hommes et al. (2002, 2005) report that in many of the experiments extreme speculative bubbles arise, although all participants can easily compute the fundamental value under perfect knowledge of dividends and interest rates. Their results can be ascribed to the specific price function of the asset that requires participants to make forecats two periods ahead. This favors tendencies to extrapolate trends. This is also the case when the price is forced into the direction of the fundamental value by artifical traders. Heemeijer et al. (2004) basically only change the price function of this experiment by collecting one period ahead forecasts. The participants still tend to create bubbles in their forecasts but these are not as extreme as in the Hommes et al. experiments.

We apply the feedback design to a simplified cooperative exchange market. Hommes et al. and Heemeijer et al. find that individuals within a market coordinate on a common prediction strategy such as naïve, adaptive or autoregressive expectations. While these authors notice strong coordination *within* the markets, we notice that the market developments *between* the groups are also extremely similar. The similarity is caused by the characteristics of the random component in the price reaction function and implies coordination on a higher level.

In the next section we discuss the exchange rate behavior and explore the impact of a speculative market environment on the expectation formation in more detail. We emphasize the relevance of psychological factors and the influence of uncertainty. Section 3 is concerned with the experimental setup. In section 4 the experimental investigation of expectation formation in a foreign exchange market context in investigated. We first analyze the aggregated market behavior and afterwards examine the individual behavior in experimental foreign exchange markets. In section 5 we discuss our findings.

2 Functioning of Speculative Asset Markets

Excessive speculation is often held responsible for the poor performance of fundamental-oriented exchange rate models. According to surveys of foreign exchange traders, the excessive speculation of market participants hinders the determination of exchange rates by macroeconomic fundamentals so that, in speculative markets, the importance of macroeconomic fundamentals obviously drops (see e.g. Cheung and Chinn, 2001).
How does speculation affect the behavior of foreign exchange traders? Common definitions of speculation illustrate that speculation usually includes two central attributes: i) speculative transactions always rest upon expectations concerning the future development of the corresponding market value, and ii) as the future development of the market value cannot be predicted for certain, speculative transactions are always accompanied by a high degree of uncertainty so that speculation is always risky. An analysis of both attributes of speculation will help to understand why excessive speculation may cause deviations from fundamental levels.

2.1 Behavioral Economics and Expectations

The first attribute of speculation is concerned with the nature of expectations. The impact of speculation on exchange rates depends primarily on the way market participants form their expectations. Traditionally, the economic literature assumes that expectations about future exchange rates are formed rationally, i.e. speculators base their speculative engagements on the fundamental value of currencies and maximize their wealth. This point of view goes back to the influential contributions of Friedman (1953), who suggests that rationally acting market participants ensure that prices correspond to fundamental values. Within this view, it is impossible for "irrational" speculators to influence exchange rates substantially as they would suffer permanent losses. In recent times, more and more economists critically scrutinize the traditional view of the impact of speculation. On the one hand, there exists a strong theoretical doubt that rational speculators always stabilize exchange rates. This criticism is mainly attributed to the limits of arbitrage induced by the institutional conditions of speculators in foreign exchange markets (see Shleifer, 2000). On the other hand, recent research raises serious doubts about the rationality assumptions in economics. According to the Behavioral Economics approach, actual human behavior deviates systematically from the predictions of economic rationality due to cognitive limitations. The new research field of Behavioral Economics explicitly considers these limitations and tries to develop a more realistic view of human behavior in the context of economics. Thereby, behavioral economists often refer to the work of behavioral decision theorists who introduced new concepts under the general heading of Bounded Rationality. The concept of Bounded Rationality is mainly associated with the work of Herbert Simon (see Simon, 1955). According to Simon, Bounded Ra-

tionality consists of two interlocking components: first, the limitations of the human mind and, second, the structure of the environments in which the mind operates. The first component requires that models of human judgment and decision-making deal with the actual functionality of human mind. In this context, Bounded Rationality is used to indicate a reasonable (procedurally rational) decision-making behavior that takes into account the cognitive limitations of the decision-maker (Simon, 1997). The second component of Bounded Rationality emphasizes the importance of considering the environmental structure because it can explain when and why a specific behavior performs well (Gigerenzer and Todd, 1999a). Against the background of the limited cognitive resources, psychologists have investigated the processes by which decision-makers reach their conclusions. Psychologists argue that human beings tend to use simple heuristics in complex decision-making situations. A simple heuristic can be characterized as a simple rule of thumb which allows quick and efficient decisions even under a high degree of uncertainty (see Fiedler and Bless, 2001). As Gigerenzer and Todd (1999b) have shown, there are many simple heuristics that provide a good compromise between economic rationality and an efficient use of scarce human cognitive resources.

