# Macroeconomic Policy and Stability in International Financial Markets

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# DECLARATION

The research presented in this thesis is the sole work of the author, and none of this research has been submitted for a degree at another university.

A paper based on part one of this thesis, under the title of 'FOREX Trading Strategies and the Efficiency of Sterilized Intervention', was presented at the IXth Spring Meeting of Young Economists in Warsaw, Poland in April 2004, where it was awarded the Best Paper Prize. Another paper based on part one, entitled 'Intervention when Misalignments are Large', was published by the Institute for International Economics (IIE) in Washington DC, U.S. in a special report entitled 'Dollar Adjustment: How Far? Against What?', in November 2004.

# ABSTRACT

This thesis examines two key areas where macroeconomic policy and stability in international financial markets intersect. Part one examines the extent to which economic policy can limit the development of misalignments in exchange rates, without sacrificing policy tools that are needed to maintain internal macroeconomic balance. This issue is addressed in a model where endogenous exchange rate fluctuations are generated by traders selecting alternative forecasting strategies on the basis of an 'evolutionary fitness rule', in the spirit of work by Brock and Hommes (1997, 1998). In this setting it is shown how, by changing the relative profitability of available strategies, sterilized intervention can coordinate traders onto strategies based on macroeconomic fundamentals. Empirical evidence in support of the model is provided based on data from interventions by the Japanese authorities in the 1990's. In addition, simulations of the estimated model are used to calculate confidence intervals for the ex ante probability that interventions of a given size will be effective in pricking bubbles in the exchange rate. It is also shown how stability in foreign exchange markets can be enhanced by imposing a type of exchange rate target zone, and furthermore that through the use of sterilized intervention, this can be achieved without inducing a commensurate increase in instability elsewhere in the economy.

Part two then moves on to examine the implications for macroeconomic policy of the exponential growth in recent years of the use of financial derivatives. A theoretical model is developed which demonstrates how firms' use of derivatives for risk management purposes, while increasing the robustness of the financial system to shocks, at the same time reduces the impact of monetary policy on the macroeconomy. This effect arises because the agency costs, which enhance the impact of monetary policy through the credit channel, are reduced by firms' usage of hedging instruments, in particular interest rate swaps. Using quarterly data on total outstanding swap contracts from 1990, empirical evidence is then presented to show how increased usage of derivatives may have influenced the impact of monetary policy in the United States.

# Part I

# Managing Instability in Foreign Exchange Markets

# Chapter 1

# Introduction

In 1972 the Bretton Woods system of pegged exchange rates was rapidly approaching a state of crisis. The pursuit of expansionary monetary and fiscal policies by the U.S. authorities, partly in order to finance the war in Vietnam, had led to irresistible inflationary pressure in the other major industrialized countries[1]. The credibility of the national monetary authorities' commitment to maintain the system was thus seriously undermined, and in 1973 the Bretton Woods system broke down, and bilateral exchange rates between the U.S., Europe and Japan were allowed to be determined freely by market forces.

The shift to floating exchange rates between the major global currencies in 1973 was widely expected to both aid adjustment to shocks, as well

[1] See the essays in Bordo and Eichengreen (1993) for detailed accounts of possible causes of the collapse of the Bretton Woods system

as to promote stability in the international financial system. In the face of a shock, standard theory suggested exchange rate flexibility could ease pressure on the domestic price level and the real sector to adjust, which would have clear economic benefits by reducing the volatility of output and unemployment. Furthermore, flexible exchange rates should also promote macroeconomic stability by automatically adjusting to a level consistent with underlying economic conditions.

The economic processes underlying this adjustment mechanism were outlined by Freidman (1953). A key argument in favour of the move to floating exchange rates was based on the notion that, following an external shock, speculators in the foreign exchange market would act to stabilize the exchange rate at its fundamental value, i.e. the value consistent with underlying economic conditions. Acting in this manner, speculators in the foreign exchange markets would ensure that the exchange rate would not persist at the wrong value for long periods, i.e. persistent misalignments would not arise.

In practice however, since the abandonment of the Bretton Woods system, G-3 exchange rates (i.e. bilateral dollar, yen and mark/euro rates) have exhibited both high short run volatility and persistent misalignments which seem largely unconnected with macroeconomic fundamentals. Figure (1.1) plots the history of bilateral monthly dollar, yen and dm exchange rates since the collapse of Bretton Woods and the advent of (managed floating) in 1973. The high degree of variability is striking.

Figure (1.2) plots the recent history of these exchange rates (since 1990), as well as the history of the (synthetic) euro along with estimates of the purchasing power parity (PPP) levels of these exchange rates[2]. We see that on average, over periods of several years, while the simple PPP relationship[3] appears to provide an anchor for these exchange rates (Frankel and Rose (1995)), they are also characterized by periods of pronounced 'misalignments'. In other words, the short to medium-term movements in real exchange rates seem to be driven by forces which are only loosely connected to underlying economic conditions.

However not only have deviations from PPP been large and persistent, they have also been volatile. The short run volatility of G3 real exchange rates is one of the most robust - and to many observers disturbing - characteristics of the post Bretton Woods floating exchange rate experience. It reflects, at

[2]The levels of the PPP exchange rates illustrated here are calculated as the sample average deviations of each exchange rate from the ratio of CPIs.

[3]PPP, or purchasing power parity, dictates that due to the forces of arbitrage, the same good should sell for the same price both at home and abroad when expressed in a common currency. If PPP were to hold continuously then the path of the real exchange rate $E$ should be described by the ratio of domestic prices $P$ to foreign prices $P^*$, so that $E = \frac{P}{P^*}$.

least in part, the fact that nominal exchange rates are forward looking asset prices that adjust to clear the global capital market whereas money goods prices are often sticky and adjust only gradually to clear the international goods markets (Dornbusch (1976); Mussa (1982)). Figure (1.3) depicts for each bilateral nominal exchange rate a rolling standard deviation of monthly log changes since 1979. It is clear from the figures that the 'noise' that dominates short-run changes in G3 nominal exchange rates has not, in general, diminished appreciably over the last 25 years. The volatility of G3 exchange rates that is actually observed was greatly underestimated by the early advocates of floating exchange rates such as Harry Johnson (Obstfeld (1995)). They predicted that "flexible exchange rates would tend to remain constant so long as underlying economic conditions (including government policies) remained constant... [I]f economic changes or policy changes occurred... the flexible exchange rate would gradually either appreciate or depreciate as required to preserve equilibrium."

A disturbing feature of these stylized facts is that they have proved extremely difficult to reconcile with standard macroeconomic theory, at least in a consistent manner. In seminal research by Meese and Rogoff (1983), it was found that standard macroeconomic models of the exchange rate have no predictive value for floating exchange rates. Even ex post, the literature on empirical studies of exchange rates [4] has found that while monetary models such as the Dornbusch 'overshooting' theory have some explanatory power in the form of reaction to news, in the short run, exchange rates are better characterized by a driftless random walk than by models based on macroeconomic fundamentals. The apparent insulation of the macroeconomy from movements in exchange rates has been termed the exchange rate 'disconnect puzzle' by Obstfeld and Rogoff (2000).

While a consistent empirical explanation of short run exchange rate behaviour has remained elusive, more recently there has been some progress made in studying exchange rate behaviour at longer frequencies. Indeed, recent research[5] has demonstrated the existence of reversion to levels dictated by macroeconomic fundamentals in the long run. However this is at a lower frequency than predicted by standard macro models.

As the relative prices of international currencies, exchange rates exert a profound influence on all international transactions, be they in international markets for goods and services, or for financial assets. As such, there are a number of key areas where the path of the exchange rate can influence domestic macroeconomic stability. In particular, the exchange rate can po-

[4] see, inter alia, Frankel and Rose (1995) for a survey

[5] See, amongst others, Taylor and Sarno (1998, 2000) and Taylor and Peel (2000).

tentially impact domestic inflation, and through its impact on international trade and the value of foreign assets, the growth of domestic output.

The high volatility and long swings observed in exchange rates thus potentially have severe consequences for economic welfare, and a large number of studies have investigated the costs associated with observed exchange rate behaviour. For example, Obstfeld and Rogoff (1998) conduct a theoretical analysis which finds that exchange rate volatility could lower welfare through both direct and indirect channels. The direct channel is based on the assumption that people have a distaste for fluctuations: in other words, they would choose a constant value of consumption over an uncertain value that is more variable. The indirect channel on the other hand stems from the costs firms incur to protect themselves from exchange rate volatility. If firms that preset prices understand the risks of future exchange rate movements, they will try to hedge against those risks. When setting the price for their goods, they will attach a risk premium as an extra markup to cover the costs of fluctuations. This higher price dampens demand, production, and, hence consumption to levels that are less than optimal for society.

Despite the plausibility of these arguments, it has proved surprisingly difficult to find widespread evidence of an adverse impact of exchange rate volatility on international trade amongst industrialised countries. This has even led some authors, for example Rogoff (2003) to describe as a 'fallacy' the notion that "... G3 exchange rate volatility is a disaster". The main argument is that although exchange rates fluctuate widely in comparison with goods prices it is not obvious from the data that exchange rate volatility has direct effects on the underlying macroeconomy[6]. In addition, the costs of excessive short-run exchange rate volatility are thought, by many authors, to be manageable - but not trivial - due to the ready and ever increasing availability of financial derivative products such as futures and options for hedging short and medium run foreign exchange exposures. The general assessment is that the feedback to the real economy is far slower and less pronounced than a model based on the Mundell-Fleming framework would predict.

That a direct link between exchange rate volatility and macroeconomic performance is difficult to observe in the data is less surprising when considered in the light of the empirical failure of exchange rate models based on macroeconomic variables discussed above. If exchange rates only respond to changes in fundamentals over the medium to long-term, it should not be surprising if the reverse were also true: that the macroeconomic

[6] Baxter and Stockman (1989) were the first to point out the difficulty in demonstrating that exchange rate volatility affects macroeconomic fundamentals, though some research has succeeded in showing that exchange rate variability can correlate negatively with trade and foreign direct investment (see, e.g. Frankel and Wei (1993) and Goldberg and Klien (1998).

stability would be most sensitive to persistent long-run misalignments in exchange rates. In this respect, the exchange rate - macroeconomy 'disconnect' maybe something of a two-edged sword: the low frequency response of the exchange rate to developments in the macroeconomy is mirrored in the apparent insulation of the macroeconomy to much of the short-run exchange rate volatility witnessed.

Does this imply that international monetary authorities can do no better than the current non-system of 'benign neglect': whereby major bilateral currencies are in principal determined wholly by market forces? There are a number of counter arguments to this proposition. Typically, the debate surrounding the optimality or otherwise of achieving macroeconomic stability by targeting the exchange rate has focused on how stability in one market can only be achieved by shifting the burden of adjustment to shocks onto another market. This trade-off was first highlighted by Poole (1970), who shows how the optimality of a given policy (e.g. an exchange rate target versus an interest rate target) depends on whether the shock impinging on the economy originates in the goods market or the money market[7]. The paradigm underlying this view of the costs of managing exchange rates asserts that exchange rates change only in response to changes in underly-

[7] A recent paper which employs the same underlying rationale to argue against reform of the international monetary system is Reinhart and Reinhart (2001)

ing macroeconomic factors. As such, attempts at reducing exchange rate volatility will result in increased variability of other economic variables, such at output or prices. However, this need not be the case when swings in exchange rates are to some degree disconnected from the changes in macroeconomic fundamentals. In this case it should, in principle, be possible to reduce the variability of the exchange rate without significantly reducing stability somewhere else in the system.

Furthermore, although macroeconomic conditions maybe to some extent insulated from short-run exchange rate movements, it is also important to note that there can be other, indirect, costs associated with extreme short-run movements in exchange rates. The existence of volatility in the sense of random fluctuations adds to uncertainty in foreign trade transactions. The uncertainty can be reduced by hedging in forward markets but this does not solve the problem. In the first place, it is not always possible to hedge when the foreign cash inflows or outflows to be hedged are themselves uncertain. In addition, hedging involves costs and these costs may be measured by the bid-offer spreads in the forward markets. It is interesting to note that these spreads have risen sharply since 1979, reflecting the increase in uncertainty in global foreign exchange markets.

Moreover, when any manufacturer enters into a hedge to protect the price of her inputs and products, the counterparty selling that insurance must take on that risk. The financial institutions which facilitate this by activity selling financial derivatives then attempt to diversify away those elements of risk they are not willing to bear by engaging in further risk spreading activities such as dynamic hedging. However, the models employed by such institutions for risk management purposes can often breakdown under extreme movements in asset prices such as exchange rates. This can lead to large losses for some institutions, and if the shock is widespread, or is transmitted to other financial intermediaries, can threaten the stability of the whole financial system.

Another important limitation is imposed by the fact that hedging is possible only over a relatively short period, typically six months and at most a year. While this is adequate for trade payments lags, it is not adequate for longer period contractual payments obligations as for example on debt servicing. At present no effective mechanisms exist to hedge against exchange rate movements over longer periods as many countries may wish to do especially in so far as debt obligations are concerned.

The net result of these vulnerabilities is that the costs of long-run, persistent exchange rate 'misalignments' are believed to be "extremely harmful to macroeconomic stability and microeconomic efficiency (McKinnon and

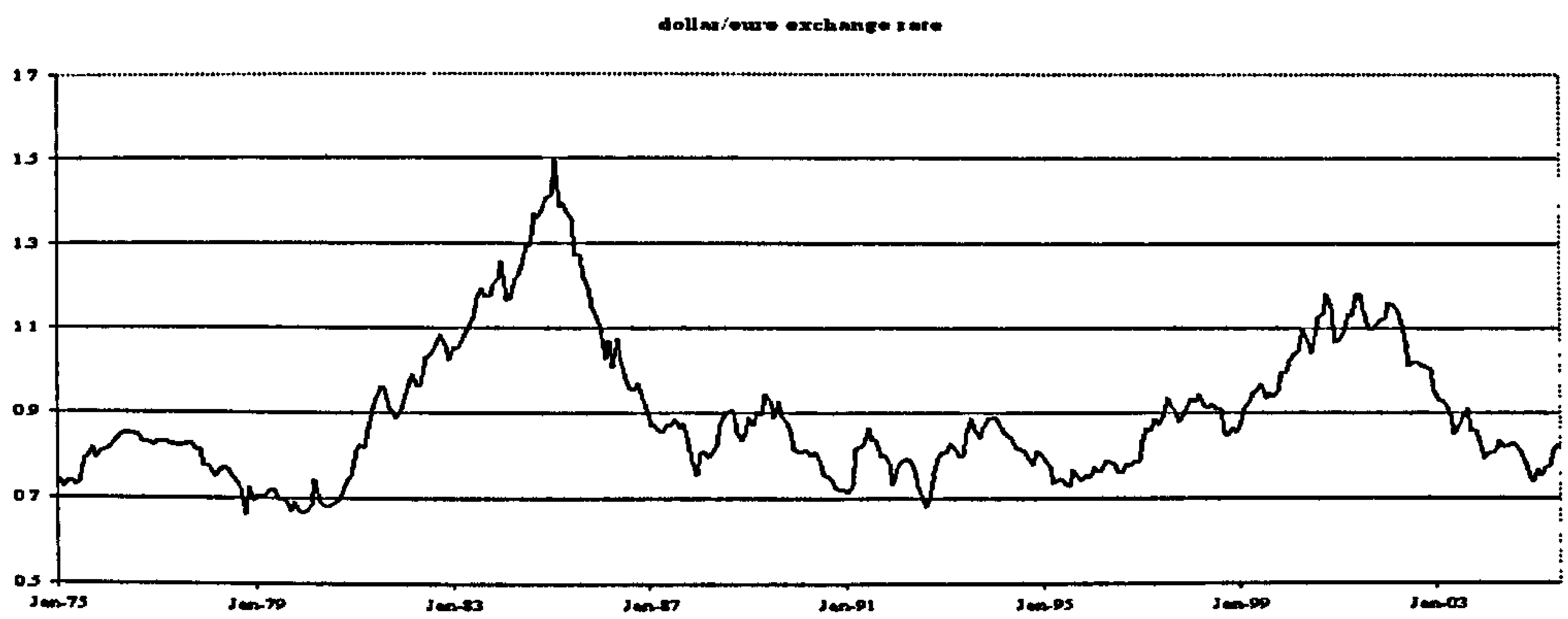
Ohno (1997) p. 52). By altering international relative prices (the terms of trade), domestic relative prices (of non traded goods), and the prices of traded commodities relative to traded differentiated products through a process McKinnon and Ohno (1997) label 'price diffusion', excessive exchange rate volatility and persistent misalignments are often held responsible for depressing bilateral trade flows, distorting investment decisions, and misallocating the outsourcing locations chosen by multinational firms. Furthermore, these costs can often lead to pressure for protectionist legislation, which increase the damage to international trade further still.

Long swings in exchange rates can entail other profound structural consequences for the economy. For example, Devereux (2005) provides a theoretical investigation of the implications of exchange rate rules for the flexibility of nominal prices, and shows how internal price flexibility may be increased by pegging the exchange rate. A further example is given by the pricing behaviour of firms. Empirical studies have convincingly demonstrated that producers of tradable goods in many countries practice third-degree price discrimination, tailoring the prices they charge to individual market destinations. Such pricing-to-market (PTM) behavior seems to be prevalent among many Organization for Economic Co-operation and Development (OECD) countries (see Goldberg and Knetter (1997)). A stylized fact of this literature is that in response to a 10 percent depreciation of a target countrys currency, exporters lower the exports own-currency price by around 5 percent in the same year. That is, the median pass-through of currency depreciation to manufacturing import prices tends to be around 50 percent over a one-year horizon. Not only is exchange rate pass-through low for many industrialized countries, evidence suggests it has been falling consistently sine the mid 1980s. One possible explanation of this is that firms have been increasingly adopting PTM behaviour in response to large-scale misalignments in exchange rates. Thus the degree of exchange rate disconnect maybe a result of an endogenous response of firms to increased exchange rate variability. This has potentially large-scale implications for economic welfare which are not immediately obvious from short-run changes in macroeconomic variables.

While the implications of persistent misalignments in G3 exchange rates for industrialised countries have proved somewhat difficult to disentangle, the implications for Emerging Market Economies (EMEs) and the developing world are somewhat more clear. Firstly, developing countries typically do not find it easy to engage in derivatives market activity so that the effective scope for hedging available to economic agents in developing countries are relative limited. This provides one potential explanation for the clear impact of G-3 exchange rate volatility on developing countries. For example, Esquivel and Larrain (2002) find that G3 exchange rate volatility has a robust and significantly negative impact on developing countries' exports. They find that a one percentage point increase in G-3 exchange rate volatility decreases real exports of developing countries by about 2 percent on average. Furthermore, they present evidence that G3 exchange rate volatility has a negative influence on foreign direct investment to certain regions, and increases the probability of occurrence of exchange rate crises in developing countries.

Crucially, for reason of inflation stabilization or to facilitate their integration into the global capital market, most countries outside the G3 invoice a large proportion of their international commerce and denominate an even greater portion of their international borrowing in a G3 currency (especially US dollars). As a result, the wide swings in bilateral G3 exchange rates that we observe have large effects on the trade flows, capital flows, portfolio composition, and - as Krugman (1997) demonstrates - the vulnerability to speculative attack in those countries that choose to peg their exchange rates to the dollar, yen, or euro. For this reason, McKinnon and Ohno (1997) recently characterized the yen-dollar exchange rate as the 'loose cannon' behind the Asia crisis.

This part of my thesis explores the forces which lead to long swings and high volatility in exchange rates, and examines policy measures by which they can potentially be reduced. In the next chapter, I begin by examining possible explanations for the exchange rate disconnect put forward in the literature. I then go on to examine some policy responses which have been proposed to limit the development of long swings in G3 exchange rates. The following chapter then develops a theoretical model which describes erratic exchange rate movements as being the results of the evolutionary selection of competing forecast rules by participants in the foreign exchange market. Within this framework, I show how sterilized foreign exchange intervention can be employed as a tool to reduce long swings in bilateral exchange rates while leaving macroeconomic fundamentals largely unaffected, thus providing a 'free-lunch' of economic stability. The final chapter in this part presents results from the empirical estimation of the model on 12 years on data on the dollar-yen exchange rate. In addition to providing empirical support for the model, I also demonstrate how the model implies a variant of an exchange rate target zone - the monitoring band - maximizes the efficiency of foreign exchange policy.

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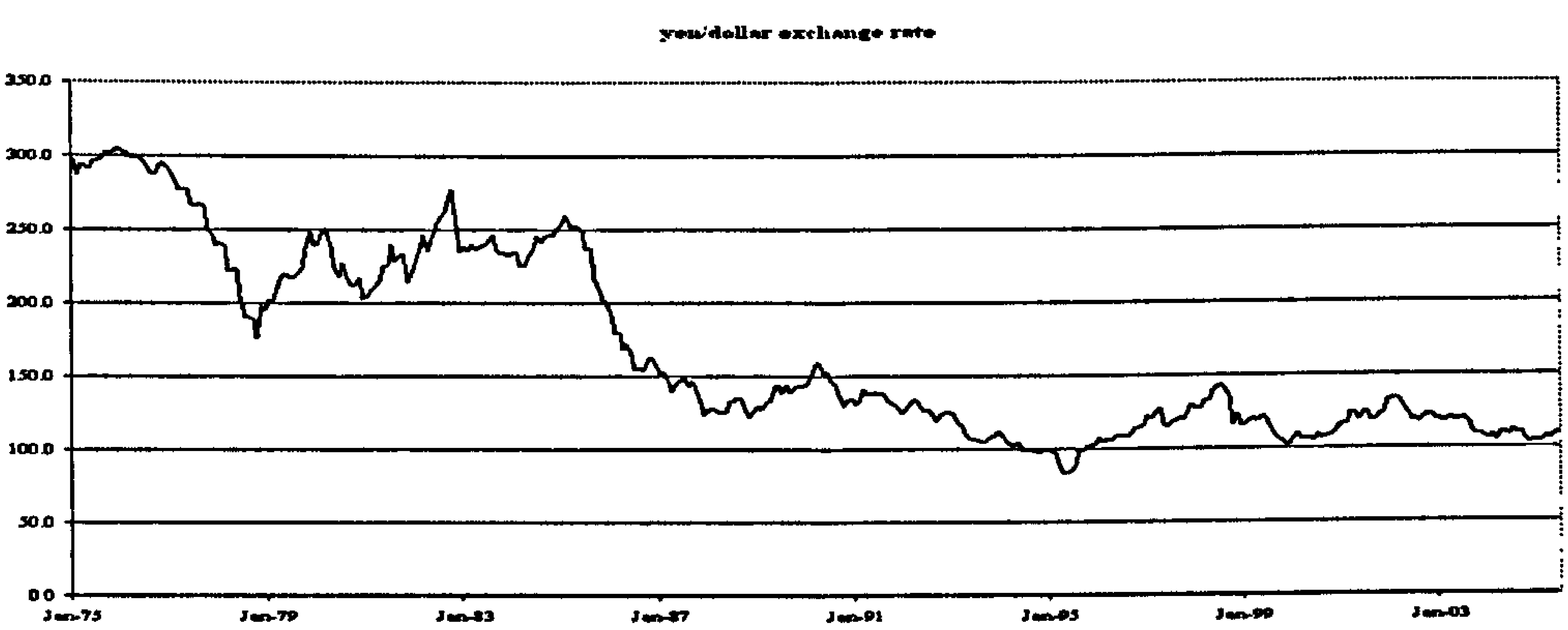


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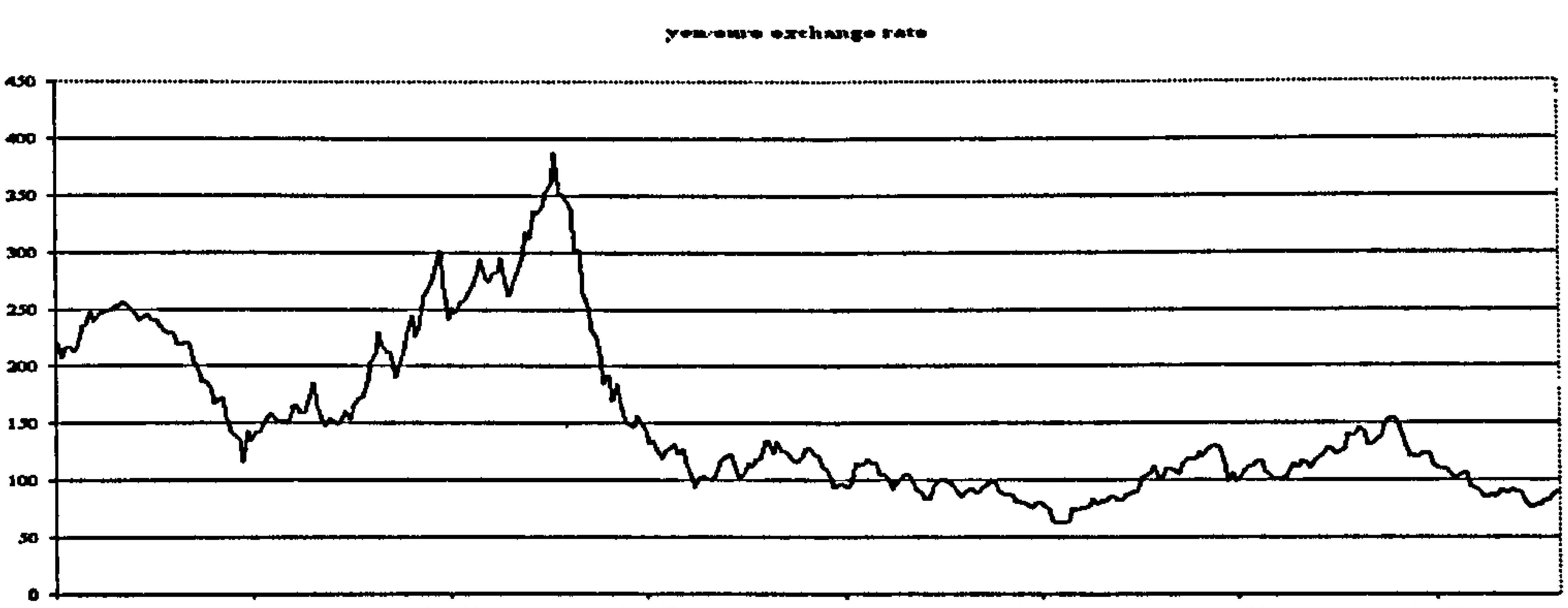


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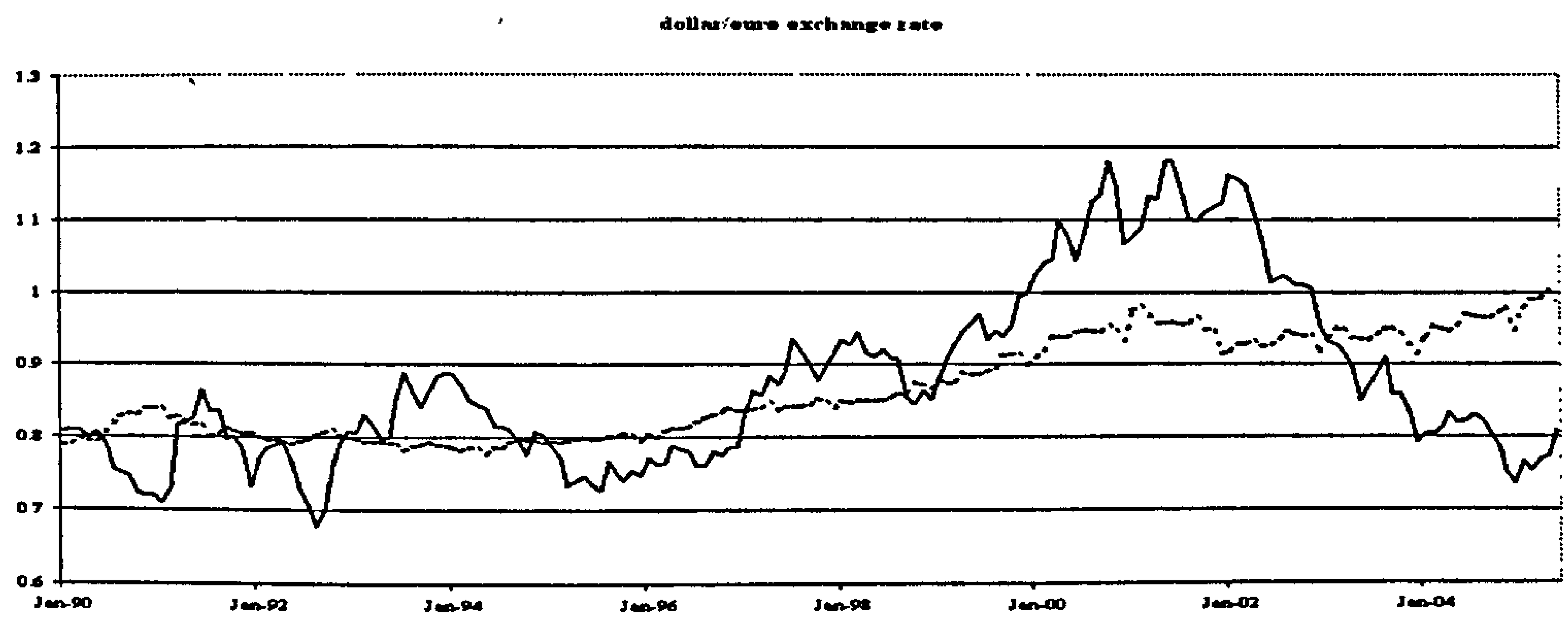
Figure 1.1: G3 nominal exchange rates 1975-2005

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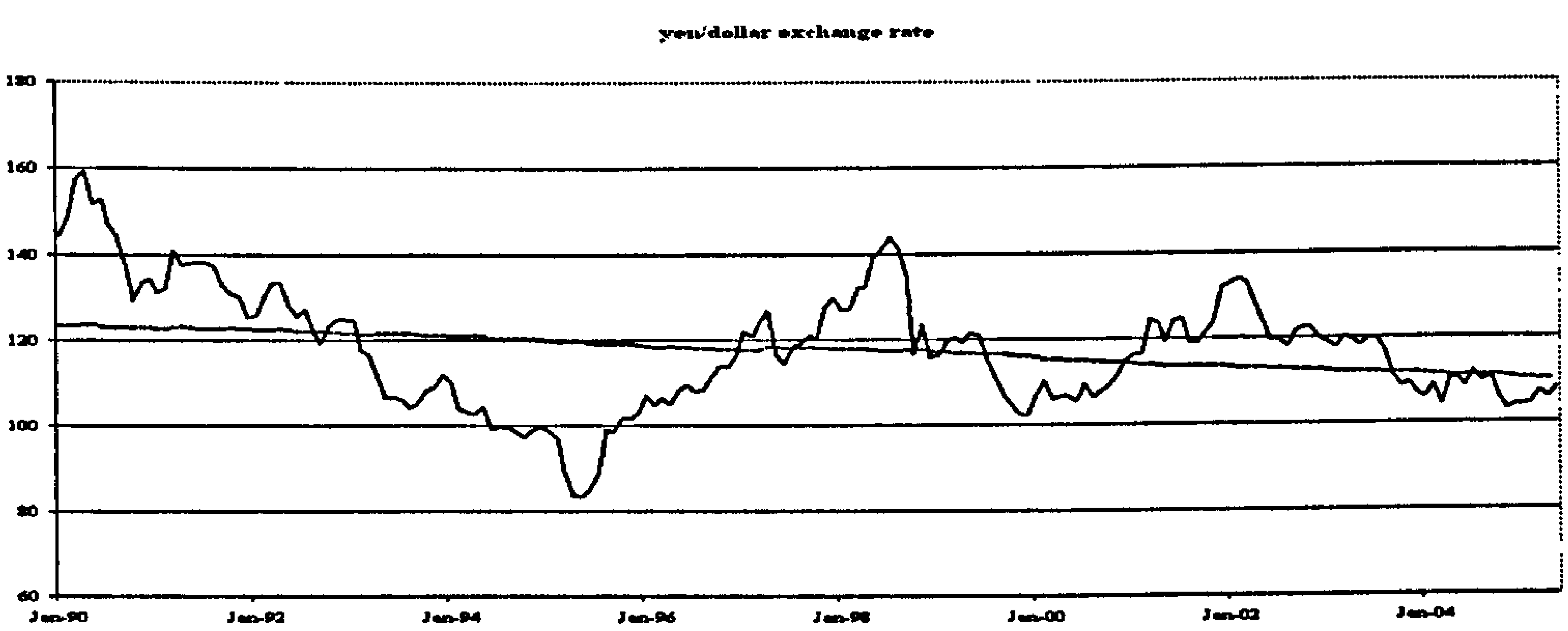


