

## Anchoring and Psychological Barriers in Foreign Exchange Markets

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*This paper develops a simple behavioral exchange rate model in which investor perception of the fundamental value is anchored to the nearest round number. Traders adjust their anchors in two ways. Some believe that exchange rates move toward (perceived) fundamentals, while others bet on a continuation of the current exchange rate trend. The behavior of the traders causes complex dynamics. Since the exchange rate tends to circle around its perceived fundamental value, the foreign exchange market is persistently misaligned. Central authorities have the opportunity to reduce such distortions by pushing the exchange rate to less biased anchors, but to achieve this, they have to break psychological barriers between anchors.*

What is the fundamental level of a currency, say, the EUR/USD exchange rate? Although the academic literature offers virtually no clues (Frankel and Rose [1995]), market practitioners frequently need an answer to this question. Shortly after the launch of the euro, one-to-one parity was the popular answer to this question.

According to Taylor and Allen [1992], nearly 95% of professional traders occasionally bet on a convergence between the exchange rate and its fundamental value. This paper explores how traders think about fundamentals and how that influences exchange rate dynamics.

Our theoretical starting point is the chartist-fundamentalist approach, which has proven very successful in replicating the stylized facts of financial markets. Contributions such as Day and Huang [1990], Kirman [1991], Brock and Hommes [1997], Lux and Marchesi [1999], Caginalp, Porter, and Smith [2000], and Farmer and Joshi [2002] explicitly analyze the interactions between heterogeneous boundedly rational agents. Both the switching between simple linear forecast rules and the use of non-linear predictors may trigger complex price dynamics.

Within these models, traders correctly compute the fundamental value of an asset. While this assumption seems appropriate for studying the basic workings of economies with heterogeneous interacting agents, it is inconsistent within a bounded rationality context. Our aim is to model the perception of the fundamental value in more realistic terms. Experiments by Tversky and Kahneman [1974] reveal that people display anchoring behavior when calculating such quantities. In particular, Shiller [2000] conjectures that agents rely

on round numbers as a proxy for the fundamental level of a market.

In order to obtain a simple model, we focus on a deterministic setting. Our main findings are as follows. Exchange rates display an intricate law of motion, e.g., periods of low volatility alternate with periods of high volatility. Volatility is excessive because agents create their own trading signals. Most importantly, anchoring leads to misalignments: Exchange rate fluctuations tend to be constrained within a band around perceived fundamentals. The lower and upper boundaries of the band resemble so-called support and resistance levels. If central authorities can break these psychological barriers, however, they may direct the exchange rate into less biased areas.

The remainder of the paper is organized as follows. We sketch the basics of the chartist-fundamentalist framework and outline some psychological evidence on the anchor and adjustment heuristic. Next we present our model followed by an investigation of its dynamics. The last section concludes the paper.

### An Empirical Microfoundation

Many psychological experiments support the notion of bounded rationality. Simon [1955] argues that agents lack the cognitive capability to derive fully optimal actions, but they nonetheless strive to do the right thing. Empirical evidence suggests that people rely on rules that have been useful in the past (Kahneman, Slovic, and Tversky [1986], Shiller [1999], and Hirshleifer [2001]). Due to natural selection pressure, the number of applied heuristics is limited, which could offer a promising line of research. If we can identify the set of heuristics applied by the agents, we may be able to model their behavior.

In the foreign exchange market, as reported by the BIS [2002], traders are mainly engaged in short-term

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speculative transactions. While day traders account for 75% of the total trading volume, international trade transactions are just 1% of the total. In accordance with the psychological literature, traders work with rather simple technical or fundamental trading rules to settle their orders (Taylor and Allen [1992], Lui and Mole [1998]). Technical analysis aims to derive trading signals from past price movements (Murphy [1999]), while fundamental analysis looks at the underlying reason behind the action (Moosa [2000]). Such behavior is also reflected in the expectation formation of agents. For instance, Ito [1990] and Takagi [1991] find that some people have destabilizing bandwagon expectations, while others display stabilizing regressive expectations.

Recently, a new class of models has emerged that concentrates on such observations. The chartist-fundamentalist approach studies the interactions between heterogeneous boundedly rational agents that rely on a limited set of rules when determining their investment positions. These models have the potential to mimic actual asset price dynamics quite closely. Complex price fluctuations result either from the use of non-linear predictors (Day and Huang [1990], Farmer and Joshi [2002]), or from switching between simple technical and fundamental forecast rules. The selection process may depend on social interactions (Kirman [1991]), expected profit opportunities (Brock and Hommes [1997]), or a combination of both (Lux and Marchesi [1999]). The structure of these models gains significant support from asset pricing experiments (Caginalp, Porter, and Smith [2000, 2001]).