2.2 The Role of Uncertainty in Foreign Exchange Markets

The second attribute of speculation is concerned with the risk that is associated with speculative activities. The risk is due to the uncertainty speculators are faced with, whereby uncertainty arises from two different sources: First, speculators are uncertain about the future development of macroeconomic fundamentals, and, second, speculators are uncertain about the evaluation of other market participants concerning the relevant exchange rate. Thus, it is useful to distinguish between two different kinds of uncertainty in this context. The first kind of uncertainty can be characterized as exogenous uncertainty as it is more or less independent of the action of speculators (see Muthoo, 1999). The second kind of uncertainty can be characterized as endogenous uncertainty. It is attributed to the impact of actions chosen by some other market participants. In this case, the state of the nature is determined strategically by some other traders because the state of the nature is a strategy choice of some other traders (Muthoo, 1999). As the characteristic of this uncertainty depends crucially on the actual behavior of market participants it can also be denoted as behavioral uncertainty. The existence and prevalence of behavioral uncertainty is due to the capacity of individuals to adapt and react to one another in a non-negligible manner (Pesaran, 1988). The extent of behavioral uncertainty is closely related to the degree to which individuals may be able to influence the actions of others by their own actions, and also to which extent they are themselves influenced by the actions of others. Obviously, the influence of behavioral uncertainty on the individual's decision-making behavior

increases with the degree of speculation in foreign exchange markets and appears to be of particular importance. A very prominent and illustrative description of the individual decision-making behavior in an environment that is primarily characterized by behavioral uncertainty was first given by Keynes (1936). He compared the individual decision-making situation in an asset market with the decision-making situation in a newspaper beauty contest. The objective of the beauty contest is to guess which picture will get the most votes. Thereby, the appropriate behavior for the participants is not to choose the picture they favor, but to elect the pictures favored by most other participants. Consequently, they have to estimate "what average opinion expects the average opinion to be" (Keynes, 1936, p. 156). Keynes describes this purpose as "information of the third degree". The implication of Keynes' parable is that an understanding of financial markets requires not only an understanding of market participants' evaluation of assets' future returns, but also an understanding of market participants' evaluation of other market participants' evaluation and higher order evaluations (Allen et al., 2003).

From a theoretical point of view, the solution of the Beauty Contest Problem can be found in the concept of "focal points". Focal points are cues that induce people to behave in a similar manner. The focal solution of a decision-making problem under behavioral uncertainty emerges because a group of people has come to believe that the members of this group will behave consistently with this equilibrium, but which solution is a priori unknown and depends on the co-ordination problem and the decision-making environment (see Young, 1996). Arrow (1986) notes that in this context the solution of such decision-making problems asks for a rationality that refers to social phenomena. As soon as one particular solution is known to be focal it becomes reasonable or "rational" for each decision-maker to expect that all others will decide consistent with this solution and to act on this expectation. An important characteristic of focal points is that nobody has an incentive to change once a common expectation has been established. Consequently, the expectations, which rely on existing focal points, feature a high degree of persistence (see Duncan and Isaac, 2000). Closely related to the concept of focal points is the concept of convention. A convention is typically defined as "a pattern of behavior that is customary, expected and self-enforcing" (Young, 1996, p. 105). The main characteristic of convention is that everyone conforms to it, everyone expects others to conform to it, and everyone has good reason to conform because conforming is in each person's best interest when everyone else plans to conform (Young, 1996). The main feature of a convention is that, out of a host of conceivable choices, only one is actually used. Hence, conventions solve problems of indeterminacy in interactions that have multiple equilibria. In general, one may discern two ways in which conventions become established: first, by authority, and second, by the gradual accretion of precedent. At first glance, in the context of asset markets, the second process by which conventions may emerge seems to be of particular interest. The idea is that, in a repeated co-ordination

game, one particular way of interaction emerges successively as a superior way of resolving the game. Thus, it reaches a greater degree of prominence, which in turn entails that more people notice it, which leads to more people using it, and so forth. Consequently, a positive feedback loop is created.

2.3 Consequences for Speculative Asset Markets

The foregoing subsections denote two interrelated effects which are, in our opinion, inevitably linked with speculative trading in foreign exchange markets. First, there is a high degree of endogenous, behavioral uncertainty. This may force market participants to base their own trading activities on the average assessment of the market. In the context of foreign exchange markets, it seems likely that the basic attitude of market participants is rather stable, i.e. market participants judge a certain currency for a certain time as strong regardless of the fundamental development. This rating of market participants consequently results in a strong trend behavior of exchange rates. In our view, such conventions about the actual strength of a currency help market participants to orientate in an environment that is mainly characterized by behavioral uncertainty.
Second, due to cognitive limitations market participants are obliged to use simple heuristics in their very complex decision-making situation. As Gigerenzer and Todd (1999b) argue, people tend to make use of such simple heuristics that provide accurate solutions for a complex decision-making situation due to their adaptiveness. Thus, an important characteristic of a reasonably simple heuristic is that it considers the environmental structure. In the context of foreign exchange markets, trends seem to characterize the environmental structure very well. Consequently, we assume the existence of simple trend heuristics in foreign exchange markets. Such a heuristic would have the advantage of saving cognitive costs by leading to a reasonable performance at the same time.