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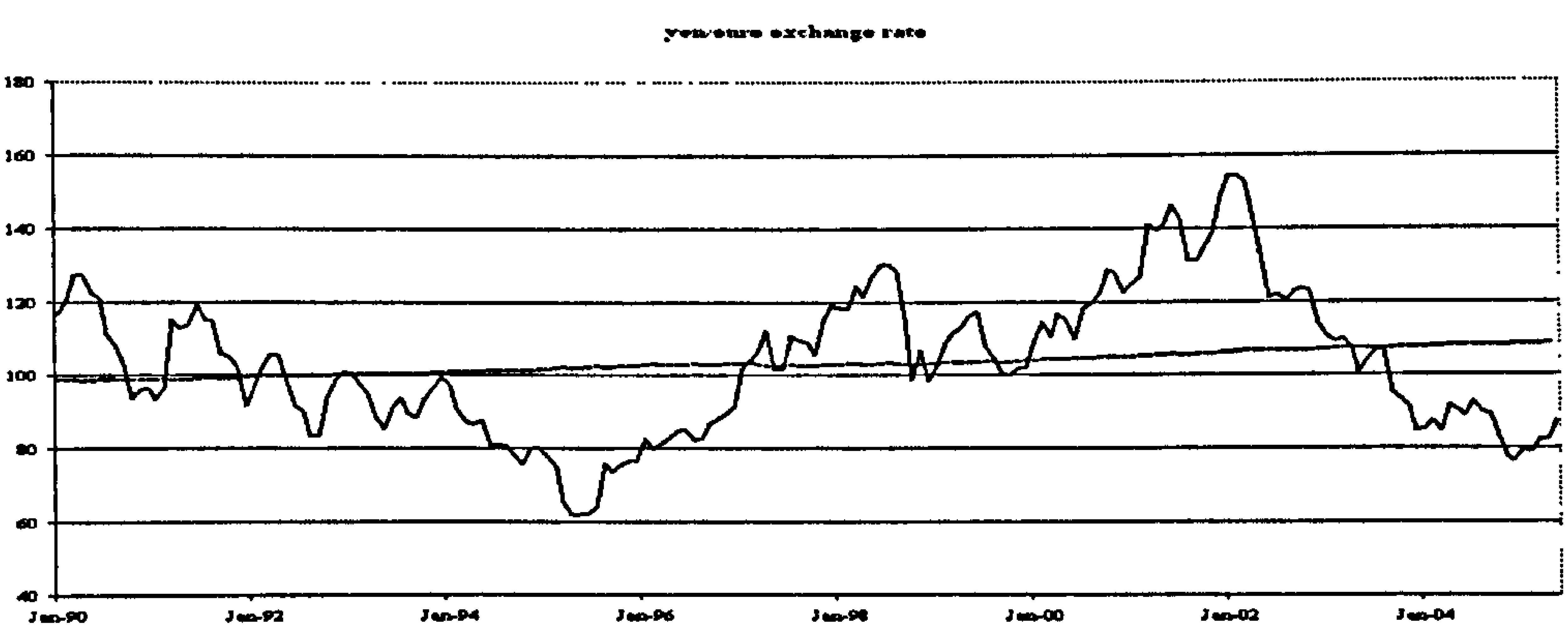


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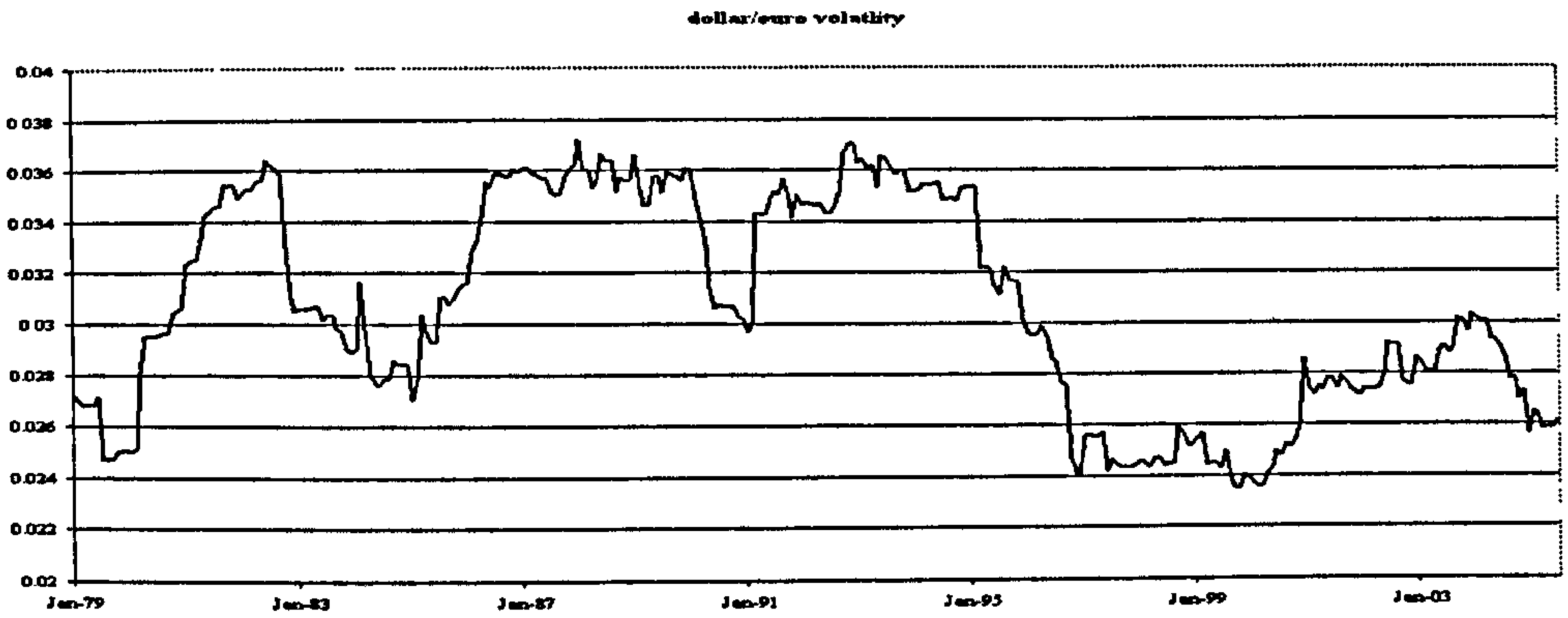
Figure 1.2: Nominal exchange rates and relative prices: 1990-2005

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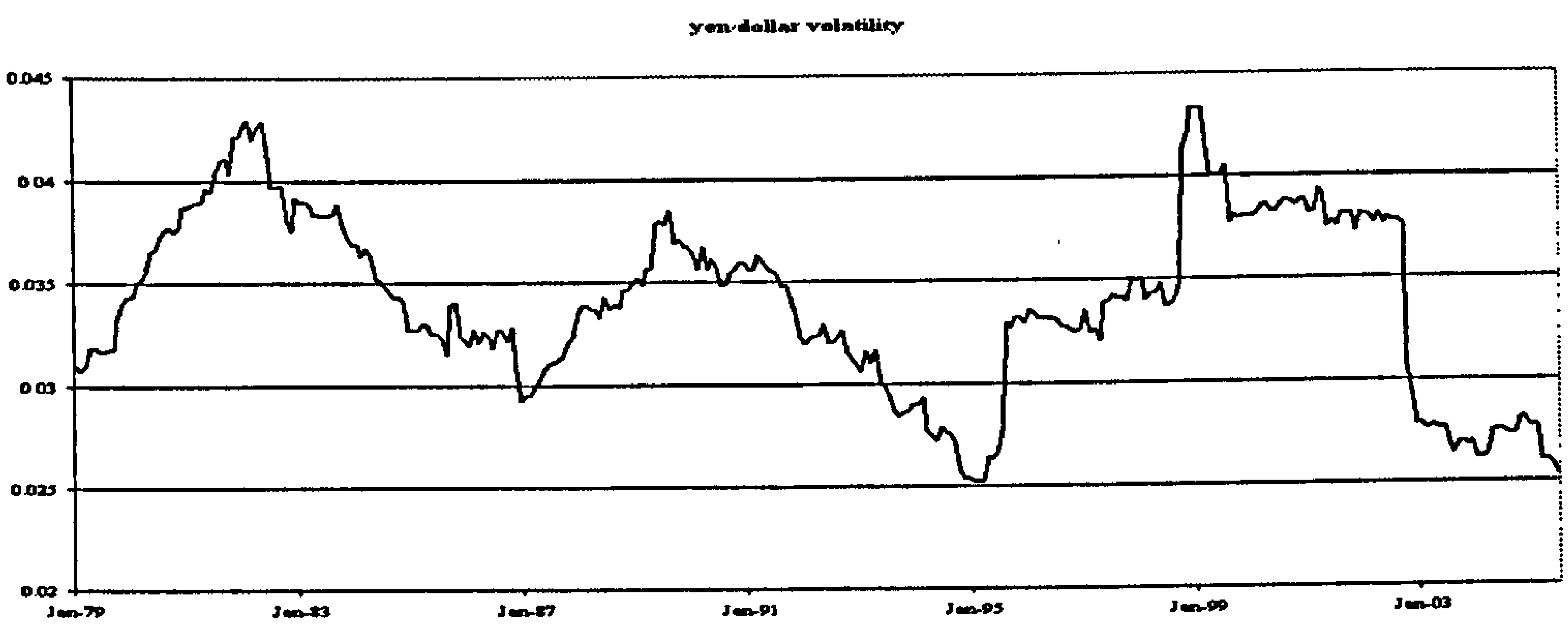


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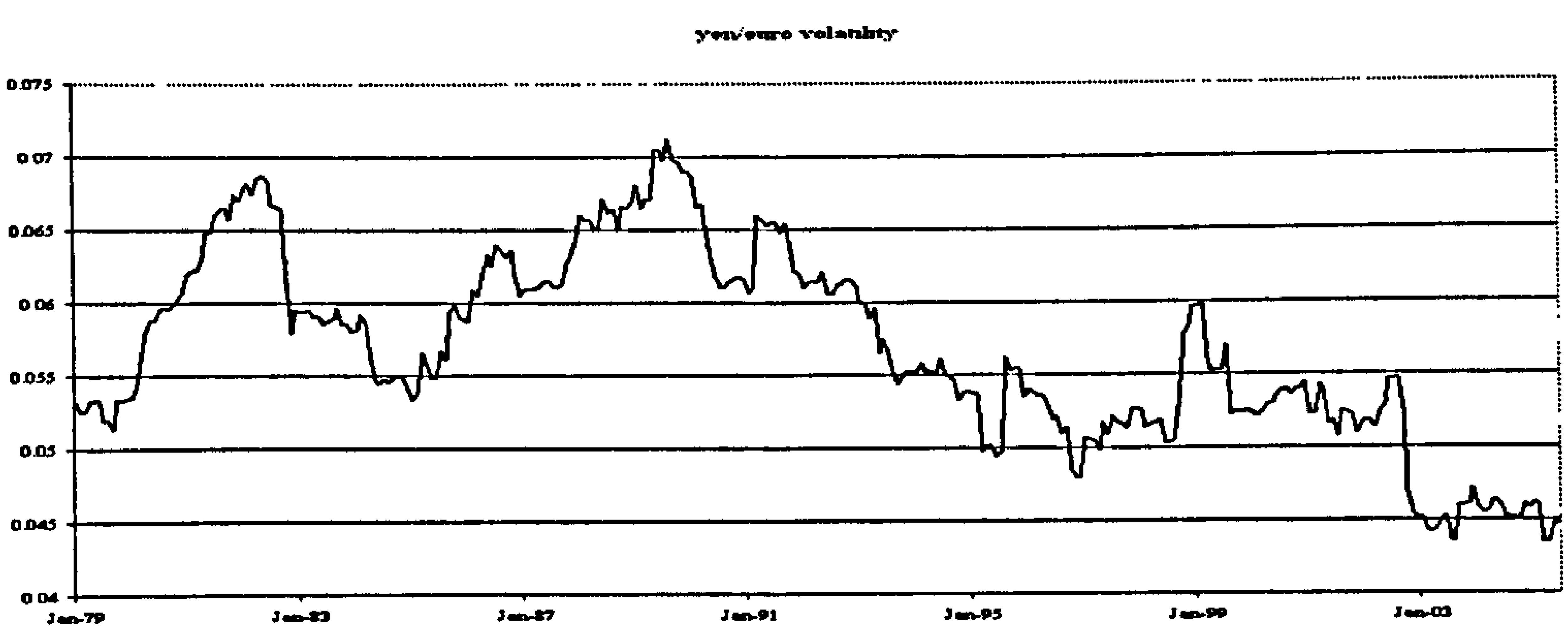


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Figure 1.3: Rolling standard deviations of monthly exchange rate changes: 1979-2005

# Chapter 2

# Exchange rate dynamics and exchange rate management

## 2.1 Introduction

The weight of evidence provided by research into the determinants of exchange rate behaviour strongly suggests that, at short horizons, macroeconomic variables play only a limited role. This chapter addresses two key questions raised by this evidence. Firstly, given the empirical failure of structural macroeconomic models, what does drive movements in exchange rates? Secondly, given the possible answers to the first question, what kind of policy tools are available to effectively limit the development of misalignments in exchange rates?

Over the course of the past twenty years, a large quantity of research has been undertaken to address issues raised by these questions. The intention of this chapter is not to provide a thorough review of this literature, rather, the aim is to examine how research in a number of key areas can be drawn together, thereby providing some orientation as to how the approach taken in this dissertation fits in to the broader literature.

## 2.2 Macro fundamentals and the determinants of exchange rate movements

The well documented failure of traditional macroeconomic models to explain exchange rate behaviour (e.g. Meese and Rogoff (1983); Cheung, Chinn, and Pascual (2006)) has led to a enormous amount of empirical research aimed at understanding the forces that drive exchange rate dynamics, and what role macroeconomic variables play in their determination.

A key finding in this research effort has been that traditional macroeconomic theories of exchange rate determination, for example Purchasing Power Parity (PPP) and the monetary model of the exchange rate, do seem to hold as medium to long-run equilibrium conditions. Evidence has been most forthcoming in recent years from studies employing panel data techniques or long horizons of data, see amongst others, Mark (1990), Lothian and Taylor (1996), and MacDonald (1999).

While the cumulative evidence from these studies recovers a role for macroeconomic fundamentals in exchange rate determination, by themselves they fail to explain the very slow speeds of convergence to equilibrium implied by the apparent near random walk behaviour of exchange rates. For example, Rogoff (1996) notes that the typical estimates of half-lives of deviations from PPP of 3 to 5 years are way in excess of those predicted by theoretical models of exchange rate adjustment, and christens this finding the 'purchasing power parity puzzle'.

One potential explanation for these findings is that real exchange rate adjustment is nonlinear, with deviations from PPP falling more rapidly the larger the misalignment. A key theoretical basis for this view relies on the presence of market frictions that impede inter-country commodity trade and arbitrage. E.g. Benninga and Protopapadakis (1988); Williams and Wright (1991); Dumas (1992), Uppal (1993), Sercu, Uppal and Van Hulle (1995) and Coleman (1995, 2004) develop dynamic general equilibrium models of real exchange rate determination which take into account transaction costs and show that the process of adjustment of RERs towards a PPP-equilibrium is non-linear. These costs include, inter alia, transport costs, trade barriers and costs of setting up or buying foreign retail distribution networks.

In many of these models, proportional or "iceberg" transport costs[1] create a band for the real exchange rate within which the marginal cost of arbitrage exceeds the marginal benefit. As a result, deviations from PPP within these bands are left uncorrected. However, deviations outside these bands (i.e., where price differences exceed transaction costs) will be arbitraged away by market forces.

Another theoretical rationale for nonlinear dynamics stems from the observation that adjustments in relative prices across borders will also be affected by the perceived uncertainty in exchange rate movements. For example, with a greater degree of uncertainty, firms become less willing to change their prices since the exchange rate may move back after the price change and another price change in the opposite direction may then be necessary (Delgado (1991)). This again predicts the existence of "bands of inaction" in exchange rate adjustment whose width is related to the uncertainty regarding the permanence of the shocks causing price changes, within which arbitrage is not profitable due to sunk costs (Dixit (1989) and Krugman (1989)).

In addition, some of these studies draw on the theory of investment under

[1] "iceberg" because a fraction of the goods are presumed to "melt" when shipped, with the fraction melting depending on the distance traveled.

uncertainty to show that the thresholds should be interpreted more broadly than simply as trade barriers and shipping costs, but also as arising from the sunk costs of arbitrage and the resulting tendency for traders to wait for sufficiently large arbitrage opportunities to appear before entering the market (e.g. Dumas, 1992 and Obstfeld and Rogoff, 2000).

Rogoff (1996) concludes that the presence of frictions such as transportation costs, threatened or actual tariffs, nontariff barriers, information costs or lack of labor mobility, create a large buffer within which nominal exchange rates can move without producing an immediate proportional response in relative domestic prices.

Other authors have investigated whether exchange rate policy actions by the authorities could themselves inject a source of nonlinear adjustment into exchange rates. For example, Hsieh (1992) develops a rational expectations monetary model with stochastic intervention rules. In his model, the authorities react to large appreciations and depreciations (rates of change) by intervening more strongly. This results in the exchange rate moving more rapidly toward fundamentals when deviations are large. This is in contrast to the target zone approach to the management of floating exchange rates, where the level of the exchange rate (or rather, its proximity to ceilings or floors) is relevant for signalling interventions. However, while these models do provide a possible rationale for nonlinear exchange rate adjustment, they fail to explain why misalignments should arise in the first place.

An important step in understanding the causes of real exchange rate misalignments is to determine the relative contribution of price and nominal exchange rate adjustment. In contrast to standard rational-expectations sticky-price models, which impose the same reversion speed for nominal exchange rates and prices, a recent study by Engel and Morley (2001) examines an empirical model that allows those variables to adjust at different speeds.

Formulating the adjustment equations as a state-space model (Morley et al., 2003), Engel and Morley evaluate the speeds at which nominal exchange rates and prices converge to their respective equilibrium levels that are unobserved. Empirical results from state-space model estimation indicate that while prices converge relatively fast, nominal exchange rates converge slowly. The differing-speed finding is intriguing. It suggests that the torpid rate of PPP reversion may come largely from slow nominal exchange rate adjustment rather than from slow price adjustment.

In a another study, Cheung, Lai, and Bergman (2004) provide supporting evidence on the mechanism by which PPP deviations are corrected. Using an empirical approach different from Engel and Morley (2001), they employ a Vector Equilibrium Correction (VEC) Model, and find further evidence for the difference in convergence speed between nominal exchange rates and prices. Although there are significant differences between the two approaches, their results corroborate and reinforce Engel and Morleys finding: it is nominal exchange rates, not prices, that converge slowly toward PPP.

What could explain the result that prices converge fairly quickly in each country to their equilibrium levels, but the exchange rate moves only very slowly to the PPP value? One possible explanation is that persistent real shocks are important.

While the PPP models of Engel and Morley (2001) and Cheung, Lai, and Bergman (2004) do not incorporate real shocks, one can imagine how a model with real shocks could produce persistent nominal exchange rate deviations. If nominal prices adjust quickly, but there are real shocks that imply a slowly-adjusting real exchange rate, then the nominal exchange rate necessarily will adjust slowly to the PPP equilibrium. However, Engel and Morley are skeptical that real shocks can explain their findings. They note that the extreme volatility of real exchange rates suggests that the underlying source of shocks is monetary or financial.

It seems then, that the balance of empirical evidence suggests persistent misalignments observed in real exchange rates can best be attributed to the behaviour of nominal rates. However, it is not clear how transaction costs, which should be relatively insignificant for foreign exchange markets, can account for the slow convergence of nominal exchange rates. This poses a direct challenge to theoretical models to explain the surprising behavior of nominal exchange rates.

Engel and Morley (2001) speculate that, when goods market frictions are present, there is more scope for herding behavior and bubbles in exchange rate markets. Bubbles or herding might temporarily send the exchange rate off on disequilibrium paths that result in the appearance of slow convergence to the equilibrium. Over the course of the last two decades a growing body of research has examined the causes of the surprisingly persistent misalignments in nominal exchange rates, with the focus being on the role of informational asymmetries. It is to this body of work which we turn in the next section.

## 2.3 Modelling exchange rate dynamics under rational expectations

A useful framework for examining potential theoretical explanations for the observed behaviour of nominal exchange rates stems from the insight that the exchange rate, as the relative price of two monies, should be viewed as an asset price. The price of a financial asset may be represented as the discounted present value of the future stream of its payoffs. Denoting the payoff at time $t$ by $Z_t$, and the (spot) asset price by $P_t$, the return on a financial asset at $t+1$ is given by:

$$R_{t+1} = \frac{P_{t+1} + Z_{t+1}}{P_t}. \tag{2.1}$$

Campbell (1991), extending work by Campbell and Shiller (1988), uses a log-linear approximation to show that the excess (i.e. unexpected) return on the asset can be written

$$r_{t+1} - E_t r_{t+1} = (E_{t+1} - E_t)\left[\sum_{j=0}^{\infty} \rho^j \Delta z_{t+1+j} - \sum_{j=1}^{\infty} \rho^j r_{t+1+j} + \lim_{j\to\infty} \rho^j (p_{t+j} - z_{t+j})\right], \tag{2.2}$$

where lower case letters represent log variables, and $\rho$ is a parameter of linearization[2]. This equation identifies a number of potential explanations for unexpected asset returns. Fluctuations in the first term in the bracket in (2.2) represent changes in expectations of future fundamentals, while changes in the second term capture changes in the discount rate. Discount

[2]In particular, $\rho = 1/(1 + \exp(z_t - p_t))$.

rates, in turn, can change because of changing expectations of future risk-free rates, changing forecasts of risk or changing risk aversion.

While at first sight there appear to be many ways of introducing variation in excess asset returns, it has become clear that, at least under the assumption of perfectly rational agents[3], most of them cannot form a basis of an explanation of excess volatility or persistent mispricing of assets. For example, Shiller (1981) and LeRoy and Porter (1981) show that changing forecasts of growth in fundamentals[4], cannot be used to drive excess returns since, if these forecasts are fully rational, it must be that excess returns predict cash-flow growth in the time series, which they do not. Neither can changing forecasts of future risk-free rates be used: once more, if the forecasts are rational, excess returns must predict interest rates in the time series, which they do not. Even changing forecasts of risk cannot work, as there is little evidence of excess returns predicting changes in risk in the time series.

The only story which remains when one assumes agents are fully rational is that of changing risk-aversion. This idea is made operational by the Campbell and Cochrane (1999) model of aggregate stock market behaviour. They

[3]The term 'rational agents' as used here refers to an assumption that agent form so-called 'strong form' rational expectations, so that prices reflect all available relevant information (both public and private).

[4]The work of Shiller (1981) and LeRoy and Porter (1981) examine this equation in the context of stock returns, hence the measure of fundamentals they examine is dividend growth.

propose a habit formation framework for modelling stock market returns in which changes in consumption relative to habit lead to changes in risk aversion and hence variation in excess returns. This variation helps to plug the gap between the volatility of fundamentals and the volatility of asset returns. In addition, the introduction of habit into agents utility functions introduces a source of persistence into returns which can explain persistent misalignments in asset prices.

However, this approach to reconciling high short run volatility of asset prices with low volatility of fundamentals implies that agents' preferences must be highly volatile in the short run. This requirement lies in stark contrast with the notion that agents' attitudes towards risk are an intrinsic feature of their behaviour. Rather, the notion that agents switch on mass from being risk averse to risk loving at daily frequencies is arguably inconsistent with the very notion of risk *preferences*.

A final possibility is to introduce variation in excess returns through the third term in equation (2.2). This kind of model is known as a 'rational bubble'. The intuition of these models is that prices are high today because they are expected to be high next period; and that they are higher next period because they are expected to be higher the period after that, and so on, forever. In their simplest form, this requires market participants to expect explosive growth in excess returns for an indefinite period. However, subsequent modifications such as Blanchard (1979) relax this by, for example, introducing an small exogenous probability of the bubble bursting.

In fact the bubble term in equation (2.2) represents an infinity of possible solutions to the asset pricing formula. However, researchers typically side-step this issue by assuming a priori that it is zero. While models incorporating rational bubbles at first seem appealing, a number of papers, most recently Santos and Woodford (1997), show that the conditions under which rational bubbles can survive are extremely restrictive.

It is clear then, that under the stringent demands of the strong-form rational expectations hypothesis, there are few available explanations for the observed behaviour of asset prices in general, and exchange rates in particular. The principle exception is to introduce time variation in agents' risk aversion, for example, by means of a 'habit term' in their utility functions. If however the assumption of complete information and frictionless trading is relaxed, a variety of possible explanations for observed exchange rate dynamics present themselves. Furthermore, as we shall see in subsequent sections, there is a wealth of empirical and experimental evidence to support the view that asymmetries in agents information sets can be important, as can limits on agents capacity to process that information.

## 2.4 Bounded rationality, market microstructure and behavioural models of exchange rate dynamics

One solution to the puzzles presented by exchange rate dynamics is to relax the requirement that agents have costless access to all relevant information. This forms the basis of a large literature on structural uncertainty and learning, in which agents do not know the parameters of the process governing fundamentals, but have to learn them over time. This approach has enjoyed some success in matching the empirical volatility of exchange rate changes (see, for example, Brennan and Xia (2001) and Veronesi (1999)). In these models, variation in excess returns comes precisely from changing forecasts of fundamentals. While these forecasts are not subsequently confirmed in the data, agents are not considered irrational - they simply don't have enough data to infer the correct model. In related work, Barsky and DeLong (1993) generate return volatility in an economy where investors forecast fundamentals using a model that is wrong, but not easily rejected with available data.

An important implication of models with fully rational actors is that any changes in exchange rates must be due to news: i.e. unexpected public information concerning changes in fundamentals. Under rational expectations and efficient markets, the news contained in public information announcements is directly impounded into prices with there being no role for trades in this process of information assimilation. However, a large number of studies (see, for example, Engel, Ito, and Lin (1990), Goodhart, Ito, and Payne (1996) and Peiers (1997)) have found that the timing of exchange rate movements is only very weakly connected to macroeconomic news. These results are summarized by the findings of Evans (2002) that "public news is rarely the predominant source of exchange rate movements over *any* horizon" (p. 1, italics in the original). These studies argue for a closer look at the behaviour of different market participants in order to more fully understand the price formation mechanism.

The role of information imperfections in explaining the observed behaviour of exchange rates can be more fully appreciated by allowing for different types of actors in foreign exchange markets. Real financial markets are composed of multifaceted people with multifactor motivations. These include motives and objectives such as international trading, international investing, noise trading, speculation, arbitrage, relative value or 'hedge' investing, dealing or market-making, underwriting and so on. Many market participants have more than one of these motivations. The different roles enacted by different players in the markets can be summarized by i) the information available to them, and ii) the way that information is used.

The introduction of heterogeneity in the type of information available to agents, and the manner in which information is processed by different market participants is desirable for a number of reasons. Firstly, it is realistic. As will be discussed in section (2.4.2), examination of the structure of financial markets demonstrates how the institutional arrangements under which trading takes place form one natural classification system under which to examine the price formation process move closely.

Furthermore, the variety, quantity and quality of information available to market participants is vast. Models which introduce some limitations in market participants' ability to process this information efficiently can prove highly successful in accounting for observed 'aberations' in exchange rate behaviour, a selection of these models are reviewed in sections (2.4.3) to (2.4.4).

### 2.4.1 A brief digression: heterogenous beliefs and 'ad hoc' assumptions

A common criticism leveled at models employing heterogenous agents is that they are add-hoc: i.e. they contain elements which are not attributable to any rigourously defined economic structure. The implication is that the results from such a model are difficult to interpret properly, and hence are of little use in improving understanding of the phenomena under investigation. In fact, an increasing number of models of this type are based upon rigourously specified theories of choice, such as prospect theory, which explicitly deal with the issues raised by the experimental failings of expected utility theory[5]. Other models do not fully specify the choice theoretic foundations of agents behaviour, but only draw more generally on recent research in that area[6]. Such modelling approaches can still provide important insights in to the determinants of asset price behaviour, and often amount to sensible shortcuts on the way to examining the phenomenon under investigation. In a similar way, macroeconomists write models with cash-in-advance constraints, money in the utility function, sticky prices and so on, not because they literally believe in these specifications but as a convenient shortcut to a money demand curve on the way to studying something else, without waiting for the 'microfoundations of money' project to be finished.

Finally, it is important to note that depending on the type of imperfection employed to account for exchange rate dynamics (and hence how different market participants are classified), the relative efficacy of alternative policy

[5]For a discussion of prospect theory, see Tversky and Kahneman (1992), while Starmer (2000) provides a survey of non-expected utility theory in general.

[6]Such models fall under the heading of behavioural finance, and are reviewed by Barberis and Thaler (2002).

measures to mitigate exchange rate instability can vary widely. The differing policy implications of different models provides a powerful tool by which to select amongst competing alternatives.

### 2.4.2 Mispricing, Volume, Liquidity, and Order Flow

The apparently endemic mispricing in foreign exchange markets following the collapse of the Bretton Woods agreement has coincided with an enormous surge in turnover in foreign exchange markets. On a typical day in the foreign exchange market approximately $1.2 trillion changes hands (BIS, 2001). This means that in less than a week foreign exchange transactions have exceeded the annual value of world trade.

In order to appreciate how this high volume of transactions is linked to the behaviour of exchange rates, it is important to examine the institutional setting of the foreign exchange markets. The spot foreign exchange market is best characterized as a decentralized multiple dealer market (Lyons (2001)). Each dealer stands ready to buy at her bid quote and sell at her offer quote. However, there is no centralized location where customers can obtain quotes from many different dealers in a consolidated format (unlike, for example, the NASDAQ in the U.S.). Neither is there any physical location or exchange where dealers meet with customers.

When setting their bid and offer quotes, each dealer observes the flow of buy and sell orders from their customers and from this flow is able to form an estimate of the fair, or 'arbitrage-free' level of the exchange rate. In addition, dealers also trade intensively with one another, and by doing so can to some extent extract the private information of other dealers, and hence improve upon their view of the fair price of each currency. Evidence indicates that around 80% of total trades are carried out between dealers themselves, not the end 'users' of foreign exchange.

The efforts of many researchers to explain 'mispricing' in asset markets in general is closely linked with the efforts to explain this observed high volume of transactions[7]. At a basic level, if there is some impact on the price of an asset from purchases or sales, then clearly highly variable turnover will be closely associated with high variability in exchange rates. After all the idea that, for example, large scale sales reduce prices is hardly revolutionary - downward sloping demand curves are a standard feature of markets which are less than perfectly competitive. However, the existence of a large body of active arbitrageurs in financial markets leans the presumption much more toward a flat demand curve. For this reason, we should be more surprised

[7] This research effort comes under the banner of 'market microstructure' research. An excellent survey of this literature is provided by O'Hara (1995), while Lyons (2001) extensively examines its application to foreign exchange markets.

to see 'price impact' of regular or expected sales or purchases in relatively frictionless financial markets.

