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## Dissipation and Chaos in Foreign Exchange Markets

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### ABSTRACT

Studies of chaos in foreign exchange markets often lack a theoretical underpinning. This paper tries to give some reasons why exchange rate movements may become chaotic. Starting from an assumption about different groups of traders that goes beyond recent models of fundamentalists' and chartists' behaviour it argues that, to capture the idea of chaos, foreign exchange markets have to be modelled as a dissipative system and not, as usual, as a closed conservative one. A qualitative system dynamics approach is chosen to demonstrate the complex interaction processes arising.

### INTRODUCTION

Studies of foreign exchange markets discussing the possibility of chaotic behaviour of exchange rates show considerable analytical deficiencies. Some authors briefly indicate the poor explanatory and predictive power of standard linear models and then switch to searching the data for hints to nonlinearities without giving any theoretical rationale. Others that do present an analytical approach still cling too much to the traditional view of exchange rates to adequately describe a chaotic system's peculiarities.

This paper tries to give some reasons why exchange rates may become chaotic. Chaos only emerges in dissipative systems. By definition, a dissipative system is one that is exposed to friction. It permanently loses "energy". But, being open and in a continuous exchange with its environment it gets impulses that hinder it from coming to a standstill. Every economic theory claiming a time series to be chaotic has to explain what in the market would become dissipated and get "lost".

In what follows, information takes this role. In foreign exchange markets, there is a permanent exchange of information with the outside world. This is the "energy" that



makes the system run. It gets lost if it bears no more incentive to trade - i.e. if it becomes known to more and more market participants being transformed to a respective set of price signals. However, information is not spread equally. Various groups of actors rely on different information sources and techniques leading to reaction "cycles" of different force and length. They may provide an explanation for observed nonlinearities.

### CHAOS: SOME BASIC IDEAS

Traditional approaches to exchange rate determination are closed equilibrium models. They need some kind of disturbance from outside for the exchange rate to fluctuate. Otherwise the system settles at a steady state. An alternative way to explain exchange rate variability is by the nonlinear dynamics of a dissipative system. There, erratic movements may occur even when outside shocks are not at work. Table 1 shows the main differences between the two.

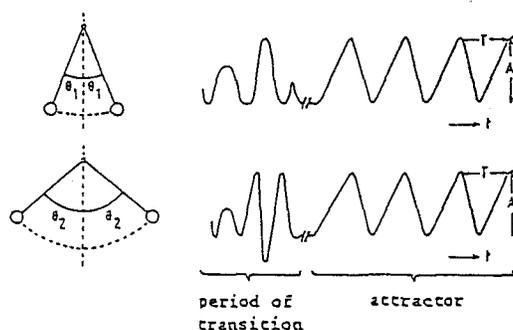
Table 1: Differences Between Conservative and Dissipative Systems

|                                   | conservative systems  | dissipative systems   |
|-----------------------------------|---|---|
| general characteristics           | closed systems, reversible processes, universal principle                           | open systems, irreversible processes, dependence on initial conditions and parameter values |
| in analogy to physics             | preserving energy, no friction  | losing energy due to friction   |
| invariants in long-term behaviour | steady states, transition from one equilibrium to another described by Hamiltonians | classical attractors: fixed points, limit circles, tori; strange attractors                 |
| stochastic behaviour              | white noise, due to exogenous disturbances, over the whole parameter range          | system immanent, only for special parameter values  |
| reaction to small disturbances    | adjustment to new equilibrium values  | after a period of transition resumption of the former path                                  |



Dissipative systems that for particular parameter values have no general solutions are called chaotic. They show two main characteristics: They never reach a single point twice and their time path is highly sensitive to the choice of parameter values and initial conditions. Therefore, it is impossible to study them by means of stability analysis. That made researchers look for another kind of invariant (Mirowski 1990). What they found was the geometric self-similarity of strange attractors in phase space.