3 Experimental design

The experimental design of the foreign exchange market focuses on the exploration of the expectation formation of the subjects. Consequently, the only task of the subjects is to forecast the exchange rate development. No trading activity is involved.
In order to make it clear to the subjects why their forecasts have an influence on the development of the exchange rate, the experiment is described as follows: The subjects are trading floor economists in different leading European banks. They watch the Euro/US Dollar exchange rate and brief the currency dealers of the bank at the beginning of each period about the expected development of the exchange rate. The participants are told that the trading decisions of the dealers and consequently the demand for Euros and US Dollars are exclusively based on their forecasts. Thus, profits from foreign exchange trading activities realized by the bank are strongly related

to the quality of the individual forecasts, and therefore the payoffs of the subjects in the experiment are inversely proportional to their forecast errors.
Besides this information about their task, the subjects are given background information about the exchange rate market. They know that the exchange rate is influenced by the forecasts of the other participants in the experiment and slightly influenced by the demand of private investors. However, the subjects do not know the exact market equilibrium equation. They also know values of domestic and foreign interest rates and expected inflation rates, which give them the possibility of calculating the fundamental values of the Euro/US Dollar exchange rate.
The price reaction function generating the experimental exchange rate S_t is given by

$$S_{t+1} = S_t + \Delta E_t^{avg} S_{t+1} + \xi_{t+1} \tag{1}$$

where $\Delta E_t^{avg} S_{t+1} = \frac{1}{n} \sum_{i=1}^{n} E_t^i S_{t+1} - S_t$ denotes the average forecasted change of n individual subjects i $(i = 1, \ldots, n)$ made in period t for the exchange rate in the period $t+1$. ξ_{t+1} is an independently normally distributed error term with $\xi_{t+1} \sim N(0, 1)$ and represents random demand and supply shocks from private investors. The initial value of the exchange rate S_1 equals 50. The fundamental value S^f is given by the standard Fisher relation

$$S_{t+1}^f = S_t + S_t(r_t - r_t^*) = S_t + S_t(\pi_t - \pi_t^*) \tag{2}$$

where r (r^*) denotes the domestic (foreign) interest rate and π (π^*) denotes the expected domestic (foreign) inflation rate. The values of these variables were chosen such that a rather stable fundamental value of about 50 is ensured. The values of the four variables were presented to the subjects in each period.
In each period t the task of the subjects is to forecast the value of the exchange rate in period $t+1$. The information set of subject i consists of the realizations of the exchange rate $S_t, S_{t-1}, \ldots, S_1$ and his/her own past forecasts $E_{t-1}^i S_t, E_{t-2}^i S_{t-1}, \ldots, E_1^i S_2$. After all participants have completed their forecast for period $t+1$, the actual exchange rate of period $t+1$ is presented on the screen and subjects are asked for the next forecast. This procedure is repeated for 49 periods. All past values of the exchange rate and the participant's own forecasts are graphed in different colors and are additionally presented in a tabular format. Furthermore, the information about the expected domestic and foreign inflation rates and interest rates are presented on the screen. The subjects are told that their forecasts have to be between 0 and 100.
The participants were recruited from an undergraduate course of business administration at the Karl Franzens University Graz. They did not have any special education in financial markets and they had never participated in a similar experiment before. They were not offered any course credit for

their participation. The reward scheme of the subjects is only related to their performance in the experiment. The payoff p_t^i of subject i in period t is given by

$$p_t^i = max\{30 - 10|S_t - E_{t-1}^i S_t|; 0\} \tag{3}$$

where the unit of p_t is cents. For a perfect forecast, the subjects are remunerated 30 Cents, for a deviation or more than 3 units, the payment equals 0. The average payoffs were 6.94 Euros for an average duration of about 45 minutes.
Altogether, 36 students participated in the experiment. The parameter n was set to 6 in all experiments, i.e. each market consists of six subjects. The random shock sequence ξ_t was identical in each of the six markets.

4 Experimental results

Our analysis of the experimental results is divided into two parts. We first examine the aggregated behavior of experimental exchange rates. In this context, we are particularly interested in the observable exchange rate developments. Furthermore, our focus is concerned with the efficiency of experimental exchange rate markets. In the second subsection, we analyze the individual behavior of the participants in the experiment in more detail. We are interested in the rationality of experimental expectations and the nature of those expectations.

