Currency Speculation Behaviour of Industrial Firms: Evidence from a Two-Country Laboratory Experiment

Johannes Kaiser* and Sebastian Kube‡

Current draft:

9th December 2005

Abstract

We analyse the behavioural components of a firm's speculation decisions. Specifically, we conducted laboratory experiments to study how firms speculate in a deterministic two-country model with two currencies. The data is used to investigate how exchange rate variations and interest rates can influence a firm's behaviour. The subjects made only small use of technical trade. We show the existence of exchange rate uncertainty and show how the subjects try to cope with it by hedging and pessimistic expectations. One can observe that central banks can curb the influence of speculation on exchange rate volatility if they are powerful enough and collude. (105 words)

JEL classification: C91, D84, E44, E52, F31

Keywords: currency speculation, exchange rate uncertainty, behavioural finance, laboratory experiment

Acknowledgements: We thank Reinhard Selten and Robin Pope for discussion and very valuable suggestions and comments. This paper was presented firstly at the North American Meeting of the Economic Science Association, Tucson, Arizona, in October 2005.

*johannes.kaiser at uni-bonn.de, University of Bonn, Laboratory for Experimental Economics, Adenauerallee 24-42, 53115 Bonn, Germany. Ph.: +49-228-73-9192.

‡kube at wior.uni-karlsruhe.de, University of Karlsruhe, Department of Economics, Kollegium IV am Schloß, 76128 Karlsruhe, Germany. Ph.:+49-721-608-3081.

1 Introduction

Currency speculation has always had a vast influence on systems of flexible exchange rates. A large variety of empirical, experimental, computational, and theoretical investigations deal with this topic. But what determines the speculative decision of a firm? Why do non-financial firms speculate? How do they deal with exchange rate uncertainty? In this paper, we describe evidence from a computerised laboratory experiment under controlled conditions, in which industrial firms have the opportunity to produce a consumption good as well as to speculate. This is the first approach in behavioural finance to cover this topic. To investigate the speculative behaviour of subjects, it is neccessary to utilise an appropriate experimental model which describes an exchange rate mechanism.

There exist some experimental designs of international economies in literature which describe the mechanism of exchange rate determination. For example, [Noussair et al. 2003] derive the exchange rate from the flow of funds theory of exchange rates and use the import and the price of goods as components of the exchange rate in a complex three-country model. In an earlier paper, [Noussair et al. 1997] use the same model of exchange rate determination in a two-country model with less agents and less markets. The model of [Arifovic 1996] utilises a purchasing power parity model for the calculation of the exchange rate. In contrast to exchange rate determination based on international trade of goods or purchasing power parity, [Fisher and Kelly 2000] let traders buy or sell two foreign currencies and one home currency in a double auction. Thus, the exchange rates are the average relative prices paid by speculative currency traders. These models take into account either international trade, purchasing power parity, or speculation. [Pope et al. 2003] create the up to now most complex model in experimental literature in which speculative currency trade, international trade of goods and materials, and central bank interventions determine the exchange rate. We will base our investigation on this model because of its rich design and give a more detailed discussion of it in chapter 2.

Our experimental investigation focuses on the influence of different economic figures

on the speculative decision of firms. [Mundell 1960] describes a model in which speculators base their actions on the observed size of the monetary reserve of central banks. Professional traders might take this figure into account, but it seems unlikely that industrial firms, whose demand for foreign currency is mainly caused by international trade and secondarily caused by speculation, consider the central bank's monetary reserve. [Keloharju and Niskanen 2001] investigate the decision of firms to raise foreign currency debts. Their findings include that firms whose exports constitute a significant fraction of net sales are more likely to raise currency debts and that the firms tend to borrow in periods when the nominal interest rate for the loan currency, relative to other currencies, is lower than usual. Our results fall in line with the latter finding. In this essay, we also demonstrate that firms which only produce goods for the domestic market and which need foreign materials for the production of those tend to borrow money rather in their own than in the foreign country. In a market survey study, [Cheung and Chinn 2001] show that technical analysis of exchange rates is used as a means of determination of currency trade decisions by only thirty percent of the the US foreign exchange traders at most. We confirm that in our experiment the influence of technical analysis on the speculation decision is rather weak compared to other determinants. In the same publication, the authors find that the importance of individual macroeconomic variables shifts over time, although interest rates always appear to be important. The data gained by our experiment suggests that there is a high proportion of subjects who adapt their speculative behaviour to economic figures besides interest and exchange rates. However, opposing to interest rates the influence of previously mentioned figures seems not to be significant.

Furthermore, we investigate the profitability of currency speculation decisions based on different factors. The literature partially states that different determinants of stock market speculation decisions don't influence their profits. For example, [Malkiel 1973] conjures up the image of a blindfolded monkey throwing darts at financial pages and doing just as well as expert stock-pickers. [Chakrabarti 2004] describes how the Wall Street Journal picked up this idea and let leading stock analysts compete against dart shooting

employees of the journal. Over the years, the analysts won - but only slightly. The evaluation of the Wall Street Journal's experiment undertaken by [Liang et al. 1995] concludes that in the long run the dartboard picks were even more profitable than the professional picks. If we omit that these papers deal with stocks as assets and not with currencies, our investigation arrives at a different result: agents who neglect the variation of the two previous consecutive exchange rates and base their decision solely on the difference of the interest rates in the countries scoop in higher speculation profits than agents who use an obscure and apparently random heuristic.

The remainder of this paper is organised as follows. First, we give a brief introduction on the experimental model as well as the procedures we used. Thereafter, we give a short descriptive overview of currency speculation and incurred profits and losses. We identify determinants of the firms' speculative behaviour in the following section and show the existence of exchange rate uncertainty. Afterwards, we show implications of the firms' incapability of predicting the upcoming of the exchange rate correctly and explore ways of how the subjects try to cope with exchange rate uncertainty. The chapter closes with a short evaluation of the influence of speculation on the exchange rate volatility. In the final chapter, we discuss our findings and conclude.

2 Experimental setup and procedure

As a vehicle for our experimental investigation we use a symmetric and deterministic two-country model as described in [Pope et al. 2003]. Originally designed to investigate the economic effects of currency unions, it provides us with all features necessary for our evaluation. The model consists of two treatments. We focus exclusively on the case without a currency union (NCU), and omit the details of the currency union case (WCU). The model has an identical game-theoretical equilibrium solution for both versions which will not be discussed here. Since this model displays a high degree of complexity, we will limit its description to the mechanisms which are related to currency speculation

and exchange rate determination[1]. The game was set up as a computer-based laboratory experiment under controlled conditions as follows:

In each of the two countries A and B, nine players act as economic entities in a round-based experiment: one government, one central bank, one labour union, one employers' association, and five firms. The model is symmetric, so in the following we will denominate a 'home' country (for example A) and view everything from its perspective. Parameters of the 'foreign' country (B in our example) are denoted by an asterisk. Two types of goods exist in each country: a domestic consumption good Q that is produced by the firms in the country, and a material M. The material is traded internationally because a firm needs materials from *both* countries, M and M^*, for the production of the domestic consumption good. The firms have two bank accounts each to their disposal: one in the home country and one in the foreign country. The model spans over multiple periods. Each period has a number of steps which follow a certain structure. In each step, the active players choose their decision variable(s) simultaneously. After each step, the decisions are made public.

First, the government chooses the total nominal expenditures D of the economy. It is assumed that this is done by means of fiscal policy. The details are not explicitly modelled. All of the expenditures will be spent later on the domestic consumption good Q. Afterwards, the central banks have to decide on three variables (see fig. 10): they set the interest factor r (defined as interest rate plus one) for their country, fix an exchange rate aim f and choose next period's target price p_+ for the domestic consumption good. The exchange rate is defined as the price of one unit of foreign currency in home currency. The actual target price p equals p_+ in the last period, and is exogenously given in the first period. Note that the exchange rate aims are not revealed to the firm players. At step 3, the union representative and the employers' association of each country bargain on the nominal wage rate w that has to be paid for one unit of local labour. If at the

[1]The interested reader can find the details of the solution and of both cases of the model in [Pope et al. 2003]

end the union wage offer w_u differs from the employers' association wage offer w_e, there will be a strike in the corresponding country. A strike causes not only a reduction of the firms' maximum production capacity Q_c to $Q_0 < Q_c$, but also a decrease of the demand D for the produced consumption good to σD. Furthermore, the wage is set to a statutory minimum wage $w_0 = \eta p$.

The firms interact in a Cournot market (as defined in [Cournot 1834]) for consumption goods. Now that the firms know how much they have to pay for interest and labour and the amount of total nominal expenditures to be spent on the consumption good, it is their turn (see fig. 9). A firm i can choose its production quantity Q_i above a minimum production quantity Q_m and below the capacity constraint Q_c. A firm needs labour, home material (M), and foreign material (M^*) to produce the good. The market for materials is modeled to be competitive. For producing one unit of material, one unit of local labor is needed at cost w. Wage payments are paid before interest, so the marginal costs of one unit of material are wr. In a competitive market we get price equals marginal costs, so the price for the material is $m = wr$, resp. $m^* = w^* r^*$. The labour L_i consists of the two components fixed labour F, which is needed to run the company, and variable labour, which is equal to Q_i. Besides that, it may borrow money for one period either from its home or foreign central bank at the interest factor r resp. r^* and offer it on the currency market, whereupon X_i (X_i^*) is the amount of home (foreign) currency offered[2]. The money borrowed must be paid back in the next period including interest. This will be labelled speculation in the following. Note that only the overall production quantity Q will be revealed to the firms in the next period, whereas neither individual production quantities and currency offers nor total currency offers are made public.

At the end of each round, the firm home (S_i) and foreign (S_i^*) accounts total to:

$$S_i = Q_i q + r(X_i^* e - L_i w - X_i) - M_i m \tag{1}$$

$$S_i^* = r^*(X_i e^* - X_i^*) - M_i^* m^* \tag{2}$$

[2]Note that here the asterisk denotes the currency rather than the country.

Two credit constraints limit the firm accounts: The sum of labour costs and the amount of home currency offered must not exceed $C_1 = \gamma_1 w$, furthermore the maximum amount of foreign currency offered is $C_2 = \gamma_2 w^*$. This limits the currency offers to:

$$\bar{X}_i = \gamma_1 w - L_i w \tag{3}$$

$$\bar{X}_i^* = \gamma_2 w^* \tag{4}$$

The next steps don't require user interaction. All costs and revenues incurred by production and speculation of a firm i get deducted from, and transferred to, respectively, the corresponding home or foreign account. The price q for one unit of the consumption good Q is defined as $q = \frac{D}{Q}$ ($q = \frac{\sigma D}{Q}$ in case of strike). The final account balances (positive as well as negative) are taken over by the firm's owner, clearing the account for the next period. They consume their profits in the next period in their home country, so they have to trade the money from the foreign account back into their home currency at next period's exchange rate e_+.

The exchange rate itself is determined by a mechanism which takes the central bank's exchange rate aims f and f^* into account. These are not known to firm players. If both exchange rate aims are the same ($f = \frac{1}{f^*}$), the exchange rate of this period e will be set to f. Otherwise, the central banks will automatically intervene on the currency market. The size of the central bank's offer of its own currency I is dependent on the previous period's raw materials price m_- and a positive constant ζ_j ($j \in \{1, 2\}$):

$$I = \begin{cases} \zeta_1 m_- & \text{if } f > \frac{1}{f^*} \text{ (low aim conflict)} \\ \zeta_2 m_- & \text{if } f < \frac{1}{f^*} \text{ (high aim conflict)} \end{cases} \tag{5}$$

Analogously, the foreign central bank's intervention totals to:

$$I^* = \begin{cases} \zeta_1 m_-^* & \text{if } f > \frac{1}{f^*} \text{ (low aim conflict)} \\ \zeta_2 m_-^* & \text{if } f < \frac{1}{f^*} \text{ (high aim conflict)} \end{cases} \tag{6}$$

with $\zeta_1 \geq \zeta_2$. The tentative exchange rate $\bar{e}$ is defined as the quotion of the total currency offers:

$$\bar{e} = \frac{X + K_- + I}{X^* + K_-^* + I^*} \tag{7}$$

This measure is the base for the determination of the actual exchange rate e of the next period:

$$e = \begin{cases} \min(f, \frac{1}{f^*}) & \text{for } \bar{e} \leq \min(f, \frac{1}{f^*}) \\ \bar{e} & \text{for } \min(f, \frac{1}{f^*}) < \bar{e} < \max(f, \frac{1}{f^*}) \\ \max(f, \frac{1}{f^*}) & \text{for } \bar{e} \geq \max(f, \frac{1}{f^*}) \end{cases} \tag{8}$$

This model of exchange rate determination is new in experimental literature, because its interpretation of currency offers is not limited to either speculation, purchasing power parity, or international trade. As can be seen, it includes central bank intervention, international trade, and speculation as influence factors on the exchange rate.