Figure 1: The effects of a once-for-all disturbance on a conservative and a dissipative system<sup>a</sup>

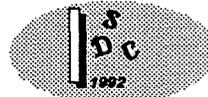


<sup>a</sup> The left-hand side represents the movement of an "ideal" pendulum in a world without friction before and after a disturbance, the right-hand side describes the adjustment of a chemical to a disturbance in the so-called Belousov-Zhabotinsky system.

Source: Nicolis, Prigogine (1987), Figure 1.8, p. 35.

An attractor is defined as a subset of the phase space towards which almost all nearby starting points eventually converge. There are fixed points, limit circles and tori representing stationarity, periodic or quasiperiodic behaviour. And, for chaotic systems that never reach the same point twice there are fractals or so-called strange attractors. That are regions rather than finite sets of points to which trajectories converge and which tend to be filled completely as time approaches infinity.

If, in traditional models, stochastic behaviour occurs it is assumed to be exhibited over the whole range of para-

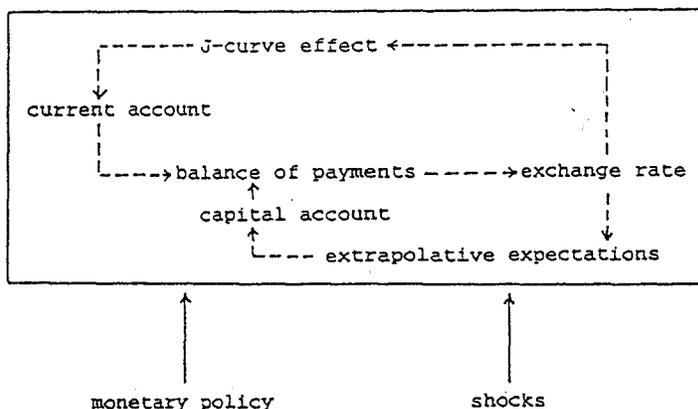


meter values. By contrast, in dissipative systems regions of stochasticity and regular motion exist simultaneously depending on the value of some forcing parameter. Accordingly, both systems' reactions to disturbances differ markedly. A conservative one, like the "ideal" pendulum in Figure 1, simply adjusts to a new equilibrium. A dissipative system like the BZ-reaction "digests" the disturbance in a way that, after some transition period, it resumes its previous long-term path as if nothing had happened.

### NONLINEARITIES IN EXCHANGE RATES

The first hints to chaos in foreign exchange markets date back to Mandelbrot (1963) on the fractal nature of highly speculative prices. Some authors took up the idea for currencies (see for an overview Kaehler 1991). What they found was a strong empirical evidence for a nonnormal distribution of exchange rates. However, they did not provide an explanation for this observation.

Figure 2: Nonlinear relations in a Dornbusch-type model of exchange rates



Since chaos means random-looking processes in a deterministic context one natural question to arise seems whether traditional deterministic models of exchange rates could not be altered in a way to capture this phenomenon. For example, this is the question De Grauwe and Vansanten (1990) tried to answer. They modified a Dornbusch-type model by two nonlinearities of different length (see Figure 2): Short term extrapolative expectations of private wealth

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holders switching between domestic and foreign assets and a longer term J-curve effect in the trade balance.

As computer simulations show, depending on the parameter values, such a system may exhibit considerable instabilities. But, those are signs of an especially entangled adjustment process, not of chaos. Fundamentally closed as it is the system needs an initial disturbance from outside the model - a policy measure or an exogenous shock - to start fluctuating, and then it only moves from one steady state to another. Nothing gets dissipated, nothing is winding down or gets "attracted" to a former path letting the disturbance become "forgotten" after some time.

For the exchange rate to become chaotic the foreign exchange market has to be treated as an open system with its interaction with the outside world being part of the model. One way to do this is to regard information as a motor or driving force.