4.1 Aggregated behavior in experimental foreign exchange markets

4.1.1 Similarity of experimental exchange rates

Figure 1 shows the realized exchange rates of the six experimental groups and the development of the fundamental value. The most striking feature of the results is the obvious similarity of the group behavior. The exchange rates start with an upswing, fall in period 5 and stabilize around periods 12 to 21. The exchange rates continue their downtrend until period 30 and turn upwards for the final 20 periods. This applies for almost all groups, only group 2 is inconsistent with this pattern. This is due to several extreme forecasts of one subject in the periods 7, 14, 31 and 33. This can be seen from the charts of individual forecasts in Figure 1. To underline these findings, the correlation of the exchange rates are presented in Table 1. The correlation coefficients are highly significant and indicate very strong associations between the groups. The correlations with group 2 are comparatively weaker, but still significant and at a minimum level of 0.614.

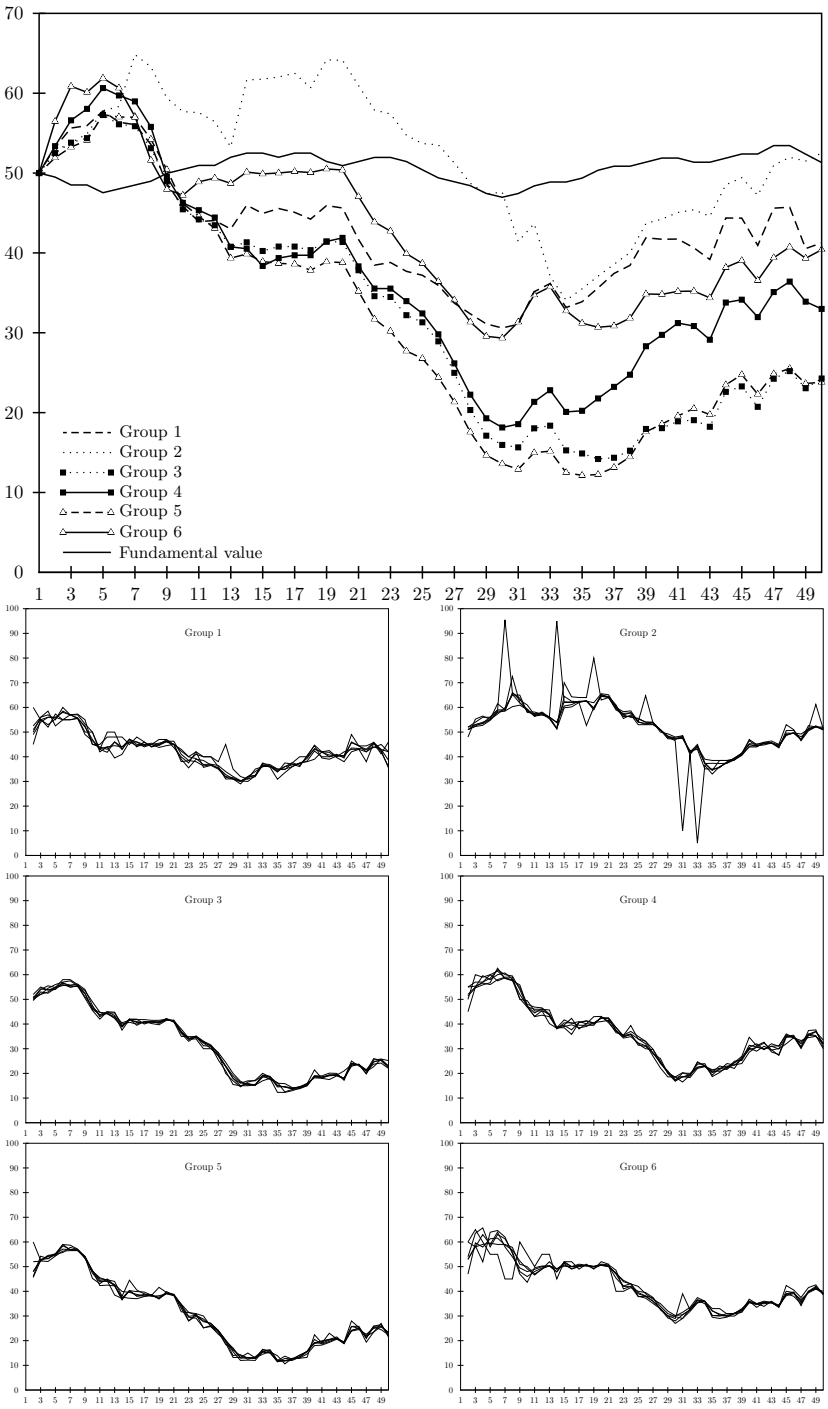

Figure 1: Realized exchange rates and individual expectations

The reason for this astonishing result can be found in the structure of the random shocks ξ of equation (1). We calculate the average changes of the predictions $\Delta E_t^{avg} S_{t+1} = E_t^{avg} S_{t+1} - E_{t-1}^{avg} S_t$ and compare them to the random shocks ξ_t. These values are highly correlated at a 99% level of significance. The corresponding correlation coefficients are reported in Table 1. Again, only group 2 shows a weaker association.