The objective of a firm v_i is its expenditure deflated profit. Thus, the payoff of a firm i is defined as

$$v_i = \frac{S_i + e_+ S_i^*}{D} \tag{9}$$

Each firm has the possibility to utilise a profit calculator (see fig. 9). The player can enter an estimate for this period's expected exchange rate (which is unknown to him at the moment of his decision) $\hat{e}$, next period's expected exchange rate $\hat{e}_+$, his own production quantity $\hat{Q}_i$, and the total production quantity of the other firms in his country $\hat{Q}_{-i}$. The firm then selects a grid constant $\hat{s}$ for the profit table, which displays the own production quantity on the ordinate, the total production of the other firms on the abscissa, and the corresponding expected profits in the fields. The table is centered around the chosen quantities $\hat{Q}_i$ and $\hat{Q}_{-i}$.[3] Furthermore, the profit calculator gives a hint on which currency offer would be the most remunerative if the exchange rate estimates are correct. This speculation hint also takes the differences of the interest factors of both countries into account. Let $h := \frac{\hat{e}_+}{\hat{e}} r^* - r$. The speculative advice will then be:

[3]In session 14, the table was not centered but $\hat{Q}_i$ and $\hat{Q}_{-i}$ were the lowest quantities for i and the competitors of i, respectively.

- "offer home currency" if $h > 0$
- "offer foreign currency" if $h < 0$
- "don't offer currency" if $h = 0$

In sessions 7 to 12, the exchange rate aims were publicly anounced, but in sessions 13 to 15 they were not known to the firms, which makes guesses on the height of the future exchange rate even more inaccurate.

The experiments were conducted as computer-based laboratory experiments in the Laboratory for Experimental Economics of the University of Bonn between January 2002 and June 2005. All participants have been students of economics for at least two years. Before the game was started, written instructions were handed out to the participants. Thereafter, an introduction of about one hour was given to them including example calculations of various figures. Some test questions were posed, and after the subjects gave the right answers, the roles were assigned by random. Then the game was started. One session lasted about 8 hours, including a lunch break of one hour. After a short debriefing session and the handing out of an ex-post questionnaire, the participants were given their converted cumulative round payoffs in euro. Each student was furthermore given a show-up fee of €5, totalling to an equilibrium payoff of €72.50. The average payoff per hour was approx. €10.23 in NCU and €10.88 in WCU. 15 sessions were conducted, thereof the first 6 with and the following 9 without a currency union. In each session, 10 players acted as firms. A total of 17 players took part in each WCU session (18 in NCU sessions). Hence, a total of 150 of 264 subjects have taken part in the experiments as firm players, whereas 90 subjects have been firm players in NCU sessions. No subject was allowed to participate more than once in the experiment.

3 Results

In the following, we display our results in four sections. Firstly, we give a brief descriptive summary of the speculation behaviour and the profitability of the speculative decisions

of the firms. After that, we describe our findings concerning the determinants of a firm's speculative behaviour and show the existence of exchange rate uncertainty. The next section outlines the consequences of the exchange rate uncertainty. The remainder of the result chapter shows the effects of speculative currency transactions on exchange rate volatility.

3.1 Descriptive summary of the speculation behaviour

According to the game theoretical solution of the model, no firm should speculate in equilibrium. Nevertheless, the aggregate speculative currency offer of all firms is never zero for any currency in one period. We will firstly give a brief descriptive overview of the speculative decisions before diving deeper into the determinants of the speculation behaviour. After doing so, the consequences of exchange rate uncertainty will be outlined.

Altogether, there have been 1800 speculative decisions in 9 sessions with 20 periods by 10 subjects each. In 1327 of those, a positive offer of either home or foreign currency was placed. If there was a positive offer of home currency, the subject offered 65.17% of the maximum home currency offer $\bar{X}$ (see equation 3) on average, whereupon the size of the foreign currency offer was on average 61.96% of the maximum foreign currency offer $\bar{X}^*$ if not 0. In 549 cases, foreign currency was offered, whereas in the remaining 778 cases home currency was offered. This seeming tendency to offer home currency more often and to a higher extent than foreign currency will be investigated further in section 3.3. The mean share of home currency offers to total home expenses was 15.38%, the mean share of foreign currency offers to total foreign expenses was 21.49%. The higher share of foreign offers to total foreign expenses can be explained by lower production costs in foreign currency, since no labour has to be paid from the foreign firm account.

To measure the profitability of individual speculative decisions, we take a look at the speculation profit:

$$v_{\text{spec}} = \frac{(\frac{e+r^*}{e} - r)(X_i - X_i^* e)}{D} \tag{10}$$

Table 1 displays a summary of the cumulative speculation profits $\sum v_{\text{spec}}$ of the players in all NCU sessions.

Table 1: Descriptive summary of cumulative speculation profits

session	agg.	players with	
	$\sum v_{\text{spec}}$	$\sum v_{\text{spec}} < 0$	$\sum v_{\text{spec}} > 0$
7	.6046015	3	7
8	.0559865	5	5
9	.4795765	3	7
10	.1411873	2	8
11	.6395505	2	8
12	.6581888	1	9
13	.0619988	1	9
14	1.429293	4	6
15	-.0894841	5	5
mean	0.44232	2.89	7.11

As can clearly be seen, a majority of 71.1 % of the players makes profits on average by speculating on the currency market. A share of 28.9 % of the players incurs losses by speculation, but in most sessions, the cumulative aggregate speculation profits are positive. We find support for positive cumulative aggregate speculation profits by a Wilcoxon signed-rank test on a significance level of $p = 0.0078$.

3.2 Determinants of the speculative behaviour

In the last section, we have shown that firms tend to speculate and make profits on average by doing so in spite of no speculative currency trade taking place in equilibrium. How can the existence of speculative currency offers be explained? We will dig deeper into the determinants of the speculative behaviour in this section. The most obvious motivation for placing speculative offers would be the difference in interest rates in both countries. This behaviour can also be observed by looking at the data.

Hypothesis 1. *The difference in interest rates in both countries in one period influences a firm's speculation behaviour.*

To test hypothesis 1, we define

$$\Delta r_t := r_t - r_t^* \tag{11}$$

as the difference in interest factors in both countries. A firm determining its speculative decision solely by the interest difference should offer home currency if $\Delta r_t < 0$, foreign currency if $\Delta r_t > 0$, and no currency if $\Delta r_t = 0$. Opposing to determining the speculative decision by Δr_t, a firm could also consider the speculative advice h given by the profit calculator. The profit calculator could be used arbitrarily often per period, so there is the possibility of entering more than one guess for actual and upcoming exchange rates. However, 75.67 % of the profit calculator utilisations were done with only one estimate for the exchange rates, and 94.45 % were done with three estimates at most.

There have been a total 1800 speculative decisions. In 1078 cases of those, either home currency was offered, and interest differences existed. We are interested in the propensity of the players to speculate either conforming to speculative advice or interest differences. Table 2 shows a direct comparision of those cases.

What can be deducted from those figures? If the speculative advice was requested and if the speculative advice recommended to offer the currency which was the cheaper one in terms of interest rates, about five times more of the speculative decisions followed both the advice and the interest difference. This is a strong indication for an influence of the interest rate on the speculative decision, because the interest rates are taken into account by both the interest difference and the speculative advice. But which both determinants is relied on more often? If the speculative advice was requested and it recommended to offer the opposite currency than the interest difference did, then a majority of three times as much speculative decisions followed the recommendation of the speculative advice opposing to interest rates. We infer that subjects prefer basing their speculative decisions on the speculative advice over basing them on interest rates. Contrariwise to

Table 2: Conformance to speculative motive (in %)

advice requested	interest difference and speculative advice point in the same direction	decision in this direction	43.9	52.8
		decision in the opposite direction	8.9	
	interest difference and speculative advice point in opposite directions	decision conforming to interest difference	4.3	16.3
		decision conforming to speculative advice	12.0	
advice not requested	decision conforming to interest difference		20.6	30.9
	decision not conf. to interest difference		10.3	

that, subjects tend to rely rather on interest rates than on other determinants if the speculative advice is not requested. Concluding, we find that interest differences do matter, but people tend to take into account also individual exchange rate estimates when placing their speculative decisions.

Do subjects usually offer the right currency with regard to Δr_t? Recall that in case of a constant exchange rate a profit-motivated subject should offer home currency if $\Delta r_t < 0$ holds true, foreign currency if $\Delta r_t > 0$, and no currency at all if there is no difference in interest factors in both countries. In the following, we show that most subjects place their currency offer according to this rule.

Hypothesis 2. *If interest rates differ, subjects tend to offer the currency with the lower interest rate.*

To check this, we look at all periods in which a difference in interest factors arose and a firm speculated. We then count how often home or foreign currency was offered. This provides us with a 2×2 table for each firm player as shown in table 3. A firm can either offer home currency or foreign currency. If subjects base their speculative decisions on interest rate differences, then they should offer foreign currency when the home interest

Table 3: 2×2 table for the computation of Yule coefficients

	offer foreign currency	offer home currency
$\Delta r_t > 0$	y_f^+	y_h^-
$\Delta r_t < 0$	y_f^-	y_h^+

rate exceeds the foreign interest rate (y_f^+), or offer home currency when the foreign interest rate is greater than the home interest rate (y_h^+), but not vice versa.

For each firm, such a 2×2 table has been determined to calculate a Yule coefficient Y as follows:

$$Y = \frac{y_f^+ \cdot y_h^+ - y_f^- \cdot y_h^-}{y_f^+ \cdot y_h^+ + y_f^- \cdot y_h^-} \tag{12}$$

The Yule coefficient ranges from $-1 \leq Y \leq 1$. In our case, Y equals 1 for subjects speculating on the right side of the market, given a certain interest rate difference.[4] For some players, a Yule coefficient could not be determined because of four possible reasons. One subject did not speculate at all in periods with interest rate differences. Eleven subjects were 'home-currency-biased:' five subjects only speculated when their home interest rate exceeded foreign interest rate but not otherwise, and six subjects only offered home currency and never foreign currency. Another five subjects were 'foreign-currency-biased'. They only speculated when the foreign interest rate exceeded the home interest rate. These subjects have not been considered in the following evaluation of Yule coefficients. This effect will be investigated further later on.

The median of the Yule coefficients' distribution is 1. Table 11 displays the session averages of Y, whereas a distributional graph of Y is shown in figure 1. The average Y is .72, or .8 if we just consider the strictly positive ones. The distribution is modal, with 47 times $Y = 1$. Only eight subjects have $Y < 0$, four of them at the extreme $Y = -1$. If we classify firms with $Y \geq .5$ as interest factor difference oriented subjects, 84% of

[4]Note that this does not imply that all other subjects behave irrational. It is possible that subjects with a Yule coefficient smaller than 1 are considering different aspects when placing their speculative currency offer.

the firms belong to this group. All session averages of Y are positive, and a Wilcoxon matched-pairs signed-rank test on these averages for $H_0 : Y \leq 0.5$ and $H_1 : Y > 0.5$ implies the rejection of H_0 at a significance level of $p < 0.01$.

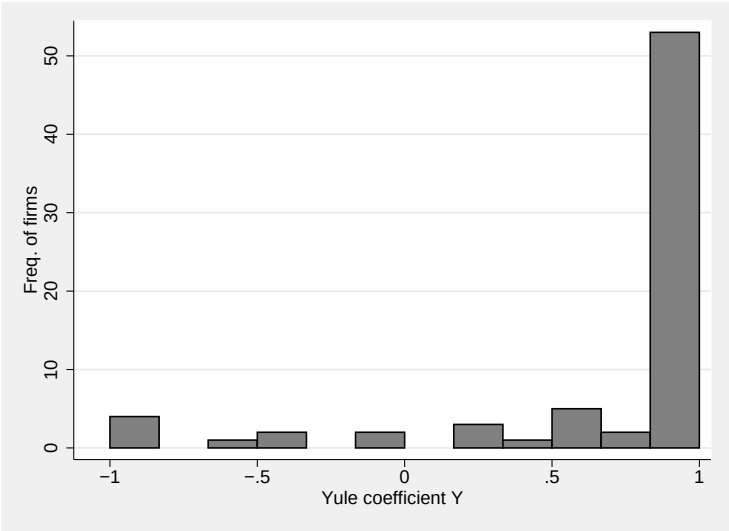

Figure 1: Distribution of the Yule coefficient

Summarising, we find an influence of interest rates on a firm's decisions to speculate. Given that there is a difference in interest rates between the two countries, subjects usually offer the right currency to reap the benefits of this situation. Although this behaviour seems rational, there are are also other factors which influence the speculation profits. The exchange rate variation can be so high that all benefits of the interest difference are eliminated. It would be wise to take the development of the exchange rate into account when placing the currency offer, but this is not an easy task to do: current and future exchange rates are not known to the players, so an estimate of the exchange rate risk is only possible by looking at other figures with only indirect effects on the exchange rate. The estimate is likely to be not very accurate, and so it is plausible to assume that subjects tend to base their speculative currency offers rather on the difference in interest factors than on the expected percentage change of the exchange rate.