#### THE FOREIGN EXCHANGE MARKET AS A DISSIPATIVE SYSTEM

Activities in foreign exchange markets depend on news. Without a permanent exchange of information trade would dry up. Market participants gather information and, in reacting to it, help to transform it into price signals. Those in turn become valuable news to others within and outside the system who, by their reactions, create new incentives to trade once again, and so forth.

Information gathering and processing does not take place uniformly. Analyses by Allen and Taylor (1990), Reszat (1991) and others show that there are several groups that can be more or less clearly identified with respect to the information sources and techniques they use. A first distinction can be drawn between fundamentalists and chartists. Fundamentalists try to find out the reasons for exchange rate movements by interpreting the influence of changes in the economic and political environment or other "fundamental" data. In contrast, chartists take the market price as only, or at least main, source of information and search past exchange rates for recurring patterns.

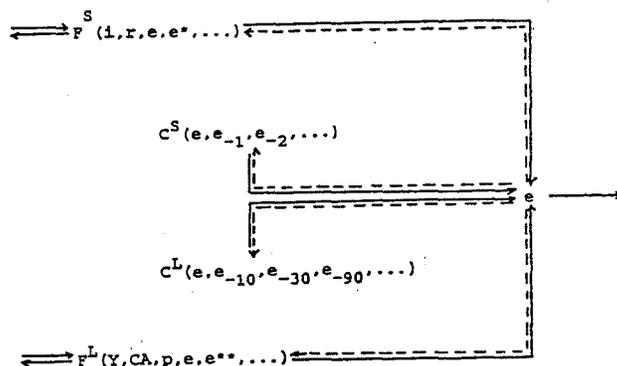
Though, in practice, both methods are used side by side, often clear preferences exist for one or the other. Those preferences depend among other things on the actors' flexibility and time horizon. For example, banks with direct market access have ample scope for using sophisticated instruments and trading strategies to benefit from very small rate discrepancies from day to day, or even within hours



or minutes. They rather concentrate on technical or chart analyses. At the other end of the spectrum are nonbanks facing strong liquidity and budget constraints and a narrow range of instruments for hedging and speculation purposes. Above all, they rely on fundamentals that are generally observable.

Figure 3 gives a very simple example of how information flows of fundamentalists and chartists evoke reaction cycles of different length that may become a route to chaos. Here, of two groups of fundamentalists one with a short-term view, denoted by  $F^S$ , is assumed to look at interest rates ( $i$ ), stock prices ( $r$ ), the current and a short-term expected future exchange rate ( $e, e^*$ ) as well as other, nonspecified, influences. The other, longer-term oriented fundamentalists ( $F^L$ ), form expectations according to developments like income, current account and prices ( $Y, CA$  and  $p$ ), and a longer-term expected future exchange rate ( $e^{**}$ ). Chartists do not directly observe the outside world. But they, too, are supposed to differ in their behaviour patterns. Some of them, denoted by  $C^S$ , try to benefit from short-term exchange rate movements while others ( $C^L$ ) search past rates for hints to a longer trend.

Figure 3: Information Flows in a Dissipative Foreign Exchange Market



The decisions of all four groups of actors overlap. At times, they reinforce each other, at times, they dampen one another's effects. Thereby, depending on the way they interact chaos can emerge and exchange rates become volatile. It should be emphasized that in this case no dramatic event or "shock" were needed. The simple monitoring and proces-

sing of per se "harmless" looking news and successive small price signals would suffice to generate fluctuations.

### A SYSTEM DYNAMICS VIEW

Considering the information side is not enough. Ultimately, exchange rates are the result of demand and supply. Thus, the links between the flows of information and resources have to be found. Here, System Dynamics offers further insights. Table 2 gives an overview of levels and flows in a hypothetical market.