An issue closely related to the price impact of a trade is liquidity: roughly speaking, some concept of how much of an asset is for sale at current quoted bid-ask spreads. Dramatic falls in liquidity are commonly observed in periods of instability in asset prices and market crashes. Intuitively, crashes in asset markets, or equivalently bursting asset bubbles, occur when the market becomes 'one-sided': market participants wishing to sell their holdings of the asset cannot find buyers willing to purchase the all of their assets at quoted bid-ask spreads. Reduced liquidity is often indicated by larger bid-ask spreads, but is most commonly quantified by the actual price impact of trades.

There are two key theoretical channels which can account for possible price impacts. The first of these arises from the presence of 'inventory risk' for exchange rate dealers. If one makes the (realistic) assumption that foreign exchange dealers are risk averse, then they will only carry higher positions on their books if a higher risk premium is paid. Dealers incentives are set such that they wish to close out their positions by the end of a working day. As such, the build up of large open positions in their books carries increased inventory risk - the risk that the value of the inventory will decline before it's sold.

Market microstructure models have an additional story for price-impact: asymmetric information. When conducting inter-dealer trades, each dealer has access to a set of private information: the buy and sell orders they receive from their customers. This information is summarized in the 'order flow': signed volume of trades which simultaneously indicates both the size of a trade and whether the dealer bought or sold the asset in question.

This order flow constitutes a noisy signal of customers information about the fundamental determinants of the asset price. Furthermore, by trading with other dealers, it is possible for dealers to gain some information regarding other dealers private information by observing their order flow[8] In addition, the informational asymmetries in the customer-to-dealer and dealer-to-dealer relationships create scope for strategic behaviour on the part of market participants.

In a series of papers, Evans and Lyons (1999, 2001, 2004) show that exchange rate movements are highly correlated with order flow. This is in particularly stark contrast to the low correlation between macroeconomic fundamentals and exchange rates. In particular, recent work by Marsh and O'Rourke

[8]That order flow can play a role in price determination stems from the idea that rational trades can occur in transition to the new equilibrium price as long as buyer/seller imbalance is unknown to the dealer.

(2005) has demonstrated that the correlation between exchange rates and the order flow from different institutional sources varies dramatically, and studies of disaggregated order flow have shown how the information content of orders varies considerably from source to source.

Evans and Lyons interpret this correlation as causal, i.e. that order flow causes the exchange rate to move, running into the illiquidity, "downward sloping demand," or "limited ability to bear risk" of dealers. However there are at least two alternative interpretations of this correlation. For example, in a similar study of the bond market Brandt and Kavajecz (2004) interpret the correlation between order flow and price movements as evidence for 'price discovery' rather than for 'illiquidity' or 'price impact'. In a market of symmetric information, that information raises prices without any trading. In a market with asymmetrically informed agents, those with the information will trade on that information as prices rise, so that price rises and buy orders will indeed be correlated.

An alternative explanation for this correlation is that the causality actually runs backwards: perhaps changes in prices encourage traders to 'follow the trend,' and pile volume in the same direction. This explanation is the subject of the following section.

In summary, while the results of the order flow approach are encouraging, it must be remembered that order flow cannot bear more than a *proximate* relationship to exchange rate movements. As yet this literature has little to say about the relationship between inter-dealer orderflow, macroeconomic variables and the forces which drive customer order flow. Ultimately, the determinants of exchange rates will not be fully understood until customer order flow unrelated to economic fundamentals is explained more fully.

### 2.4.3 Chartism, heterogenous expectations and exchange rate dynamics

The microstructure literature discussed in the previous section principally focuses on the relationship between inter-dealer order flow and exchange rate dynamics. In doing so, the motivations and information available to the customers placing orders with dealers are largely treated as a black box. An alternative literature, which has developed in parallel with work on order flow, has focused instead on the behaviour of customers, whilst treating inter-dealer relationships as a black box. This work attempts to explain the large misalignments and high volatility in exchange rates by augmenting macroeconomic models of exchange rates by explicitly modelling the expectation formation of currency traders, and the forecasting techniques they employ (e.g. Jeanne and Rose (2002)). There is wide spread evidence (see, e.g. Allen and Taylor (1990)) that, rather then base their forecasts solely on economic fundamentals, traders base their short-run forecasts on the past movements of exchange rates, thus extrapolating recent trends. This body of theory essentially suggests that the high volatility of exchange rates can be understood to be due to fads or bubbles generated by the use of trading rules.

In the literature, particular focus has been given to the role of chartist or 'technical' rules employed by practitioners when forecasting exchange rates. While 'fundamentalist' trading strategies employed by traders are based on underlying economic determinants of the exchange rate, chartism or 'technical analysis' refers to forecasting techniques employed by traders which use past realizations of exchange rates to detect patterns which they extrapolate into the future, thus ignoring information embodied in 'structural' exchange rate models. In addition to simple charts of past exchange rate behaviour, a technical analyst may use a variety of trading rules based on statistical and mathematical techniques. Popular examples include the 'head and shoulders' reversal pattern, and a variety of moving average rules for predicting turning points. The behaviour of traders using chartist techniques adds a 'positive feedback' into the exchange rate, tending to accentuate deviations from the equilibrium level implied by economic fundamentals. In contrast, the behaviour of traders forecasting on the basis of fundamentals adds a 'negative feedback' into the exchange rate, since when the exchange rate deviates from its equilibrium value they expect it to return there.

There are now a large number of survey articles which document the widespread use of technical analysis in forex markets the world over. Allen and Taylor (1990) and Taylor and Allen (1992) conducted a survey of 400 chief forex dealers in the London markets, and found that approximately 90 percent of respondents based their forecasts to some degree on chartist techniques at short time horizons. As the time horizon increased from one month to one year, they found that the weight given to economic fundamentals increased. Similar studies have been carried out in the German markets (Menkoff(1997, 1998)), the Hong Kong markets (Lui and Mole (1998)), the Hong Kong, Tokyo and Singapore markets (Cheung and Wong (1999, 2000)), and the US markets (Cheung and Chinn(1999)). In general, these studies find that the vast majority of forex dealers employ some sort of technical forecasting technique, especially at short horizons.

### 2.4.4 The Noise Trader Approach

An alternative approach to the chartist fundamentalist framework outlined above, which builds largely on the model of the stock market by De Long et al (1990), views analysts who employ chartist techniques as 'noise traders'.

The essential difference between these models and those outlined above is that the presence of noise traders injects an additional element of volatility in the mean of asset returns: in contrast to fundamentalists, noise traders have imperfect knowledge of the fundamental determinants of the exchange rate. Whilst they are typically assumed to perceive the second moments of returns correctly, their perception of the first-moments is assumed to be affected by noise that is unrelated to economic fundamentals. For example, in the De Long et al (1990), in each period the noise traders price the asset as its true fundamental value plus an error term. Such incorrect pricing generates additional risk in holding the asset. This risk limits the willingness of the fundamentalist traders to go against the noise traders even if they know the true value of the asset. Hence arbitrageurs do not drive the asset's price toward economic fundamentals. In addition, the risk generated by the noise traders results in them earning higher average returns than those of the sophisticated traders, so that the noise traders are difficult to drive out of the market. Crucially, this is also accompanied by a higher variance of returns. In this way, the noise trader approach is well suited to modelling the excess volatility in exchange rates, but provides fewer insights into the formation of the persistent exchange rate misalignments which are of most concern from a macroeconomic policy perspective.

**Chartist-Fundamentalist Models**

Since the seminal paper by Frankel and Froot (1986), there have been a large number of models which attempt to model the dynamics of exchange rates with the heterogeneity of expectations which is implied by the use of fundamentalist and technical trading strategies. Most of these models can be represented in the following simple form:

$$s_t = z_t + c(E_t^{market}[s_{t+1}] - s_t) \tag{2.3}$$

which summarizes the 'asset market view' of the exchange rate, where $s_t$ represents the spot exchange rate, $z_t$ a vector of economic fundamentals. Here, $E_t^{market}[s_{t+1}]$ represents the markets expectation of the exchange rate next period, and is given by a weighted average of the forecasts made with fundamentalist and technical trading strategies, so that:

$$E_t^{market}[s_{t+1}] = \omega_t E_t^{chart}[s_{t+1}] + (1 - \omega_t) E_t^{fund}[s_{t+1}] \tag{2.4}$$

The various models in the literature differ principally in the process by which the weights given to each strategy, $\omega_t$, evolve. For example, in Frankel and Froot's (1986) model, it is postulated that

$$\omega_t - \omega_{t-1} = \delta(\hat{\omega}_{t-1} - \omega_{t-1}) \tag{2.5}$$

where $\hat{\omega}_{t-1}$ is defined as the weight, computed *ex post*, that would have accurately predicted the contemporaneous change in the spot rate. This weight $\hat{\omega}_{t-1}$ is defined as

$$\hat{\omega}_{t-1} = \frac{\Delta s_t}{\theta(\tilde{s} - s_{t-1})} \tag{2.6}$$

so that the change in weight becomes

$$\omega_t - \omega_{t-1} = \delta\frac{\Delta s_t}{\theta(\tilde{s} - s_{t-1})} - \delta\omega_{t-1} \tag{2.7}$$

The value of $\delta$ is crucial for the stability of the system. It determines the importance of the most recent information on updating the weights. If $\delta$ is large, then the system is stable. If it is small, then the system is unstable. Exactly how large $\delta$ needs to be for stability depends on $\theta$.

In this model, both groups of traders behave in a different manner because they have different information sets, so that each agent is acting rationally subject to certain constraints. The information set of fundamentalists includes fundamentals, while that of chartists contains only past values of the exchange rate which they use to extrapolate into the future.

The De Grauwe, Dewatcher, and Embrechts (1994) model is similar to that of Frankel and Froot with two exceptions. First the Chartist equation takes an autoregressive form for the expected future exchange rate, so that it nests Frankel and Froot's specification. Secondly, the weights are assumed to evolve according to

$$\omega_t = 1 - \frac{1}{[1 + b(\tilde{s} - s_{t-1})^2]} \tag{2.8}$$

where $b > 0$. Hence the weight on the fundamentalist element is an increasing function of the deviation from economic fundamentals.

De Grauwe et al's rationale for this weighting function appeals to a normally distributed noise term in agents forecasts of the fundamental exchange rate. When the actual value of the exchange rate is equal to the fundamental value, half of the fundamentalists view the exchange rate as overvalued, and half as undervalued. This difference in opinion makes fundamentalist' net demand zero so they have no effect on the market. When the exchange rate is far from the true fundamental value, the majority of fundamentalists are able to agree whether the exchange rate is under or overvalued. This agreement results in the fundamentalists working together to move the exchange rate back towards fundamentals, with the degree of mean reversion increasing with the deviation from equilibrium.

This model also highlights an intriguing possibility: that the apparent unpredictability of the exchange rate is caused by the underlying dynamics being chaotic. The authors show that when the degree of extrapolation by chartists is sufficiently high, the dynamic path of the exchange rate becomes highly sensitive to small variations in the initial values of the parameters (technically, this is termed sensitive dependence upon initial conditions). Furthermore, the time series produced by the model seem apparently random in the time domain, in spite of the fact that no noise is added to the model. This finding is important, because it shows that the model provides a structural theory which can account for the apparent failure of economic models to forecast exchange rates.

While chaotic series appear random in the time domain, they do contain well defined structure in the frequency domain. This allows for the construction of statistical tests which can potentially distinguish between series dominated by deterministic chaos, and those which are largely stochastic. These tests include the BDS test (Brock, Dechert, and Scheinkman (1987)), as well as tests based upon correlation dimensions and maximum Liapunov exponents. However, extensive testing by a number of studies (see, inter alia, Hsieh (1989) and LeBaron (1994)), have typically been unable to find evidence of chaotic dynamics, and have instead attributed the evidence of nonlinear dynamics in exchange rates to lower dimension nonlinearities. These findings provide some of the motivation for the types of nonlinear behaviour studied in subsequent chapters.

## 2.5 Policy Options to Address Misalignments

### 2.5.1 The Tobin Tax

The explosion in foreign exchange trading since the collapse of the Bretton Woods agreement in 1973 has coincided with a string of spectacular currency crises, with recent examples ranging from the collapse of the European Exchange Rate Mechanism in 1992-3 to the contagious currency crises which ripped through Asia in 1997, and the traumatic experience of Argentina in 2001, amongst others. One view which gained popularity in the mid 1990s was that there is a strong connection between these crises and the extremely high foreign exchange trading volume discussed in the previous section.

This has led some researchers and policy makers to postulate that if there is a causal relationship from trading volume to exchange rate volatility, then policy measures which reduce the 'wrong-kind' of trading could help stabilize exchange rates. Surveys suggest[9] that more than 40% of all transactions in foreign exchange markets involve round trips of fewer than three days. Since this type of short term trading is unlikely to be for purposes of, e.g. long-term capital investment, it has been highlighted as a likely source of short-run volatility. Because of this, there have been periodic calls to "throw sand into the wheels of international capital markets" in order to reduce the destabilizing speculation blamed for the apparent inefficiency in foreign exchange markets.

One policy measure which is designed to achieve this goal is the 'Tobin tax'. In its original form this is a small tax rate applied to transactions in foreign currency. First fully articulated by Tobin (1978), the goal of such a tax would be to reduce the influence of destabilizing speculative activity in foreign exchange markets. Some of the intended benefits include the following: a) Reduce the volume of foreign exchange transactions and thereby reduce the volatility of foreign exchange rates. b) Reduce the returns to short-term speculation. c) Reduce the amount of speculation and the incidence of speculative currency attacks. d) Reduce the volume of speculative flows of 'hot money' and other short-term investments, and encourage long-term investment. e) Reduce the volatility of international capital flows.

[9]See, BIS (2002)

The key feature of a Tobin tax is that it designed to discourage short-term speculative trading. Because it is a tax on transactions, it is paid twice, once when purchasing an asset, and once when selling it. As such it automatically discriminates against short-horizon capital flows. For example, a 0.2% tax on a round-trip investment to another currency costs 48% a year if transacted every business day, 10% if every week, 2.4% if every month. But it is a trivial charge on commodity trade or long-term investments.

An important assumption inherent in the Tobin tax proposal is that a significant proportion of short-run trading amounts to destabilizing speculation. Frenkel (1996) develops a variation of the chartist-fundamentalist model outlined in section (2.4.4) to illustrate how a Tobin tax can weaken destabilizing forces in this case. He distinguishes between two groups in the market: investors and speculators. The behaviour of investors is oriented on the long term, and they trade only on deviations of the exchange rate from its fundamental equilibrium value. Speculators, by contrast, take a short-term view and buy currency that is already (slightly) overvalued, i.e. they exacerbate exchange rate misalignments. The total demand for home currency is given by a function that captures the different behaviour of the two groups.

Now assume that the actual exchange rate (expressed in units of foreign currency per unit of home currency) is higher than its equilibrium value, so that the foreign currency is overvalued. Investors will then buy the home currency which tends to depreciate the exchange rate, whereas speculators sell. The Tobin tax then emerges as an instrument that strengthens demand by long-term investors with stabilizing expectations since the tax only has a small impact on their (relatively infrequent) trades, whilst having a large impact of the (frequent) trades of speculators.

The underlying effects of the tax are modelled more fully in an evolutionary framework by Westerhoff (2003). He develops a model of heterogeneous interacting agents who either speculate by employing a trend-following forecasting rule, invest on the basis of macro fundamentals, or abstain from the market completely. Their decision depends on both the past profitability of different strategies, as well as communication between agents. He shows how, in this set up, the imposition of Tobin tax leads to a crowding out of speculators and stabilizes the dynamics. However, since to a lesser extent fundamentalists are crowded out as well, their decreasing numbers can result in persistent misalignments if tax rates are too high.

These models provide a broad picture of the likely effects of the tax on dealers. A tax on foreign exchange transactions must increase the bid-ask spread of dealers and reduce the volume of trading. At the same time, the average maturity of foreign exchange transaction would increase in length. This is illustrated in existing markets, where bid-ask spreads caused by transactions costs explain a relatively strong decline of spot transactions relative to outright forward contracts.

While the bifurcated view of the market given above provides a useful model for understanding the causes of exchange rate volatility and misalignments, the theoretical effects of the tax are significantly altered once allowance is made for the risk-management role of inter-dealer trading. In fact, there is a significant risk that a potentially dramatic reduction in trading volume which could be produced by a Tobin tax, may well lead to an *increase* in erratic movements in markets.

As mentioned in the section (2.4.2), around 80% of trades in the foreign exchange market are carried out between dealers in 'hot potato' trading. Having received an order from a customer, hot potato trading is the search process for a counterparty which is willing to accept the new currency position. Lyons (2001) suggests hot potato trading is consistent with a dealer's optimizing behaviour. Every currency dealer wants to restore the equilibrium befitting her degree of risk aversion when she is too long or short a currency due to a customer order. Thus the passing of unwanted positions is a consequence of dealers' risk management.

There are two key implications of this process: first, the price decline of the foreign currency will be smaller if many dealers carry only a fraction of the initial order instead of one dealer who is willing to hold all. This stems from the (realistic) assumption that dealers are risk averse. Higher positions will only be carried if a higher risk premium is paid. Second, total risk is shared amongst many dealers and therefore can be spread around more efficiently. When viewed from this perspective, the levying of a Tobin tax could have severe consequences for market efficiency. As De Grauwe (2000) points out, a tax on each trade causes the search for risk spreading to become more expensive, and consequently ends up with more risky positions being taken in the market and higher volatility.

In response to these concerns, Tobin (1996) suggests that the tax should only be applied to customer-dealer transaction, not to inter-dealer. However, it is not clear how this could be achieved in practice. On the one hand, exempting inter-dealer trades from the tax would simply encourage tax-free transactions by and through intermediaries; while taxing them would entail efficiency costs (Spahn (1996)).

Furthermore, a Tobin tax might prove a greater burden on an international (real) trade transaction followed by hot potato trading than for short-term speculative transactions without hedging. By way of example, Davidson

(1997) compares the effect of a Tobin tax of 0.5 percent on a purely speculative trade, and foreign trade in goods and services followed by a chain of four hot-potato trades. The former would be equivalent to a tax of 0.5%, while the latter would amount to a tax of 2% - exactly the opposite of the tax's original intention.

The customers of wholesale dealers range from exporters and importers, direct investors or portfolio investors (such as hedge funds, investment funds, insurance companies) and other institutional investors. The government and central bank also take part as actors on foreign exchange markets. Finally, a small proportion of the trade is executed in retail transactions through commercial banks or credit card companies for tourism or for cross-border transactions of private households.

Final customers in general, and particularly traders in the retail segment are able to profit from relatively large bid-ask spreads. These spreads are wider, the lower the liquidity in the particular segment of the market, the less price-elastic local demand, and the higher the degree of information asymmetry that warrants some monopoly rents. If the effect of the tax is a widening of spreads and a reduction in wholesale trading, this would affect different market participants in the following way (see Felix and Sau (1996)).

At the shortest end of the market, i.e. in particular for 'covered interest rate arbitraging', transactions costs create something like a 'neutral zone' within which there are no profits from arbitrage and transactions therefore do not take place at all (Spahn (2002)). This zone would be widened by the transactions tax, making it more difficult for currency traders to pass on their 'hot potatoes' to other traders.

A similar argument also applies to currency trading by hedge funds. The risks of highly speculative and risky trading conducted at uncovered interest parity (i.e. through the deliberate exposure to risks through 'open positions'), are extremely high, and frequently amplified by leveraged borrowing. As a result, the hedge fund market segment requires large bid-ask spreads. For this reason, a transactions tax with a relatively small rate adding to an already large neutral zone for trading is unlikely to exhibit deterring effects (Spahn (2002)).

However, a Tobin tax could potentially contribute to lower volatility and therefore limit the scope of action for speculative trading by hedge funds (Felix and Sau (1996)). Note however, that this would only be the case if the tax did indeed lower volatility, not increase it as may in fact be the case (see above). Felix and Sau also argue that the central bank could use the greater freedom to act under the umbrella of a Tobin tax to speculate against the hedge funds and therefore reduce (or even eliminate) their profits - although this scenario seems somewhat far-fetched.

In addition to these concerns, the Tobin tax also faces considerable problems of enforceability. If the tax were imposed in only part of the world, then it would lead to the relocation of trading into other, untaxed countries. This would suggest that enforcement of the tax would require global political cooperation. Tobin (1996) argued that cooperation might be enforced by allowing local governments to keep the tax revenue, but this would simply shift the problem to the size of the tax rather than enforcement per se.

Although it was originally proposed that the tax would only be applied to foreign exchange transactions, it is clear that it would be possible to avoid the tax by trading in derivatives. The markets would likely develop cash substitutes that would escape the tax; hypothetical short-term instruments, similar to banker's acceptances and commercial paper, could be used to evade a cash-based tax, as could foreign exchange market funds and repurchase agreements (made against collateral and not settled on central bank accounts). Moreover, financial derivatives (such as forwards, futures and swaps) permit the transformation of 'long trading' into 'short trading' with important repercussion on spot markets.

This problem cannot be resolved simply by extending the tax to transactions in derivatives because the size of such transactions cannot be related to the underlying long transactions in a straightforward manner. A Tobin tax on the transactions themselves would understate the volume of funds that can be channeled through foreign exchange markets; however, taxing the notional value of a derivatives contract would probably severely damage the efficiency of derivatives markets. Given the important role played by the forwards and futures markets in hedging risks related to exchange rate fluctuations, the weakening of derivatives markets would also increase the sensitivity of the economy to spot market fluctuations.

Another option which has been proposed by Spahn (1996) to avoid these problems is the so-called 'two-tiered' Tobin tax. This proposal has two levels of taxation, one low rate which applies during 'normal' market conditions, and a so-called 'exchange rate surcharge': a high tax rate intended to deter speculation, and triggered only when the exchange rate crosses a pre-determined threshold.

The Spahn (1996) proposal is aimed at addressing a major problem of a Tobin tax: if imposed at a high rate the tax would seriously impair the normal operations of financial markets; while if the tax is imposed at a low rate it would not deter currency traders who expect significant short-term changes in currency values. The top tier of Spahn's proposed tax–the exchange surcharge–would function as an automatic circuit breaker whenever speculative attacks against currencies occurred. Spahn argues that when the surcharge was triggered, transactions costs would rise enough to cause some traders to delay transactions, thus smoothing out changes in the value of the currency. Revenues from the tax might be allocated to the countries of origin, to an international body, or in some other fashion.

Unfortunately, this two-tiered tax also suffers from a number of problems. Firstly, in common with Tobin's original proposal, in particular the impact on liquidity of the exchange rate surcharge would potentially be enormous, and could severely damage traders' risk management. Furthermore, the two-tiered tax would also suffer from the need for worldwide enforcement and potential tax evasion via the derivatives markets. In addition to these concerns, Spahn's proposal suffers from other problems due to the use of a variable rate tax. In practice, such taxes are rarely used. The main reason for their unpopularity is that they create uncertainty over prices in markets. This is, in fact, the feature of Spahn's proposed variable surcharge that could make it effective in altering market behavior. But at the same time, in the absence of volatility, the additional uncertainty it would create in financial markets is likely to impair their operation and increase spreads. Variable-rate taxes are also rarely used because they complicate considerably the burdens on taxpayers and tax administrations. This effect would be particularly severe in the case of a two-tier Tobin tax because the number of separate transactions to which the tax would apply is so huge.

In general then, although the Tobin tax seems an appealing approach at first sight, there are clearly many problems with its potential use for the reduction of exchange rate misalignments. In the next section, I turn to a policy measure which has most frequently been employed by industrialized countries since 1973, that of sterilized intervention.

### 2.5.2 Managed floating and sterilized intervention

### 2.5.3 Foreign exchange intervention

The Tobin tax discussed above represents a controversial policy measure to tame excessive exchange rate fluctuations. The simplest alternative is for monetary authorities to maintain their bilateral exchange rates within some bounds via sales or purchases of foreign currency. However this kind of intervention amounts to the dedication, at least to some degree, of monetary policy to maintaining a stable exchange rate.

In this way, large, persistent deviations in exchange rates from equilibrium can create something of a dilemma for monetary policy makers[10], since

[10]See, for example Wadhwani (2000)

monetary policy targeted at correcting exchange rate misalignments may be at odds with maintaining internal balance in the economy. In order to avoid the problems which may arise in using monetary policy to correct exchange rate misalignments, monetary authorities occasionally engage in *sterilized* foreign exchange intervention.

In a *non*-sterilized intervention, the authorities may try to influence the exchange rate by purchasing foreign currency denominated bonds using domestic currency. In this way the authorities' demand for foreign bonds would put upward pressure on the foreign currency, and hence tend to lower the value of the domestic currency. However, the domestic central bank has to increase the domestic money supply in order to fund the purchase, and thus puts pressure on domestic interest rates to fall.

To offset this pressure, the authorities can 'sterilize' the intervention. To do so, they must reverse the pressure on domestic interest rates by selling home currency denominated bonds in return for domestic cash. The net effect is to raise the relative supply of home currency verses foreign-currency bonds held by the public. The 'portfolio balance' theory of intervention holds that, if domestic and foreign assets are imperfect substitutes, then a risk averse public will require an increased return on the domestic currency bonds to willingly hold the increased supply which, given that interest rates have remained constant, can only be effected by a depreciation in the domestic currency.

At the outset it should be noted that there are several important caveats which, in theory at least, limit the potential impact of sterilized intervention. For example, the rational described above for the effect of sterilized intervention depends on a change in the relative supplies of domestic and foreign outside assets. Outside nominal assets are those nominal assets which do not net out when aggregating across the private sector; that is, non-indexed government bonds and the monetary base. However, the distinction between inside and outside bonds is meaningless in models where infinitely lived homogeneous agents leave bequests to their infinitely lived family units. For example, Obstfeld (1982) and Stockman (1979) rigourously demonstrate the impotence of sterilized intervention in such models, even where bonds denominated in different currencies are imperfect substitutes due to exchange rate risk.

Furthermore, sterilized intervention will alter the government's net asset position and thus necessitate fiscal changes that maintain intertemporal budget balance. Therefore in a world where Ricardian equivalence holds, so that private agents offset expected future tax payments (which will be required to service extra government debt) against currency holdings of domestic bonds, imperfect substitutability alone would no longer be sufficient for sterilized intervention to influence the current exchange rate.

In addition to these theoretical concerns, how effective interventions are in practice is also a matter of some controversy. The evidence that intervention operations have the desired effects on exchange rates through conventional channels: by changing the 'fundamental' level of the exchange rate through portfolio balance channels, or by signaling to markets the future course of monetary policy is somewhat mixed.

The majority of previous literature has focused on the workings of sterilized intervention either through the portfolio balance effect, or via the signaling of future government policies. There are many excellent and detailed surveys are on the empirical evidence regarding these effects of sterilized intervention, provided, for example by Dominguez and Frankel (1993b), Edison (1993) and Almekinders (1995), and more recently by Sarno and Taylor (2001). As described above, the portfolio-balance effect can be motivated by the theory of mean-variance portfolio selection, where risk averse agents choose their optimal portfolio, which is composed of domestic and foreign currencies and bonds, so as to maximize their terminal wealth. Then sterilized intervention will affect the exchange rate when agents readjust their portfolios of domestic and foreign-denominated bonds in line with the changes in the outside supplies of those assets. This approach has been pursued by Dominguez and Frankel (1993a,b), with critiques provided by Humpage (1988), Obstfeld (1989), and Ghosh (1992). Given the small size of intervention operations compared with the size of asset stocks, there can be little surprise that evidence in support of the theory is in short supply.

The second channel whereby intervention can influence exchange rates is termed the signalling, or information channel. This view of intervention as a signal of the central banks's future monetary policy implies that a sterilized purchase of foreign currency is expected to lead to a depreciation of the exchange rate if the purchase is assumed to signal a more expansionary domestic monetary policy. Klien and Rosengen (1991) find no consistent relationship between intervention and monetary policy, while Kaminsky and Lewis (1996) report that the impact of intervention on the exchange rate has sometimes been inconsistent with the implied monetary policy. Humpage (1997) concludes that the US authorities in the 1990's had no information superior to the market so that intervention could not be viewed as signalling new information about monetary policy. The apparent failure of the signalling hypothesis is perhaps not so surprising given the monetary model's failure to predict exchange rate movements. If there is little direct transmission between changes in relative money supplies and movements in short term exchange rates, then it is also unclear why signalling monetary policy should have a substantial effect on exchange rates.

### The noise trader channel

The general view taken by monetary authorities of how sterilized intervention effects exchange rates in practice seems to differ markedly from the 'traditional' channels outlined above. Rather than attempt to influence the *equilibrium* level of the exchange rate, sterilized intervention operations are generally undertaken when the authorities view the exchange rate to be under or overvalued. Thus interventions are carried out with the intent of reducing current *misalignments*, or indeed excessive volatility. The rationale for this kind of intervention operation is best viewed in the light of the use of technical analysis by FOREX traders discussed in the previous section. Wadhwani (2000) notes "Under some circumstances, FX intervention can give the fundamentals-based traders greater confidence to initiate positions during overshoots. Alternatively, in an over-extended market, intervention can sometimes directly affect the behaviour of the momentum-based traders." The analogy employed by Dominguez and Frankel (1993b) for FX intervention emphasizes this nicely. They liken the role of intervention to the role of herd dogs amongst cattle. Clearly a small number of dogs cannot always sustain control of the steers. So, when a stampede gets underway because each panicked steer is following its neighbours, the herd can wander off quite far from their initially desired direction. However, the dogs can be helpful in a stampede because, by turning a few steers around, they might induce the herd to follow.

While this provides a strong intuitive description of how intervention may 'prick bubbles' in exchange rates, it is only very recently that researchers have begun to rigorously examine the mechanisms by which intervention may produce this kind of effect. One notable example is work by De Grauwe and Grimaldi (2003). Independently of the work undertaken for this dissertation, these authors employ a similar approach to that taken here, investigating the impact of sterilized intervention in a model based on the framework introduced by Brock and Hommes (1997). However these authors focus on the impact of intervention on the second moments, or volatility of the exchange rate. They find that sterilized interventions can be effective in reducing the noise generated by the use of trading rules. Other related work is conducted by Jeanne and Rose (2002), who have employed the noise trader approach to provide an explanation of the excessive volatility of exchange rates under a float. In a similar spirit to the model presented here, they show that the presence of noise traders can lead to multiple equilibria in the forex market. Employing an exchange rate "target zone" following

Krugman and Miller (1993), they show how an exchange rate target zone can allow the policymaker to co-ordinate activity to a low volatility equilibrium while leaving macroeconomic fundamentals unchanged. An important difference between the research presented here and that of Jeanne and Rose (2002) is to show how essentially the same goal can be achieved by using *sterilized* intervention.

In addition there are two empirical studies which test for the kinds of effect modelled in this dissertation. Hung (1997), employs a noise trading framework to explain the impact of US intervention on exchange rate volatility. He finds that intervention by the US FED reduced both yen/dollar and DM/dollar exchange rate volatilities during 1985-1986, but increased them during 1987-1989. Taylor (2003) examines the effectiveness of intervention within the context of a Markov-switching model for the real exchange rate. The probability of switching between stable and unstable regimes depends nonlinearly upon intervention, the degree of misalignment and the duration of the regime. Applying this to dollar-mark data for the period 1985-1998, he finds that intervention increases the probability of stability when the rate is misaligned, and that its influence grows with the degree of misalignment.

# Chapter 3

# Sterilized intervention in a model with trader heterogeneity: theory

## 3.1 Introduction

In order to examine the effectiveness of sterilized intervention in a framework where there can be large and persistent deviations from equilibrium exchange rates, I focus on models of the forex market which explain exchange rate dynamics as in a world with heterogenous expectations. In particular, I draw on the work of Brock and Hommes (1997, 1998, 1999) on periodically collapsing bubbles in the stock market. In their work, traders are modelled as selecting alternative forecasting strategies on the basis of an 'evolutionary fitness rule'. I.e. The forces of evolution - the survival of the fittest - determine which trading strategies survive to be used in the following period. The 'fitness' of a trading strategy can be modelled in a variety of ways, e.g. as a function of realized net profits or mean squared prediction errors. A key parameter in these models is the 'intensity of choice', which measures how sensitive traders are to differences in fitness across strategies when selecting their optimal trading rule. In this framework, Brock and Hommes have demonstrated how price fluctuations are characterized by irregular switching between phases of fluctuations close to fundamentals, phases of optimism where most agents follow an upward trend, and phases of pessimism with small or large market crashes. This class of model provides an explanation for temporary speculative bubbles which are triggered by noise and reinforced by evolutionary forces.