The objective function of central banks punishes the central bank player if the interest factor in the own country is not equal to an ideal interest factor r_0. Hence, the likelihood of a high difference in interest factors in both countries is low and only marginal speculation

gains can be made by simply exploiting the interest rate difference in both countries. Contrary to that, the variation of the exchange rate between two consecutive periods might be high. We find support for this thesis in the data gathered through our experiment (see table 4) and try to confirm it in the following.

Hypothesis 3. *A firm's speculation behaviour is influenced more by the difference in interest factors in both countries than by difference between previous period's exchange rate and the exchange rate two periods before.*

The firms lack the capability of computing the real value of the exchange rate because they don't know the size of central bank interventions, total firm currency offers, and foreign firm accounts. Hence, they may only use technical analysis of the exchange rate as an instrument to estimate this and next period's exchange rate. Note that a subject could also take a great variety of other factors with only an indirect influence on the exchange rate into account. The answers given by some subjects in the ex-post questionnaires indicate that players also consider wages, expenditures, material's prices, this and previous period's total amount of production, and the target price. However, we could not find a visible correlation between these figures and the speculative amounts.

Table 4: Summary statistics on interest factor and exchange rate differences

variable	n	average	std. dev.	min.	max.
Δr_t	175[a]	-.0007974	.0180979	-.096	.0549999
Δe_{t-1}	171	.009667	.1180933	-.5213502	.5213502

[a] 5 observations have been filtered out due to obvious typing errors

The most simple measure for estimating upcoming exchange rates by technical analysis is the difference between the previous period's exchange rate and the exchange rate in the period therebefore. This is by no means the only way to use technical analysis, but we will limit our investigation to it because an all-embracing evaluation of technical analysis in the currency market is not subject of this essay. To investigate technical analysis of the exchange rate as a determinant of a firm's speculative offers we take a look at the behaviour of each of the firm players. We define Δe_{t-1} as the difference between the

exchange rate of the previous period and the period therebefore:

$$\Delta e_{t-1} = e_{t-1} - e_{t-2} \tag{13}$$

To test the correlation between Δe_{t-1} and the speculative offers of firms, a standardised measure ψ of the latter needs to be created for each firm and each period. This can be done by dividing the actual currency offers by the maximum currency offers (see eqn. 3 resp. 4). ψ ranges between 0 and 1; the lower ψ is, the lower the relative speculative offer has been. We thus define:

$$\psi_i = \left(\frac{X_i}{\bar{X}_i} + \frac{X_i^*}{\bar{X}_i^*} \right) \tag{14}$$

Now we calculate Spearman's rank correlation coefficient ρ of each player's standardised currency offer (ψ_i) and the possible speculation determinants Δr_t and Δe_{t-1}. The correlation coefficient would be positive if trends were extrapolated and negative if a return to the second last value is expected. In the following we use the absolute value of ρ, since we are interested in the strength of the correlation and not in its direction. If a player did not take an active part in currency speculation, this figure could not be determined. Figure 2 displays the session averages of the absolute values of the correlation coefficient for each player. The actual values can be found in table 12. A one-tailed Fisher-Pitman permutation test for paired replicates applied to the session averages with $H_0 : |\rho^{\psi_i,\Delta e_{t-1}}| \geq |\rho^{\psi_i,\Delta r_t}|$ and $H_1 : |\rho^{\psi_i,\Delta e_{t-1}}| < |\rho^{\psi_i,\Delta r_t}|$ rejects H_0 with a significance of $p = 0.05$. The statistical evidence confirms hypothesis 3.

Although the exchange rate differences have a much higher influence on speculation profits than interest factor differences, firms rather use the difference in interest factors than the difference in historical consecutive exchange rates as a tool for determining the size of their speculative currency offers. This behaviour seems to be naïve at first sight and is likely to be caused by the incapability of predicting changes in exchange rates. As in section 3.3 will be shown, the negligence of the exchange rate change is by no means unsophisticated. Having gained great circumstantial evidence for the incapability of subjects to estimate changes in the exchange rate correctly it seems necessary to us to

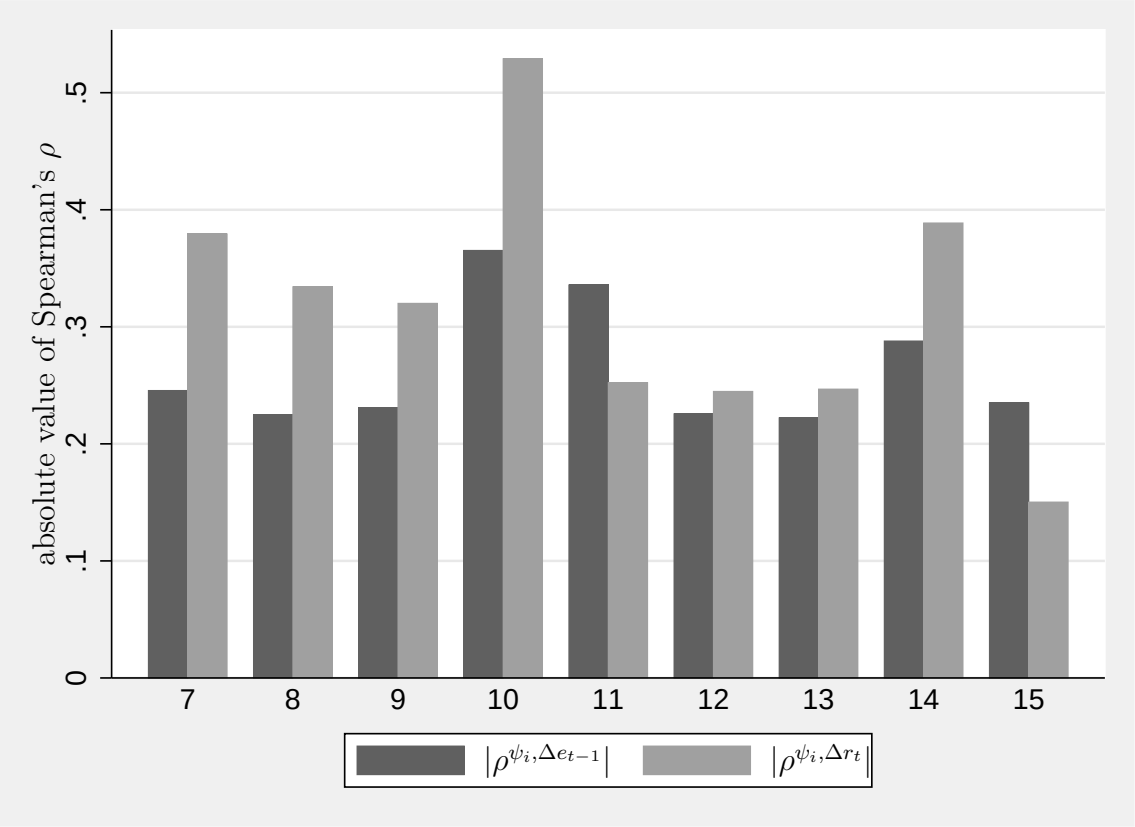

Figure 2: Correlation between standardised currency offer and exchange rate variation resp. interest factor difference

find evidence for the existence of exchange rate uncertainty. We will do so by comparing the exchange rate estimates entered into the profit calculator with the actual exchange rates.

Hypothesis 4. *Subjects estimate the percentage change of the exchange rate incorrectly.*

Recall from the second chapter that the speculative advice h takes into account only the relation of $\hat{e}$ to $\hat{e}_+$ but not their absolute values. We calculate the estimated percentage change of the exchange rate $\tilde{e}_g := \frac{\hat{e}_+}{\hat{e}} - 1$ and the real percentage change of the exchange rate $\tilde{e}_r := \frac{e_+}{e} - 1$. If the estimated change in the exchange rate is correct, $\tilde{e}_r = \tilde{e}_g$ holds true. Figure 3 shows a scatterplot of both measures.

In only 158 of 1262 profit calculator utilisations the estimated percentage change of the

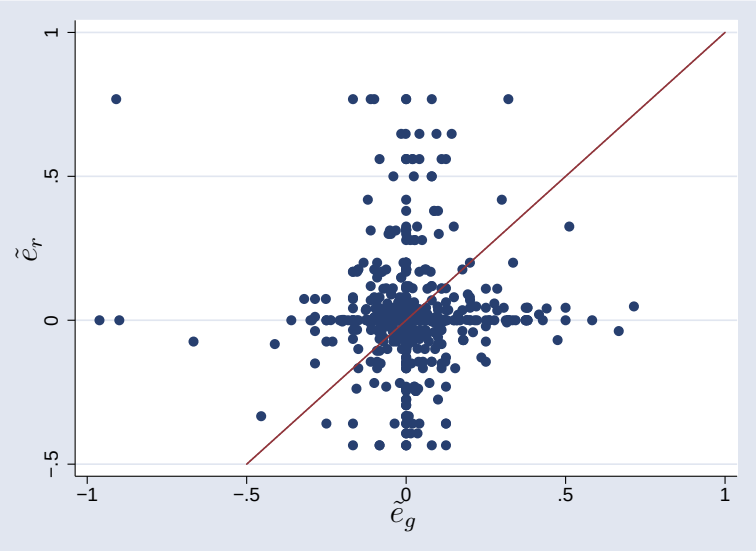

Figure 3: Scatterplot of real and estimated percentage change of the exchange rate. The line denotes correct estimates

exchange rate has been correct. This figure seems rather high at first sight, but it really is not: There have been experimental sessions with long phases of a constant exchange rate, and 155 out of the 158 correct estimates have been true predictions of no exchange rate change at all. No obvious correlation between $\tilde{e}_r$ and $\tilde{e}_g$ can be observed in figure 3. A linear regression for the equation

$$\tilde{e}_g = b_0 + b_1 \tilde{e}_r \tag{15}$$

shows an extremely low R^2 value of 0.0002. Spearman's rank correlation coefficient for both figures equals 0.0017. All these figures let it seem safe to assume that the subjects' exchange rate estimates are mostly wrong.

Table 13 displays the session values of these measures. A one-tailed Fisher-Pitman permutation test for paired replicates implies that the absolute value of Spearman's rank correlation coefficient is lower than 0.15 on a significance level of $p = 0.05$. The same test states that the R^2 value is lower than 0.03 on the same significance level. We find strong evidence for the existence of exchange rate uncertainty. In many cases, subjects were not able to predict the change of the exchange rate correctly. If we only consider the cases in

which there was a change in the exchange rate, only three exchange rate estimates have been correct. As we have seen in the previous section, firms seem to know or at least to learn that their estimates are likely to be wrong. This is the reason why they don't rely on their own predictions and rather base their decisions on the difference of the interest rates.

So far, we investigated the determinants of the speculative behaviour of firms. We found that subjects base their speculative decisions rather on differences of the interest rates than on the change of the exchange rate and that subjects also tend to borrow money rather in the country with the lower interest rate to offer currency. It seems that the firms do not always trust their own exchange rate estimates, because they ignore the speculative advice provided to them by the profit calculator. The reason for this behaviour is likely to be the observed incapability to predict the change in the exchange rate precisely.

3.3 Consequences of exchange rate uncertainty

The results gained suggest that subjects are incapable of predicting exchange rate changes correctly and thus base their speculative decisions rather on differences of the interest factors. We will now evaluate the consequences of this exchange rate uncertainty and explore ways of how the firms try to cope with it.

When we investigated the determinants of firms' speculative behaviour, we distinguished three different classes of speculative decisions: Some decisions rigorously followed the speculative advice h, some of them went in the opposite direction because the difference in interest factors Δr_t was in favour of the other currency, and the rest based the speculative decision on a heuristic unknown to us. In the following, we will call these three classes h, Δr_t, and u. A special interest arises in the profitability of the currency trades in the different classes. The most profitable decision class would be h if the percentage exchange rate variation was guessed correctly. If this variation estimate was wrong, the other two classes could scoop in higher profits. The previously gained results suggest to assume:

Hypothesis 5. *Speculation decisions taking individual exchange rate estimates into account lead to less revenue than speculation decisions based on interest rate considerations alone.*

The average values of the speculation profit v_{spec} for each class of speculative decisions are shown in figure 4 whereas the actual values can be seen in table 14.