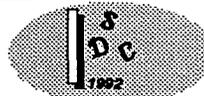
Table 2: LEVELS AND FLOWS IN THE FOREIGN EXCHANGE MARKET

| Actors        | Resources of Foreign Exchange | States   | Information Flows                               | Resource Flows                         |
|---------------|-------------------------------|--|---|--|
| Nonbanks      | Foreign Trade                 | Profitability/Riskiness (constrained)                  | Short and Long Term Fundamentals ( $F^S, F^L$ ) | Payments, Leading and Lagging          |
|               | Portfolio Investments         | Profitability/Riskiness (constrained)                  | Short and Long Term Fundamentals ( $F^S, F^L$ ) | Interest Arbitrage                     |
|               | Outright Transactions         | Profitability/Riskiness (unconstrained)                | Long Term Technical Analyses ( $C^L$ )          | Forward Transactions, Futures, Options |
| Banks         | Arbitrage                     | Profitability (Riskless per Definition, unconstrained) | Short Term Technical Analyses ( $C^S$ )         | Spot Transactions, Swaps               |
| Central Banks | Official Reserves             | Instrumental (constrained)                             | Volatility Measure, Target Deviation            | Spot Intervention                      |

==== Organisational Boundaries

Here, foreign exchange positions are assumed to be held for five reasons: in connection with international trade, portfolio investments, outright forward transactions and (spot) arbitrage and as official reserves. Accordingly, there are three groups of actors involved: nonbanks, banks and central banks. Nonbanks' and banks' decisions are based on risk/return considerations. Some of their transactions, related to foreign trade and portfolio investments, face considerable liquidity or budget constraints. The same holds for official market interventions. For others, i.e. outright transactions and arbitrage, in principle few limits exist because there are no capital requirements except for losses.

Again information sources and techniques differ. In foreign trade or for portfolio investments nonbanks are assumed to



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rely solely on short and longer term fundamentals which are provided free or at low costs. In contrast, outright transactions - where actors are supposed to have a long term view, too, but are more willing to make an extra information effort - are based on long term technical analyses. Arbitrage, in theory riskless by definition but in practice, as Reszat (1991) argues, a highly risky instrument of the interbank market, is based entirely on short term charts. Finally, central bank interventions are thought to depend on some nonspecified volatility measure or reaction function for exchange rate deviations from a given target.

Figure 4 gives a graphical presentation of the scenery: Essentially, the foreign exchange market is an interbank market. Each nonbank wanting to buy or sell foreign currency needs a bank. The bank in turn acts for the nonbank as a mere intermediary. It will close open positions due to nonbanks' activities at once. But, banks' reactions to nonbanks make only a small part of their business. Most of the time they deal on their own account for arbitrage reasons.

One particularity here to be mentioned is the possibility of revolving. Banks - as well as nonbanks with forward transactions - that decide to keep an open position longer than originally intended can prolong it by a swap. This is indicated by the arrows directly from the outflows back to the respective inflows. On the one hand, this adds to the actors' flexibility. On the other hand, it makes the share of trades unrelated to developments in international goods and capital markets even greater than otherwise. Since, here, both spot arbitrage and outright forward transactions are based on chart analyses this puts an extra weight on these techniques.