The chartist-fundamentalist approach has clearly improved our understanding of financial markets. Asset price dynamics may not only be the result of random shocks, i.e., the news arrival process. They may also have a strong endogenous component. However, although traders are boundedly rational, they can compute the fundamental level of the asset in which they are trading. But due to the lack of academic coverage of this topic, (Frankel and Rose [1995]), we regard this assumption as inadequate.

One of the most popular psychological findings is the anchor and adjustment heuristic. Tversky and Kahneman [1974] report that people make estimates by starting from an initial value that is partially adjusted to yield the final answer. Moreover, people tend to be unduly influenced in their assessment of some quantity by arbitrary quantities mentioned in the statement of the problem, even when they are clearly uninformative. Since adjustments are typically insufficient, different starting points yield different outcomes.

But how do traders compute fundamentals in practice? Shiller [2000] claims that market participants, in the absence of better knowledge, may use the nearest round number as a proxy. For example, if the exchange rate fluctuates around 100, they may think that 100 is a reasonable value for the fundamental. Clearly, agents

do not work with numbers such as 99.72 because it would be too complicated for information processing.

Such anchoring behavior may be responsible for unusual price movements surrounding certain prices. Note that a critical value exists between two anchors, which enforces switching. After a transgression of the threshold, the exchange rate may be attracted in a self-fulfilling manner by the new anchor of the agents. As observed empirically, certain price levels do halt advances or declines, and are said to act as psychological support or resistance levels (Mitchell [2001]). The next section merges our reflection into a simple exchange rate model.

### A Behavioral Exchange Rate Model

We consider three types of agents: market makers, international firms, and speculators. Demand for currency is expressed in terms of market orders, which are mediated by market makers. They quote the exchange rate for period  $t + 1$  as

$$S_{t+1} = S_t + a^M (D_t^T + W_t D_t^C + (1 - W_t) D_t^F) \quad (1)$$

where  $S$  denotes the exchange rate,  $a^M$  is a positive scale factor, and  $D^T$ ,  $D^C$ , and  $D^F$  are the orders of the firms, the chartists, and the fundamentalists, respectively. The demand of the latter two types of speculators is weighted by their market shares  $W$  and  $(1 - W)$ . Equation (1) states that excess buying drives prices up, and excess selling drives prices down.

The demand from international operating firms follows standard current accounting principles. If the exchange rate is above (below) its fundamental value, exports exceed (fall short of) imports. Put differently, a current account surplus (deficit) results in sell (buy) orders. The firms' demand is given as

$$D_t^T = a^T (F - S_t) \quad (2)$$

where  $a^T$  is a positive reaction coefficient, and  $F$  is the time-invariant fundamental exchange rate.

Traders buy currency if they expect the exchange rate to increase. They sell if they expect a price decline. Demand from speculators is expressed as

$$D_t^C = a^C (E_t[S_{t+1}] - S_t) \quad (3)$$

and

$$D_t^F = a^F (E_t[S_{t+1}] - S_t) \quad (4)$$

The reaction coefficients of chartists  $a^C$  and fundamentalists  $a^F$  are both positive.

Chart rules extrapolate the current exchange rate trend into the future

$$E_t^C [S_{t+1}] = S_t + b^C (S_t - S_{t-1}) \quad (5)$$

Fundamental rules assume a convergence between the exchange rate and its fundamental. Denoting the perceived fundamental exchange rate by  $F_t^P$ , one may write

$$E_t^F [S_{t+1}] = S_t + b^F (F_t^P - S_{t-1}) \quad (6)$$

The expected adjustment speeds of the predictors are restricted to  $0 < b^C, b^F < 1$ .

Most traders are familiar with both types of forecast rules and regularly switch between them. The market fraction of chartists is formulated as

$$W_t = \frac{1}{1 + c^1 + c^2 (F_t^P - S_t)^2} \quad (7)$$

while that of fundamentalists is given by  $(1 - W)$ . The intuition of (7) is as follows. The more the exchange rate deviates from its perceived fundamental value, the more traders regard the market as either overbought or oversold. Fearing the bubble will burst, they turn to fundamental analysis. The selection of predictors depends on  $c^2 > 0$ . However, some traders prefer fundamental analysis no matter what the state of the market. Assuming  $c^1 > 0$ , the weight of fundamentalists is at least  $1 - 1/(1 + c^1)$ .