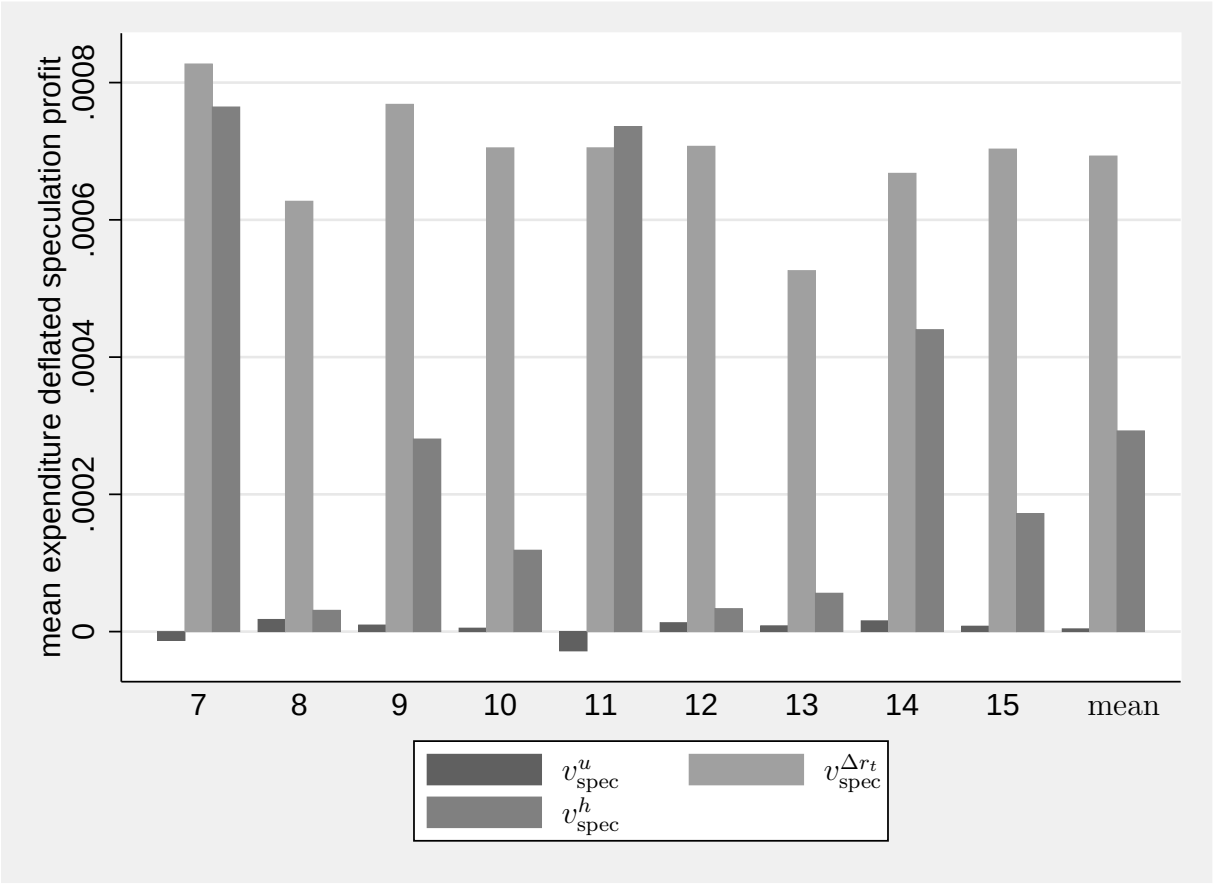

Figure 4: Average profitability of different classes of speculative decisions

To check wether the resulting speculative profit differs between these cases, we ran a Friedman two-way analysis of variance by ranks. At least two of the cases have different profits with significance at 0.1% level. A Wilcoxon signed-rank test shows that the payoffs of classes h and u as well as the payoffs of Δr_t and u differ with 1% significance. The difference in payoffs between Δr_t and h is also significant at 5% level (all Wilcoxon tests: asymp. significance, 2-tailed). The results of the statistical tests imply that

speculative decisions which are in line with Δr_t are most profitable on average, followed by the decisions in line with h. The lowest speculation profits were earned by subjects who base their decisions on determinants that we were not able to classify.

So far, we only classified the speculative decisions to investigate the profitability of different speculation determinants. Now we classify the players according to their conformance to the three possible speculative motives. Firstly, we count how often each player's speculative decision was conform to Δr_t, h, and u. We then create a classifying variable κ for each player with the following rule:

$$\kappa = \begin{cases} 1 & \text{if } \#u > \#h \wedge \#u > \#\Delta r_t \\ 2 & \text{if } \#\Delta r_t > \#h \wedge \#\Delta r_t > \#u \\ 3 & \text{if } \#h > \#\Delta r_t \wedge \#h > \#u \end{cases} \tag{16}$$

Altogether, there have been 18 subjects who mostly speculated conforming to Δr_t, 26 to h, and 41 subjects who prefered other heuristics. 5 subjects could not be classified with this rule: in one case the subject equally preferred h and u over Δr_t, and in 4 other cases the subject equally preferred h and Δr_t over u. To make the profits of the players comparable, we utilize the standardized speculation profit

$$\bar{v}_{\text{spec}} = \begin{cases} \dfrac{v_{\text{spec}}}{X_i} & \text{if} X_i > 0 \\ \dfrac{v_{\text{spec}} \cdot e_-}{X_i^*} & \text{if} X_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

The standardized speculation profit $\bar{v}_{\text{spec}}$ describes the profit of one unit of currency offered. Furthermore, we have to multiply the speculation profit with the previous period's exchange rate to make the currency offers comparable. The actual session averages are displayed in table 15. Note that a dash ("-") in a column denotes that there has been no player of this class in this session. Figure 5 illustrates the mean standardized speculation profits per session and speculator class.

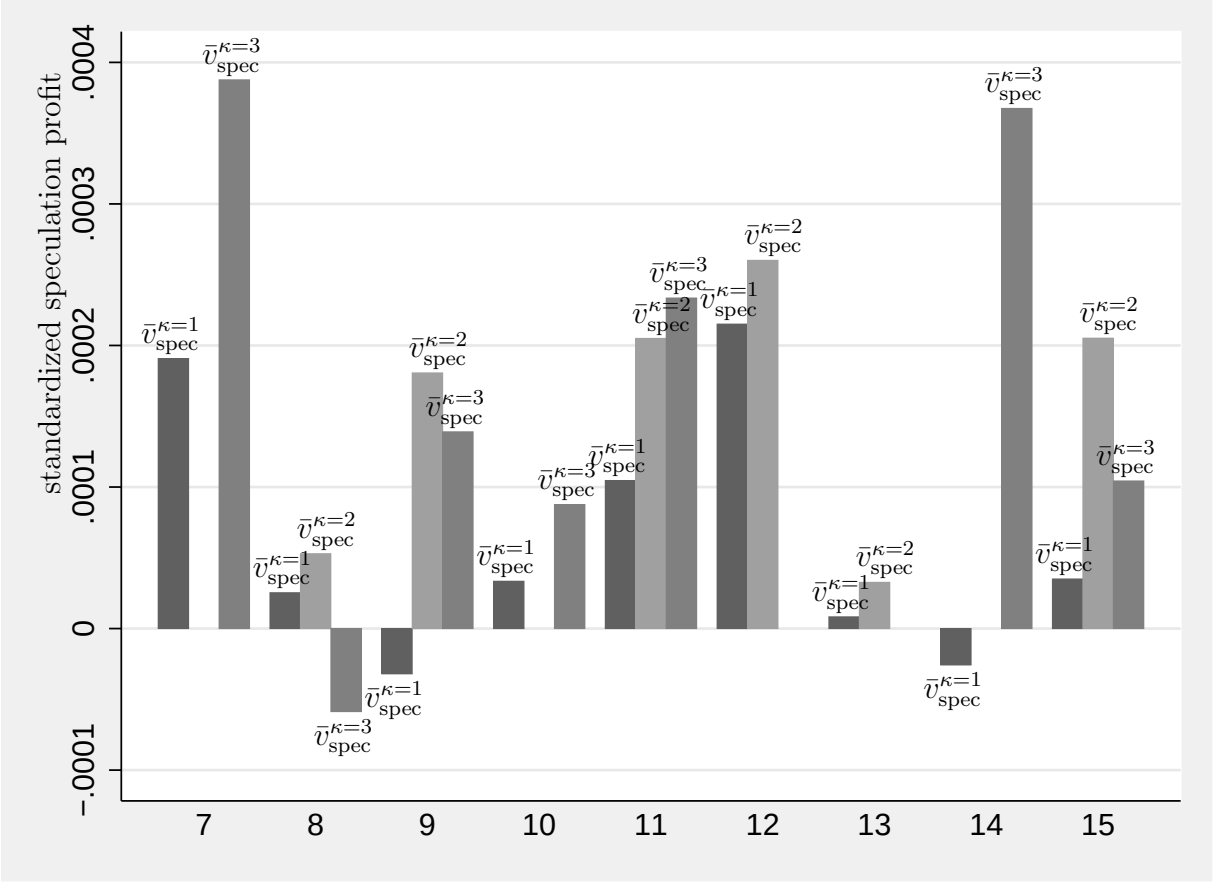

Figure 5: Mean standardized speculation profits per session and speculator class

We now apply the Fisher-Pitman test for paired replicates on all combinations of two speculator's classes. Table 5 shows the results of the tests. It is important to mention that not every speculator's class was present in each session. The amount of tested sessions is displayed in the column labelled n.

Table 5: Test results for the profits of different player classes

H_0	H_1	n	p-value
$\bar{v}_{\text{spec}}^{\kappa=1} \geq \bar{v}_{\text{spec}}^{\kappa=2}$	$\bar{v}_{\text{spec}}^{\kappa=1} < \bar{v}_{\text{spec}}^{\kappa=2}$	6	0.015625
$\bar{v}_{\text{spec}}^{\kappa=1} \geq \bar{v}_{\text{spec}}^{\kappa=3}$	$\bar{v}_{\text{spec}}^{\kappa=1} < \bar{v}_{\text{spec}}^{\kappa=3}$	7	0.03125
$\bar{v}_{\text{spec}}^{\kappa=3} \geq \bar{v}_{\text{spec}}^{\kappa=2}$	$\bar{v}_{\text{spec}}^{\kappa=3} < \bar{v}_{\text{spec}}^{\kappa=2}$	4	0.125

How can the significance levels be interpreted? It is obvious that subjects whose

decsions conform to u make the least profits by speculating. Although there is a tendency of subjects motivated by the speculative advice not to make as high profits as subjects motivated by interest differences solely, we consider the significance level of $p = 0.125$ not high enough to be convincing evidence. However, we only have 4 sessions in which there have been mainly speculative advice motivated *and* mainly interest motivated subjects. This can be a reason for the weak explanatory power of our results. Nevertheless we are sure to be able to show that interest motivated players scoop in the highest profits with more data gained by follow-up experiments.

The previously discovered evidence of the superiority of interest rate motivated speculative decisions can be confirmed for player types, too, albeit to a lesser extent. Thus, hypothesis 5 can be confirmed. Remember that the speculative advice h differs from Δr_t only by the consideration of the estimated percentage change of the exchange rate. Hence, the only reasonable explanation for the supremacy of Δr_t-based decisions over h-based decisions is the incapability of subjects to estimate the variation of the exchange rate correctly.

So far, we have found that the difference of interest factors not only seems to have the highest influence on the speculation decision of individuals, but also that decisions based solely on the interest difference make the highest profits on average. In the following, we will create a decision rule on which base a firm realises most likely speculative gains.

Hypothesis 6. *The difference in interest factors is a profitable decision rule in most cases if a constant currency amount is offered.*

Assume that a subject always speculates in the direction postulated by the difference in interest factors Δr_t. To normalise the size of the speculative currency offer, we assert that an individual always offers the same absolute amount of home currency $\dot{X}$ if it offers home currency at all. The corresponding height of the foreign currency offer if $\Delta r_t > 0$ would be $\dot{X}^* = \frac{\dot{X}}{e}$. Since the current exchange rate e is not known to the firm player, we replace it by the exchange rate in the previous period e_{-}. Formally expressed, the optimal currency offers would be:

$$X = \begin{cases} \dot{X} & \text{if } \Delta r_t < 0 \\ 0 & \text{else} \end{cases} \tag{18}$$

$$X^* = \begin{cases} \dfrac{\dot{X}}{e_-} & \text{if } \Delta r_t > 0 \\ 0 & \text{else} \end{cases} \tag{19}$$

Now, we evaluate this simple decision rule. For reasons of simplicity, we assume that $\dot{X} = 1$. In doing so we avoid exceeding the credit constraints for both accounts. We then calculate the theoretical cumulative speculation profits $\sum v_{\text{spec}}$ for one firm in each country in all sessions. The influence of the speculative currency offer on the exchange rate will be neglected in this case. It is safe doing this because the influence of the speculative currency offer of a single firm on the exchange rate is only marginal at best. The results of this evaluation are shown in table 6.