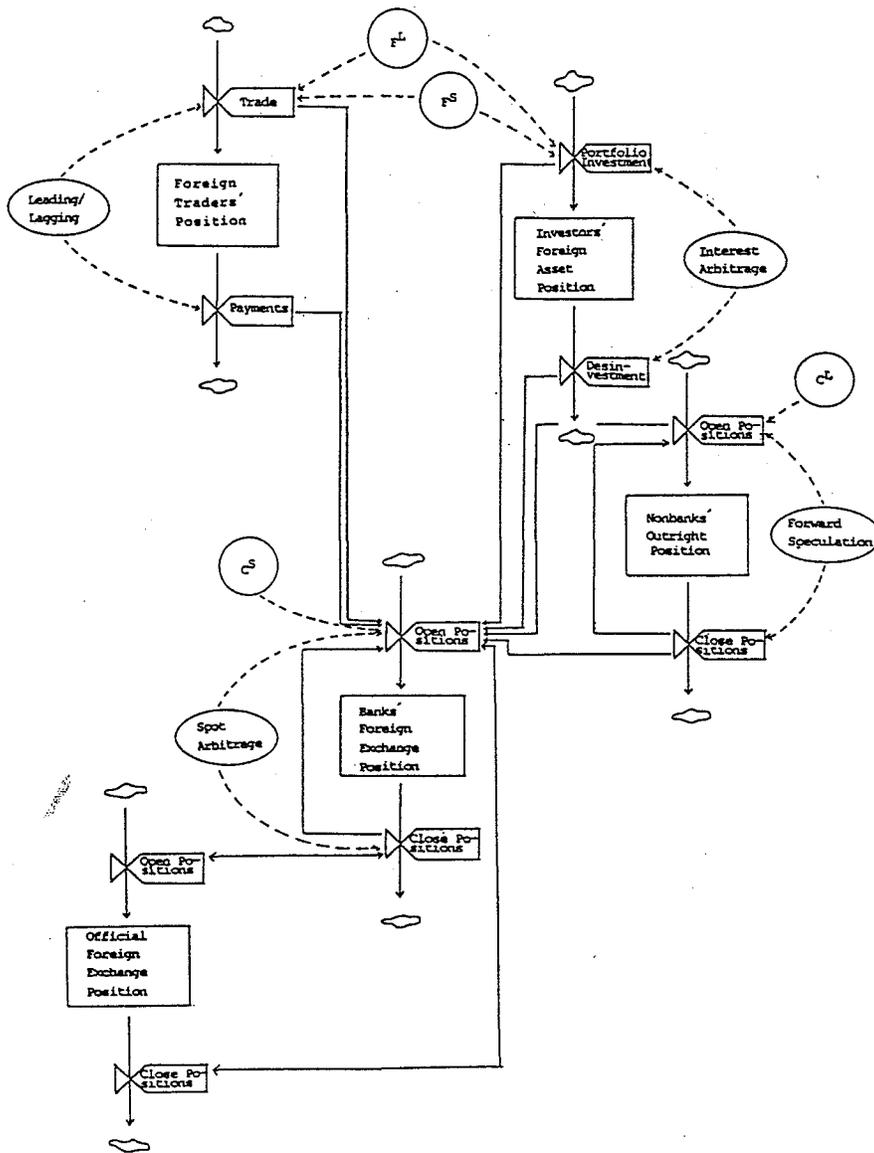
Each time supply and demand in the interbank market do not match there are two possibilities: Either the exchange rate changes or the central banks intervene to keep it constant. In a pure float there were no role for intervention. On the other hand, in a system of totally fixed exchange rates the central banks would permanently act as a counterpart of private banks. In the current system of world wide managed float intervention takes place only sporadically adding a further cycle of reactions, determined by its own laws, to the system.

#### CONCLUSIONS

The described flows of information and resources lead to reaction cycles of different length and force. They determine the system's degrees of freedom and its long term be-



Figure 4: Interactions in the Foreign Exchange Market



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haviour. Thereby, a cycle's length depends on the respective actors' motives and time horizon: Decisions based on short term fundamentals or charts differ from those relying on longer term techniques. A cycle's force is determined by actors' market access and flexibility and by their share in total trades. Arbitrageurs with direct market access and nearly unlimited flexibility play by far the biggest role. They are able to exert a very strong influence on market conditions. On the other hand, exporters and importers or private capital holders facing high costs and budget or liquidity constraints necessarily account only for a small part of trades. Nevertheless, at times their effects can be decisive if others do not find enough incentives to act and stay apart in a wait-and-see attitude.

This is still a very rudimentary view of the market. But, in principle, each change in the reaction cycles may drive the exchange rate to chaos or back from a chaotic state to stability. This, for example, opens new prospects for central bank interventions - which up to now were said to be rather ineffective - but also for regulators and governments. Further research will characterize the structures and interdependencies in the market and the scope for policy action in this context in more detail.

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