Group	**1**	**2**	**3**	**4**	**5**	**6**
2	0.614**	-	-	-	-	-
3	0.846**	0.823**	-	-	-	-
4	0.953**	0.739**	0.952**	-	-	-
5	0.891**	0.803**	0.992**	0.977**	-	-
6	0.901**	0.777**	0.968**	0.955**	0.968**	-
Shock	0.881**	0.653**	0.962**	0.937**	0.969**	0.900**

** denotes that correlation is significant at the 0.01 level (two tailed)

Table 1: Correlation between aggregated group forecasts and correlation between forecasted changes and random shocks

The development of the exchange rate is obviously driven by the random shocks to a high degree. The occurrence of local extrema and longer trends can be ascribed to the number of random shocks. The periods 12 to 21 are representative for this phenomenon. The random shocks are very small in five periods successively. They amount to absolute values of about 0.5. In periods 21 and 22, random shocks of -3.33 and -2.06 occur, respectively, and start a downtrend that lasts for about ten periods. Between the periods 21 and 31 the random shocks are negative in nine cases, and a large positive shock stops the trend. The exchange rates have many characteristic local minima and maxima in common due to the same random shocks in all experiments. This is especially noticeable in the final periods, e.g. periods 43, 45 and 46. The changes of average forecasts correspond to the sign of the shocks in almost all periods. Only in group 2 can larger deviations be observed, due to the reasons discussed above.
It can be concluded that the subjects extrapolate the trends that are mainly caused by random shocks. The influence of the shocks is remarkably stable for all experiments. Furthermore, our findings of mainly shock-driven aggregated forecasts imply that the fundamental value of the exchange rate does not have a noticeable influence on the realized prices in all groups.

4.1.2 Efficiency of experimental foreign exchange markets

A central building block of traditional exchange rate models is the assumption that exchange rates are determined in efficient markets. A testable

implication of the efficient market hypothesis is that excess returns $x_t = ln(S_t) - ln(S_{t-1})$ should be serially uncorrelated with any excess return in the past or future.
To analyze the autocorrelation of excess returns we carry out a variance ratio test proposed by Lo and MacKinlay (1988). The variance ratio test exploits the fact that the variance of the increments in a random walk time series must be linear in the sampling interval. That is, if a time series follows a random walk process, the variance of its q-differences would be q times the variance of its first difference:

$$var(S_t - S_{t-q}) = q \cdot var(S_t - S_{t-1}) \tag{4}$$

Therefore, the relevant null hypothesis of the variance ratio test implies that the following ratio is equal to one:

$$VR = \frac{\sigma^2(q)}{\sigma^2} = 1, \tag{5}$$

where $\sigma^2(q)$ is $1/q$ times the variance of the q-th period returns and σ^2 is the variance of the one-period returns. With regard to the autocorrelation structure of the time series, Cochrane (1988) shows that the variance ratio, $VR(q)$, can be approximated by the following expression:

$$VR(q) \cong 1 + 2\sum_{j=1}^{q-1} \frac{q-j}{q} = \widehat{\rho}_j, \tag{6}$$

where $\widehat{\rho}_j$ denotes the q-th order autocorrelation coefficient estimator of the first differences of X_t (see Cochrane, 1988). Equation (6) provides a simple interpretation for the variance ratios computed with an aggregation value q: They are approximately linear combinations of the first $q-1$ autocorrelation coefficient estimators of the first differences with arithmetically declining weights (see Lo and MacKinlay, 1999). Thus, variance ratios larger than unity indicate the presence of positive serial correlation in the series, which is consistent with trend behavior in exchange rate series and, in contrast, variance ratios smaller than unity suggest the presence of negative serial correlation, which is consistent with a mean reverting behavior in exchange rate series.
The results for the variance ratio test are summarized in Table 2. Almost all $VR(q)$'s are larger than 1, indicating a tendency for trend behavior in the exchange rate. Only the $VR(3)$ for the "shock price" is well below 1. However, the $VR(q)$'s for group 1 and group 2 are on the whole not statistically significant, so we have to conclude that those experimental exchange rates do not exhibit an autocorrelation pattern which can be exploited for abnormal trading profits. In contrast, the results for the $VR(q)$'s of the experimental exchange rates in group 3 to 6 show distinct evidence for positive autocorrelation in the excess returns. All $VR(q)$'s are statistically significant above one and thus indicate a strong trend behavior in those exchange

rates. Skeptics might suspect that the positive serial correlation in the excess returns is due to the chosen shock sequences. We therefore also analyze the autocorrelation of the exchange rate, which is only determined by the shock sequence. The results indicate that this exchange rate exhibits no tendency for significant autocorrelation patterns in excess returns. Thus, the positive autocorrelation in most of the experiments is probably caused by the behavior of the participants in the experiment.