Table 6: Hypothetical cumulative speculation profits for a firm if the decision rule is applied

session	$\sum v_{\text{spec}}$ for a firm in		
	country A	country B	avg (A&B)
7	0.0002792	0.0001633	0.00022125
8	-0.00000995	0.00000896	-0.000000495
9	0.0000865	0.0000757	0.0000811
10	0.0000705	0.0000369	0.0000537
11	0.000096	0.0000973	0.00009665
12	0.0002586	0.000229	0.0002438
13	0.0000264	0.0000175	0.00002195
14	0.0004435	0.0001999	0.0003217
15	0.0003842	0.0002659	0.00032505
avg	0.000181661	0.000121607	0.000151634

Note that the profits shown in table 6 are only *hypothetical* profits. The speculative decision of a firm has few but existing influences on the exchange rate of the next period,

on the own speculative offer in the following periods, on the height of next period's exchange rate aims of the central banks, and probably even on the production decision of the firm. By neglecting these influences we might get less accurate results in our prediction, but we are convinced that the general direction of the decision rule is correct because of the marginal relevance of these influences. Nevertheless, the profitability of this decision rule would probably change strongly if every firm in both countries made use of it.

As we see, there was only one case in which a firm would have made losses by applying this decision rule and speculating. Session 8 is marked by an almost monotonic increasing exchange rate for country A: In only 3 non-consecutive periods the exchange rate decreased weakly. This explains the failure of the decision rule in session 8. In every other case, our decision rule seems to be a successful way of deciding which currency to offer.

It is possible to calculate a comparable measure for the observed speculation profits in our experiment (compare table 7). Again, the size of the speculative currency offer is normalized to an amount of one unit of home currency or the corresponding height of the foreign currency. In case of a home currency offer, we divide the speculation profit by the amount of home currency offered. When foreign currency is offered, we proceed in an analogous manner, but furthermore divide by e_{-}.

Comparing the average session values of the hypothetical decision rule and the actual decisions, we find that the former is significantly higher (one-tailed Fisher-Pitman permutation test for paired replicates $p < 0.1$ (lower tail $p = 0.086$)). This further strengthens the assumption of supremacy of this rather simple decision rule which currency to offer if future exchange rates are unknown.

It seems likely that a firm can predict an exchange rate which has been relatively stable up to the moment of the speculative decision more precisely than a volatile exchange rate. We now show that the speculative currency offers decrease with increasing session volatility of the exchange rate.

Hypothesis 7. *A higher exchange rate volatility leads to a decrease in the speculative*

Table 7: Real normalized cumulative speculation profits for a firm

session	$\sum v_{\text{spec}}$ for a firm in		
	country A	country B	avg (A&B)
7	0.00192673	0.00052717	0.00245390
8	0.00000538	0.00002501	0.00003039
9	0.00017778	0.00050793	0.00068571
10	0.00033375	0.00011989	0.00045364
11	0.00073558	0.00037866	0.00111424
12	0.00102848	0.00108748	0.00211596
13	0.00008636	0.00004883	0.00013519
14	0.00089394	0.00032527	0.00121921
15	0.00081920	-0.00003358	0.00078562
avg	0.000133493	0.000066370	0.00009993

offers of firms.

As a figure for the cumulative exchange rate volatility per period, a symmetric measure seems appropriate. Hence, we compute the value of

$$\bar{\delta}_t = \sum_{j=1}^{t} \left(\frac{e_j}{e_{j-1}} + \frac{e_{j-1}}{e_j} - 2 \right)^2 \tag{20}$$

for each period in each session. The value of $\bar{\delta}_t$ increases monotonically over time; the more it increases in one period, the higher the exchange rate volatility has been. To test the correlation between $\bar{\delta}_t$ and the speculative offers of firms, we use the aggregate value of the standardised speculative offers (see hypothesis 3):

$$\psi = \sum_{i=1}^{10} \left(\frac{X_i}{\bar{X}_i} + \frac{X_i^*}{\bar{X}_i^*} \right) \tag{21}$$

Now, Spearman's rank correlation coefficient $\rho^{\psi,\bar{\delta}_t}$ between aggregate standardised speculation ψ and cumulative exchange rate volatility per period $\bar{\delta}_i$ gives us further information (see table Appendix A:). As later will be shown in table 10, the overall volatility was extremely small in session 13. This explains the relatively high correlation in this period.

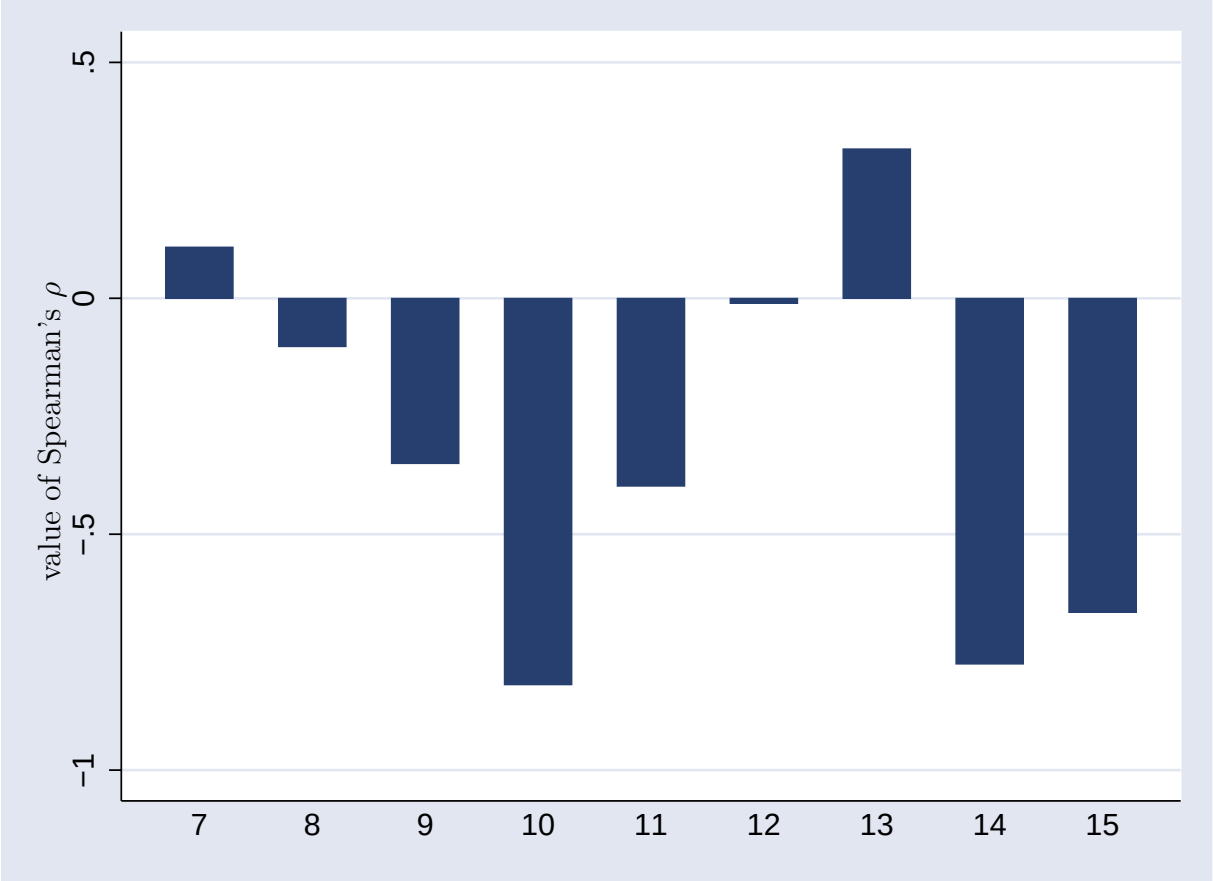

Figure 6: Spearman's rank correlation coefficient ρ of cumulative exchange rate volatility and aggregate standardised speculation

Running a one-tailed Fisher-Pitman permutation test for paired replicates for $H_0: \rho^{\psi,\bar{\delta}_t} \geq 0$ and $H_1: \rho^{\psi,\bar{\delta}_t} < 0$, we can reject a positive correlation at a significance level of $p = 0.0292$. This shows that experience with volatility over time seems to matter. [5]

This rather strong result is completely in line with our other findings: the subject's speculative offers decrease with increasing exchange rate volatility. The high volatility in the past leads to a higher exchange rate uncertainty. More profits could be earned with a higher volatility, but since the firm owners find it hard to predict the direction of the

[5] One might object the explanatory power of testing a monotonically growing measure against the aggregate standardised home currency offer, because the latter one could also be correlated with the time. However, neither time nor a normalised volatility figure are significantly correlated with it.

changes, they decide to decrease their speculative offers: a great disadvantageous change of the exchange rate will certainly destroy the gains made by exploiting the difference in interest factors.

When we looked at the data to investigate hypothesis 2, we found that a certain amount of speculative decisions is home-currency-biased. In the literature, a home bias is known as the phenomenon which lets investors prefer to buy domestic assets over foreign (see [Fellner and Maciejovsky 2003], [Lewis 1999], and [Cooper and Kaplanis 1994]). Note that the opposite occurs in our investigation: subjects *offer* home currency to *buy* foreign currency. In the following, we thus label this effect *home currency bias*. Before we outline the possible reasons for this behaviour, the significance of the tendency towards higher home currency offers compared with foreign currency offers is shown.

Hypothesis 8. *Subjects tend to offer more home currency than foreign currency.*

As a tool for measuring the relative size of home and foreign currency offers, the cumulative aggregate standardised home and foreign currency offers $\psi_{\mathrm{h}} = \sum_{t=1}^{20} \sum_{i=1}^{10} \frac{X_{i,t}}{\bar{X}_{i,t}}$ and $\psi_{\mathrm{f}} = \sum_{t=1}^{20} \sum_{i=1}^{10} \frac{X^*_{i,t}}{\bar{X^*}_{i,t}}$ are used for each session. Since the standardised home and foreign currency offers range between 0 and 1 in each period and since there are 10 firms and 20 periods, both ψ_{h} and ψ_{f} range between 0 and 200. The actual values for the non-currency union sessions can be found in table 17, whereas a graphical representation of the values is displayed in figure 7.

The standardised home currency offers have always been higher than the standardised foreign currency offers. We find support for this thesis through a one-tailed Fisher-Pitman permutation test for paired replicates with a significance of $p < 0.01$.