Within this framework, I model the effects of sterilized foreign exchange intervention in the spirit of the portfolio-balance class of models: where intervention changes the outside supplies of domestic and foreign assets, resulting in a change in the risk premium. In general this 'portfolio balance effect' has only found weak support in empirical studies: the size of sterilized intervention operations conducted by monetary authorities are generally deemed to be too small to have significant portfolio balance effects in practice. However, in the evolutionary model presented here, changes in the supplies of assets may affect the exchange rate substantially: by inducing a change in the composition of the forecasting rules employed by traders in the market. Since realized profits are determined by the realized excess return of foreign bonds, realized profits are also influenced by the risk premium. Thus the fitness of a forecasting strategy may also be influenced by sterilized intervention operations. *The authorities may use intervention to co-ordinate traders on to trading strategies which are based on economic fundamentals rather than strategies based on technical trading rules and trend-chasing.*

The plan of this chapter is as follows. Section (3.2) presents the model, while the numerical analysis of the exchange rate dynamics in the model without intervention are examined in section (3.3). The effects of intervention on the exchange rate are analyzed in section (3.4), and section (3.5) concludes.

## 3.2 The model of strategy choice

While the chartist-fundamentalist models outlined in chapter 1 have considerable intuitive appeal there seems to be room for improvement on a number of fronts. The key implication of Frankel and Froot's model is that in the short run, the weight of traders who employ each strategy changes according to the group's respective wealth. As long as chartists continue to make money, in the long run fundamentalists will be driven out of the market entirely. This would imply an explosive path for the exchange rate, with the potential for no mean reversion. An appealing alternative to this approach is developed in a series of papers by Brock and Hommes (1997, 1998, 1999). I draw on their work to model how beliefs are updated over time i.e. how the fractions $\omega_{ht}$ evolve. The framework they develop represents a significant advance on previous studies for a number of reasons. Firstly, rather than select the appropriate trading strategy on the basis of the essentially ad hoc measures proposed in other studies, agents select forecast rules in a (boundedly) rational manner, on the basis of a 'fitness' or 'performance' measure which is a function of the profits from each strategy. Agents are boundedly rational in the sense that they choose the strategy with the highest fitness, so that strategies with highest performance will dominate the evolutionary dynamics. Brock and Hommes make this evolutionary selection operational by drawing on random utility models and the theory of discrete choice.

### 3.2.1 The set of available trading strategies

In order to keep the discussion as simple as possible, heterogeneity in the expectations of traders is modeled in the following way. Each period, given the level of last periods exchange rate $s_t$, traders may either pay a fixed cost[1], $C$, to purchase a forecast based on macroeconomic fundamentals:

$$f_{fund,t} = vs_{t-1} \qquad 0 < v < 1. \tag{3.1}$$

or they may simply extrapolate recent trends by employing a generic chartist rule:

$$f_{chart,t} = gs_{t-1} \qquad g > 1, \tag{3.2}$$

The assumption that $g > 1$ implies that traders following the chartist strategy expect the overvaluation of a currency to extend further next period. $0 < v < 1$ implies that traders using the fundamentalist strategy expect any currency overvaluation to be reduced next period, at a rate of $1 - v$.

### 3.2.2 Selection between competing trading strategies

The model of strategy choice extends work by Brock and Hommes (1997), so that traders select their strategy on basis of an evolutionary 'fitness mea-

[1]This cost represents the information gathering cost necessary to correctly forecast the level of the equilibrium exchange rate, and may by no means be insignificant. For example, De Grauwe, Dewatcher, and Embrechts (1994) note that in a world where authorities are bound by few commitments the number of possible future paths of debt and money is increased. This is due, both to the move toward floating exchange rates, and also to the dramatic increase in international capital mobility allowing for a much wider range of debt financing options than before. The net effect is that correct forecasting of the equilibrium exchange rate is more difficult, and hence costly.

sure'. There are a number of possible candidates for the variables which influence the fitness of each strategy. Brock and Hommes specify the fitness rule as depending on accumulated realized profits, while Gaunersdorfer and Hommes (2000), specify evolutionary fitness given by risk adjusted profits. In a recent paper, De Grauwe and Grimaldi (2004) develop a model of the forex market where the fitness measure is a function of the one-period earnings of investing in the foreign asset. The authors point out that this ensures strategy selection is influenced only by the relative *profitability* of the strategies, and not by the amount invested. They motivate this specification of the fitness rule by it's emphasis on the selection of strategy independent of agent's stock of wealth. In Brock and Hommes (1998) it is shown how, with realized profits as the fitness measure, stock prices may be characterized by endogenously expanding and collapsing bubbles. However, with this simple form this result is only obtained either when traders beliefs are biased in some way, or when traders employing *all* strategies continuously make losses.

One method of rectifying this situation to adopt the approach of Gaunersdorfer and Hommes (2000), for example. In that paper, the fitness of any strategy is assumed to be conditioned upon the deviation from equilibrium. This has the effect of ruling out explosive paths for the asset price, even when the profits to traders following chartist strategies increase as more traders co-ordinate onto that strategy. Hommes (2000) justifies this conditioning upon fundamentals as a weakening of the transversality (no bubbles) condition in a perfectly rational world, allowing for temporary speculative bubbles.

In this thesis I adopt an alternative approach to those discussed above. In addition to evaluating past realized profits from each strategy, traders are also assumed to consider their opportunity cost from not investing an identical amount in the alternative strategy. In effect, traders care about both the *potential* winnings from a gamble, as well as their observation of the gambles *past performance.* Thus, in this thesis the fitness of each available strategy is assumed to be given by a weighted function of past realized profits, and expected profits next period[2].

The fitness of strategy $h$ then takes the form:

$$U_{h,t} = (1-\delta)\rho_t z_{h,t-1} + \delta z_{j,t} z_{h,t} - C_h, \tag{3.3}$$

where $\rho_t$ is the excess return on the risky asset, $z_{h,t}$ represents the demand

[2]It should be noted that at a technical level this amounts to including additional lags in the fitness function, and is observationally equivalent to traders having longer memory when comparing past realized profits.

for the risky asset by traders employing strategy $h$ and $z_{j,t}$ strategy $j$, and $\delta$ is an exogenous parameter giving the weight traders place on the expected component of the fitness function. $C_h$ represents the cost of purchasing each strategy, and for the chartist strategy is assumed to be zero so that $C_c = 0$, and $C_f = c$. This form of fitness function assumes that, when deciding upon which strategy to employ, traders compare both the realized profits last period, and the size of expected profits next period from each strategy.

While the fitness measures of all trading strategies are publicly available, they are subject to noise arising from shifts in preferences. The random utility model for evaluating such rules is given by

$$\widetilde{U}_{ht} = U_{ht} + \varepsilon_{ht} \tag{3.4}$$

where $\varepsilon_{ht}$ is IID across $h = 1, \dots, H$ and drawn from a double exponential distribution. As the number of traders goes to infinity, the probability that an agent chooses the fundamentalist strategy is given by the discrete choice model:

$$\omega_{f,t} = \frac{1}{1 + \exp(\beta(U_{c,t-1} - U_{f,t-1}))}. \tag{3.5}$$

Thus the higher the fitness of trading strategy $h$, the more traders will select $h$. The 'intensity of choice' parameter $\beta$ measures the proportion of traders who select the optimal prediction strategy. $\beta$ is inversely related to the variance of the noise terms $\varepsilon_{ht}$. If $\beta = 0$, the variance of the noise is infinite, so that traders are unable to discern any difference in the fitnesses of available strategies and all fractions (3.5) will be fixed over time to equal $1/H$. The other extreme case $\beta = \infty$ corresponds to the case without noise, so that the deterministic part of the fitness measure can be observed perfectly, and in each period, *all* traders choose the optimal forecast. In general, higher values of the intensity of choice $\beta$ represent an increase in the degree of rationality of traders when selecting their strategy.

To summarize: financial markets are modeled as an evolutionary system between competing trading strategies, following Brock and Hommes (1997,1998). While all traders are aware of the fitness of each competing strategy, they are unaware of the proportion of traders employing each strategy at any given time. The fitness of each strategy is modelled as a function of it's realized profits last period, and it's prospective gain next period.

As will be seen later, these evolutionary dynamics can result in the exchange rate displaying persistent, endogenous, exchange rate fluctuations which are triggered by a rational choice between speculative, self-fulfilling trading strategies.

### 3.2.3 Foreign Exchange Market

To establish the equilibrium level of the exchange rate implied by macroeconomic fundamentals, we begin by considering a simple monetary model of the exchange rate. With money market equilibrium in the home and foreign countries, and assuming PPP holds continuously

$$m_t - p_t = \gamma y_t - \alpha i_t \tag{3.6}$$

$$m_t^* - p_t^* = \gamma y_t^* - \alpha i_t^* \tag{3.7}$$

$$s_t = p_t - p_t^* \tag{3.8}$$

so that:

$$s_t = (m_t - m_t^*) - \gamma(y_t - y_t^*) + \alpha(i_t - i_t^*) \tag{3.9}$$

Sterilized foreign exchange intervention is introduced into the model via the portfolio-balance view that changes in the outside supplies of assets denominated in domestic and foreign currency alter the risk premium on foreign bonds. Let $E_{h,t}$ denote the forecast of a trader employing strategy type $h$. Then such a trader who has entered the foreign bonds market invests $z_{h,t}$ in foreign bonds so as to maximize the utility of her end of period wealth, expressed in terms of the domestic currency. Then, traders following strategy $h$ are assumed to have the following portfolio allocation problem at time $t$:

$$max_{z_{h,t}} U_{h,t} = E_{h,t}[-exp(-aW_{h,t+1})] \tag{3.10}$$

where $W_{h,t+1}$ is the end of period wealth of trader type $h$. Wealth dynamics are given by

$$W_{h,t+1} = \alpha(1+i)w_{h,t} + (1-\alpha)(\rho_{t+1})z_{h,t} \tag{3.11}$$

where $\rho_{t+1}$ is the excess return on foreign bonds between $t$ and $t+1$, and $\alpha$ is the share of the investors portfolio in domestic bonds. It is well known that maximizing (3.10) when returns are normally distributed, is equivalent to the problem

$$max_{z_{h,t}} \{E_{h,t}[W_{t+1}] - \frac{a}{2} V_{h,t}[W_{t+1}]\} \tag{3.12}$$

so that, solving the maximization problem we have

$$z_{h,t} = \frac{E_{h,t}[\rho_{t+1}]}{aV_{h,t}[\rho_{t+1}]} \tag{3.13}$$

Assuming that $V_{h,t}[\rho_{t+1}] = \sigma^2 \; \forall h$, the demand for foreign bonds by a trader of type $h$ can be written as

$$z_{h,t} = \frac{E_{h,t}[\rho_{t+1}]}{a\sigma^2} \tag{3.14}$$

so that total demand for foreign bonds is given by

$$Z_t = \sum_{h=1}^{H} \omega_{h,t} \frac{E_{h,t}[\rho_{t+1}]}{a\sigma^2} \tag{3.15}$$

In equilibrium, equating world demand for foreign bonds with world supply, it can be shown (see, for example Flood and Marion (2000)) that the linearized risk premium on foreign bonds is given by

$$a\sigma^2(c + b_t - b_t^* - s_t) = i_t - i_t^* - \sum_{h=1}^{H} \omega_{h,t} E_{h,t}[s_{t+1} - s_t] \tag{3.16}$$

Equation (3.16) is the interest parity condition, which shows how the domestic interest rate deviates from the foreign interest rate, $i_t^*$, by the markets' expectation of the rates of change of the exchange rate, $\sum_{h=1}^{H} \omega_t E_{h,t}[s_{t+1} -$

$s_t]$, plus a time varying risk premium, $a\sigma^2(\cdot)$. The risk premium is influenced by the relative private holdings of domestic and foreign government securities, agents's attitudes towards risk, and uncertainty about the future exchange rate. The term $(b_t - b_t^* - s_t)$ measures the worldwide private holdings of domestic relative to foreign government securities. The term $a\sigma^2(\cdot)$ summarizes how desired asset holdings are influenced by tastes toward risk and uncertainty about returns. If intervention operations increase the supply of domestic relative to foreign assets held by the market, then investors will require a higher expected return on domestic assets to willingly hold the larger outstanding stock, leading to a depreciation of the domestic currency.

In order to directly consider the effects of sterilized intervention on the determination of the exchange rate, note that the relative stock supplies of outside assets are equivalent to cumulated intervention[3] $\Upsilon_t$.

So that (3.16) may be written

$$s_t = (i_t^* - i_t) + a\sigma^2\Upsilon_t + \sum_{h=1}^{H} \omega_{h,t} E_{h,t}[s_{t+1}] \tag{3.20}$$

[3]Sterilized intervention is equivalent to the *change* in demand for foreign bonds, i.e.

$$a\sigma^2\Upsilon_t = E_t[\rho_{t+1}] - E_{t-1}[\rho_t] \tag{3.17}$$
$$= E_t[\rho_{t+1}](1 - \mathcal{L}) \tag{3.18}$$

So that

$$E_t[\rho_{t+1}] = (1 - \mathcal{L})^{-1} a\sigma^2\Upsilon_t \tag{3.19}$$

Integrating the interest parity relation (3.20) and the simple monetary model implied by (3.9) we can express the market equilibrium equation as

$$s_t = \frac{1}{(1+\alpha)}(m_t - m_t^* - \gamma(y_t - y_t^*)) + \frac{\alpha}{(1+\alpha)} a\sigma^2 \Upsilon_t + \frac{\alpha}{(1+\alpha)} \sum_{h=1}^{H} \omega_{h,t} E_{h,t}[s_{t+1}] \tag{3.21}$$

Which is essentially a standard portfolio balance model of the exchange rate, augmented to allow for heterogenous expectations of market participants.

### 3.2.4 Updating Beliefs

In the above model of the forex market, realized profits may be written as

$$\pi_{h,t} = (i_t^* - i_t + (s_{t+1} - s_t)) \frac{(i_t^* - i_t + E_{h,t}[s_{t+1} - s_t])}{a\sigma^2} \tag{3.22}$$

Now, denoting relative money velocity $z_t = (m_t - m_t^*) - \gamma(y_t - y_t^*)$, and substituting in for the interest differential from (3.9), the excess return at time $t$ from holding foreign bonds is given by the following expression

$$\rho_t = (i^*_{t-1} - i_{t-1}) + (s_t - s_{t-1}) \tag{3.23}$$

$$= \frac{1}{\alpha} z_{t-1} + s_t - \frac{(1+\alpha)}{\alpha} s_{t-1} \tag{3.24}$$

It is useful to rewrite the model in terms of deviations from the benchmark fundamental, rational expectations (perfect foresight) level of the exchange rate, $s^*_t$. So that

$$s_t = x_t + s^*_t \tag{3.25}$$

where $x_t$ is the deviation of the exchange rate from fundamentals. Then,

$$\rho_t = x_t + s^*_t + \frac{1}{\alpha} z_{t-1} - \frac{(1+\alpha)}{\alpha}\left(x_{t-1} + s^*_{t-1}\right) \tag{3.26}$$

$$= x_t - \frac{(1+\alpha)}{\alpha} x_{t-1} + s^*_t + \frac{1}{\alpha} z_{t-1} - \frac{(1+\alpha)}{\alpha} s^*_{t-1} \tag{3.27}$$

Since from the equilibrium equation (3.21)

$$s^*_t + \frac{1}{\alpha} z_{t-1} - \frac{(1+\alpha)}{\alpha} s^*_{t-1} = -a\sigma^2 \Upsilon_{t-1} \tag{3.28}$$

we then have

$$\rho_t = x_t - \frac{(1+\alpha)}{\alpha}x_{t-1} - a\sigma^2\Upsilon_{t-1} \tag{3.29}$$

Using this to express the fitness rule (3.3) for each strategy in terms of deviations from fundamental equilibrium, the relative fitness of the chartist strategy can be simplified considerably. Letting $q = g - v$, and combining the model of equilibrium in the forex market with the equations governing updating of beliefs, the general form of the model may then be written as

$$x_t = \frac{\alpha g}{(1+\alpha)}x_{t-1} - \frac{\alpha q}{(1+\alpha)}\omega_{f,t-1}x_{t-1} + \varepsilon_t \tag{3.30}$$

$$\omega_{f,t} = \frac{1}{1+\exp(\beta(U_{c,t-1} - U_{f,t-1}))} \tag{3.31}$$

$$U_{c,t-1} - U_{f,t-1} = \Big((1-\delta)x_{t-1} - \frac{(1+\delta)(1+\alpha)}{\alpha}x_{t-2} + \delta(g+v)x_{t-3} \tag{3.32}$$

$$- (1+\delta)a\sigma^2\Upsilon_{t-2}\Big)\frac{qx_{t-3}}{a\sigma^2} + c. \tag{3.33}$$

Note that a stochastic term, $\varepsilon_t$, is introduced to represent model approximation error

## 3.3 Exchange Rate Dynamics in the Absence of Intervention

The evolutionary selection of trading strategies by market participants described in previous sections can lead to endogenous fluctuations in the exchange rate which are unrelated to economic fundamentals. In this section, the processes by which these fluctuations arise are examined in detail. Initially, exchange rate dynamics are examined in the case where there is no intervention, i.e. where the outside supply of foreign bonds is normalized to zero. In conducting the stability analysis, we will initially consider the dynamics of the deterministic skeleton of (3.30) - (3.33). However, later we will conduct some simulation exercises in the presence of iid noise to better gauge the effect of interventions.

### 3.3.1 Analysis of Steady States

In the absence of intervention, the model closely resembles that considered by Brock and Hommes (1998). A key parameter governing the dynamics of the system (3.30) - (3.33) is the intensity of choice $\beta$. Recall that this parameter captures how sensitive the mass of traders are to deviations in expected profits from the available strategies. Thus, as $\beta$ increases, the proportion of traders on the most profitable strategy in net terms increases. The existence and stability of the steady states of the system as the intensity of choice varies is examined in the following lemma.

**Lemma 1 (Existence and stability of steady states with $\Upsilon = 0$).** *Let the steady state mass of chartists, $w^* = \frac{g}{q} - \frac{1+\alpha}{q\alpha}$. Then for $g < \frac{1+\alpha}{\alpha}$, there is* *a unique fundamental steady state* $E_0 = (0, \omega^{**})$, *with* $\omega^{**} = 1/(1+\exp[\beta c])$. *For* $g > \frac{1+\alpha}{\alpha}$, *there are two possibilities:*

1. $E_0$ *is the unique steady state if either*

   *(a)*

   $$(g+v) > 2 + \left(\frac{1+\delta}{\alpha\delta}\right) \quad \textit{and} \quad \exp(\beta C) > \frac{1-\omega^*}{\omega^*}$$

   *or*

   *(b)*

   $$(g+v) < 2 + \left(\frac{1+\delta}{\alpha\delta}\right) \quad \textit{and} \quad \exp(\beta C) < \frac{1-\omega^*}{\omega^*}$$

   .

2. *The fundamental steady state* $E_0$ *is unstable, and there are two stable, non-fundamental steady states* $E_1 = (x^*, \omega^*)$, $E_2 = (-x^*, \omega^*)$ *if either:*

   *(a)*

   $$(g+v) < 2 + \left(\frac{1+\delta}{\alpha\delta}\right) \quad \textit{and} \quad \exp(\beta C) > \frac{1-\omega^*}{\omega^*}$$

   *or*

   *(b)*

   $$(g+v) > 2 + \left(\frac{1+\delta}{\alpha\delta}\right) \quad \textit{and} \quad \exp(\beta C) < \frac{1-\omega^*}{\omega^*}$$

   .

From Lemma (1), we can see how the number and stability of the steady states changes according to the degree of extrapolation by chartists $g$. When this is low, $(0 < g < \frac{(1+\alpha)}{\alpha})$, then the fundamental steady state $E_0$ is globally stable. If costs $C = 0$, half of the traders are trend chasers, and half are fundamentalists for any value of $\beta$. If $c > 0$, then the mass of traders employing the fundamentalist strategy decreases to zero as $\beta$ or $c$ tends to $+\infty$. As the intensity of choice $\beta$ increases the proportion of traders on the most profitable strategy in net terms increases.

When chartists strongly extrapolate recent trends, so that $g > \frac{(1+\alpha)}{\alpha}$ and there are positive information costs for obtaining the fundamentalist strategy, for large a enough value of $\beta$, the qualitative behavior of the system changes. For $\beta = 0$, $\exp(\beta c) < \frac{\omega^*}{(1-\omega^*)}$, whereas for large $\beta$, $\exp(\beta c) > \frac{\omega^*}{(1-\omega^*)}$. Hence, as the intensity of choice increases, a *pitchfork* bifurcation occurs for some $\beta = \beta^*$, in which the fundamental steady state $E_1$ becomes unstable and two additional stable, non-fundamental steady states $E_2 = (x^*, \omega^*)$ and $E_3 = (-x^*, \omega^*)$ are created, one above and one below the fundamental. These non-fundamental steady states correspond to a special case where there are a constant proportion of traders using both the fundamentalist and chartist strategies. However, if these steady states were stable, it would imply that traders do not adjust their strategy choice despite the fact that both strategies consistently produce incorrect forecasts[4]. However, as we shall see in the next section, as the value of $\beta$ increases further, the non-fundamental steady states become unstable leading to endogenous fluctuations in the exchange rate. It is these fluctuations around the non-fundamental steady states which we refer to as 'bubbles' in this paper.

### 3.3.2 Endogenous Exchange Rate Fluctuations

As $\beta$ increases still further above $\beta^*$, the exchange rate begins to exhibit periodic fluctuations about the non-fundamental steady states. This process is described in Lemma (2).

**Lemma 2 (Secondary bifurcation, $\theta = 0$).** *Let $E_1$ and $E_2$ be the non-fundamental steady states as in Lemma (1). Assume $c > 0$ and $g > \frac{(1+\alpha)}{\alpha}$, and let $\beta^*$ be the pitchfork bifurcation value. Then as $\beta$ increases above $\beta^*$ there exists some $\beta^{**}$ at which $E_1$ and $E_2$ undergo a Hopf bifurcation at which $E_1$ and $E_2$ become unstable, and two limit cycles are created about $E_1$ and $E_2$.*

[4]It is interesting to compare the weighting of traders in the non-fundamental steady states here with that implied by De Grauwe and Grimaldi (2004). In their paper traders' strategies are defined in terms of exchange rate changes, with chartists expecting no change and fundamentalists expecting a move toward the fundamental equilibrium. In this case the non-fundamental steady state occurs where all traders follow the chartist strategy - so that the totality of traders expected no change in the exchange rate, thereby generating a self-fulfilling prophecy.

For sufficiently high values of $\beta$ the exchange rate dynamics are characterized by limit cycles around the unstable, non-fundamental steady states. An example is illustrated in the phase diagram, figure (3.1) below.

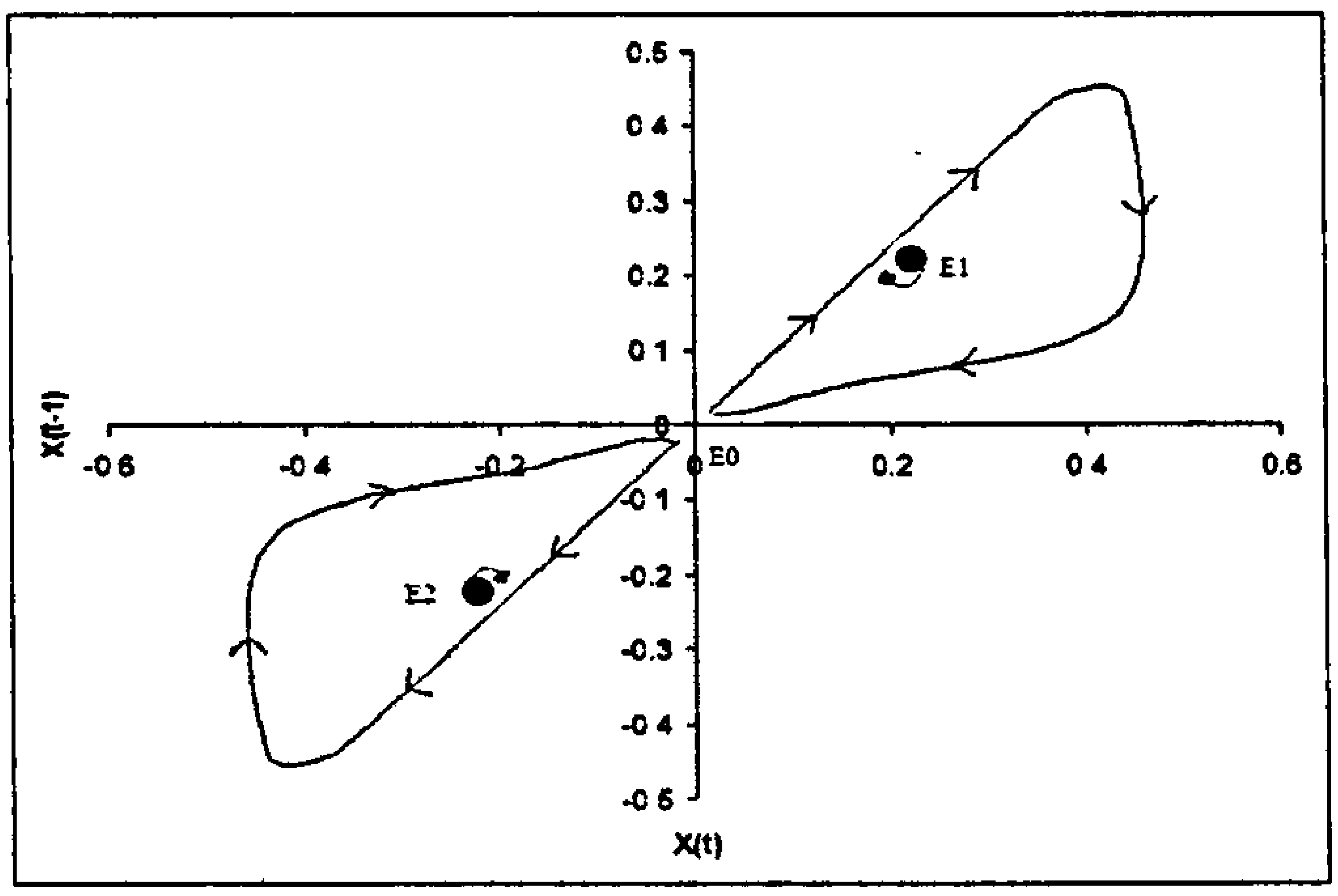



Figure 3.1: Limit cycles around the unstable non-fundamental steady states E1 and E2.

It is useful at this point to examine in some detail the processes at work in the market which lead to these periodic fluctuations, as illustrated in figure (3.2). The top two figures (a) and (b) show the path of the deviation of the exchange rate from equilibrium. It is characterized by movements away from equilibrium which gain in momentum, before a short dip in towards the fundamental, followed by a market crash. The one period excess returns to holding foreign bonds are illustrated in figures (c) and (d). Returns grow to a maximum as the exchange rate moves away from equilibrium to it's peak, and become negative when the crash occurs. Figures (e) and

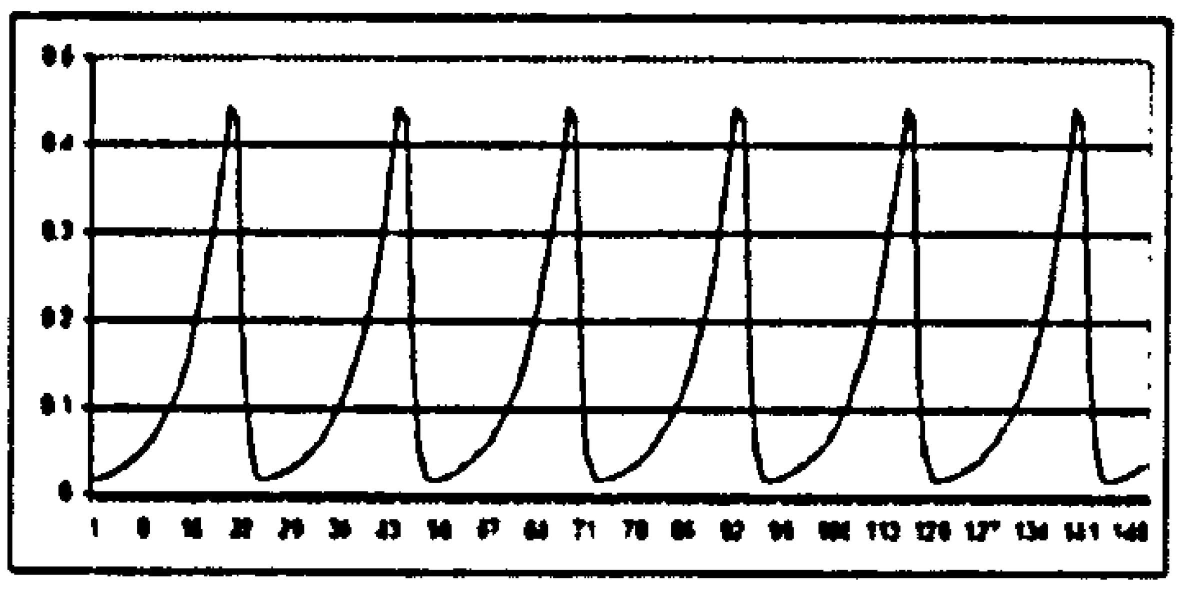
(f) show the demands for foreign bonds by traders employing the chartist and fundamentalist strategies respectively. It is clear from the figures that chartists purchase larger quantities of foreign bonds the further the exchange rate gets from equilibrium, while fundamentalists sell foreign bonds ever more strongly.

Profits to traders following each type of strategy are show in figures (g) and (h). Clearly, as long as the exchange rate moves away from the fundamental, chartists make profits, however, when the market crashes large losses are suffered by those traders who continue to follow the chartist strategy. Fundamentalists endure losses from the cost of obtaining the strategy, together with trading losses that rise as the deviation from equilibrium increases. However, once the market reversal begins, large gains are made.

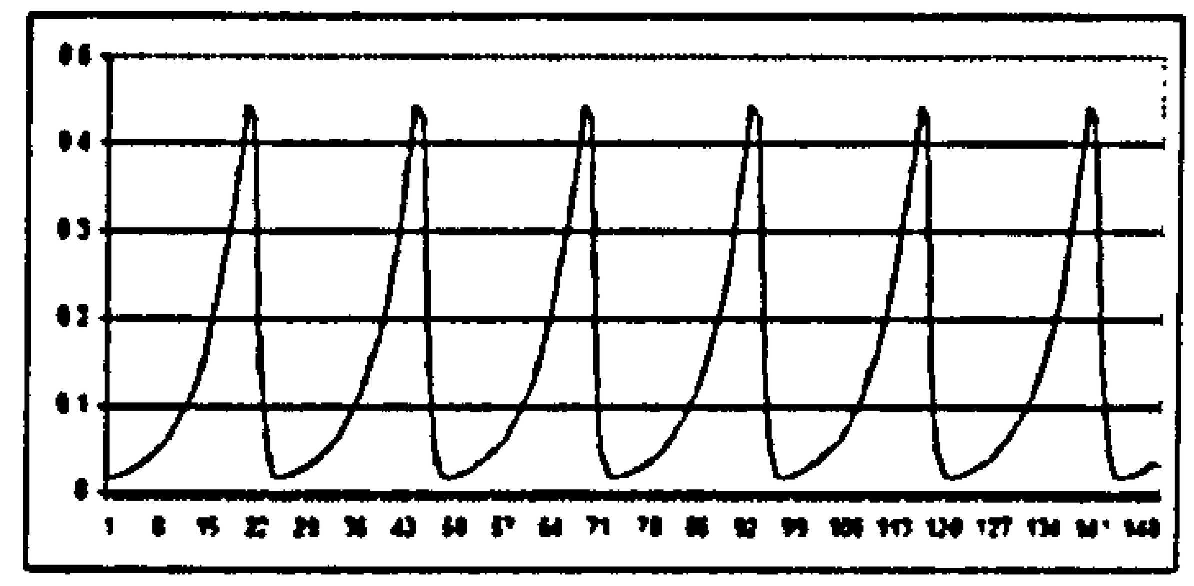
Finally, the proportions of traders following each strategy are illustrated in figures (i) and (j). Crucially, as the deviation from equilibrium rises, the mass of traders on the chartist strategy falls. This is because, as the deviation from equilibrium increases, the *prospective gains* from implementing the fundamentalist strategy rise at a faster rate than those of the chartist strategy. As a result, the relative prospective profitability of the chartist strategy over the fundamentalist strategy falls the further the exchange rate moves away from fundamentals. This leads traders to switch from the chartist to the fundamentalist strategy at an increasing rate as the degree of misalignment increases.