Group	**1**	**2**	**3**	**4**	**5**	**6**	**Shock**
VR(2)	1.154	1.060	1.314	1.493	1.481	1.406	1.005
T-stat	1.077	0.417	2.199	3.452	3.365	2.844	0.033
(hom.)	(0.282)	(0.677)	(0.028)	(0.001)	(0.001)	(0.005)	(0.974)
T-stat	1.342	0.414	2.046	3.112	3.014	2.760	0.038
(het.)	(0.180)	(0.679)	(0.041)	(0.002)	(0.003)	(0.006)	(0.970)
VR(3)	1.099	1.201	1.496	1.765	1.829	1.550	0.942
T-stat	0.459	0.945	2.328	3.592	3.891	2.583	-0.273
(hom.)	(0.646)	(0.345)	(0.020)	(0.000)	(0.000)	(0.010)	(0.785)
T-stat	0.531	0.888	2.171	3.288	3.483	2.594	-0.302
(het.)	(0.595)	(0.374)	(0.030)	(0.001)	(0.001)	(0.010)	(0.763)
VR(4)	1.213	1.429	1.760	2.058	2.211	1.691	1.123
T-stat	0.797	1.606	2.843	3.960	4.530	2.585	0.465
(hom.)	(0.426)	(0.108)	(0.005)	(0.000)	(0.000)	(0.010)	(0.642)
T-stat	0.881	1.486	2.643	3.671	4.077	2.661	0.491
(het.)	(0.378)	(0.137)	(0.008)	(0.000)	(0.000)	(0.008)	(0.623)
VR(5)	1.290	1.561	1.874	2.289	2.490	1.679	1.137
T-stat	0.925	1.793	2.791	4.119	4.759	2.170	0.439
(hom.)	(0.355)	(0.073)	(0.005)	(0.000)	(0.000)	(0.030)	(0.661)
T-stat	1.009	1.674	2.602	3.855	4.325	2.275	0.454
(het.)	(0.313)	(0.094)	(0.009)	(0.000)	(0.000)	(0.023)	(0.650)

Notes: p-values are given in parenthesis.
hom. denotes the standard normal test statistic under homoscedasiticity
het. denotes the heteroscedasticity-consistent test statistic

Table 2: Variance ratio test

Overall, we have to reject the hypothesis of efficient markets in the context of our experimental analysis in 4 of 6 cases. The rejection of the efficient market hypothesis is always due to positive autocorrelation in excess returns suggesting trend behavior. Furthermore, the rejection of the efficient market hypothesis cannot be linked to the shock sequence.

4.2 Individual Behavior in Experimental Foreign Exchange Markets

4.2.1 Rationality of Individual Expectations

For asset pricing models, the rational expectations hypothesis (REH) is of crucial importance. The hypothesis states that agents' subjective expectations with respect to a variable (e.g. exchange rates) are equal to the

mathematical expectations conditional on an information set containing all publicly available information. The conditional mathematical expectation value is thereby based on the true probability distribution of the variable. Within asset pricing models the conditional mathematical expectation value is derived from the 'true' economic model and it is assumed that the market participants behave as if they form their subjective expectations as the conditional mathematical expectations, so that subjective and objective expectations coincide. A major drawback of the rational expectations hypothesis is that it makes implausible demands on the human information processing capabilities.
The REH first implies that forecast errors of rational subjects (e_t) conditioned on the available information set (Ω_t) should be purely random,

$$e_{t+1} = S_{t+1} - E(S_{t+1}|\Omega_t), \text{with } e_{t+1} \sim (0, \sigma^2) \tag{7}$$

where S denotes the nominal spot exchange rate and E is the rational expectations operator. Thus, the unbiasedness hypothesis implies that under REH forecasts errors are expected to be zero, i.e. they fluctuate randomly so that ex post no systematic deviations of the actual spot rate from the expected rate should be observed. The unbiasedness hypothesis can be tested econometrically by regressing the actual change in the spot exchange rate on the expected change according to the professional forecasts. Thus, the null hypothesis of unbiasedness implies that it is possible to decompose $s_{t+1} - s_t$ as

$$s_{t+1} - s_t = \alpha + \beta(E_t s_{t+1} - s_t) + \epsilon_{t+1} \tag{8}$$

where s is the logarithm of the nominal spot exchange rate, $\alpha = 0$, $\beta = 1$ and ϵ_{t+1} has a mean of zero and is uncorrelated with $E_t S_{t+1} - S_t$.
A second implication of the rational expectation hypothesis is that forecast errors of rational subjects are serially uncorrelated. This condition can directly be tested by estimating

$$e_t = \alpha + \beta_1 e_{t-1} + \beta_2 e_{t-2} + \ldots + \beta_n e_{t-n} + \epsilon_t \tag{9}$$