This behaviour could also be explained by exchange rate uncertainty. A home currency offer is transferred to the foreign account at this period's exchange rate ($X_i er^*$). This is the only positive component of the firm's foreign account balance. Expenses for foreign currency offers ($-X_i^* r^*$) and costs of foreign materials ($-M_i m^*$) are deducted from the

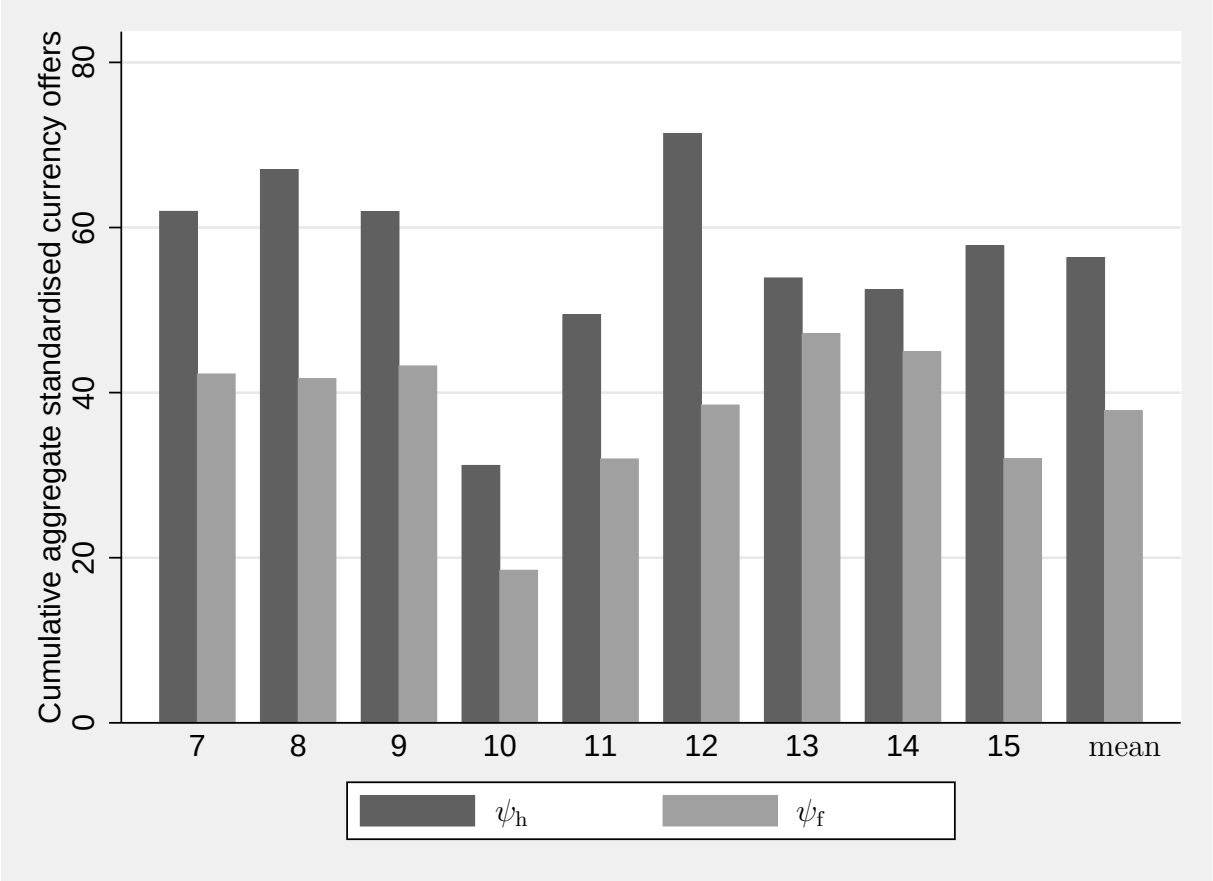

Figure 7: Cumulative aggregate standardised home and foreign currency offers

foreign account. In the following period, the account balance gets transferred to the firm owner at the actual exchange rate. If a subject wants to pay parts or all of its foreign account debts rather now than in the next period, it should place a positive home currency offer. A behaviour like this makes only sense if the subject doesn't want to risk a higher debt caused by a possibly lesser exchange rate in the following period. The propensity to settling the foreign account debts in the actual period rather than in the following can be regarded as a very simple and primitive form of hedging against exchange rate risks. To investigate the hedging behaviour of firms, we define

$$\Psi := \frac{r^*(\frac{X_i}{\hat{e}} - X_i^*)}{M_i^* m^*} \tag{22}$$

as the relation of currency offers to foreign account debt. A Ψ greater than zero expresses the percentage of foreign account debts settled by the home currency offer at

the estimated exchange rate, a Ψ smaller than zero equals the increase of foreign account debt by foreign currency offers. Table 8 shows the session averages of Ψ.

We now compare Ψ for positive home currency offers ($\Psi_{X_i>0}$) with the absolute value of Ψ for positive foreign currency offers ($|\Psi_{X_i^*>0}|$). A one-tailed Fisher-Pitman permutation test for paired replicates of $H_0 : \Psi_{X_i>0} \leq |\Psi_{X_i^*>0}|$ and $H_1 : \Psi_{X_i>0} > |\Psi_{X_i^*>0}|$ is significant for $p < 0.01$. If a subject feels secure about its own prediction and if this subject wishes to hedge against an increasing exchange rate, a Ψ of 1 would be the ideal value. We interpret a $\Psi < 1$ as an expression of uncertainty about the own exchange rate estimate and find that in most cases, Ψ is even smaller than 0.5 if $X_i > 0$. If subjects do follow our thesis of hedging, they still don't feel very secure about their exchange rate estimates.

What at first seems to be an unostentatious result appears in a new light when we compare the session average of the relation of currency offers to foreign account debt with the respective overall session's exchange rate volatility: Spearman's rank correlation coefficient between the session exchange rate volatility and the relation of currency offers to debt has the high value of $\rho = 0.6667$. This means we can reject the hypothesis that those two figures are not at all or negatively correlated at a significance level of $p = 0.02495$ (one-tailed). One might object that increasing speculation activities destabilise the exchange rate and that the reason might be the consequence in this case. Contrariwise, we will show later that speculation has no significant influence on exchange rate volatility.

We can deduct that a higher exchange rate volatility increases the propensity of firms to engage in hedging activities to safeguard exchange rate risks which might influence the height of production profits. Although this finding also includes that firms only seldomly settle their foreign account debts to their full extent, it seems to be one way of how firms deal with exchange rate risks.

How does a firm cope with its exchange rate uncertainty if it engages in hedging

Table 8: Relation of currency offers to debt (session averages) and overall session exchange rate volatility

session	Ψ if $X_i > 0$	Ψ if $X_i^* > 0$	Ψ	δ
7	.36552487	-.30605193	.06577762	.0363223
8	.44483818	-.3111075	.02944369	.000035
9	.48100904	-.33237057	.07760347	.0010411
10	.46563531	-.23704799	.10555662	.0009401
11	.40150467	-.30142939	.04477621	.0125613
12	.37167138	-.24952556	.11123972	.0023613
13	.24726002	-.27796907	.03284282	.0000001
14	1.2918399	-.47550419	.35278018	.3426598
15	.41020969	-.29141708	.11093025	.0709927

only to a relatively small amount? Another way of doing so would be to enter rather pessimistic exchange rate estimates into the profit calculator.

If a firm expect the exchange rate to rise in the next period with no difference in interest factors in both countries in this period, it would be profitable to offer home currency. More home currency is offered in almost each session, so it is plausible to assume that subjects have expectations of growing exchange rates more often than they expect falling exchange rates.

Hypothesis 9. *Subjects expect the exchange rate rather to grow than to fall.*

To confirm this hypothesis, the gathered profit calculator data can be used. As already done in the investigation of hypothesis 1, only the last guess for the exchange rate is taken into account. Firstly, we generate a measure to describe the exchange rate expectations in each session. For each session, let

$$\epsilon^{+} := \frac{\#(\hat{e}_{+} - \hat{e} > 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{23}$$

$$\epsilon^{-} := \frac{\#(\hat{e}_{+} - \hat{e} < 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{24}$$

$$\epsilon^{=} := \frac{\#(\hat{e}_{+} - \hat{e} = 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{25}$$

In general parlance, ϵ^{+} is the relation of the number of expectations of a growing exchange rate to the number of all existing exchange rate estimates. Similarly, ϵ^{-} ($\epsilon^{=}$) denotes the percentage of falling (constant) exchange rate estimates. The sum of ϵ^{+}, ϵ^{-}, and $\epsilon^{=}$ equals always 1 in one session. Figure 8 shows the ϵ values for each session. The actual values are displayed in table 18.

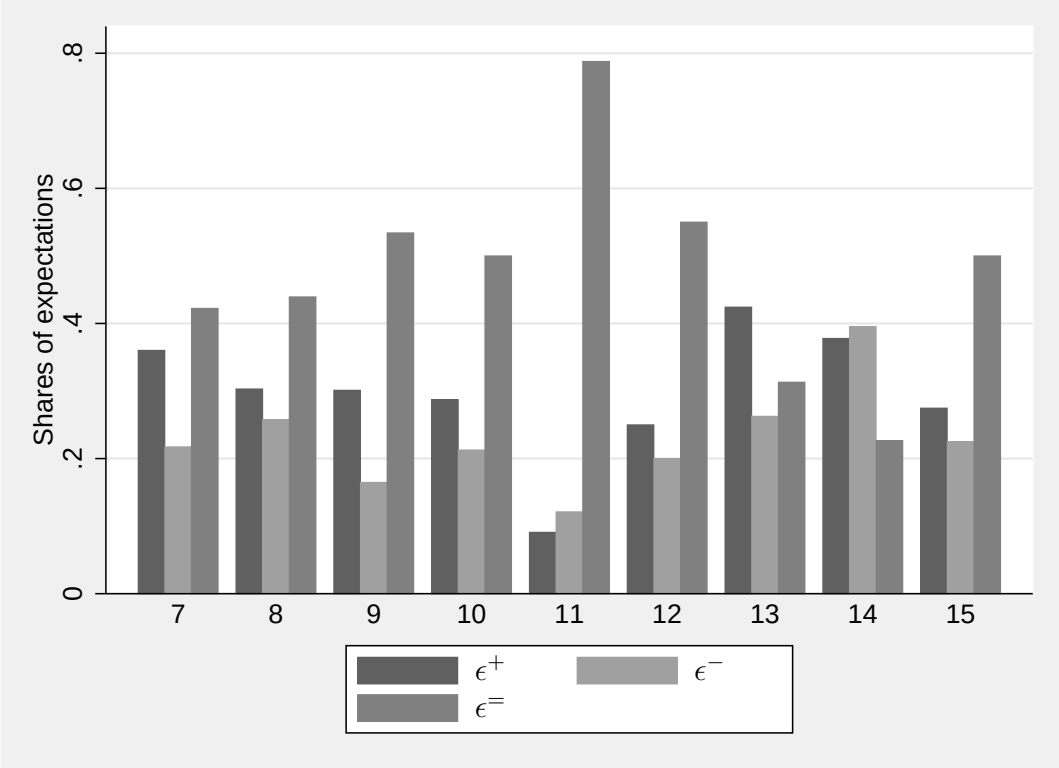

Figure 8: Shares of growing, falling, and constant exchange rate expectations

They demonstrate that constant exchange rate estimates have the greatest share in most sessions, and that in 2 of 9 sessions rising exchange rates are expected more

frequently than falling ones. We ran Fisher-Pitman permutation tests for paired replicates for different hypotheses and gained some significant conclusions. The test results are shown in table 9.

Table 9: Results of permutation tests for paired replicates

H_0	H_1	p
$\epsilon^+ \leq \epsilon^-$	$\epsilon^+ > \epsilon^-$	0.00976
$\epsilon^= \leq \epsilon^-$	$\epsilon^= > \epsilon^-$	0.00585
$\epsilon^= \leq \epsilon^+$	$\epsilon^= > \epsilon^+$	0.02539
$\epsilon^= \leq \epsilon^+ + \epsilon^-$	$\epsilon^= > \epsilon^+ + \epsilon^-$	0.32812

The significance levels of the tests imply that exchange rate expectations are rather constant than either growing or falling, but also rather growing than falling, and that a tendency towards constant exchange rate expectations being more frequent than *both* growing or falling expectations cannot be supported. Thus, we can conclude that hypothesis 9 is confirmed.

What can be deduced from this finding? Taking a look at the production profit structure of a firm

$$v_{\text{prod}} = \frac{1}{D}\left(Q_i q - L_i w r - M_i m - e_+ M_i^* m^*\right) \tag{26}$$

and neglecting the speculative profits, it becomes clear that a growing exchange rate lowers the production profit by $(e_+ - e)M_i^* m^*$. Consequently, firms have rather *pessimistic* expectations concerning the development of the exchange rate. The pessimism is likely to be caused by exchange rate uncertainty - subjects are feeling insecure in predicting changes of the exchange rate, so they tend to calculate with rather downbeat expectations to obtain a worst-case profit estimate by the use of the profit calculator. Again, this result falls into line with our other findings. It also explains why people tend

not to settle the foreign account debts in its full size in spite of exchange rate uncertainty.

3.4 Consequences of speculative currency trade

The existence of macroeconomical consequences of speculation cannot be denied for the real world. Neoclassical theory states that currency speculation must have a stabilising effect on exchange rate volatility. [Friedman 1953] asserts that stabilising speculation is equivalent to profitable speculation: If speculators buy an asset when its price is high and respectively sell it when its price is low, this will drive the asset's price towards its equilibrium. This sight on the relation between speculation and stabilisation seems tenuous. [Long et al. 1990] find that because noise traders can earn higher profits than long term investors and both types of speculators are trading, Friedman's model appears incomplete. [Carlson and Osler 2000] argue that Friedman's line of reasoning does neither incorporate interest rates nor a risk model, which both could in fact make speculators sell an asset when its price is low and buy it when its price is high, thus destabilising the price. In general, most post-Keynesian authors assert the opposite of Friedman's theory. In the following, we show the effects of speculation in our experiment. We think that the monetary policy and the implicit cooperation of strong central banks are able to rein back the influence of speculation on the exchange rate volatility.