As suggested by experiments, traders may use round numbers as a proxy for the fundamental price of the currency. We model the perception process as

$$F_t^P \begin{cases} N^1 \text{ for } (N^1 + N^2)/2 < S_t < \infty \\ N^2 \text{ for } (N^2 + N^3)/2 < S_t < (N^1 + N^2)/2 \\ \dots \\ N^K \text{ for } 0 < S_t < (N^{K-1} + N^K)/2 \end{cases} \quad (8)$$

where  $N^1 > N^2 > \dots > N^K$  represent  $K$  round exchange rates. Depending on the current exchange rate, agents anchor their perception to the closest round value. The threshold values of the anchors are defined by their midpoints.

The law of motion for the exchange rate is obtained by combining (1)–(8)

$$S_{t+1} = f(S_t, S_{t-1}, F_t^P) \quad (9)$$

which is a three-dimensional non-linear deterministic difference equation. Since (9) precludes closed analysis, we proceed with the numerical analysis.

## Simulation Analysis

### Calibration

Most coefficients of chartist-fundamentalist models are not directly observable. One typically chooses parameters so that the dynamics come close to what is observed empirically. One notable exception is Caginalp, Porter, and Smith [2000], who estimate their framework from actual and experimental data. Since such a procedure is beyond the scope of this paper, though, we follow the “traditional” route. But it should be straightforward to repeat the simulation analysis with alternative coefficients, which is an advantage of our model over more complicated contributions. Let us briefly discuss our (educated) guess.

For the reaction coefficients and expectation formation, we assume  $a^M = 2$ ,  $a^T = 0.015$ ,  $a^C b^C = 2.1$ , and  $a^F b^F = 1$ . Note that a low reaction coefficient for international firms corresponds with the fact that trade transactions account for only 1% of the total trading volume (BIS [2002]). Since a small fraction of traders always relies on fundamental analysis (Taylor and Allen [1992]), we set  $c^1 = 0.075$ . Selection of predictors is calibrated by  $c^2 = 30$ .

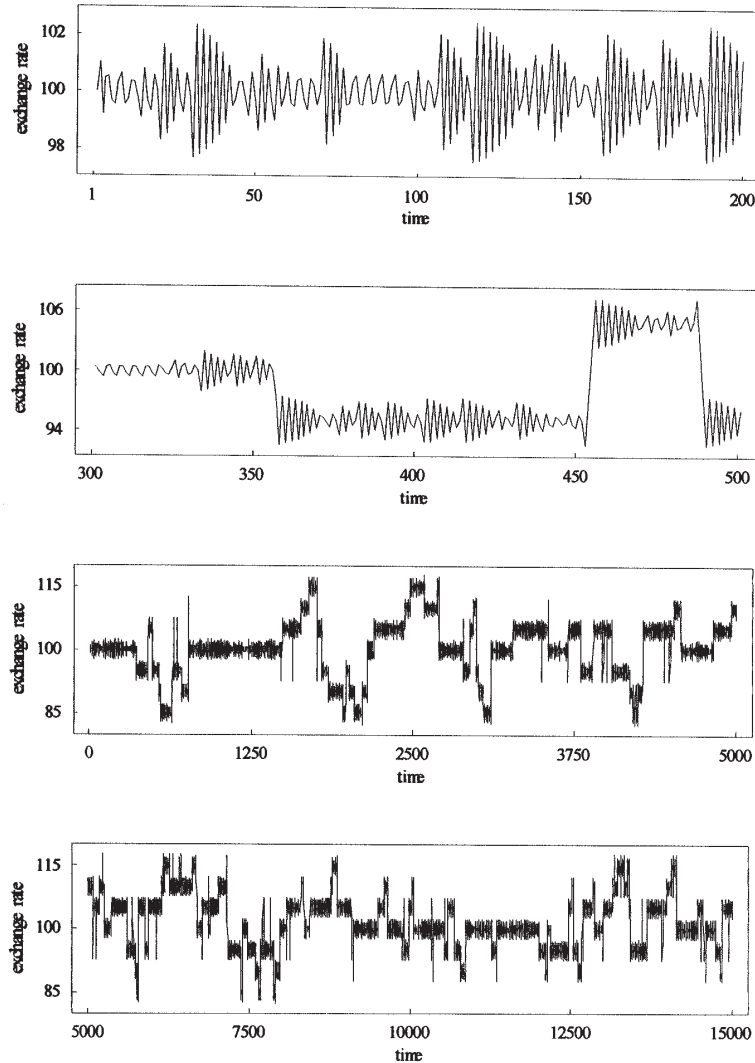
The fundamental value is fixed at  $F = 100$ . The traders consider seven round numbers as potential proxies for the fundamental:  $N^1 = 115$ ,  $N^2 = 110$ ,  $N^3 = 105$ ,  $N^4 = 100$ ,  $N^5 = 95$ ,  $N^6 = 90$ , and  $N^7 = 85$ . One of the anchors is indeed correct, but others deviate up to 15% from the true value. Finally, the exchange rate in period 1 is equal to its fundamental ( $S^1 = 100$ ), but in period 2, a 1% shock occurs ( $S^2 = 101$ ).