The hypothesis of serially uncorrelated forecast errors implies that $\alpha = \beta_1 = \beta_2 = \ldots = \beta_n = 0$. Furthermore, the rational expectation hypothesis implies that rational subjects generate their forecasts by using all available information efficiently. This implication is often called the orthogonality condition. According to the orthogonality hypothesis, rational forecasts incorporate all available information, so that their predictive power cannot be improved by the inclusion of any variable that is known at the time of expectation formation. Consequently, forecast errors must be uncorrelated with any variable in the available information set. The orthogonality hypothesis can be tested by regressing the ex post forecast errors against some known information available when market participants form their forecasts,

$$s_{t+1} - E_t s_{t+1} = \alpha + \beta X_t + \epsilon_{t+1} \tag{10}$$

where X_t is a set of information known at time t and the orthogonality hypothesis holds if $\alpha = 0$ and $\beta = 0$. In our regression approach, the information set X_t contains lagged exchange rates, so that the regression equation is given as

$$s_{t+1} - E_t s_{t+1} = \alpha + \beta_1 s_t + \beta_2 s_{t-1} + \ldots + \beta_n s_{t-n-1} + \epsilon_{t+1} \tag{11}$$

Table 3 summarizes the results of the tests for rational expectations. The results reveal that, although forecasts anticipate the future direction of change rather well (almost all β coefficients are larger than zero), the hypothesis of unbiased forecast is rejected for most of the participants in the experiment. Furthermore, the participants tend to make only inefficient use of past information. Thus, the orthogonality hypothesis must be rejected in most cases. We reach a similar conclusion for the hypothesis of uncorrelated forecast errors. Nearly all participants form expectations concerning future exchange rates in a way that the forecast errors are serially correlated. Consequently, we have to reject the hypothesis of serially uncorrelated forecast errors.

Group	No. of Subjects	Unbiased forecasts	$\beta > 0$	Efficient use of information	Uncorrelated forecast errors
1	6	1	6	2	1
2	6	1	5	1	4
3	6	3	5	0	0
4	6	2	6	1	2
5	6	3	6	0	3
6	6	0	5	1	1

Note: the figures are based on the results of the corresponding F-tests; the considered significance level is 10%.

Table 3: Tests for Rational Expectations

4.2.2 Individual expectation formation mechanisms

Our analysis of how participants in the experiment form their expectations concerning the future exchange rate is based on adaptive, extrapolative and regressive expectation mechanisms. The adaptive expectations hypothesis describes the change of the prediction as an adjustment depending on the error between the actually observed exchange rate S_t and the last forecast $E_{t-1}S_t$. For this reason it is also referred to as the error-learning model:

$$E_t S_{t+1} - E_{t-1} S_t = \alpha + \beta(S_t - E_{t-1} S_t) + \epsilon_t \tag{12}$$

The adaptive expectation hypothesis requires that $0 \leq \beta \leq 1$. In this case, expectations are judged to be stabilizing in the sense that an unexpected

appreciation of the exchange rate leads to an expected depreciation of the exchange rate. In contrast, for $\beta > 1$ those expectations are characterized as destabilizing since an unanticipated appreciation leads to a continued expected appreciation of the exchange rate. The case $\beta = 1$ represents static expectations.
According to extrapolative expectations, the forecasts are affected solely by past realizations:

$$E_t S_{t+1} - S_t = \alpha + \beta(S_t - S_{t-1}) + \epsilon_t \tag{13}$$

Crucial for the interpretation of the results is the sign of the coefficient β. If $\beta < 0$, expectations are stabilizing in the sense that a recent movement in the exchange rate gives rise to the expectation of a reserve change in the future. For $\beta > 0$, market participants expect that current exchange rate movements will recur in the future. This phenomenon is called bandwagon expectations. For $\beta = 0$, individuals have static expectations. In the regressive model, the exchange rate is expected to develop towards a reference level, for instance a constant or a fundamental value. We test whether the subjects adjust their forecasts according to changes of the fundamental value S_t^f by estimating the equation:

$$E_t S_{t+1} - S_t = \alpha + \beta(S_t^f - S_{t-1}) + \epsilon_t \tag{14}$$

Here, $\beta > 0$ indicates that individuals expect the exchange rate to move towards the reference level. In contrast, $\beta < 0$ corresponds to an expected deviation of the exchange rate from its reference level. Again, $\beta = 0$ alludes to static expectations.
Table 4 presents the summarized results of the tests for various expectation formation mechanisms. Our results indicate that for group 1 and group 2 the majority of individuals show static expectations. However, some individuals depart significantly from the static expectation formation mechanism, especially in group one in which at least three participants form trend-extrapolative expectations. For group 3 to 6 we can conclude that trend-extrapolative, destabilizing expectations play a decisive role. In all of these groups, most participants generate expectations consistent with the extrapolative expectation model. As most β coefficients are larger than zero, those expectations can be characterized as bandwagon expectations. Conforming to our findings for the extrapolative expectation scheme, the results for the adaptive expectations indicate that individuals either possess static expectations or form destabilizing expectations in the sense that they expect a continued appreciation of the exchange rate due to an unanticipated appreciation.
The results for the regressive expectation scheme demonstrate that the fundamental value of the exchange rate has only a minor influence on the expectation formation of individuals. Thus, the regressive expectation hy-

pothesis has to be rejected for the majority of the subjects.[2]