Note that an essential element of this story is the assumed asymmetry between the chartist and fundamentalist strategies highlighted in section (3.2.2). I.e. agent's loss aversion leads them to select values of $g$ and $v$ such that the speed of mean reversion, $(1 - v)$, is greater than the speed of trend extrapolation, $(g - 1)$.

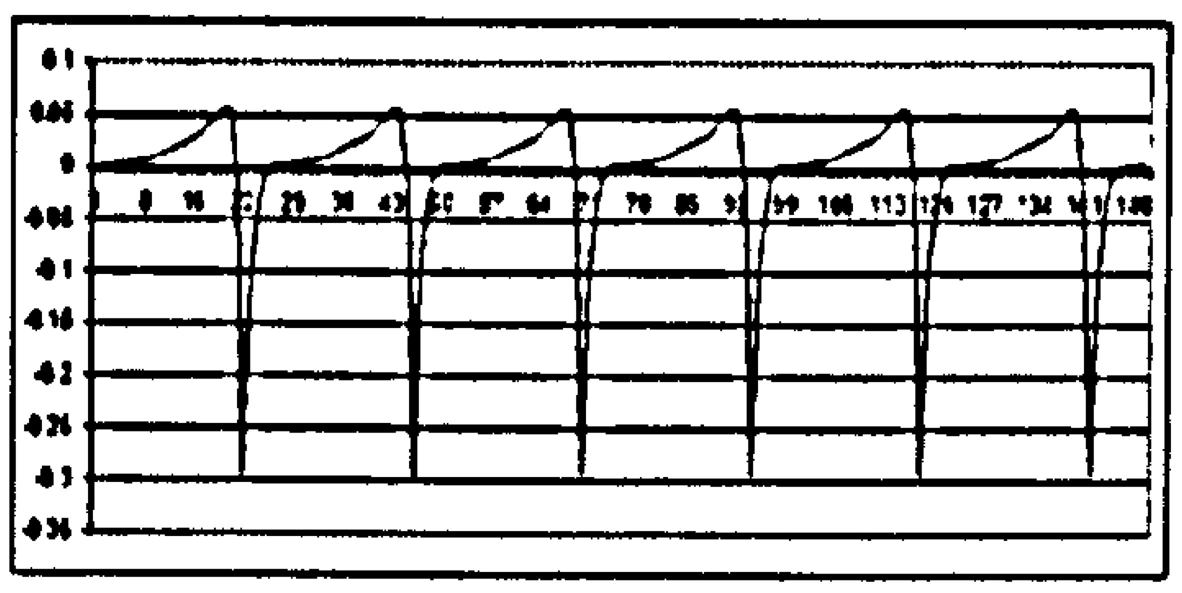
The process which sustains the cycle of growth and collapse of bubbles in the model now becomes clear. Due to costs of obtaining the fundamental strategy, the majority of traders employ a chartist strategy when the exchange rate is close to fundamentals. The chartists push the exchange rate further and further away from equilibrium in the desire to reap profits from the (self-fulfilling) bubble. However, the larger the bubble becomes, the greater the difference in the prospective profits from following the fundamentalist strategy over the prospective profits from following the chartist strategy, leading traders to switch to the fundamentalist strategy at an increasing rate. As soon as the mass of traders on the chartist strategy is no longer sufficient to maintain the growth of the bubble, the exchange rate dips slightly toward the fundamental, profits to the chartist strategy become negative prompting a sudden switch to the fundamentalist strategy, and the bubble collapses.



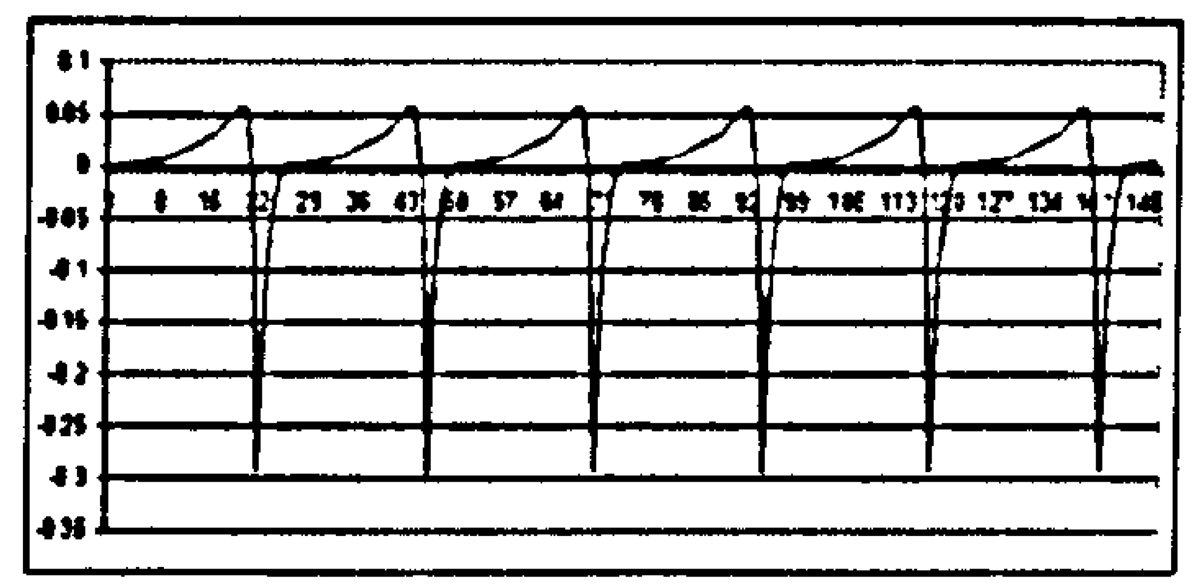
(a) Deviations from equilibrium.



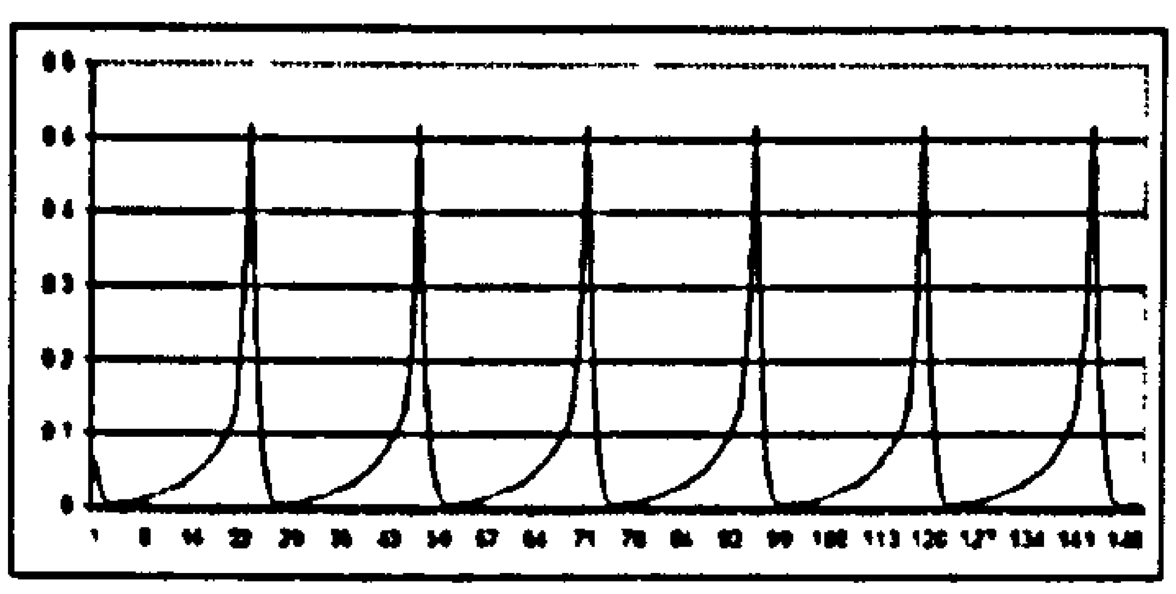
(b) Deviations from equilibrium.



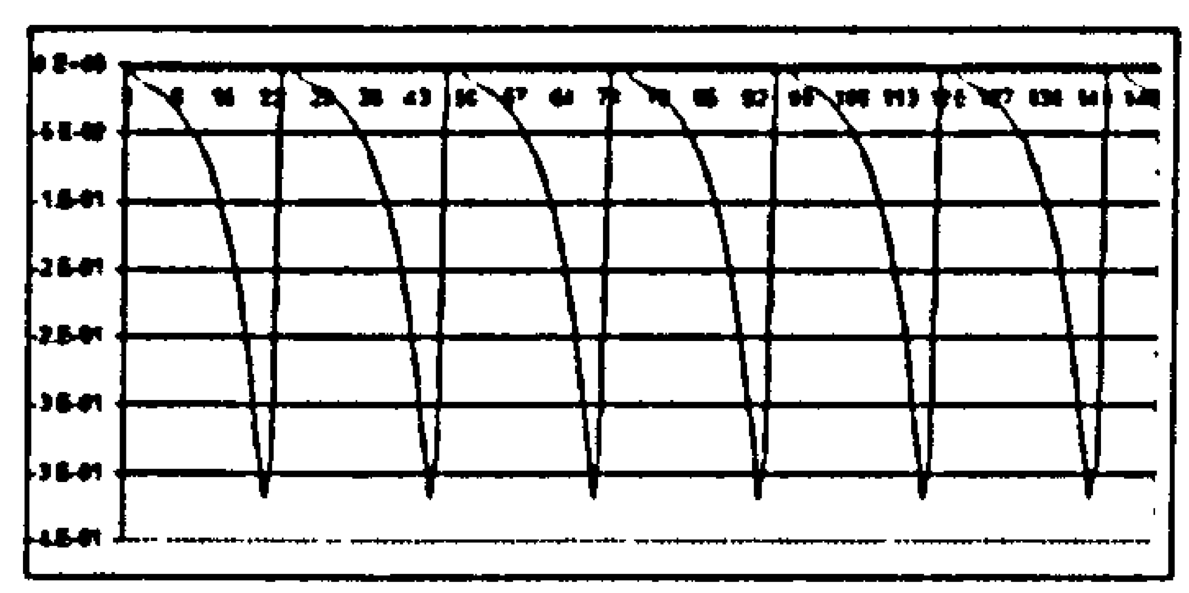
(c) Excess returns on foreign bonds



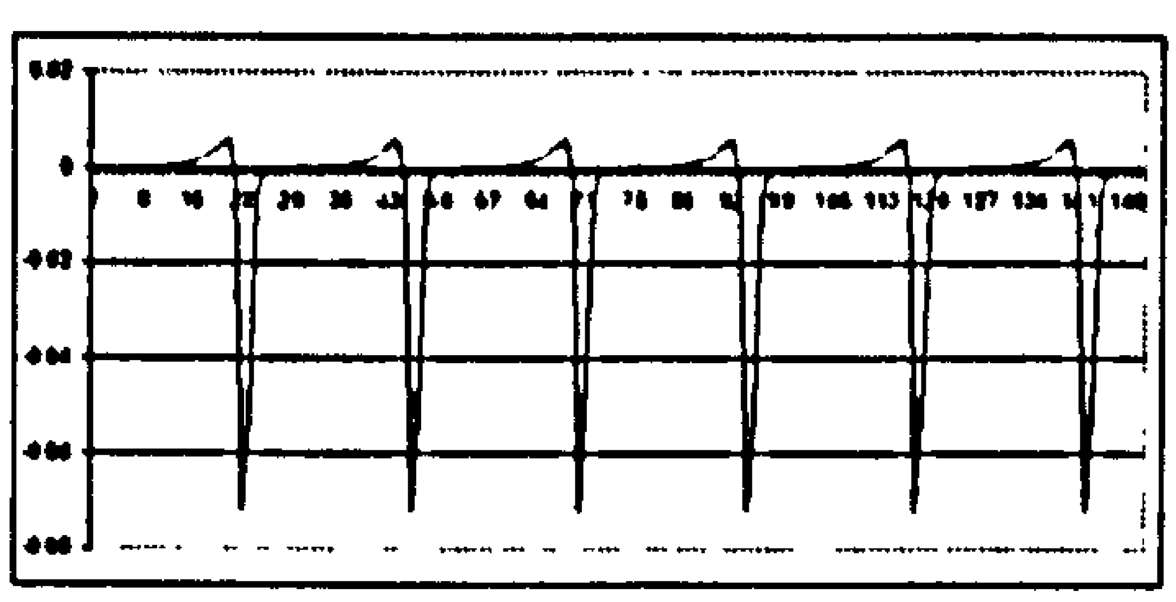
(d) Excess returns on foreign bonds



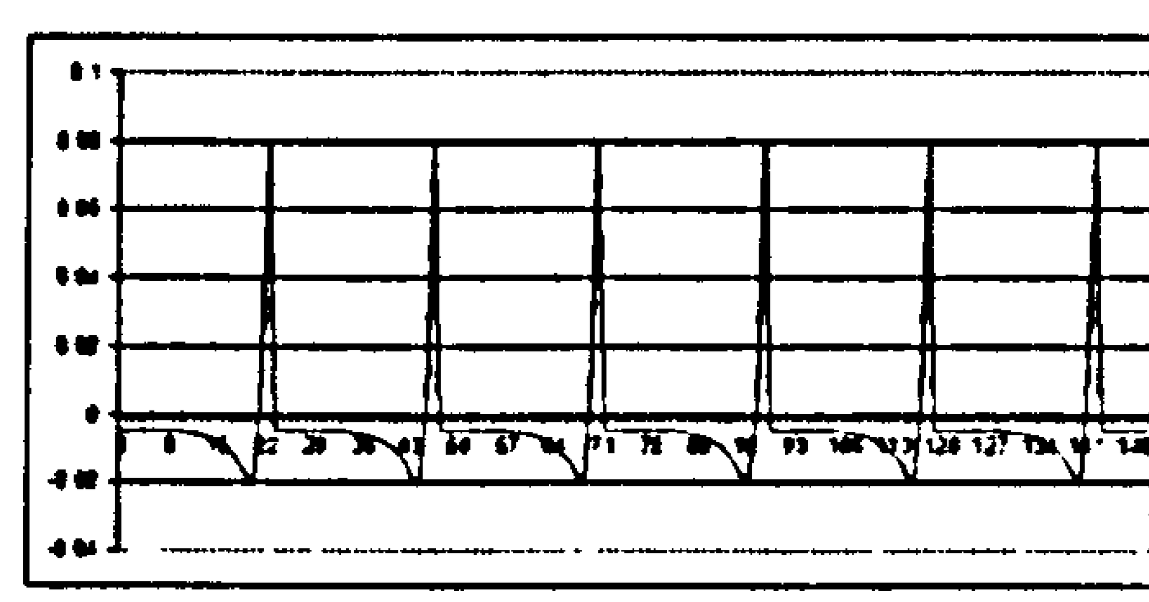
(e) Demand by chartists



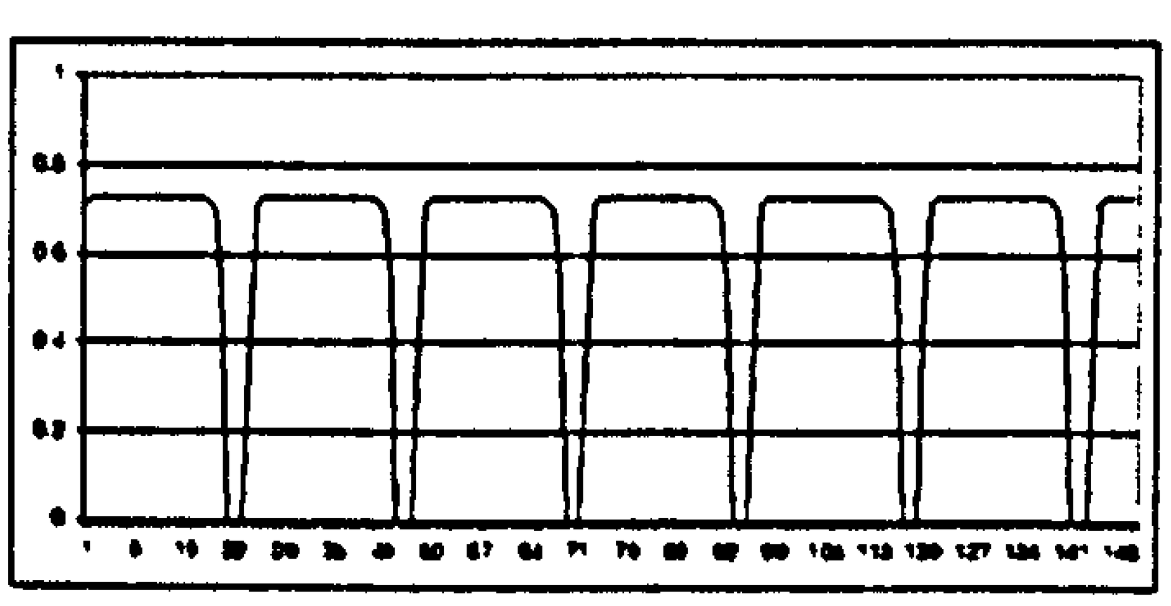
(f) Demand by fundamentalists



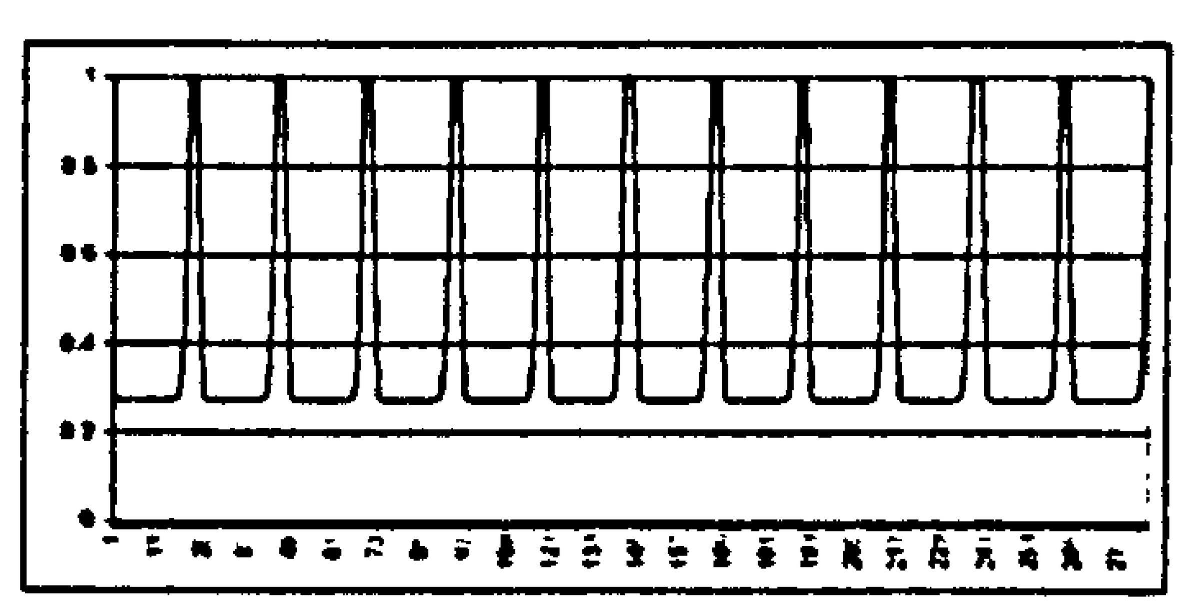
(g) Profits to chartists



(h) Profits to fundamentalists



(i) Weight on chartist strategy



(j) Weight on fundamentalist strategy

Figure 3.2: Periodically collapsing bubbles in the forex market.

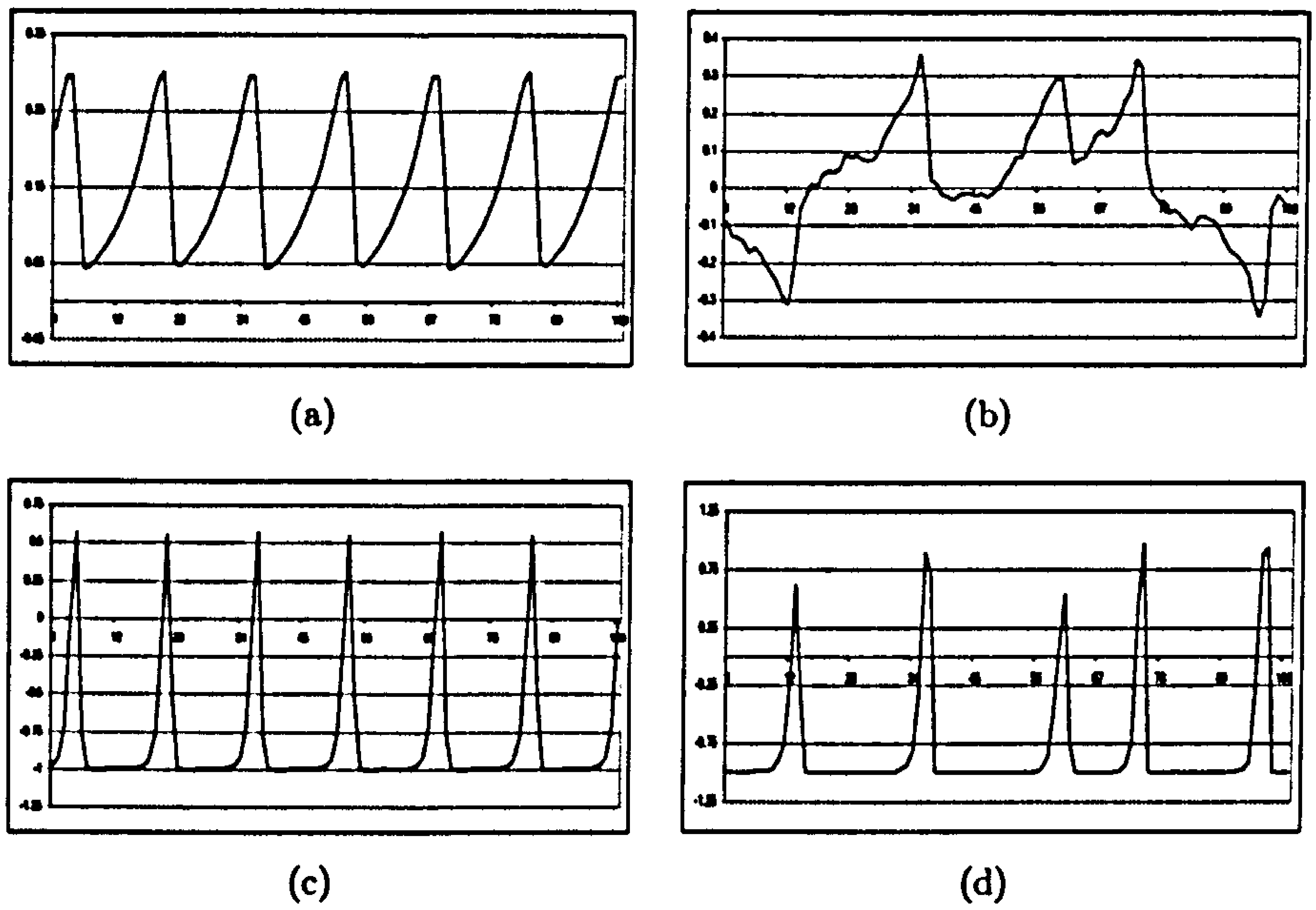



Figure 3.3: Hopf bifurcations without noise (a) and with noise (b). With corresponding ratios of fundamentalists to chartists, (c) and (d) .

Given this apparently simple, periodic behavior in the absence of noise, it is tempting to question whether such apparently predictable fluctuations could represent a plausible description of exchange rate behavior. One may postulate that given apparently predictable turning points of fluctuations, traders would soon learn to exploit the opportunities for profits that they represent, such that these kinds of fluctuations could be ruled out by a process of backward induction. However, once the dynamics of the exchange rate are examined in the presence of noise, it immediately becomes clear that predicting market crashes or turning points is no easy task.

The same model is illustrated in figures (3.3) (a) and (b) in the case where the system is being buffeted with noise. Here, the random shocks to the system result in flips between the steady states $E_1$ and $E_2$, and periods close to the fundamental.

Thus, in the absence of intervention, the exchange rate can exhibit prolonged deviations from equilibrium, periods of high volatility, and market crashes. Qualitatively, this behavior is consistent with the observed behavior of floating exchange rates. Furthermore, it is clear that the shocks to the exchange rate result in fluctuations which appear random to the naked eye, thereby making the exploitation of periodic fluctuations by arbitrageurs all but impossible.

## 3.4 Official Intervention Policy

### 3.4.1 Exchange Rate Dynamics Under Intervention

The previous section examined the processes which can lead to endogenous exchange rate fluctuations and persistent deviations from levels implied by economic fundamentals. From the monetary authorities point of view a key question is to what extent can intervention reduce these prolonged deviations from equilibrium, i.e. 'burst' bubbles. In this section we begin by examining the effects of a one-off intervention operation on the exchange rate dynamics[5]. We then proceed to discuss how the authorities can exploit the processes governing the endogenous collapse of exchange rate bubbles to increase the efficiency of intervention operations.

**Lemma 3 (Existence and stability of steady states under constant intervention: $\Upsilon = \pm\theta$).** *Let $E_1$, $E_2$, $E_3$, be the steady states as in Lemma (1). Consider intervention operations such that for $x > 0$, the authorities conduct sterilized sales of foreign bonds of size $\theta$, so that $\Upsilon = -\theta$. Similarly, for $x < 0$, $\Upsilon = \theta$. Then, as the size of interventions increase, the non-fundamental steady states are drawn towards the fundamental equilibrium. I.e. As $|\theta| \to \infty$, $|x^*| \to 0$, and furthermore, for large enough $\theta$, the non-fundamental steady states $E_2$, $E_3$ become stable.*

Lemma (3) shows how interventions operations reduce exchange rate fluctuations by firstly shifting the non-fundamental steady states closer toward the fundamental, and secondly, reducing the amplitude of fluctuations about the non-fundamental steady states.

To see the intuition behind this result, consider the implications of the exchange rate dynamics described by the model. Observed deviations in

[5]Strictly speaking, the theory outlined in section (3.2.3) emphasizes how the stock of intervention can influence the risk premium. However, the flow of intervention may also influence the risk premium if the rate of adjustment of asset stocks held is proportional to the difference between desired asset stocks (a function of the risk premium), and the actual holdings of asset stocks (Dominguez and Frankel (1993b)).

exchange rates from economic fundamentals are due to the evolutionary selection of trading strategies by market participants. In such a setting, intervention can only be effective in reducing persistent deviations from equilibrium if it can increase the proportion of traders employing strategies which forecast a move towards the fundamental equilibrium. Upon examination of the system (3.30) - (3.33), the role of intervention in the model becomes clear: *strong interventions, indicated by a large value of $\theta$, reduce the realized profits from chartist strategies and result in a larger ratio of fundamentalists to chartists in the market.* Increasing $\theta$ represents the authorities selling overvalued currencies more vigorously - thereby inflicting losses on chartists who have been pushing the currency up. As the chartist rules become less profitable, the proportion of traders selecting those rules declines, and the exchange rate moves back toward equilibrium.

Intervention has an equivalent effect to a reduction in traders' sensitivity to differences in profits between strategies. So that under intervention, the mass of traders on the most profitable strategy at any point in time is reduced. Thus intervention reduces the amplitude of periodic fluctuations about unstable steady states, reducing short and medium run volatility. In addition, interventions draw the non-fundamental steady states closer to the fundamental. Both of these effects are illustrated in figure (3.4).

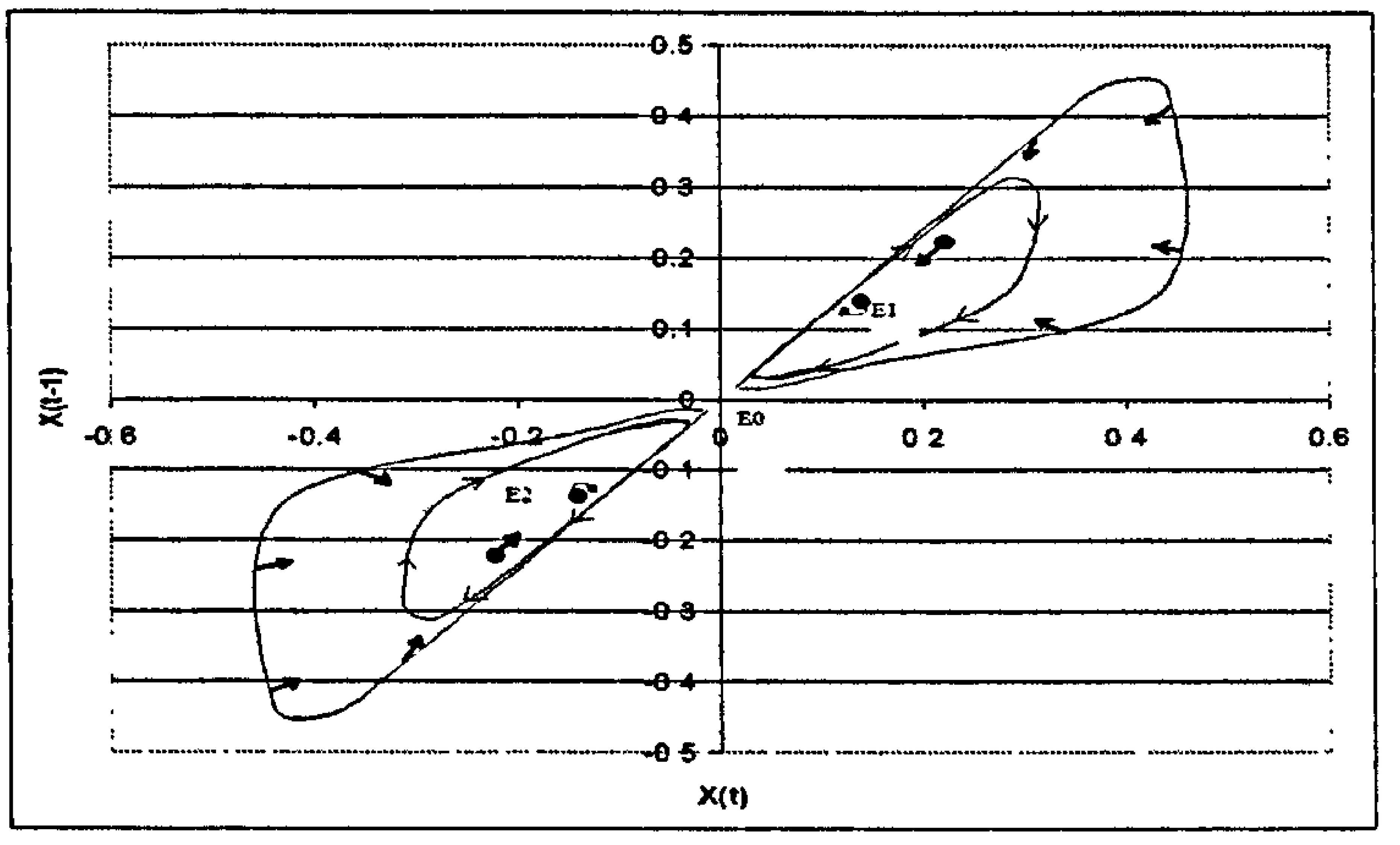



Figure 3.4: The effect of intervention on the non-fundamental steady states. Stronger interventions draw $E_1$ and $E_2$ closer to the fundamental, and reduce the amplitude of associated limit cycles.