### Exchange Rate Dynamics

Figure 1 illustrates the workings of our model. The top panel shows the dynamics for the first 200 periods. Visual inspection reveals that the exchange rate fluctuates in a complex fashion around its fundamental value.<sup>1</sup> Since the model is only perturbed once, volatility is unequivocally excessive. The deviations from the fundamental may be interpreted as short-term bubbles. Furthermore, periods of low volatility alternate with periods of high volatility. All in all, the model has the potential to produce time series that mimic some properties of actual exchange rate dynamics (see Guillaume et al. [1997] or Lux and Ausloos [2002] for detailed surveys on the features of foreign exchange markets).

Let us try to understand what is happening in the market. If the exchange rate is close to its (perceived) fundamental value, most traders will rely on technical analysis. Since bandwagon expectations are destabilizing, the exchange rate is driven away from the fundamental. Afraid of a bursting bubble, more and more traders change to stabilizing fundamental rules. The exchange

**FIGURE 1**  
**Exchange Rate Dynamics**



*Note:* The figure shows the evolution of the exchange rate for the periods 1–200, 300–500, 1–5,000 and 5,000–15,000, respectively. Parameter setting as in section titled Calibration.

rate returns to its fundamental until the pattern repeats itself. Note that after sharp exchange rate movements, volatility stays elevated because traders receive distinct and reinforcing trading signals. Volatility declines only gradually as market sentiment cools off. To sum up, the dynamics of foreign exchange markets may not necessarily be caused by exogenous shocks. They may result at least in part from an endogenous law of motion. The trading signals needed to keep the process going are generated by the activity of the traders.

The second panel of Figure 1 shows the exchange rate path between periods 300 and 500. At around  $t = 360$ , the exchange rate drops for the first time below  $S = 97.5$ . The traders immediately turn to  $F^P = 95$ , and the whole dynamics shifts down. For nearly 100 periods,

the exchange rate circles below its true equilibrium value. Shortly after  $t = 450$ , the exchange rate jumps again above 97.5. Then something interesting happens. The exchange rate does not stay in the region of 97.5–102.5, but passes it in one move. Such overshooting is likely to occur when both types of predictors indicate the same direction for trading. Since the traders use  $F^P = 100$  in that instant, the currency appears undervalued and fundamental analysis suggests it should be bought. Increasing exchange rates also produce an additional technical buy signal. Combined, these effects cause a strong momentum, which drives the price above  $S = 102.5$ .

The financial press often describes the behavior of exchange rates in terms of psychological barriers.

These barriers, also called support or resistance levels, tend to repulse the exchange rate: When below a barrier, it “hesitates” to move toward it. Once it passes the barrier, however, it accelerates away from it.

De Grauwe and Decupere [1992] find that psychological barriers are significant in the USD/JPY market. Stock markets seem to display the same price behavior (Donaldson and Kim [1993], Koedijk and Stork [1994]). A striking example is the 1,000 level of the Dow Jones Industrial Average: It was first touched in early 1966, but was not solidly crossed until late 1982.

Within our model, psychological barriers emerge naturally from the anchoring behavior of the traders. In the third panel of Figure 1, the exchange rate is plotted for the first 5,000 observations. The market tends to stay within a certain region for some time. The lower and upper ranges of the exchange rate band resemble support and resistance levels. Close to these values, the majority of traders rely on fundamental analysis, and a convergence toward the anchor usually sets in. Only sometimes, when the market impact of chartists is strong, does the exchange rate pass a psychological barrier. Traders then take on another anchor, which again attracts the system. If the exchange rate crosses the barrier from below (above), a resistance (support) level becomes a support (resistance) level.<sup>2</sup>

Although the time the exchange rate fluctuates within a certain area appears random, not all anchors are evenly visited. From panel 4 of Figure 1, which contains the exchange rate for  $t = 5,000 - 15,000$ , it appears that anchors closer to  $F = 100$  are more frequently used. The reason is that the demand from international trade stabilizes the dynamics. The more the exchange rate deviates from its long-run equilibrium value, the stronger the current account imbalance. Such transactions push the exchange rate in the direction of the true fundamental value. In the next section, we investigate whether central authorities can exploit anchoring behavior.