Group	Extrapolative			Adaptive			Regressive		
	b=0	b>0	b<0	b<1	b=1	b>1	b=0	b>0	b<0
1	2	3	1	1	4	1	4	2	0
2	5	1	0	0	5	1	3	3	0
3	0	6	0	0	4	2	6	0	0
4	0	6	0	0	2	4	5	1	0
5	0	6	0	0	0	6	6	0	0
6	1	5	0	0	2	4	6	0	0

Table 4: Individual expectation formation mechanisms

Overall, the results for the individual expectation formation correspond with the aggregated behavior of the market participants discussed above. The subjects extrapolate the trends initiated by random shocks and therefore show a high degree of similarity between the groups. The fundamental value is obviously not considered in the expectation formation process of the market participants. In our opinion, the previous results inevitably raise the question of coordinated expectations as suggested by Keynes (1936).

4.3 Keynes Beauty Contest - Coordinated Expectations?

Keynes' (1936) metaphor of the beauty contest suggests that market participants tend to coordinate their expectations concerning future asset prices in speculative markets. As Figure 1 shows, participants within one group tend to coordinate their expectations. We test for coordinated expectations by estimating

$$E_t^i s_{t+1} - E_t^{avg} s_{t+1} = c_i + \epsilon_{t+1} \tag{15}$$

where $E_t^i s_{t+1}$ are the individual (log) expectations for s_{t+1} and $E_t^{avg} s_{t+1}$ is defined as $\frac{1}{n}\sum_{i=1}^{n} E_t^i s_{t+1}$. Under the null hypothesis of nonsystematic deviations in expectations which consequently corresponds to homogeneous expectations, it is expected that the mean c_i should be zero. Estimating equation (15) using the corresponding expectations of participants in

[2]We furthermore estimated a more general framework for the analysis of expectation formation mechanisms as was suggested by MacDonald (2000). The three concepts are nested in one regression of the form: $E_t s_{t+1} - s_t = \alpha + \beta_1(s_t - s_{t-1}) + \beta_2(E_{t-1} s_t - s_t) + \beta_3(s_t^f - s_t) + \epsilon_{t+1}$. The results obtained from these tests were similar, but we chose the isolated tests as some subjects did not have any significant coefficients and could not be classified.

groups 1 to 6 yields to 0/1/0/1/0/1 subjects with heterogeneous expectations. These results indicate that the expectations of participants in each group do not deviate systematically from the average group expectations. Thus, the results of testing for heterogeneous expectations provides further evidence for homogenous, coordinated expectations in each group.

5 Discussion of the results and conclusion

Our experiment deals with the expectation formation of subjects. We are particularly interested in whether the subjects tend to coordinate their expectations as suggested by Keynes (1936) and whether they base their expectations on trends.

A central result of our experiment is that participants tend to coordinate their expectations on a common prediction strategy. Merely a few participants deviate significantly from the average expectations. Thus, it is reasonable to conclude that Keynes‘ description of how individuals form their expectations in asset markets is quite accurate. In this context, Lawson (1985) states that the Keynesian "conventional judgment" is not irrational as it allows for an efficient usage of scarce cognitive resources.

Akerlof (2002) characterizes Keynes as the progenitor of the modern Behavioral Economics view of asset markets. This brings us directly to our second proposition. According to Behavioral Economics, market participants use simple heuristics instead of calculating exact, rational solutions. We suggest that it is reasonable for market participants to use a simple trend heuristic. This suggestion is also approved in our experimental setting. For most of the participants in the experiment we find that a trend-extrapolative, destabilizing expectation formation mechanism is an accurate description of their prediction strategy. This is especially true for the groups that show a high tendency for coordinated expectations.

Most of the realized prices in the experiments by Hommes et al. show strong oscillations, of which some were persistent over the whole duration of the experiment and some were converging to the fundamental value. Asset prices were fairly stable only in a few groups and thus more consistent with our results. While Hommes et al. observe coordination within the groups but find clear differences between the groups, our results of six different market exchange rates show very similar behaviors of market participants. This finding can be ascribed to the random shocks that mainly cause deviations from coordination results. The subjects do not know whether the trend is generated by a random shock, other market participants or robot traders who forecast the fundamental value. The subjects also do not need to know. They simply apply the heuristic of trend following. We relate our findings to the concept of focal points. It is suggested that subjects do not have an incentive to deviate from a forecast once a common expectation has been established. This is exactly what we observe.

Our results provide a plausible explanation for the behavior of market participants in speculative environments such as exchange markets.

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