### 3.4.2 The Magnitude of Effective Interventions

In practice, given that any exchange rate bubbles which develop will inevitably collapse, it is possible for the authorities to limit the degree of exchange rate fluctuations without continually intervening in the markets. Rather, the authorities can exploit the processes governing the endogenous collapse of exchange rate bubbles to increase the efficiency in intervention operations. Indeed, if the goal of the authorities is to maintain the exchange rate within a band or target zone about equilibrium, all that is needed is a series of one-off interventions of sufficient size when the exchange rate reaches the edge of targeted band[6].

[6]Note that Lemma 3 investigates the dynamic implication of continuous intervention, and the results do not carry over to the discrete intervention case. In practice, one-off interventions will not change shape of limit cycles: this could only be achieved by

To see why this is the case, recall the discussion in the previous section which highlighted a mechanism for the endogenous collapse of exchange rate bubbles. This is due to the proportion of traders employing chartist strategies deceasing as the deviation from the fundamental equilibrium increases, since the expected loss from employing a chartist strategy in the event of a collapse in the bubble rises with the deviation from equilibrium. The bubble bursts (endogenously) when the weight of traders on the chartist strategy is no longer sufficient to maintain it's growth. Thus, in order to maintain the exchange rate within a desired band all that is required is for intervention to be large enough to effect a temporary shift towards fundamentals, after which the mechanism governing *endogenous* collapse of a bubble will take hold, returning the exchange rate to equilibrium.

A further implication of this is that, since the proportion of traders employing the chartist strategy is falling as the deviation from equilibrium increases, relatively smaller interventions are required for the weight of traders using the fundamentalist strategy to reach the 'critical mass' necessary for the bubble to collapse. Essentially, since when the deviation from equilibrium is large there are relatively few traders still employing the chartist

interventions lasting for several periods. This implies that sustained intervention over a period of days may be more effective than simple 'one-off' intervention operations. In this regard it is interesting to note (as shall be seen in the following chapter) that in practice the Japanese authorities often conduct intervention operations in 'bursts' of sustained intervention lasting a number of days at a time strategy, the authorities need to turn fewer traders to the fundamentalist strategy to facilitate a return to equilibrium of the exchange rate. Alternatively, *interventions of a fixed size become more effective the greater the deviation from equilibrium.* This effect is illustrated in the model without noise in figure (3.5) below.

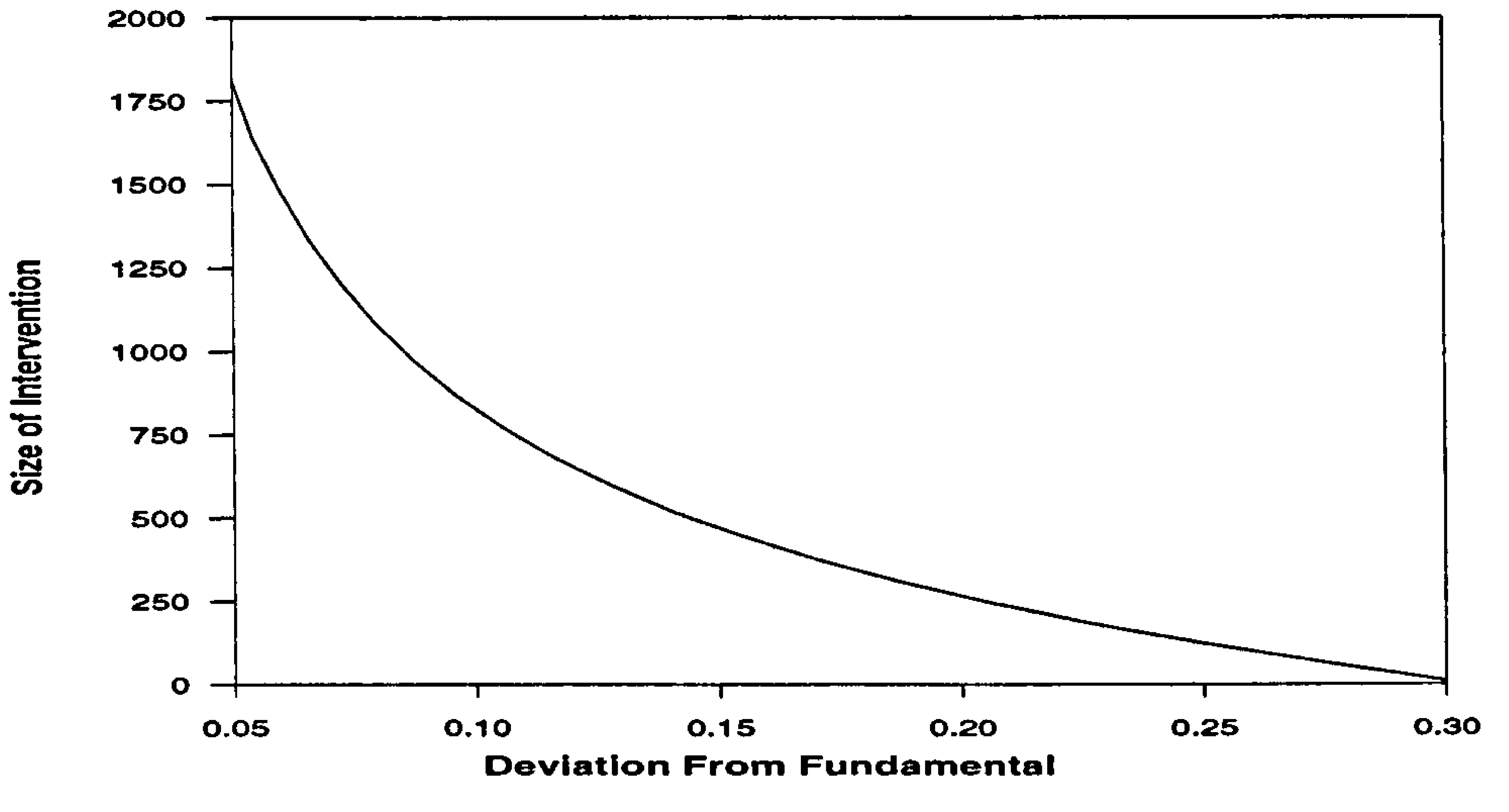



Figure 3.5: Absolute Value of Intervention Necessary to Create Turning Point

This feature of the model provides a rationale for the infrequent nature of intervention operations conducted by monetary authorities. The cost of effective interventions when the exchange rate is close to equilibrium is prohibitively high, and welfare losses associated with poor competitiveness are only likely to become a significant problem when the exchange rate persists at large deviations from fundamentals. Thus interventions are likely most cost effective when triggered by the exchange rate passing through a predetermined band.

## 3.5 Conclusion

In this chapter a model has been developed of the effects of sterilized intervention in a setting where endogenous exchange rate fluctuations are generated by the use of trading rules by market participants. Recent work on the presence of noise traders and chartists in the foreign exchange market suggests that the large and persistent swings evident in G-3 exchange rates have little relation to movements in economic fundamentals. Monetary authorities and policy makers the world over seem well aware of this exchange rate disconnect. As a result, intervention operations are frequently designed specifically to influence the strategies of traders in the foreign exchange markets, in an attempt to reduce the severity of such swings.

The central hypothesis of the model presented here is that such interventions can be successful by reducing the profitability of destabilizing trading strategies, thereby inducing market participants to base their forecasts on economic fundamentals. It has been shown how even when interventions are sporadic in nature they can significantly alter the path of the exchange rate in the medium term, effectively bursting bubbles in the exchange rate.

In the next chapter, we turn to empirical testing and estimation of the model in the context of the Japanese experience with sterilized intervention in the 1990's. In addition, we shall also examine the influence of shocks to the exchange rate on the efficiency of intervention operations. This analysis will permit an examination of the implications of the model for exchange rate policy. In particular, it will inform a discussion in the next chapter of the implications of the model for the choice of exchange rate regime.

## 3.6 Appendix

*Proof of Lemma 1.* Firstly, note from the market equilibrium equation (3.30), that the only possible steady states occur when either $x^* = 0$, or

$$\frac{(1+\alpha)}{\alpha} = g - \omega^* q \tag{3.34}$$

$$w^* = \frac{g}{q} - \frac{1+\alpha}{q\alpha} \tag{3.35}$$

Now, we require that $0 \leq w^* \leq 1$, so that non-fundamental steady states exist only if $\omega^* < 1$, so that

$$\frac{(1+\alpha)}{\alpha} > v, \tag{3.36}$$

which always holds. Also, if $\omega^* > 0$, then $\frac{g}{q} - \frac{1+\alpha}{q\alpha} > 0$. I.e.

$$g > \frac{(1+\alpha)}{\alpha} \tag{3.37}$$

When $\Upsilon = 0$, the steady state deviation from equilibrium, $x^*$, is given by the solutions (if they exist) to

$$\omega^* = \frac{1}{1 + \exp\left[\frac{\beta q}{\alpha\sigma^2}(x^*)^2\left(\delta(g+v) - \frac{\delta(2\alpha+1)+1}{\alpha}\right) + \beta C\right]}, \tag{3.38}$$

in which case

$$\frac{\beta q}{a\sigma^2}(x^*)^2\Big(\delta(g+v)-\frac{\delta(2\alpha+1)+1}{\alpha}\Big)+\beta C=\ln\Big[\frac{1-\omega^*}{\omega^*}\Big], \tag{3.39}$$

and

$$x^*=\pm\sqrt{\frac{\alpha a\sigma^2}{\beta q}\Big(\frac{1}{1+\delta(2\alpha+1)-\alpha\delta(g+v)}\Big)\Big(\beta C-\ln\Big[\frac{1-\omega^*}{\omega^*}\Big]\Big)}. \tag{3.40}$$

Now, these values for the non fundamental steady states, $x^*$, are real if either

1.

$$(g+v)<2+\Big(\frac{1+\delta}{\alpha\delta}\Big) \qquad \text{and} \qquad \exp(\beta C)>\frac{1-\omega^*}{\omega^*}$$

or

2.

$$(g+v)>2+\Big(\frac{1+\delta}{\alpha\delta}\Big) \qquad \text{and} \qquad \exp(\beta C)<\frac{1-\omega^*}{\omega^*}$$

.

Thus non-fundamental steady states exist if $\beta$ is small and $g+v>2+\left(\frac{1+\delta}{\alpha\delta}\right)$, or if $\beta$ is large and $(g+v)<2+\left(\frac{1+\delta}{\alpha\delta}\right)$. □

### 3.6.1 Stability of steady states

Consider the change of variables given by

$$\mathcal{Y}_{t-1} := \begin{pmatrix} x_{t-3} \\ x_{t-2} \\ x_{t-1} \end{pmatrix} = \begin{pmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \end{pmatrix} \tag{3.41}$$

Now define the functions:

$$f_1 = y_{2t} \tag{3.42}$$

$$f_2 = y_{3t} \tag{3.43}$$

$$f_3 = \frac{\alpha}{(1+\alpha)} g y_{3t} - \Phi(y_{1t}, y_{2t}, y_{3t}, \theta, \beta, C) \frac{\alpha}{(1+\alpha)} q y_{3t} \tag{3.44}$$

where

$$\Phi(\cdot) = \left(1 + \exp[\gamma(y_{1t}, y_{2t}, y_{3t})]\right)^{-1}, \tag{3.45}$$

and

$$\gamma(\cdot) = \beta\Big((1-\delta) y_{3t} - \frac{(1+\delta)(1+\alpha)}{\alpha} y_{2t} + \delta(g+v) y_{1t} - \tilde{\theta}\Big) \frac{q y_{1t}}{a\sigma^2} + \beta c, \tag{3.46}$$

where $\theta = (1+\delta)a\sigma^2\Upsilon_{t-2}$ represents a one-off intervention by the authorities.

The system (3.30) - (3.33) may then be represented by

$$\mathcal{Y}_t = \mathcal{F}(\mathcal{Y}_{t-1}) \tag{3.47}$$

where

$$\mathcal{F}(\mathcal{Y}_{t-1}) = \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix} \tag{3.48}$$

The Jacobian of this system is given by

$$\begin{pmatrix} \frac{\partial f_1}{\partial y_1} & \frac{\partial f_1}{\partial y_2} & \frac{\partial f_1}{\partial y_3} \\ \frac{\partial f_2}{\partial y_1} & \frac{\partial f_2}{\partial y_2} & \frac{\partial f_2}{\partial y_3} \\ \frac{\partial f_3}{\partial y_1} & \frac{\partial f_3}{\partial y_2} & \frac{\partial f_3}{\partial y_3} \end{pmatrix} \tag{3.49}$$

Observe that

$$\begin{array}{lll} \frac{\partial f_1}{\partial y_1} = 0 & \frac{\partial f_1}{\partial y_2} = 1 & \frac{\partial f_1}{\partial y_3} = 0 \\ \frac{\partial f_2}{\partial y_1} = 0 & \frac{\partial f_2}{\partial y_2} = 0 & \frac{\partial f_2}{\partial y_3} = 1 \end{array} \tag{3.50}$$

The remaining derivatives are calculated as follows.

$$\frac{\partial f_3}{\partial y_{1t}} = -\frac{\alpha}{(1+\alpha)} q y_{3t} \frac{\partial \Phi}{\partial y_{1t}} \tag{3.51}$$

$$\frac{\partial f_3}{\partial y_{2t}} = -\frac{\alpha}{(1+\alpha)} q y_{3t} \frac{\partial \Phi}{\partial y_{2t}} \tag{3.52}$$

$$\frac{\partial f_3}{\partial y_{3t}} = \frac{\alpha}{(1+\alpha)} g - \frac{\alpha}{(1+\alpha)} q \Phi - \frac{\alpha}{(1+\alpha)} q \frac{\partial \Phi}{\partial y_{3t}} y_{3t}. \tag{3.53}$$

Now since

$$\frac{\partial\Phi}{\partial y_{it}} = -\frac{\partial\gamma}{\partial y_{it}}\exp[\gamma](1+\exp[\gamma])^{-2}, \qquad i=1,2,3, \tag{3.54}$$

and, evaluated at the non-fundamental steady state $x^*$,

$$\omega^* = (1+\exp[\gamma|_{x=x^*}])^{-1} \tag{3.55}$$

$$(1-\omega^*) = \exp[\gamma|_{x=x^*}](1+\exp[\gamma|_{x=x^*}])^{-1} \tag{3.56}$$

so that

$$\exp[\gamma|_{x=x^*}](1+\exp[\gamma|_{x=x^*}])^{-2} = \omega^*(1-\omega^*), \tag{3.57}$$

at the non-fundamental steady state we have

$$\left.\frac{\partial\Phi}{\partial y_{it}}\right|_{x=x^*} = -\left.\frac{\partial\gamma}{\partial y_{it}}\right|_{x=x^*}\omega^*(1-\omega^*). \tag{3.58}$$

These derivatives are given by

$$\frac{\partial\gamma}{\partial y_{1t}} = \left((1-\delta)y_{3t} - \frac{(1+\delta)(1+\alpha)}{\alpha}y_{2t} + 2\delta(g+v)y_{1t} - \tilde{\theta}\right)\frac{\beta q}{a\sigma^2} \tag{3.59}$$

$$\frac{\partial\gamma}{\partial y_{2t}} = -\frac{(1+\delta)(1+\alpha)}{\alpha}\frac{\beta q}{a\sigma^2}y_{1t} \tag{3.60}$$

$$\frac{\partial\gamma}{\partial y_{3t}} = (1-\delta)\frac{\beta q}{a\sigma^2}y_{1t} \tag{3.61}$$

Now define

$$\zeta = \frac{\beta q^2}{a\sigma^2}(x^*)^2\omega^*(1-\omega^*), \tag{3.62}$$

then from (3.52) - (3.53) and (3.58), we have

$$\left.\frac{\partial f_3}{\partial y_{1t}}\right|_{x=x^*} = \left(\frac{2\alpha\delta(g+v-1)-(1+\delta)}{(1+\alpha)} - \frac{\alpha(1+\delta)a\sigma^2\tilde{\theta}}{(1+\alpha)x^*}\right)\zeta, \tag{3.63}$$

$$\left.\frac{\partial f_3}{\partial y_{2t}}\right|_{x=x^*} = -(1+\delta)\zeta, \tag{3.64}$$

$$\left.\frac{\partial f_3}{\partial y_{3t}}\right|_{x=x^*} = 1 + \frac{\alpha(1-\delta)}{(1+\alpha)}\zeta, \tag{3.65}$$

where the last relation follows since at the non-fundamental steady state

$$\frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q\omega^* = 1. \tag{3.66}$$

Similarly, evaluating these derivatives at the fundamental steady state, $x = 0$, yields:

$$\left.\frac{\partial f_3}{\partial y_{1t}}\right|_{x=0} = 0 \tag{3.67}$$

$$\left.\frac{\partial f_3}{\partial y_{2t}}\right|_{x=0} = 0 \tag{3.68}$$

$$\left.\frac{\partial f_3}{\partial y_{3t}}\right|_{x=0} = \frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q(1+\exp[\beta c])^{-1} \tag{3.69}$$

### Stability analysis of fundamental steady state

The characteristic equation for the system at the fundamental steady state is constructed by evaluating the Jacobian at $x = 0$. Then, from (3.68)-(3.69) corresponding Jacobian is

$$\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & \frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q((1+\exp[\beta c]^{-1}) \end{pmatrix} \tag{3.70}$$

The characteristic equation is then

$$\begin{vmatrix} -\lambda & 1 & 0 \\ 0 & -\lambda & 1 \\ 0 & 0 & \frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q((1+\exp[\beta c]^{-1}) - \lambda \end{vmatrix} = 0 \tag{3.71}$$

Expanding gives

$$\lambda^2\Big(\frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q((1+\exp[\beta c]^{-1}) - \lambda\Big) = 0 \tag{3.72}$$

So that the eigenvalues are

$$\lambda_1 = 0, \qquad ,\lambda_2 = 0, \qquad ,\lambda_3 = \frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q((1+\exp[\beta c]^{-1}) \tag{3.73}$$

Note firstly that since $q = g - v$, $q < g$ and also $(1+\exp[\beta c])^{-1} \leq 1$, so that $\lambda_3$ must be real and positive.

Now, the fundamental steady state looses stability when the eigenvalue $\lambda_3$ crosses the unit circle.

$\lambda_3 > 1$ iff

$$\frac{\alpha}{(1+\alpha)}g - \frac{\alpha}{(1+\alpha)}q((1+\exp[\beta c]^{-1}) > 1, \tag{3.74}$$

or

$$v + g\exp[\beta c] > \frac{(1+\alpha)}{\alpha} + \frac{(1+\alpha)}{\alpha}\exp[\beta c]. \tag{3.75}$$

Consider the following sketch of the left and right hand sides of the inequality (3.75) under the assumption that $g > \frac{(1+\alpha)}{\alpha}$. Since $v < \frac{(1+\alpha)}{\alpha}$ and $g > \frac{(1+\alpha)}{\alpha}$, while for small $\beta$ the LHS of (3.75) is less than the RHS, as $\beta$ increases there must be some value whereafter (3.75) is satisfied.

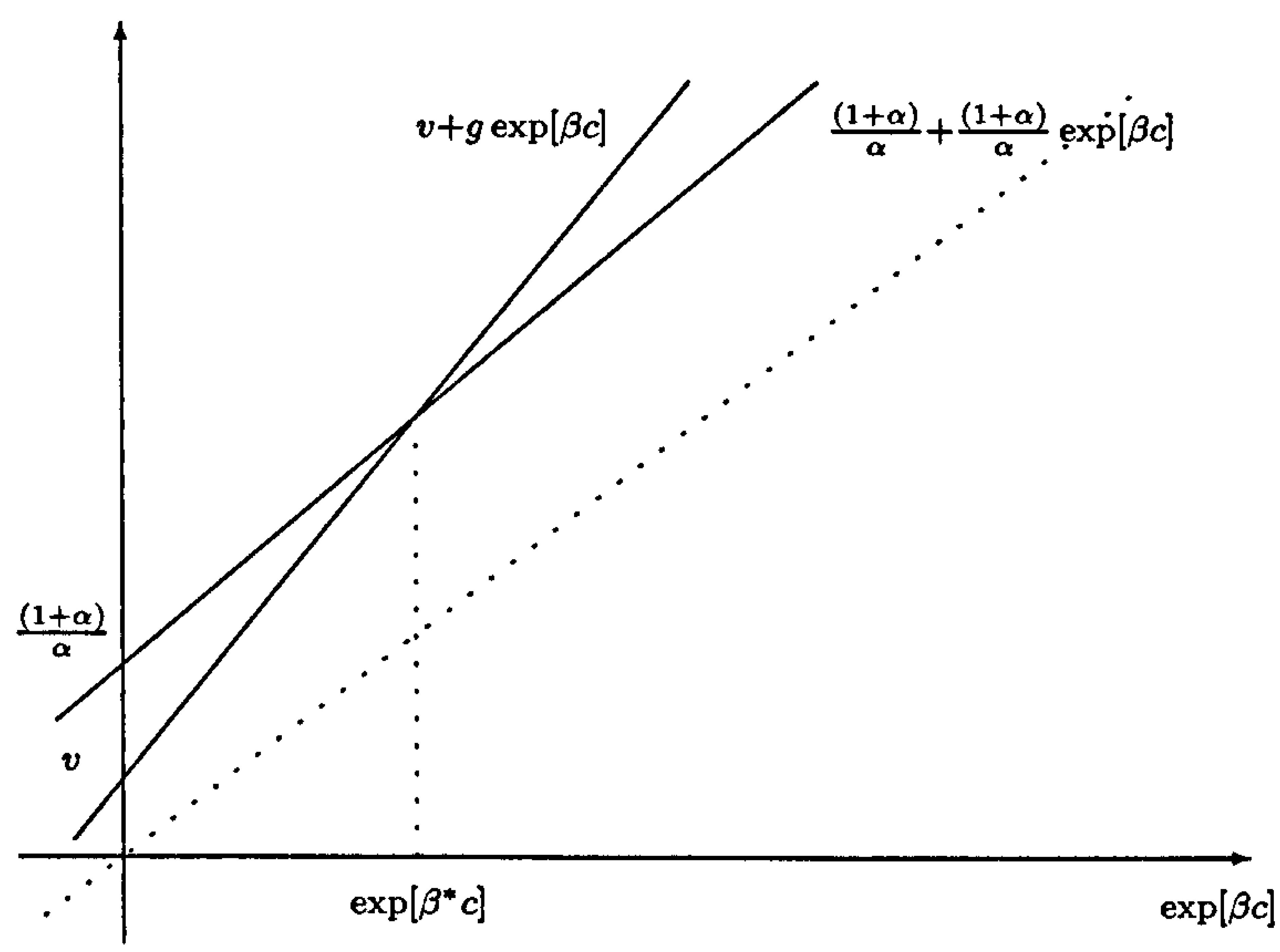



Figure 3.6: Level of intensity of choice where fundamental steady state undergoes pitchfork bifurcation

In general then, for $g > \frac{(1+\alpha)}{\alpha}$, as $\beta$ increases there exists some $\beta^*$ for which $\lambda_3 = 1$, where a pitch-fork bifurcation leads to the creation of the two non-fundamental steady states.

**Stability analysis of non-fundamental steady states with no intervention**

Turning to the characteristic equation for the system at the non-fundamental steady states,

$$\begin{vmatrix} -\lambda & 1 & 0 \\ 0 & -\lambda & 1 \\ \phi_1 & \phi_2 & (\phi_3 - \lambda) \end{vmatrix} = 0 \tag{3.76}$$

where $\phi_i = \frac{\partial f_3}{\partial y_{it}} \mid_{x=x^*}$ for $i = 3, 2, 1$ respectively. The characteristic equation is then

$$\lambda^3 - \phi_3\lambda^2 - \phi_2\lambda - \phi_1 = 0, \tag{3.77}$$

so that substituting in for $\phi_3, \phi_2, \phi_1$ from equations (3.64)-(3.65) and setting $\tilde{\theta} = 0$ gives

$$g(\lambda) = \lambda^3 - \left(1 + \frac{\alpha(1-\delta)}{(1+\alpha)}\zeta\right)\lambda^2 + (1+\delta)\zeta\lambda - \left(\frac{2\alpha\delta(g+v-1) - (1+\delta)}{(1+\alpha)}\right)\zeta \tag{3.78}$$

At the pitchfork bifurcation value $\beta = \beta^*$, $x^* = 0$, so that $\zeta = 0$. For $\beta$ slightly larger than $\beta^*$, $\zeta$ is slightly larger than 0 and (3.78) has three real eigenvalues inside the unit circle. Hence, for $\beta$ slightly larger than $\beta^*$, the non-fundamental steady states $(\pm x^*, \omega^*)$ are stable. As $\beta$ increases, $\zeta$ also increases, and $\zeta \to +\infty$ as $\beta \to +\infty$. Hence, one of the eigenvalues must cross the unit circle at some critical $\beta = \beta^{**}$ and the non-fundamental steady states $E_1$ and $E_2$ become unstable.

Now, for $\beta > \beta^*$,

$$g(1) = \frac{2(1+\delta) + 2\alpha\delta(2 - g + v)}{(1+\alpha)}\zeta \tag{3.79}$$

Which, for $(g+v) < 2 + \left(\frac{1+\delta}{\alpha\delta}\right)$, is positive for all $\zeta$, implying eigenvalues of $\lambda = +1$ are not allowed.

Similarly,

$$g(-1) = -2 - 2\alpha\left(\frac{\delta(g+v)+1}{(1+\alpha)}\right)\zeta \tag{3.80}$$

is negative for all $\zeta$, so that eigenvalues of $\lambda = -1$ are also not allowed. Thus, as $\zeta \to \infty$ there must be a complex conjugate pair of eigenvalues crossing the unit circle at $\beta = \beta^{**}$, implying that a Hopf bifurcation occurs at $\beta = \beta^{**}$.

**Model with intervention**

Under a one off intervention of size $(1+\delta)a\sigma^2\Upsilon_t = \tilde{\theta}$, the steady state deviations from equilibrium, $\pm x^*$, are given by the solutions (if they exist) to

$$\omega^* = \frac{1}{1+\exp\left[\frac{\beta q}{a\sigma^2}(x^*)^2\big(\delta(g+v) - \frac{\delta(2\alpha+1)+1}{\alpha} - \frac{\tilde{\theta}}{x^*}\big) + \beta C\right]}, \qquad (3.81)$$

in which case the non-fundamental steady states are gives by

$$x^* = \frac{\mu \pm \sqrt{\mu - 4\vartheta}}{2} \qquad (3.82)$$

with

$$\mu = \tilde{\theta}\Big(\frac{\alpha}{1+\delta(2\alpha+1)-\alpha\delta(g+v)}\Big) \qquad (3.83)$$

$$\vartheta = \frac{a\sigma^2}{\beta q}\Big(\frac{\alpha}{1+\delta(2\alpha+1)-\alpha\delta(g+v)}\Big)\Big(\ln\Big[\frac{1-\omega^*}{\omega^*}\Big] - \beta C\Big). \qquad (3.84)$$

As for the case with no intervention, these values for the non fundamental steady states, $x^*$, are real if either

1.

$$(g+v) < 2 + \Big(\frac{1+\delta}{\alpha\delta}\Big) \qquad \text{and} \qquad \exp(\beta C) > \frac{1-\omega^*}{\omega^*}$$

or

2.

$$(g+v) > 2 + \left(\frac{1+\delta}{\alpha\delta}\right) \qquad \text{and} \qquad \exp(\beta C) < \frac{1-\omega^*}{\omega^*}$$

.

Furthermore, $-\frac{\mu}{2}$ is the abscissa of the turning point of the polynomial which has $x^*$ as its solution. Clearly this is zero when there is no intervention by the authorities, and the two non-fundamental steady states are equally spaced about zero. When $x$ is positive, the authorities intervene to purchase domestic assets so that $\theta$ is negative. This shifts the positive solution of $x^*$ closer to the origin. Similarly, when $x$ is negative the authorities sell domestic assets which shifts the negative solution of $x^*$ closer to the origin.

### 3.6.2 Effects of Intervention on Stability of Steady States

In the simplest case, such that for positive deviations from equilibrium, and interventions are given by $\Upsilon = -\tilde{\theta}$, and for negative deviations from equilibrium $\Upsilon = \tilde{\theta}$, characteristic equation is given by

$$\lambda^3 - \phi_3\lambda^2 - \phi_2\lambda - \phi_1 = 0, \tag{3.85}$$

where $\phi_3, \phi_2, \phi_1$ are as in equations (3.64)-(3.65) with $\tilde{\theta} \neq 0$.

Now, recall that the roots of the general cubic polynomial must satisfy the following conditions:

$$\lambda_1 + \lambda_2 + \lambda_3 = \phi_3 \tag{3.86}$$

$$\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3 = -\phi_2 \tag{3.87}$$

$$\lambda_1\lambda_2\lambda_3 = \phi_1 \tag{3.88}$$

Furthermore, complex conjugate roots cross the unit circle when

$$\lambda_1\lambda_2 = 1 \tag{3.89}$$

$$|\lambda_1 + \lambda_2| < 2 \tag{3.90}$$

Combining these conditions, we find that the following condition must hold when complex conjugate roots cross the unit circle:

$$|\phi_3 - \phi_1| < 2. \tag{3.91}$$

Substituting in for $\phi_1$ and $\phi_3$, this reduces to the condition

$$\left|1 + \left(\frac{(1+\delta)(1+\alpha) - 2\alpha\delta(g+v)}{(1+\alpha)}\right)\zeta - \frac{\alpha(1+\delta)a\sigma^2\tilde{\theta}}{(1+\alpha)x^*}\zeta\right| < 2. \tag{3.92}$$

For reasonable values of the parameters, the numerator of the first fraction in this condition is positive. Now consider the situation where there is initially no intervention so that $\tilde{\theta} = 0$, and $\beta$, and hence $\zeta$ is just large for the non-fundamental steady states to become unstable, i.e. $\beta = \beta^{**}$. At the corresponding value of $\zeta$ condition (3.92) will be satisfied. However, whatever the value of $\zeta$ we can always find some $\tilde{\theta} = \breve{\theta}$ such that (3.92) no longer holds, and the non-fundamental steady states are stable.

# Chapter 4

# Empirical evidence

## 4.1 Introduction

This chapter presents some empirical evidence in support of the model using data on sterilized intervention operations conducted by the Japanese authorities during the 1990s. Estimating the model amounts to a joint test of nonlinear exchange rate behaviour and the coordination channel of intervention. Section (4.2) provides a brief survey of the empirical literature on nonlinear behaviour in exchange rates, and also the literature on the effectiveness of sterilized intervention. The following section details the model estimation procedure and results. In section (4.4), a procedure is developed to quantify the efficiency of intervention operations from the model estimation results. Drawing on these results, section (4.4.1) discusses the implications of the findings for the choice of exchange rate regime for the

G-3 economies. Perhaps the most striking result to emerge is strong support for a type of exchange rate target zone, in particular a so-called 'monitoring band'. The calculations of the efficiency of interventions are then employed in section (4.4.2) to examine the relative success of the various policy styles used by the Japanese authorities when conducting intervention operations. Section (4.5) then concludes.

## 4.2 Evidence of nonlinear adjustment in exchange rates

While many studies have found evidence of nonlinearity in the volatility of exchange rates (principally of the GARCH type), there has been somewhat less examination of the evidence for nonlinearity in the conditional mean of exchange rate returns.