Hypothesis 10. *Central banks can curb the influence of speculation on exchange rate volatility.*

We utilise the measure already used to confirm hypothesis 7

$$\bar{\delta} = \sum_{t=1}^{20} \left(\frac{e_t}{e_{t-1}} + \frac{e_{t-1}}{e_t} - 2 \right)^2 \tag{27}$$

for determining the exchange rate stability in one session of the experiment - the higher $\bar{\delta}$ is, the more volatile e has been. Now, we compare the actual exchange rate e with a hypothetical exchange rate e_h, which is defined as the exchange rate which would have prevailed if no firm had placed speculative currency offers. Furthermore, we constructed a binomial distributed variable ϖ which is 1 for sessions with a hypothetical

volatility higher than the actual volatility and 0 in the opposite case. Table 10 shows the volatility of actual ($\bar{\delta}^{\text{spec}}$) and hypothetical exchange rates ($\bar{\delta}^{\text{nospec}}$) as well as ϖ for each session. The mean volatility suggests that volatility decreases with speculation. In

Table 10: Actual vs. hypothetical exchange rate volatility

session	$\bar{\delta}^{\text{spec}}$	$\bar{\delta}^{\text{nospec}}$	ϖ
7	0.0363223	0.0791757	0
8	0.0000350	0.0001090	0
9	0.0010411	0.0008752	1
10	0.0009401	0.0005754	1
11	0.0125613	0.0014151	1
12	0.0023613	0.0048185	0
13	0.0000001	0.0000002	0
14	0.3426598	0.4068589	0
15	0.0709927	0.0664837	1
mean	0.0518794	0.0622569	

spite of that, we could neither circumstantiate a significant difference in the exchange rate volatility in the different cases by applying Wilcoxon's signed-rank test, the Fisher-Pitman permutation test for paired replicates, nor Walsh's test for a symmetric distribution of differences. The same holds true for different asymmetric volatility measures $\bar{\delta}_e^{\text{asym}} = \sum_{t=1}^{20} \left(\frac{e_t}{e_{t-1}} - 1\right)^2$ and $\bar{\delta}_e^{\text{asym}} = \sum_{t=1}^{20} \left(\frac{e_{t-1}}{e_t} - 1\right)^2$. The mean value for ϖ is 0.44444. Note that a value of 0.5 would indicate no influence of speculation on exchange rate volatilities. However, the Wilson confidence interval at a level of 0.9 for the expected value of ϖ is $[0.2180471; 0.6965233]$. We consider this interval not tight enough to deduce that speculation has no influence on the exchange rate volatility. Hence, we can neither reject nor confirm hypothesis 10.

Although there is a visible difference in the exchange rate volatility in the cases with and without speculation, the firm's currency offers have no significant influence on exchange rate volatility. However, currency crises in the late nineteennineties have been sparked off by wrong monetary policies and speculation (e. g. see [KÖHLER 1998]). We could not show this in our experiment. There are two possible explanations for this find-

ing. At first, the calculated volatility in case of no speculation is only *hypothetical*. The line of reasoning is the same as when we evaluated the prosperity of the decision rule (see hypothesis 6): If no firm speculated, it would probably influence production decisions, fiscal and monetary policy, and the outcome of wage bargaining. Thus, the figures displayed in table 10 need not necessarily be accurate. At second, the central banks are relatively powerful in the experimental design: if the tentative exchange rate turns out not to lie in the range of the exchange rate aims, both central banks cooperate to push the exchange rate to the upper or lower limit of the range. The monetary reserves of the central banks are unlimited, and professional traders do not exist in the currency market. Furthermore, the central banks do not have to accommodate the firms' demand for their currency. The strength of the central banks surely is one reason for the insignificance of the influence of speculation on the exchange rate volatility. According to [Cheung and Chinn 2001], the prevailing opinion among professional currency traders states the opposite: US currency traders think that central bank interventions do not have any substantial effect on exchange rate besides increasing exchange rate volatility. This antagonism might be a consequence of the relative weakness of central banks in the real world compared to the central banks in our experiment.

4 Concluding remarks

We analysed the speculative decisions of industrial firms in a laboratory experiment. The experimental design was very rich, that is with subjects in the role of numerous institutions, there was wide scope for endogenous shocks or variations in exchange rates and interest rates. Opportunities to speculate arose, and our firms tried to reap the benefits.

We identified two determinants of the speculative behaviour, namely subjects who based their decision on interest rate differences or on individual exchange rate estimates. A third fraction acted according to some other heuristic that we could not capture. The firms usually borrowed money to place their currency offer from the account with the lower interest rate. The influence of simple technical analysis of the exchange rate on

the speculation behaviour was significantly lower than the influence of the difference in interest rates. This might be due to the fact that subjects fail to estimate the exchange rate correctly. The estimates being stated by the firms confirm this hypothesis, because they were mostly inaccurate.

Although the firms used the given profit calculator tool when they based their speculation offer on individual exchange rate estimates, their speculative gains were on average significantly below the ones of subjects reacting to interest rate differences. We created a simple decision rule by the use of which a firm could have made positive speculation profits in most cases. The decision rule postulates to always offer a fixed amount of home currency if the interest rate in the home country is lower than in the foreign country, offer the same fixed amount in foreign currency at previous period's exchange rate if the home interest rate exceeds the foreign, and offer no currency at all if the interest rates in both countries are the same. A growing session volatility of the exchange rate led to a higher exchange rate uncertainty and thus to lower speculative currency offers. Not only the risk, also the possible gains were affected by a volatile exchange rate, but subjects feared the risk and speculated less often when past exchange rates showed major fluctuations. The subjects usually offered home currency to a higher extent and more often than foreign currency. We labelled this phenomenon as home-currency-bias and believe that the subjects try to cope with their exchange rate uncertainty by preferring home currency offers, because they want to settle their foreign account debts rather in the actual than in the next period. Another way of meeting exchange rate uncertainty would be to calculate with pessimistic expectations. We found significant evidence for the existence of these. Although the influence of speculation on the exchange rate cannot be denied, neither a significant increase nor decrease of the volatility could be located in our experimental sessions: central banks are strong enough to curb the influence of speculation on volatility.

The firms' overconfidence in the criterion of interest rate difference surprises us, because the variation of the exchange rate had the larger impact on the resulting payoff. That leads us to the assumption that subjects just *like* to base decisions under risk on

safe facts rather than on their beliefs about uncertain future events. Room for future research is left not only on this topic. Especially the heuristic that could not be explained by our experiment should be investigated more closely. Future laboratory experiments might be run with an adjusted experimental setup in order to evaluate the impact of different transaction taxation schemes (for example, taxes as described in [Tobin 1978] or in [Spahn 1996]) on speculative decisions. One could also think of a currency market in which both industrial firms and professional traders are involved and see if they behave differently. The central banks have a very strong influence on the exchange rate: they fix the definite range in which the exchange rate is allowed to flow. In the real world, this can only be done to a certain extent and by drawing on the monetary reserve. Note that the experimental design chosen by us does limit the speculative currency offers of the firms, but it doesn't limit the currency offers of the central bank. A currency crisis cannot arise in this model. Because of the strength of the central banks and the only low influence of currency speculation on the exchange rate, financial phenomena such as bubbles, crashes, or fat tails cannot be observed. Furthermore, a model with three countries could give deeper insights on the strength of the determinants of the speculative behaviour. Our work and the experimental design of Pope et al. should be seen as a starting point for future experimental research.

Appendix A: Tables

Table 11: Session averages of the Yule coefficient

session	mean of Y
7	0.660509447
8	0.717647059
9	1
10	0.714285714
11	0.685887846
12	1
13	0.364303959
14	0.714285714
15	0.689426144

Table 12: Correlation between standardised currency offer and exchange rate variation resp. interest factor difference

session	$\rho^{\psi_i,\Delta e_{t-1}}$	$\rho^{\psi_i,\Delta r_t}$
7	.2455976	.3793693
8	.2247791	.3342151
9	.2307252	.3200829
10	.3652776	.5290438
11	.3357749	.2522709
12	.2256564	.2448294
13	.2222274	.2467859
14	.2878838	.388714
15	.2350855	.1502816

Table 13: Correlation measures of $\tilde{e}_g$ and $\tilde{e}_r$ per session

session	$\rho^{\tilde{e}_g,\tilde{e}_r}$	R^2
7	.24156232	.00860725
8	-.0553194	.01056194
9	.0622224	.00299655
10	.09360007	.0799354
11	-.19678558	.00004638
12	-.16077205	.00980022
13	.0007471	.00000013
14	-.06672657	.00314537
15	.0533577	.01553479
total	.00174475	.00023264

Table 14: Profitability of different classes of speculative decisions

session	u	Δr_t	h
7	-0.0000129	0.0008271	0.0007644
8	0.0000177	0.0006271	0.000031
9	0.00000952	0.0007683	0.0002806
10	0.00000504	0.0007049	0.0001186
11	-0.0000281	0.000705	0.000736
12	0.000013	0.0007072	0.0000335
13	0.00000841	0.000526	0.0000559
14	0.0000157	0.0006678	0.00044
15	0.00000788	0.0007031	0.000172
mean	0.00000402	0.000692944	0.000292444

Table 15: Session averages of standardized speculation profits per speculator class

session	$\bar{v}_{\text{spec}}^{\kappa=1}$	$\bar{v}_{\text{spec}}^{\kappa=2}$	$\bar{v}_{\text{spec}}^{\kappa=3}$
7	.00019079	-	.0003877
8	.00002533	.0000529	-.00005867
9	-.00003201	.00018062	.00013901
10	.00003344	-	.00008763
11	.00010462	.00020501	.00023354
12	.00021509	.00026016	-
13	.00000829	.00003267	-
14	-.00002572	-	.00036751
15	.00003503	.00020517	.0001043

Table 16: Correlation between cumulative exchange rate volatility and aggregate standardised speculation

session	$\rho^{\psi,\bar{\delta}_t}$
7	.10857596
8	-.10248707
9	-.35036669
10	-.82100541
11	-.61775789
12	-.04612983
13	.31677962
14	-.77531099
15	-.66592277

Table 17: Cumulative aggregate standardised home and foreign currency offers

session	ψ_{h}	ψ_{f}
7	61.95385	42.25773
8	67.0229	41.67973
9	61.93498	43.23082
10	31.17691	18.48489
11	49.43409	31.9665
12	71.39223	38.49543
13	53.88873	47.14093
14	52.4529	44.96228
15	57.7877	31.99247
mean	56.33825	37.8012

Table 18: Shares of growing, falling, and constant exchange rate expectations

session	ϵ^{+}	ϵ^{-}	$\epsilon^{=}$
7	.36024845	.2173913	.42236024
8	.30303031	.25757575	.43939394
9	.30113637	.16477273	.53409094
10	.28723404	.21276596	.5
11	.09090909	.12121212	.78787881
12	.25	.2	.55
13	.42424244	.26262626	.3131313
14	.37790698	.39534885	.22674419
15	.27472529	.22527473	.5

Appendix B: Calibration

$Q_m =$	20	$\eta =$	0.14
$Q_c =$	60	$\zeta_1 =$	600
$Q_0 =$	45	$\zeta_2 =$	500
$\gamma_1 =$	80	$L_a =$	600
$\gamma_2 =$	20	$L_b =$	720
$\sigma =$	0.6	$r_0 =$	1.05
$F =$	15		

Appendix C: Symbols

Δe_{t-1}	difference in the height of exchange rate between period t and $t-1$
Δr_t	difference in the height of interest factors of both countries
Ψ	relation of currency offers to foreign account debt
$\bar{\delta}$	exchange rate volatility
ϵ	exchange rate expectation measure
γ_1, γ_2	constants with $\gamma_1 > \gamma_2 > 0$
η	strike wage coefficient
ψ	standardised speculative currency offer
ζ_1, ζ_2	constants with $\zeta_1 \geq \zeta_2 > 0$
C_1	credit constraint on the home account of firms
C_2	credit constraint on the foreign account of firms
D	total expenditures as determined by government
e	exchange rate, price of one unit of foreign money in home currency
$\bar{e}$	tentative exchange rate
e_+	next period's exchange rate
$\hat{e}$	a firm's estimate of this period's exchange rate
$\hat{e}_+$	a firm's estimate of next period's exchange rate
F	fixed labour needed to run the firm
f	exchange rate aim

h measure for the speculative advice

I total home central bank currency offer

K total home account balances of foreign firms transferred to owners

K^* total foreign account balances of home country firms transferred to owners

K_- value of K in the previous period

K^*_- value of K^* in the previous period

L_i amount of labour needed for producing Q_i

m price of home materials in home currency

m_- price of home materials in the previous period

p target price of the current period

p_+ next period's target price

q price of the home country consumption good

Q_0 production capacity (in the case of wage conflict) with $Q_0 < Q_c$

Q_c production capacity (in the case of wage agreement)

Q_i production of firm i

Q_{-i} production of all firms except firm i

Q_m minimum production

$\hat{Q}_i$ estimate on the height of its own production of firm i

$\hat{Q}_{-i}$ estimate of firm i on the height of the total production of all other firms in its home country

r interest factor

r_0 ideal interest factor

S_i home account of firm i

S^*_i foreign account of firm i

$\hat{s}$ scale for the profit calculator of a firm

v expenditure deflated total profit with $v = \frac{\Pi}{D}$

v_i expenditure deflated profit of a home country firm i with $v_i = \frac{\Pi_i}{D}$

v_{prod} production profit

v_{spec} speculation profit

w nominal wage rate

X	total offer of home currency by firms with $X = \sum_{i=1}^{10} X_i$
X^*	total offer of foreign currency by firms with $X^* = \sum_{i=1}^{10} X_i^*$
X_i	amount of home currency offered by firm i
X_i^*	amount of foreign currency offered by firm i
$\bar{X}_i$	maximum foreign currency offer of firm i
$\bar{X}_i^*$	maximum foreign currency offer of firm i
Y	Yule coefficient for a firm player
y	measure for calculating Y

Appendix D: References

[Arifovic 1996] Arifovic, J. (1996). *The Behavior of the Exchange Rate in the Genetic Algorithm and Experimental Economies*. The Journal of Political Economy, 104(3), 510–541.