### Policy Implications

Table 1 summarizes the following simulation experiment. For a given reaction coefficient of international firms  $a^T$ , we simulate 1 million data points and deter-

mine how often the agents use which anchor. For example, if the exchange rate is located 265,000 times between  $97.5 < S < 102.5$ , then the agents use  $F^P = 100$  in 26.5% of the cases. We vary  $a^T$  between 0.01 and 0.022.

For  $a^T = 0.01$ , the exchange rate remains at  $F^P = 85$  4.1% of the time, and at  $F^P = 115$  3.7% of the time. The true equilibrium value  $F = F^P = 100$  is only visited in 26.5% of all cases. If  $a^T$  increases, we see a contraction of the system. For  $a^T = 0.018$ , the outer anchors are only occupied by 1.5% and 1.6% of the observations. In 36.2% of the cases, the agents identify the fundamental value correctly. The picture changes again if  $a^T$  increases further. For  $a^T = 0.022$ , the lower and upper anchors together contain more than 25% of all data points.

Within our model, current account transactions are the only orders consistently based on the true fundamental exchange rate. But central bank interventions in support of the fundamental exchange rate are qualitatively equivalent to international trade transactions. By trading in the direction of the long-run equilibrium value, the central bank may push the exchange rate over or prevent it from crossing certain psychological barriers. If traders rely on less biased anchors, the market is obviously less mispriced. However, Table 1 also indicates the existence of an optimal  $a^T$ . If  $a^T$  is too high, the exchange rate bounces back and forth between the extreme anchors.

### Conclusions

Solid psychological research shows that agents follow rule-governed behavior. In foreign exchange markets, traders switch between technical and fundamental trading rules to determine their orders. This paper explores a simple behavioral exchange rate model in which traders use the nearest round number as a proxy for the fundamental value. The interplay between different predictors leads to complex dynamics. The exchange rate fluctuates around its perceived fundamental value, volatility is excessive, and periods of turbulence alternate with periods of tranquility.

Due to anchoring, exchange rates are persistently misaligned. Such behavior also establishes support and resistance levels. As long as the exchange rate deviates

**Table 1.** Location of the Exchange Rate

$a^T$	$F_t^P = 85$	$F_t^P = 90$	$F_t^P = 95$	$F_t^P = 100$	$F_t^P = 105$	$F_t^P = 110$	$F_t^P = 115$
0.010	4.1	10.4	22.4	26.5	22.1	10.8	3.7
0.012	3.6	8.2	25.0	26.7	24.4	8.4	3.8
0.014	3.3	8.0	24.3	28.2	24.5	8.2	3.4
0.016	2.6	7.3	23.0	33.6	23.6	7.4	2.5
0.018	1.5	6.0	24.6	36.2	24.3	5.8	1.6
0.020	4.8	4.9	22.0	37.1	23.4	5.0	2.8
0.022	14.3	3.3	16.0	34.8	16.4	3.1	12.1

*Note:* The table indicates the percentage use of round numbers in the top line for increasing  $\alpha^T$ . Estimates are based on 1 million observations. Parameter setting as in section titled Calibration, but  $\alpha^T$  as indicated in the left-hand column.



from the anchor—but does not come too close to neighboring round numbers—traders increasingly speculate on a convergence between the exchange rate and its anchor. Support and resistance levels, given as midpoints between two anchors, have an endogenous origin. Fortunately, central authorities can exploit this property. If central banks manage to drive the exchange rate to a less distorted level, traders will pick up a new anchor and confirm it through their trading behavior.

### Notes

1. A time series is said to be chaotic if its time path is sensitive to a microscopic change in the value of the initial conditions (the so-called butterfly effect). In addition, a chaotic time series often displays complex structure in phase space, i.e., the emergence of a strange attractor. Since we find a Lyapunov exponent of around 0.29 and a correlation dimension of about 1.5, the model produces not only complex but chaotic motion. For an introduction into chaos theory, see Rosser [2000].
2. Since psychological barriers are easily noticeable, it is not necessary to verify them statistically. In reality, however, the evidence naturally appears less clear-cut. However, introducing random shocks such as news into the model should not only enrich the dynamics but also blur the existence of support and resistance levels. Nevertheless, they still exist. In order to make a simple argument we abstain from such extensions.

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