Early work in this area focused on broad tests for nonlinearity of unspecified type in exchange rates. For example, both Hsieh (1989), who used daily exchange rate changes for five currencies between 1974 and 1989, and Kruger and Lenz (1990), with weekly data for ten currencies in the period 1979 to 1989, found nonlinear dependence in some series which was not of the pure ARCH or GARCH type by applying the correlation dimension-based independence test [the BDS-test] proposed by Brock, Dechert, and Scheinkman

(1987).

As recent advances in nonlinear time series econometrics have become more widely disseminated, researchers have begun to model the nature of the nonlinearity in exchange rates more explicitly. In testing for nonlinear exchange rate adjustment, most research to date has focused on reduced form models. In particular, analysis has concentrated on the simplest type of nonlinearity possible: that of a switching process between two (or more) linear processes. Of the possible types of switching regime models, there are three which have received most attention in the literature. These model the switching process as either a discrete change in the parameters of the model when some predetermined variable reaches a critical value - the so-called Threshold Autoregressive (TAR) model; a smooth shift in the parameters of the model, so that at any point in time the exchange rate is modelled as a weighted function of two linear processes - the Smooth Transition autoregression (STAR) model; and finally a probabilistic process governed by a Markov (or semi-Markov) process - the Markov Switching (MS) model. We now turn to a brief survey of the findings of each of these classes of models with respect to exchange rate dynamics.

### 4.2.1 Threshold Autoregressive (TAR) models

The TAR model is discussed extensively in Tong (1990). It assumes that the regime is determined by the value of an observed variable relative to a threshold value $c$. A special case arises when the threshold variable is taken to be a lagged value of the time series itself, in which case the resulting model is termed a Self-Exciting TAR (SETAR) model. For example, if an AR(1) model is assumed in both regimes, a 2-regime SETAR model is given by

$$y_t = \begin{cases} \phi_{0,1} + \phi_{1,1} y_{t-1} + \epsilon_t & \text{if } y_{t-1} \leq c, \\ \phi_{0,2} + \phi_{1,2} y_{t-1} + \epsilon_t & \text{if } y_{t-1} > c \end{cases} \tag{4.1}$$

where it is typically assumed that $\epsilon_t \sim \text{iid}(0, \sigma^2)$.

TAR-type behaviour in exchange rate adjustment is suggested by a number of the economic rationales for nonlinear exchange rate adjustment surveyed in Chapter 2. Perhaps most attention in the literature has focused on the role of transactions costs in producing TAR adjustment in real exchange rates. For example, Obstfeld and Taylor (1996) employ disaggregated data on different commodity classes from 1980 to estimate a TAR model for the US real exchange rate, and find evidence that adjustment outside a 'band of inaction' implies half-lives of price deviations measured in months rather than years. Furthermore, they find that the thresholds correspond to popular rough estimates as to the order of magnitude of actual transportation costs. In contrast, using broad aggregated data for a range of countries in a TAR specification, OConnell (1998) finds evidence that large deviations from PPP between most countries appear to be at least as persistent as small deviations, and perhaps even more so. However he does find evidence for exceptions for some intra-EC real exchange rates. The conclusion he draws is that market frictions alone do not explain the observed extent of the persistence of deviations from PPP.

The use of stabilizing, non-sterilized interventions by monetary authorities as a source of TAR adjustment in nominal exchange rates has also been tested by a number of researchers. Kräger and Kugler (1993) use such a model to empirically implement the rational expectations monetary model of stochastic (non-sterilized)intervention rules due to Hsieh (1992). However, they do not employ data on actual intervention operations, but instead appeal to Hsieh's framework to justify the presence of possible threshold dynamics. They find statistically significant threshold affects for five currencies using a decade of weekly data. Clements and Smith (2001) update the work of Kräger and Kugler (1993), and in addition consider the forecasting performance of two SETAR exchange rate models, again drawing on Hsieh

(1992) to justify their approach. They find convincing evidence against linear adjustment for the yen/dollar exchange rate, and also some evidence against for the deutschemark/dollar exchange rate. In addition, they conclude that whether nonlinearities in the data can be exploited to forecast better than a random walk depends on the regime the process is in at the time of forecasting, and that evaluation of the whole density of the two models may offer further improvements. Similar studies by Brooks (1997), Brooks (2001) and Boero and Marrocu (2004) provide further supporting evidence. Chiarella, Peat, and Stevenson (1993) also detected nonlinearity of the bilinear and threshold varieties, in a study of eight European and Pacific Basin currencies using monthly and weekly data from 1978 to 1993, as well as daily observations between 1983 and 1992.

### 4.2.2 Smooth Transition Autoregressive (STAR) models

Granger and Teräsvirta (1993) observe that while economic theory often suggests switching or threshold models with a sharp switch, if the economy consists of many firms or individuals, each of whom switches sharply but at different times, a smooth model may be more appropriate for the aggregate.

One such reduced form model discussed by Granger and Teräsvirta (1993), which has become increasingly popular in empirical studies, is the smooth transition autoregression model. In this class of model, a variety of continuous, so-called 'transition functions' on the interval $(0,1)$ are employed to weight the two regimes. The resultant model may be written

$$\begin{aligned} y_t =&(\phi_{0,1} + \phi_{1,1} y_{t-1})(1 - G(y_{t-1};\gamma, c)) \\ &+ (\phi_{0,2} + \phi_{1,2} y_{t-1})(G(y_{t-1};\gamma, c)) + \epsilon_t. \end{aligned} \tag{4.2}$$

In the empirical exchange rate literature, a popular choice for the transition function is the exponential function, so that

$$G(y_{t-1};\gamma, c) = 1 - \exp(-\gamma(y_{t-d} - c)^2), \tag{4.3}$$

and the resulting model is referred to as an exponential STAR (ESTAR) model. The parameter $\gamma$ in these models determines the smoothness of the change in the transition function, and thus the transition from one regime to another. Small values of $\gamma$ indicate relatively smooth transition, while as $\gamma$ approaches infinity, the transition function approaches a step function and the model resembles a TAR model.

Another popular form for the transition function is the logistic function, where by

$$G(y_{t-1};\gamma,c) = \frac{1}{1+\exp(-\gamma(y_{t-d}-c))}. \tag{4.4}$$

Here, the parameter $c$ can be interpreted as the threshold between the two regimes corresponding to $G(y_{t-1};\gamma,c) = 0$ and $G(y_{t-1};\gamma,c) = 1$, in the sense that the logistic function changes monotonically from 0 to 1 as $y_{t-1}$ increases, while $G(c;\gamma,c) = 0.5$.

Note that an important difference between the ESTAR and LSTAR models is that while the logistic function is odd, in the sense that $G(-\infty) = 0$ and $G(+\infty) = 1$, the exponential function is even, so that $G(\pm\infty) = 0$ and $G(0) = 1$. This has led some authors a priori to model exchange rate adjustment with ESTAR models, whereby the exchange rate follows a random walk when close to equilibrium, and a mean reverting process far from equilibrium. The ESTAR model seems more suitable since it enforces symmetric adjustment whether the exchange rate is under or overvalued.

A number of authors have estimated ESTAR models of real exchange rate adjustment on aggregate data. For example, Michel, Nobay, and Peel (1997) find that the mean reversion is significant for sizeable deviations from PPP. Other studies find similar supporting evidence for a range of and time periods, a partial list is Bleaney and MIzen (1996b,a), Goldberg, Gosnell, and Okunev (1997), Taylor and Sarno (1998), and Taylor, Peel, and Sarno (2001).

Nonlinear adjustment in nominal exchange rates has been modelled with STAR models by, amongst others, Taylor and Peel (2000) and Westerhoff and Reitz (2003).

### 4.2.3 Markov Switching Autoregressive (MS) models

While TAR and STAR models assume model parameters shift according to the value of some observed, predetermined or exogenous variables, it is also possible to model such shifts as the outcome of unobserved variables. One class of models which models the switch with an unobserved, discrete stochastic variable, is the Markov switching model introduced by Hamilton (1989). In these models, the dynamic properties depend on the present regime, with the regimes being realizations of a hidden Markov chain with a finite state space.

For example, if we denote the unobserved state variable by $s_t$, in the case of only two regimes, $s_t$ can be assumed to take on the values of 1 or 2. Assuming an AR(1) model in both regimes then gives

$$y_t = \begin{cases} \phi_{0,1} + \phi_{1,1} y_{t-1} + \epsilon_t & \text{if } s_t = 1, \\ \phi_{0,2} + \phi_{1,2} y_{t-1} + \epsilon_t & \text{if } s_t = 2. \end{cases} \tag{4.5}$$

Or, using an alternative notation,

$$y_t = \phi_{0,s_t} + \phi_{1,s_t} y_{t-1} + \epsilon_t. \tag{4.6}$$

The model is completed by specifying the process by which $s_t$ evolves. The simplest (and most popular) model is to assume a first-order Markov process, so that the current regime, $s_t$ is determined only by the previous period's regime, $s_{t-1}$. The evolution of the Markov chain is determined by the transition probabilities:

$$P(s_t = 1 | s_{t-1} = 1) = p_{11}$$

$$P(s_t = 2 | s_{t-1} = 1) = p_{12}$$

$$P(s_t = 1 | s_{t-1} = 2) = p_{21}$$

$$P(s_t = 2 | s_{t-1} = 2) = p_{22}.$$

Popular extensions consider increased numbers of regimes, different processes in each regime, and time variation in the transition probabilities.

Markov switching models have been applied to exchange rate modeling by a umber of authors. For example, Engle and Hamilton (1990), Engle (1994), Vigfusson (1997), Bollen, Gray, and Whaley (2000), Dewachter (2001), Klaassen (2002), Beine, Laurent, and Lecourt (2003), and Dueker and Neely (2004), among others, investigate regime switching in foreign exchange rates;

Engle and Hamilton (1990) have found evidence of regime shifts in US real exchange rates leading to so-called 'long swings'; Bollen, Gray, and Whaley (2000) argue that different exchange rate policy regimes give rise to different exchange rate behavior; and Vigfusson (1997) constructs a two state Markov switching model for exchange rate dynamics, based on the Frankel and Froot (1986) model of chartists and fundamentalists in the market, and identifies their corresponding regimes, using daily Canada US exchange rates. Ahrens and Reitz (2003) apply Vigfussons empirical model to German US data.

### 4.2.4 Structural models of nonlinear exchange rate adjustment

While the empirical literature on modelling nonlinear exchange rate adjustment has met with some success, the interpretation of these results can be difficult. Typically, rather than specifying the model on the basis of an economic model, the underlying form that nonlinearity takes is often simply assumed in a somewhat ad hoc manner.

Unfortunately, statistical difficulties in selecting amongst non-nested models also make model selection on empirical grounds difficult. For example, while statistical tests are available to assess the evidence for a given type of nonlinearity against a specified alternative[1], the range and variety of nonlinear models is boundless (in the sense that everything which is not linear is nonlinear), and the researcher clearly cannot test against every available alternative model.

For this reason, when examining evidence for nonlinearities in data, it becomes increasingly important to carefully articulate the economics structure which is expected to give rise to the nonlinearity under examination. A key element of the approach taken in this dissertation is the integration of such a theoretical model with empirical estimation, in an effort to extract as much economic content from the estimation results as possible. There are a small number of other examples of this approach in the literature, for example the empirical implementation by Kräger and Kugler (1993) of the stochastic intervention rule model of Hsieh (1992). The approach taken here is very much in the spirit of this earlier work.

There are a number of distinctive features suggested by the theoretical set

[1]For example, see the discussion in Granger and Teräsvirta (1993).

up investigated in the previous chapter which have clear implications for empirical testing. For example, an assumption which is often employed in empirical work with nonlinear models is that one 'regime' should correspond to a random walk. However, the model in the previous chapter indicates that under certain conditions exchange rate dynamics can be globally stable and bounded even when one regime is mildly explosive. Furthermore, the characterization of the dynamics as limit cycles thus implied, also provides a plausible explanation for the very large misalignments in G-3 exchange rates which have at times been observed over the last 20 years. While an intermittent random walk can explain the high persistence of deviations from equilibrium, it is more difficult to rationalize the emergence of misalignments approaching 50% (e.g. in the case of the dollar/mark exchange rate in the mid 1980s).

Another example is the frequently employed assumption of an exponential type transition function when estimating STAR models for exchange rates. As noted above, these assumption is often made on the grounds that the implied adjustment toward equilibrium is symmetric, which would not be the case under a logistic transition function. However, the insights provided by the modelling in the previous chapter indicate that this need not be the case. The model under examination here can be thought of as an example of an LSTAR model, albeit with a somewhat complicated transition function. As shown in chapter 2, the dynamics implied by the model evolve according to two limit cycles, symmetrically position on either side of the fundamental equilibrium.

An important feature of the model developed here is the assumption that traders select their strategy on the basis of it's relative profitability; and furthermore, that sterilized intervention operations can be effective by altering this relative profitability. We now turn to a brief survey of the evidence on intervention, strategy selection and the profitability of trading rules.

### 4.2.5 Empirical evidence on the use of chartist analysis

Not only is there considerable evidence of the widespread use of technical trading strategies in the foreign exchange markets[2], there is also a growing body of literature demonstrating it's profitability[3]. In the model presented here, excess trading rule returns for some traders are explained by the presence of other traders who employ the 'wrong' strategy. However, many authors have speculated that trading rule profitability may in practice be

[2]The literature of the use of trading strategies in the foreign exchange markets is surveyed in Chapter (2)

[3]See, inter alia, Levich and Thomas (1993), Neely, Weller, and Dittmar (1997), Osler and Chang (1999), and Sweeney (1986).

a direct result of intervention by the monetary authorities (e.g. Dooly and Schafer (1983), Corrado and Taylor (1986), and Sweeney (1986)). Furthermore, a number of recent studies have found that there is a high degree of correlation between interventions and trading rule returns (for example, LeBaron (1993) and Szakmary and Mathur (1997)). However, in contrast to previous studies, Neely (2002) has directly tested whether the timing of intervention and returns supports the hypothesis that intervention generates trading rule profits. He finds that in practice, abnormally high trading rule returns actually precede intervention operations, and rejects the hypothesis that they are generated by intervention. This lends support to a central result of the model: that intervention by the authorities can reduce misalignments by reducing the profitability of destabilizing trading rules.

Another perspective on the effectiveness of intervention can be gained by considering the profits achieved by the intervening authority when they conduct intervention operations. For intervention to be effective, it must be the case that the monetary authorities buy when the currency is low and sell when it is high, in which case they themselves should make profits from intervention operations. Ito (2002) finds that the Japanese interventions earned close to 9 trillion yen during the 1990s from realized capital gains, unrealized capital gains, and interest rate differentials. He thus concludes that the Japanese authorities were a successful, and thus stabilizing, speculator.

### 4.2.6 Evidence on the effectiveness of sterilized intervention

There is a large literature which empirically examines the effectiveness of sterilized intervention, growing in particular since the 1980's. Empirical work designed to test the channel through which intervention is effective has met with mixed success. Regarding the portfolio balance channel, because of the small size of interventions relative to the outstanding stocks of bonds, most authors (e.g. Rogoff (1984)) have been skeptical that intervention could have a large impact. Indeed, many studies do not find evidence to support this channel, and those that do, such as Dominguez and Frankel (1993b), Evans and Lyons (2001) and Ghosh (1992), suggest that it is weak. The literature assessing the importance of the signalling channel has also, as yet, failed to reach a consensus regarding it's importance. While Dominguez and Frankel (1993b) find a stronger effect of the signalling channel than that of the portfolio balance channel, in order for this channel to have an on going effect, the central bank must be seen to follow through with appropriate changes in monetary policy. However, Fatum and Hutchinson (1999) are unable to find an explicit link between intervention and future monetary policy, while Lewis (1995) and Kaminsky and Lewis (1996) suggest it occasionally operates in the wrong direction.

More recently, a number of studies have concluded that intervention can indeed be effective, but which leave the question of the channel of influence open. These papers typically employ an event study or case study approach. See, for example, Edison (1998), Fatum (2002), and Fatum and Hutchinson (2003). Of particular relevance to the study at hand is work by Ito (2002), which examines the Japanese experience with intervention in the 1990's. Ito finds that Japanese interventions were successful in producing intended effects on the yen during the second half of the 1990s.

## 4.3 Testing the model

In this section the model is estimated using monthly Japanese data from January 1991 to April 2003. In July 2001 the Japanese Ministry of Finance (MOF) took an important step by releasing all data on sterilized intervention operations to the public[4], which provides a useful and timely test-bed for the model. The data indicates that the Japanese monetary authorities have intervened frequently, especially in the dollar/yen market, and also

[4]An analysis of the aims and efficiency of these intervention operations is conducted in a linear framework by Ito (2002).

occasionally in the yen/euro (yen/mark) market.[5] The Japanese experience therefore provides a wealth of data, making it ideally suited to empirical analysis.

### 4.3.1 The equilibrium exchange rate

In any study of exchange rate 'misalignments', the model employed to calculate the equilibrium exchange rate is of central importance. The monetary model offers a simple measure of exchange rate fundamentals, and recent studies have concluded that they perform well in the long run (for an overview, see Frankel and Rose (1995)). The estimated deviations from rational expectations equilibrium, $\hat{x}_t$, may then be calculated as the residuals from an OLS regression of the spot yen/dollar rate on a constant and monetary fundamentals:

$$s_t = \mu + \alpha((m_t - y_t) - (m_t^* - y_t^*)) + x_t \tag{4.7}$$

where $s_t$ is the log of the spot yen/dollar exchange rate, $m_t$ domestic (Japanese) M1, and $y_t$ the log of the domestic industrial production index. Starred variables indicate similar quantities for the US.

[5]This is in stark contrast to the US authorities, which since 1995 have intervened only once in the dollar/euro market (in 2001), and once in the yen/dollar market (in mid 1998).

It is important to note at the outset that, as is familiar from the literature on co-integrated time series (see, e.g. Hamilton (1995)), since the money supply and real output can be characterized as nonstationary $I(1)$ variables the monetary model is only valid if the residuals, $x_t$, are (globally) stationary.

Monthly data for the spot Yen/Dollar exchange rate are taken from the IMF's International Financial statistics database, as are the data for US M1. Industrial production indices are used as a proxy for aggregate demand in the Japan and the US, and these series are also taken from the IFS database. Japanese M1 is taken as a measure of Japanese money supply, with the data obtained from the Bank of Japan's (BOJ) website, whilst data on the Japanese sterilized intervention operations are taken from the MOF website.

Applying Augmented Dickey-Fuller tests, it was found that the null hypothesis of a unit root could not be rejected in any of these variables at standard significance levels, furthermore tests indicated that all variables are integrated of order one, suggesting there may exist a cointegrating relationship between them.

The estimated value of the coefficients in equation (4.7) were $\hat{\mu} = 2.6837$, and $\hat{\alpha} = 0.1562$, with standard errors of (0.5890) and (0.0445) respectively. If the variables are indeed cointegrated, then OLS regression yields super-consistent estimates of the parameters Stock (1987). However, inference of the statistical significance of the variables in complicated by the fact that the coefficients do not in general have asymptotic t-distributions. Rather, determination of whether the model does indeed represent an equilibrium relationship for the exchange rate is determined by whether or not the misalignment term, $x_t$, is stationary.

Figure (4.1) below illustrates the estimated equilibrium exchange rate together with the actual spot rate over the period under study.

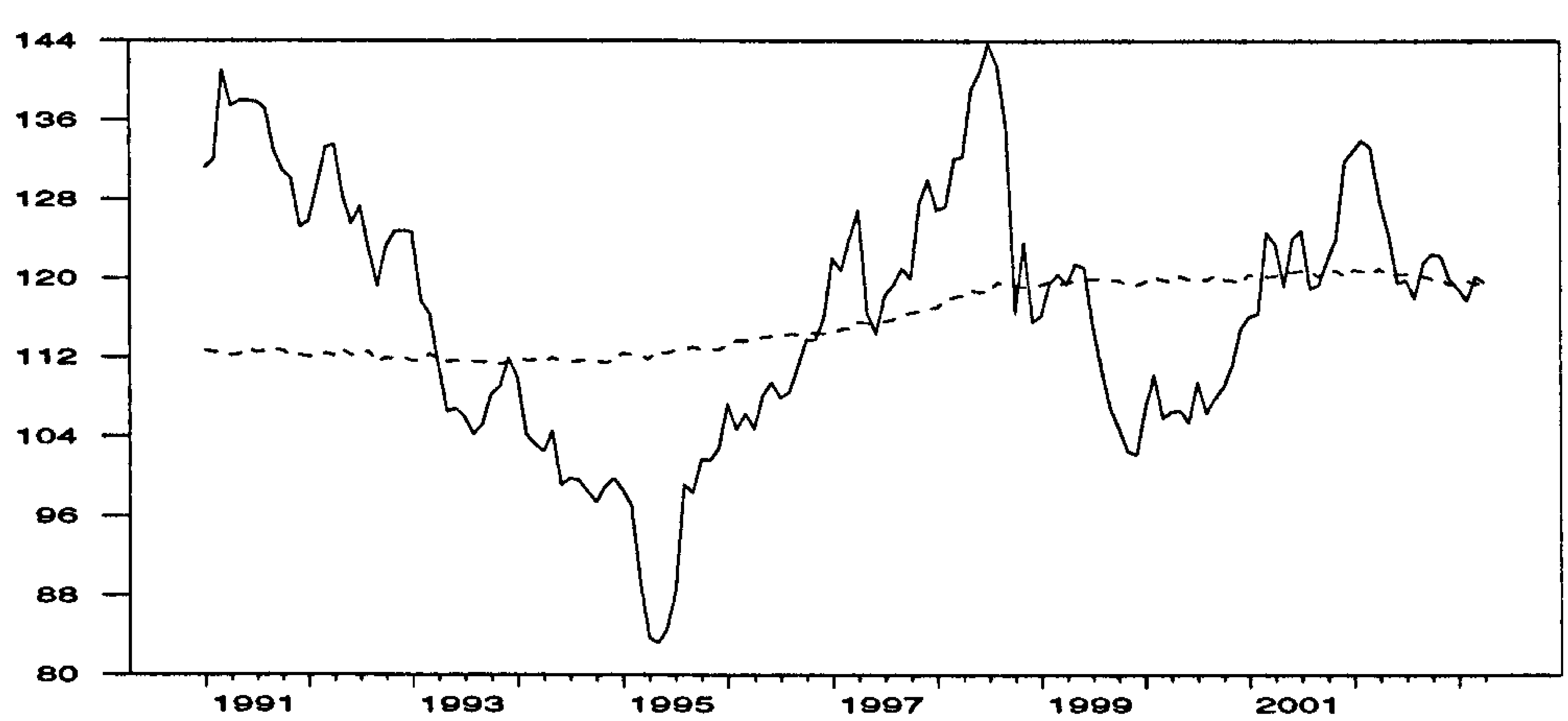



Figure 4.1: Spot yen/dollar exchange rate and estimated equilibrium rate

Clearly, more sophisticated approaches to the estimation of the equilibrium exchange rate could be employed to allow for the influence of factors such as productivity differentials (along the lines of the Balassa-Samuelson effect (see, for example, Froot and Rogoff (1995)), or the size of current account deficits (as, for example in the FEER suggested by Williamson (1984)).

However, the simple monetary model-based specification used here does seem to produce plausible estimates for the equilibrium rate. PPP based estimates for the yen/dollar rate typically produce relatively high values for the dollar, or the order of 150-170 yen, while FEER estimates are often much lower (90-100 yen) (e.g. Wren-Lewis (2000)). The estimates used in this paper all range between 111 and 120 yen to the dollar. For example, the estimated equilibrium exchange rate reaches a minimum of 111.2 yen to the dollar in November 1993, and returned to a level of 119.4 yen to the dollar in December 2002.

### 4.3.2 Empirical framework

Graphs of the deviation of the exchange rate from equilibrium implied by monetary fundamentals, $\hat{x}_t$, together with sterilized monthly sales of Yen (in billions of Yen) by the Japanese authorities are given in figure (4.2).

A general specification for testing the model is

$$x_t = \phi_0 Int_t + \sum_{j=1}^{p} \phi_j x_{t-j} - \sum_{j=1}^{p} \phi_j' x_{t-j} \Psi(\cdot) + \epsilon_t \qquad (4.8)$$

where $\epsilon_t \sim iid(0, \sigma^2)$. The transition function, $\Psi(\cdot)$, maybe written in reduced form as

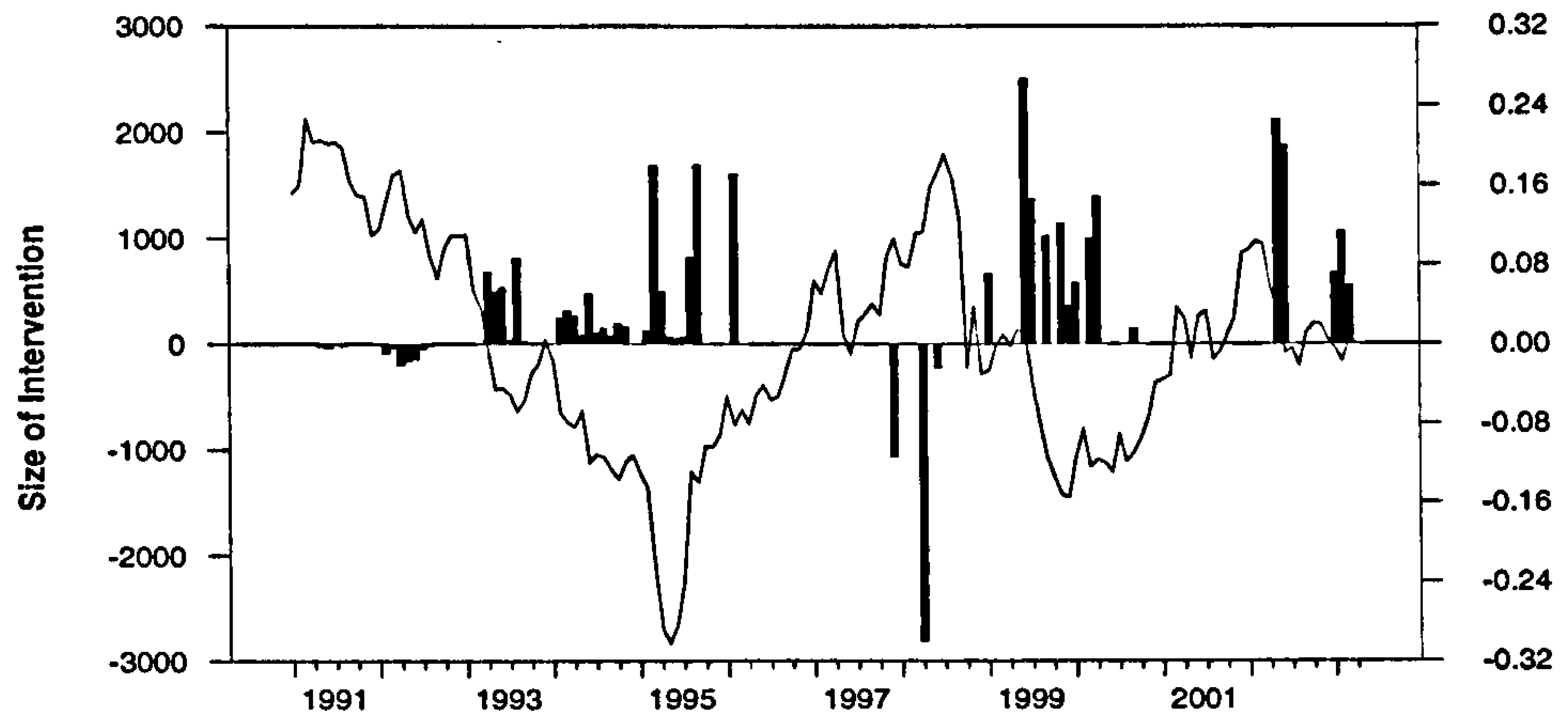



Figure 4.2: Interventions and Deviation from Equilibrium

$$\Psi(\cdot) = [1 + \exp(-\gamma(-\beta_1 x_{t-1} + \beta_2 x_{t-2} + \beta_4 x_{t-3} - \beta_5 Int_t) x_{t-3} + c)]^{-1} \quad (4.9)$$

It is worth pointing out that the model provides a market based rationale for the application of Smooth Transition Autoregression Models (STAR) discussed in section (4.2.2). The function $\Psi(\cdot)$ maybe recognized as an (albeit complicated) form of logistic transition function used in LSTAR models.

### Testing for nonlinearity

Following Granger and Teräsvirta (1993), an LM test for linearity with optimal power against the type of nonlinearity implied by the model employs a three step procedure based on a first-order Taylor approximation of the transition function around about $\gamma = 0$.

1. Estimate the linear model

$$x_t = \phi_0 Int_t + \sum_{j=1}^{p} \phi_j x_{t-j} + u_t \tag{4.10}$$

and save the residuals $\hat{u}_t$. Define $SSR_0 = \sum \hat{u}_t^2$.

2. Use these residuals to run the regression

$$\hat{u}_t = \psi_0 Int_t + \sum_{j=1}^{p} \psi_{1j} x_{t-j} + \sum_{j=1}^{p} x_{t-j} \Big( \psi_{2j} x_{t-1} + \psi_{3j} x_{t-2} + \varphi_j Int_t \Big) x_{t-3} + v_t \tag{4.11}$$

and save the residuals $\hat{v}_t$. Define $SSR_0 = \sum \hat{v}_t^2$.

3. Compute the test statistic $LM = T(SSR_0 SSR_1)/SSR_0$, where T is the number of observations. Under the null hypothesis, LM is distributed $\chi^2(pk)$. In small samples, the equivalent F statistic is $F = [(SSR_0 - SSR_1)/pk]/[SSR_0/(T - (2pk + 1))]$.

Proceeding in this manner yields an F-statistic of 32.59, so that the null hypothesis of the true model being linear is easily rejected at the 95% significance level. The test thus provides strong support for the type of non-linearity implied by the theoretical model.

### The question of stationarity

An important point to consider is that estimation methods for this type of nonlinear model are as yet only applicable to stationary data. However, note that it is possible for the dynamics to be explosive in some regions, with $\sum_{j=1}^{p} \phi_j > 1$, as long as the model exhibits global stationarity, which requires $\sum_{j=1}^{p} \phi_j + \sum_{j=1}^{p} \phi'_j < 1$. Indeed, a test of this condition, i.e. a test of the stationarity of $x_t$, also amounts to a test of the monetary model as an equilibrium relationship, in which case the model may be seen as an example of a nonlinear error correction model.

The question of the global stationarity of the model is also a key feature of the theoretical results presented in the previous chapter. To see this, observe that the condition for global stationarity, $\sum_{j=1}^{p} \phi_j + \sum_{j=1}^{p} \phi'_j < 1$ is equivalent to the condition, $(g+v) < 2$, i.e. that the rate of extrapolation of the chartist strategy is smaller than the rate of mean reversion employed in the fundamentalist strategy. Recall that this feature of the model was motivated by appealing to prospect theory, in particular investor loss-aversion relative to the status quo. In addition, the case where $(g+v) < 2$ was an important feature of the theoretical results demonstrating the circumstances in which limit cycles could arise in the deterministic model.

Aside from these technical issues, the question of stationarity in this framework also has considerable conceptual importance. A characterizing feature of the framework presented here is that the 'equilibrium' described by the monetary model is inherently unstable. Rather, a more appropriate notion of equilibrium is in fact a dynamic one - described by the evolution of the limit cycles which characterize the deterministic dynamics. Note that even though the 'fundamental' steady state is unstable in this world, the misalignments remain stationary since they are bounded - i.e. the limit cycles act as the true attractors. A key point arising from this framework is the view that the behavioural characteristics of market participants - their strategies and the institutional features of their interactions - are in fact the true 'fundamentals' which determine the value of the exchange rate most of the time.