[Carlson and Osler 2000] Carlson, J. and Osler, C. (2000). *Rational Speculators and Exchange Rate Volatility*. European Economic Review, 44(2), 231–253.

[Chakrabarti 2004] Chakrabarti, R. (2004). *Should you bet on your broker's advice? A study of analyst recommendations in India*. Money and Finance, Forthcoming.

[Cheung and Chinn 2001] Cheung, Y. and Chinn, M. (2001). *Currency traders and exchange rate dynamics: a survey of the US market*. Journal of International Money and Finance, 20(4), 439–471.

[Cooper and Kaplanis 1994] Cooper, I. and Kaplanis, E. (1994). *Home Bias in Equity Portfolios, Inflation Hedging, and International Capital Market Equilibrium*. Review of Financial Studies, 7, 45–60.

[Cournot 1834] Cournot, A. (1834). *Recherches sur les principes mathématiques de la théorie des richesses*: Hachette.

[Fellner and Maciejovsky 2003] Fellner, G. and Maciejovsky, B. (2003). *The Equity Home Bias: Contrasting An Institutional With A Behavioral Explanation*. Discussion Papers on Strategic Interaction, (3), 1–34.

[Fisher and Kelly 2000] Fisher, E. and Kelly, F. (2000). *Experimental foreign exchange markets*. Pacific Economic Review, 5(3), 365–387.

[Friedman 1953] Friedman, M. (1953). *The Case for flexible Exchange Rates*. Essays in positive Economics, pp. 157–203.

[Keloharju and Niskanen 2001] Keloharju, M. and Niskanen, M. (2001). *Why Do Firms Raise Foreign Currency Denominated Debt? Evidence from Finland*. European Financial Management, 7(4), 481–496.

[Köhler 1998] Köhler, C. (1998). *Spekulation contra Entwicklungspolitik. Eine Analyse der ostasiatischen Währungskrise*. International Politics and Society, 2.

[Lewis 1999] Lewis, K. (1999). *Trying to Explain Home Bias in Equities and Consumption*. Journal of Economic Literature, 37(2), 571–608.

[Liang et al. 1995] Liang, Y., Ramchander, S., and Sharma, J. (1995). *The Performance of Stocks: Professional versus Dartboard picks*. Journal Of Financial And Strategic Decisions, 8(1).

[Long et al. 1990] Long, J. D., Shleifer, A., Summers, L., and Waldmann, R. (1990). *Noise Trader Risk in Financial Markets*. The Journal of Political Economy, 98(4), 703–738.

[Malkiel 1973] Malkiel, B. (1973). *A Random Walk Down Wall Street*. New York: W. W. Norton & Co.

[Mundell 1960] Mundell, R. (1960). *The Monetary Dynamics of International Adjustment under Fixed and Flexible Exchange Rates*. Quarterly Journal of Economics, LXXIV(2), 227–257.

[Noussair et al. 1997] Noussair, C., Rott, C., and Riezman, R. (1997). *The Principles of Exchange Rate Determination in an International Finance Experiment*. Journal of Political Economy, 105(4), 822–861.

[Noussair et al. 2003] Noussair, C., Rott, C., and Riezman, R. (2003). *Production, Trade and Exchange Rates in Large Experimental Economies*.

[Pope et al. 2003] Pope, R., Selten, R., and von Hagen, J. (2003). *Design for a Currency Union Experiment*.

[Spahn 1996] Spahn, P. (1996). *The tobin tax and exchange rate stability*. Finance and Development, pp. 24–27.

[Tobin 1978] Tobin, J. (1978). *A proposal for international monetary reform*. Eastern Economic Journal, 4(3-4), 153–159.

Appendix E: Screenshots

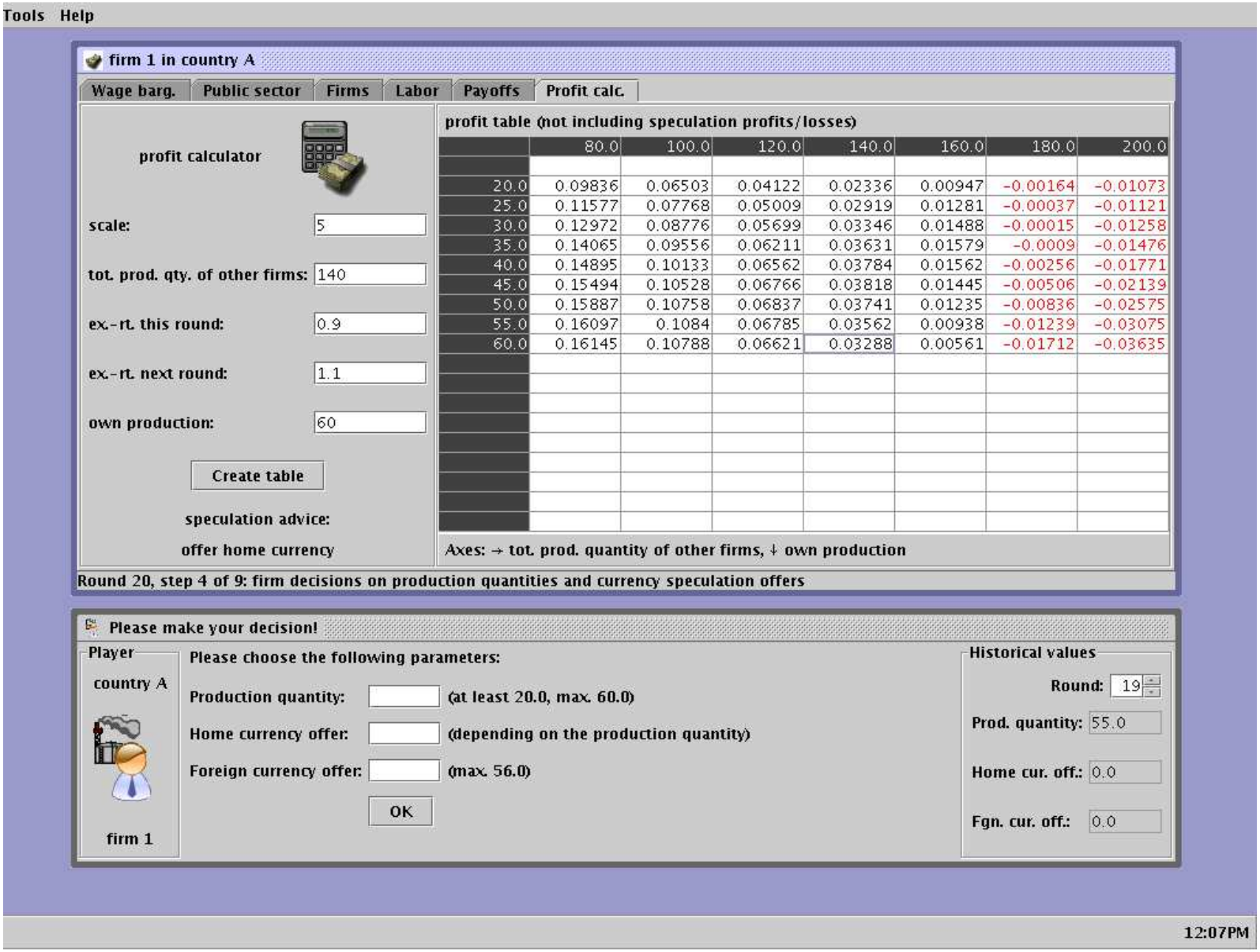

Figure 9: Screenshot of the firm's input frame.

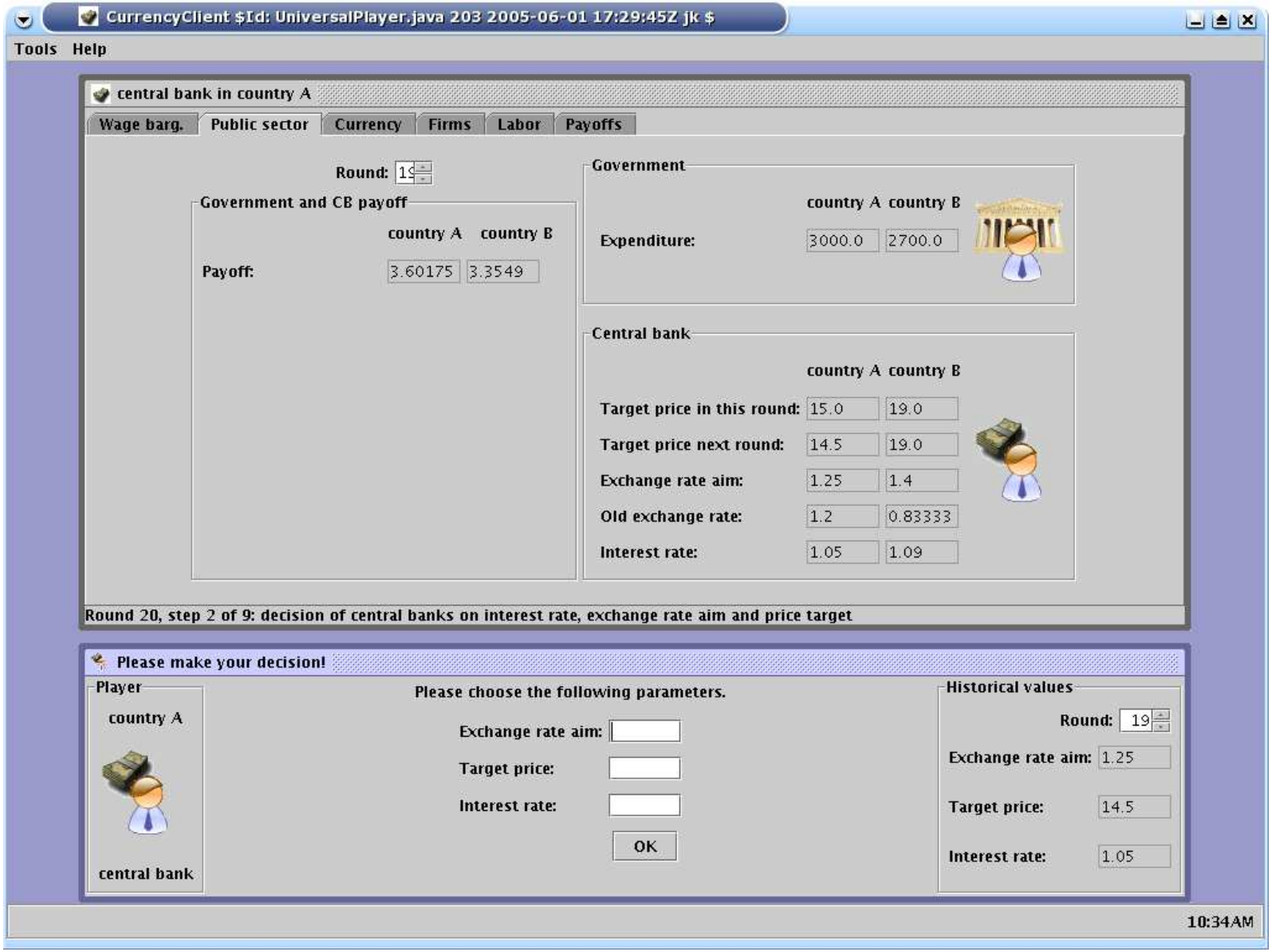

Figure 10: Screenshot of the central bank's input frame.