### Estimation method

A problem frequently encountered in the literature assessing the impact of intervention is that of simultaneity bias. The problem arises because exchange rates and asset supplies maybe simultaneously determined. For example, a domestic currency appreciation may result in a change in the relative supplies of domestic and foreign assets through current account imbalances, or through endogenous market intervention. Indeed, the rapid reaction of market participants to official intervention implies that at all but the highest frequencies the problem of simultaneity bias is likely to arise. Typically, studies that do not take account of simultaneity bias find that the estimated coefficients on asset supplies are statistically significant, but enter with the wrong sign.

This kind of bias can complicate estimation of a model since the application of a standard least squares estimator would lead to error terms which are correlated with the explanatory variables. This leads to parameter estimates which are both biased and inconsistent. The standard approach to deal with this problem is to apply an instrumental variables estimator to the regression[6].

Consider the following reduced form of the model (4.8):

$$x_t = z_t(\Phi) + \epsilon_t, \qquad \epsilon_t \sim \mathrm{IID}(0, \sigma^2), \tag{4.12}$$

note that $z(\Phi)$ is a function of both current endogenous variables (i.e. $Int_t$), as well as predetermined variables, $x_{t-i}$ $i = 1, \ldots p$.

Instrumental variables (IV) regression employs a matrix of instruments, $W$, which are predetermined variables assumed to be independent of the error

[6] For a detailed discussion of instrumental variables estimators, see, for example Davidson and MacKinnon (1993).

terms, $\epsilon$. This set of instruments is then employed to separate the vector space described by the dependent variable $x$, into two subspaces, $\mathcal{S}(W)$ and $\mathcal{S}^{\perp}$. The IV estimator is then defined to minimize only the portion of the distance between $x$ and $z(\Phi)$ that lies in $\mathcal{S}(W)$. If indeed $W$ is independent of $\epsilon$, all correlation between $\epsilon$ and $z(\Phi)$ must asymptotically lie in $\mathcal{S}^{\perp}(W)$. The effects of correlation between $\epsilon$ and $z(\Phi)$ can therefore be avoided by restricting minimization to $\mathcal{S}(W)$.

When applying IV to the nonlinear regression model, the parameters are chosen to minimize the criterion function

$$\|P_W(x - z(\Phi))\|^2 = (x - z(\Phi))^{\top} P_W(x - z(\Phi)), \tag{4.13}$$

where $P_W$ is the matrix which projects orthogonally onto $\mathcal{S}(W)$. The first order conditions that characterize the IV estimates $\tilde{\Phi}$ are

$$Z^{\top}(\tilde{\Phi}) P_W(x - z(\tilde{\Phi})) = 0, \tag{4.14}$$

where the matrix of derivatives has typical element

$$Z_{ti}(\Phi) = \frac{\partial z_t(\Phi)}{\partial \Phi_i}.$$

The foc's (4.14) state that the residuals $x - z(\tilde{\Phi})$ must be orthogonal to the matrix of derivatives $Z(\tilde{\Phi})$ once they have been projected onto $S(W)$. They cannot, in general be solved analytically, but must instead be solved using a numerical optimization algorithm.

Instruments for the model (4.8) were chosen to be $x_{t-1} \dots x_{t-6}$, and $Int_{t-1}x_{t-3} \dots Int_{t-6}x_{t-9}$ to account for the nonlinear dependencies in the data generating process. Estimation was carried out with the RATS software package, using the simplex numerical optimizer.

### Estimation results

The final parameter estimates, together with bootstrapped confidence intervals, are given below[7].

[7]The procedure used for calculating the confidence intervals was as follows. On each replication an artificial data set was constructed using a draw with replacement from the residuals of the estimated model. These residuals were then fed recursively into the model to generate a path for the dependent variable, $x$, while the actual series for intervention operations was used at each step. The model was then re-estimated on the simulated data, and the parameter estimates saved. This process was repeated 1000 times, and the estimated values of the model parameters from all replications used to form an empirical distribution for each parameter. These distributions formed the basis of the confidence intervals reported in the table.

| Parameter | Estimate | 95% Confidence Interval |
|---|---|---|
| $\phi_0$ | $2.62 \times 10^{-6}$ | $-8.23 \times 10^{-07} \pm 1.1576 \times 10^{-05}$ |
| $\phi_1$ | 1.1968 | $1.1927 \pm 0.0686$ |
| $\phi_2$ | 0.4650 | $0.4699 \pm 0.0878$ |
| $\beta_1$ | −8474.2600 | $-15012.6000 \pm 7712.7880$ |
| $\beta_2$ | −10767.3000 | $-21038.7000 \pm 10994.7400$ |
| $\beta_3$ | 1712.4700 | $1093.6470 \pm 2367.7020$ |
| $\beta_4$ | −3.5227 | $-4.8025 \pm 2.9740$ |
| $c$ | −97.5961 | $-163.6640 \pm 92.8260$ |

$$x_t = 2.62 \times 10^{-6} Int_t + 1.1968 x_{t-1} - 0.4650 x_{t-1}$$

$$[1 + \exp(-(-8474.26 x_{t-1} + 10767.30 x_{t-2} + 1712.47 x_{t-3} - 3.52 Int_t) x_{t-3} + 92.83)]^{-1} \quad (4.15)$$

The estimation results provide strong evidence of nonlinear behavior consistent with the theoretical model. The parameter estimates $\hat{\phi}_1$ and $\hat{\phi}_2$ indicate that the endogenous fluctuations in the exchange rate move away from the fundamental equilibrium at a rate of 19.68% per month when all traders employ the chartist strategy, and towards fundamentals at a rate of 53.5% when all traders follow the fundamentalist strategy. Furthermore, large values of the estimates of $\beta_1$, $\beta_2$, $\beta_3$, and $c$ indicate that switches between the extreme cases where all traders employ either one of the available strategies occur rapidly, so that the dynamics of the exchange rate can be classified as belonging to either an explosive regime or a strongly mean reverting regime, depending on the strategy employed. The regime classification suggested by the model is illustrated in figure (4.3).

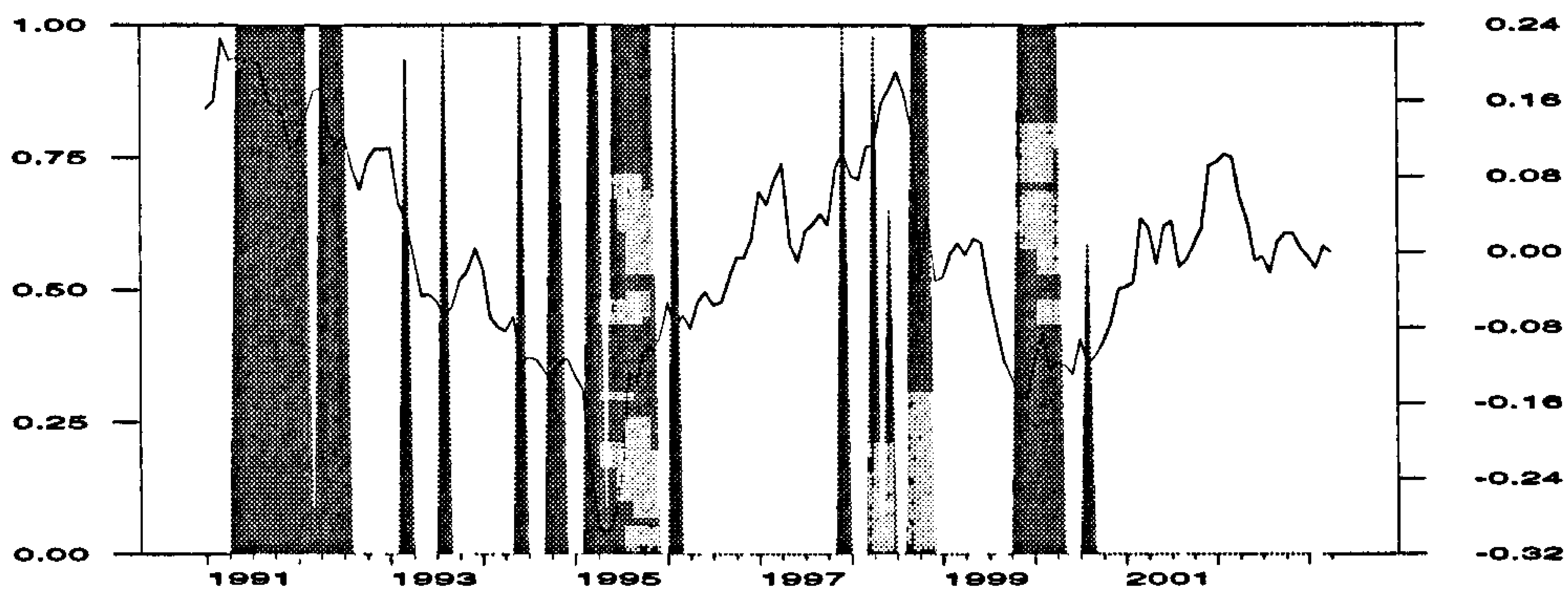



Figure 4.3: Regime Identification. The estimated proportion of traders employing the fundamentalist strategy is indicated by grey shading (left scale).

In the absence of noise the estimation results imply that the true value of the intensity of choice is large enough that, consistent with Lemma 1, the steady state corresponding to the fundamental equilibrium is unstable, and that the exchange rate oscillates about two (unstable) non-fundamental steady states. The results suggest the exchange rate follows a pair of limit cycles about the non-fundamental steady states, thus giving further empirical support to the analysis presented in section (5). Were there to be no shocks to the exchange rate, the parameter estimates indicate the exchange rate would evolve according to a pair of limit cycles as illustrated in figure (4.4).

The parameter $d$ represents the lag with which intervention influences the exchange rate dynamics, and a value of $d = 0$ was chosen on the basis of

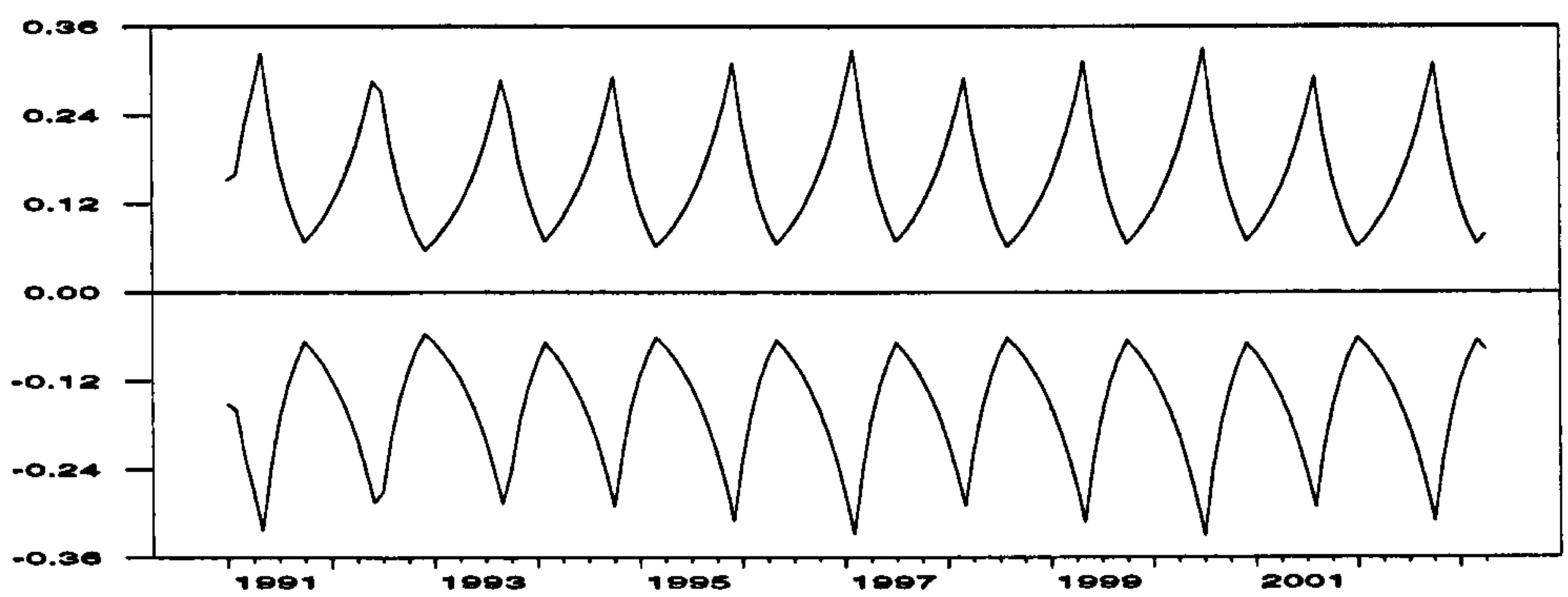



Figure 4.4: Estimated Limit Cycles

likelihood ratio tests. Consistent with the consensus from previous studies[8], the linear effect of interventions on the equilibrium exchange rate is small and insignificantly different from zero. However, the data strongly support the models' prediction that interventions may have a strong non-linear effect on deviations of the exchange rate from fundamentals[9]. Recall that the mechanism by which the nonlinear effect of intervention can significantly influence the exchange rate dynamics, while the linear effect is negligible, is due to a high degree of sensitivity amongst traders of differences in profitability between the available strategies. I.e. the strong nonlinear and weak linear effects of intervention are primarily due to the large estimate of the intensity of choice implied by the parameter estimates.

[8]See, inter alia, Dooley and Isard (1982), Dooley and Isard (1983), Frankel (1982), and Rogoff (1984).

[9]While the results from the model using intervention flows suggested strong effects on the exchange rate, the coefficient on cumulated intervention was not significant, and for this reason are not reported here.

The finding that only intervention flows have a significant effect on the exchange rate are consistent with the common reports in the literature that the effects of sterilized intervention are typically short-lived. However, while the initial impact of intervention is limited to the short run the highly nonlinear dynamics of the exchange rate, and resultant path-dependance, result in the actual effects of intervention on the exchange rate being highly persistent. This effect is discussed in more detail in section (8).

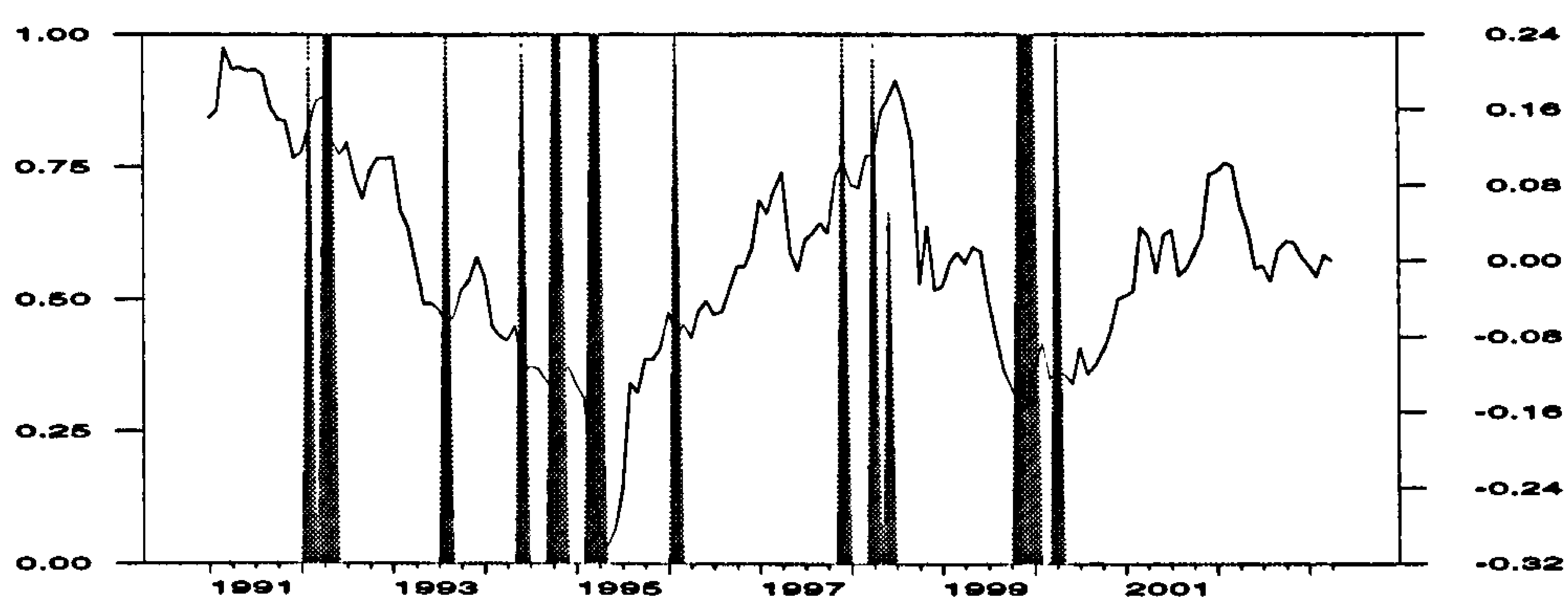



Figure 4.5: Switches to fundamentalist strategy caused by intervention operations.

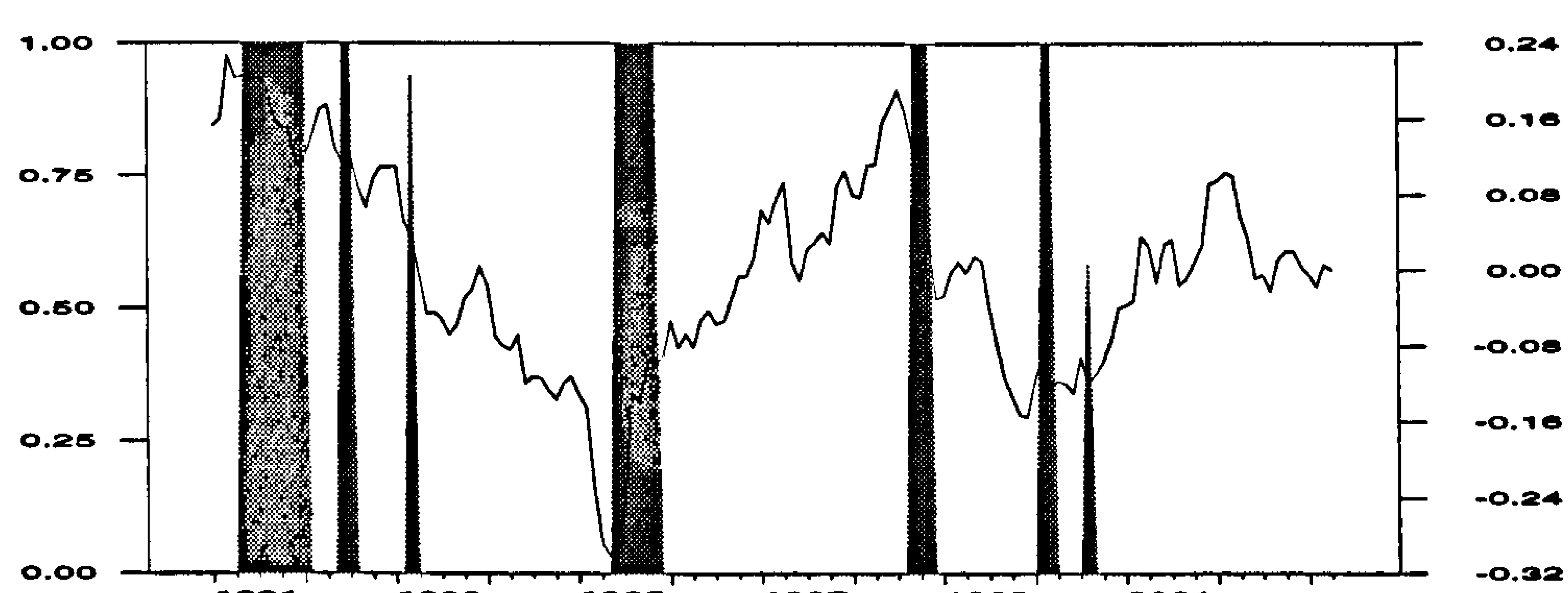



Figure 4.6: Endogenous switches to the fundamentalist strategy.

Figure (4.5) shows the instances in which intervention operations resulted in switches from the chartist to the fundamentalist strategy by traders, while figure (4.6), illustrates cases where traders switch from the chartist to the fundamentalist strategy occurred independently of such interventions. As is clear from the figures, a large proportion (estimated to be 32%) of periods when traders employed fundamentalist strategies can be attributed to the use of intervention operations by the authorities. However, there are also a large number of intervention operations which apparently failed to result in a shift from chartist to fundamentalist strategies by market participants. Clearly, an important question for the monetary authorities is how large should interventions be in order to instigate a movement toward equilibrium in the exchange rate? In the next section, this question is addressed directly, along with the implications of the results for the conduct of exchange rate policy.

## 4.4 The Efficiency of Intervention Policy

In this section it is shown how the model has strong implications for exchange rate policy designed to limit market induced misalignments. Firstly we present a simulation procedure for computing confidence intervals for intervention necessary to reverse misalignments. As will be seen, the results provide a new source of ammunition to the case for exchange rate management based on 'target zones'. The discussion then moves to an assessment of the efficiency of intervention policy in Japan during the 1990's. It is shown how the estimation results imply that, consistent with the findings of ?, interventions under Eisuke Sakakibara were particularly effective. Finally, efficacy of intervention implied by the model is further emphasized with a discussion of the counter-factual exchange rate that would have prevailed had the authorities failed to intervene.

The discussion in section (3.4.2) identified how, in the deterministic model, it is possible for the monetary authorities to prick bubbles in the exchange rate with a one-off intervention of sufficient size. Furthermore, evidence from simulations suggested that the necessary size of interventions decreases as the size of the misalignment grows.

When moving to a stochastic environment however, a number of complications arise. In particular, the size and sign of exogenous shocks to the exchange rate will have important consequences for the efficiency of interventions. For example, a shock which reinforces the trend in the exchange rate away from fundamentals, and which occurs in the same period as the intervention could easily nullify its effects if it is of sufficient size. Conversely, a shock which moves the exchange rate toward equilibrium would result in a smaller than usual intervention being necessary to achieve the desired objective. Under the assumption that the authorities cannot observe the size and sign of shocks before intervening, in this section a bootstrap procedure is presented for the calculation of confidence intervals for the size of effective interventions (a detailed description of the procedure is given in the appendix).

The model is assumed know, so that sample variability is not taken into account. Shocks for periods 0 through $s$ are drawn with replacement from the residuals of the estimated model and, for a given initial history of the deviation $x$, fed through the estimated model to produce a simulated data series. The data series thus constructed is a forecast of the exchange rate conditional on the set of initial values and a given sequence of shocks. Next, the same procedure is followed except that a single intervention operation of size $\theta$ is included once the absolute value of $x$ has reached a given level $\delta$. The point of intervention is fixed such that intervention occurs only when the exchange rate is following a trend leading away from equilibrium, and when the trend would be sustained in the absence of intervention (i.e. the baseline forecast is moving away from equilibrium). The intervention is deemed to be effective if it results in a movement in the exchange rate toward equilibrium, i.e. $|x_\tau| < |x_{\tau-1}|$, where the intervention occurs at time

$t = \tau$. Conditional on the initial history, sequence of shocks, and threshold at which intervention occurs, the smallest value of intervention which is effective in moving the exchange rate towards equilibrium is then determined by a grid search. Levels of effective intervention are computed in this way for 1000 draws from the residuals to give a distribution conditional on the initial history and intervention threshold. The process is repeated for 30 different initial histories of $x$, and the results averaged to produce a distribution of effective intervention conditional only on the intervention threshold. Figure (4.7) shows how the 25, 60 and 70 percentiles of the distributions thus calculated vary as the intervention threshold changes. They give an approximate method of determining the probability that total monthly intervention operations of a given size, carried out at a given deviation of the exchange rate $\bar{x}$, will be effective.

For example, in order to have a 70 percent chance of moving the exchange rate toward fundamentals when the deviation from equilibrium is 13 percent, interventions of approximately 1 trillion yen are required. To achieve the same probability of mean reversion at a deviation from equilibrium of 9 percent requires interventions of around 5 trillion yen per month. However, within the sample there were only 13 months in which total interventions exceeded 1 trillion yen, and the largest total intervention in a single month

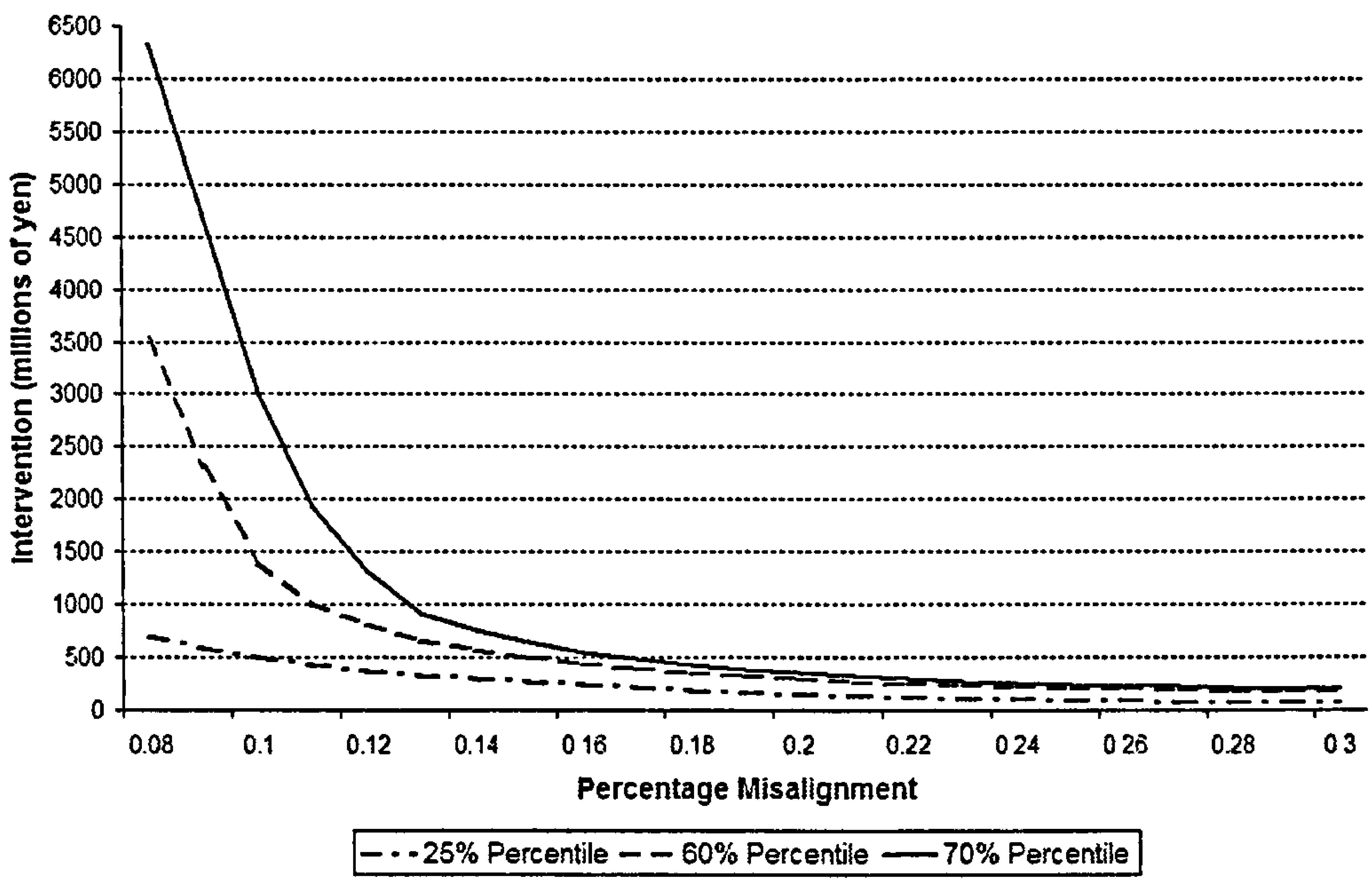



Figure 4.7: Probability of Interventions Effectively Inducing a Turning Point

was of the order of 2.8 trillion yen.

Qualitatively, these findings suggest that sterilized intervention can be used with greater efficiency when the degree of misalignment is large. Furthermore, the quantitative results indicate that the efficiency of intervention decreases exponentially as the degree of misalignment falls. For example, the empirical findings above show that to achieve a reasonable probability of mean reversion in the exchange rate when closer to equilibrium than say 12 percent, the size of intervention needs to be so large that it is unfeasible. These predictions have strong implications for the exchange rate policy regime (or lack of) adopted by the G-3. The next section examines this issue in more detail.

### 4.4.1 Implications for the choice of exchange rate regime

The growing evidence that sterilized intervention can indeed be effective, together with the finding that intervention is much more successful when misalignments are large, has strong implications for exchange rate management regimes based on sterilized intervention in a world with free movement of capital.

Firstly, the finding that sterilized intervention can have strong effects on misalignments, but negligible effects on the equilibrium rate is in-keeping with the received wisdom that a country cannot maintain an exchange rate policy wholly independent of other policy choices. Instead, the role of intervention is likely limited to maintaining exchange rates at levels broadly in keeping with underlying economic conditions. Secondly, the large gains in efficiency of intervention when misalignment are large provides further ammunition to the case for intermediate exchange rate regimes based on exchange rate bands. Clearly, the quantity of intervention required to keep the exchange rate within a band falls rapidly as the width of the band increases. More importantly perhaps, the size of intervention necessary to significantly influence the exchange rate when it is close to equilibrium is so large as to make such a policy unworkable in practice.

A key feature of much of the discussion surrounding the likely success of a target zone is the focus on the credibility of the authorities' commitment. For example, Krugman and Miller (1993) argue that traders' speculation shifts from being destabilizing to stabilizing as long as they are assured that the target zone will be maintained. Their argument focuses on the role of stop-loss traders, who cover their exposure to large losses by selling their assets when prices fall below a certain level. If a target zone commands sufficient credibility to assure such traders that their stop-loss orders will not be triggered, it removes the fuel for destabilizing speculation. A similar case is put forward by Jeanne and Rose (2002), who suggest that a sufficiently credible commitment to keep the volatility of the exchange rate within a preannounced range can prevent destabilizing speculators entering the market. This effect is achieved by lowering the risk premium on foreign bonds which removes the high excess returns on foreign assets which lure destabilizing speculators in the first place. Note however, that the results discussed here suggest that an exchange rate band could still prove effective even when laking full credibility. While an even partially credible announcement to intervene does improve the effectiveness of intervention in the model presented here[10] it is not necessary to reduce the attractiveness of chartist strategies. This is because, by it's very nature, chartist behavior is backward looking. Intervention which reduces the profitability of technical rules in one period therefore affects the strategy choice the next.

What kind of exchange rate band would be most appropriate given these results? A key implication of the use of *sterilized* intervention is that even massive interventions may not be immediately successful in reversing destabilizing trends. Given this observation, and the well documented susceptibility to speculative attack of target zones where the authorities are committed to defending the edges of the band, the most appropriate arrangement would seem to be the 'Monitoring Exchange Rate Band' proposed by the Tarapore committee and discussed by Williamson (1998). In a monitoring band, the authorities announce their intention to maintain the exchange rate within a band, but are not committed to intervene when the edge of the band is reached. Thus there is a public threat that intervention may be triggered once the exchange rate reaches a preannounced deviation from fundamentals, whereafter interventions continue until the exchange rate is brought back inside the band. This allows for flexibility in the face of overwhelming

[10] An announcement by the authorities to intervene improves interventions effectiveness when market participants condition their choice of forecasting strategy on the likelihood of intervention. They do so because they are aware that intervention will reduce the profitability of chartist strategies.

market pressure, and removes the threat of speculative attack.

This kind of regime would take full advantage of the increased efficiency of intervention at large misalignments. The results presented here demonstrate that, since interventions of a practical size only have a reasonable change of success outside a region of around 12 percent around fundamentals, a monitoring band policy is exactly what is called for in order to place realistic limits on the size of persistent exchange rate fluctuations. There is also no requirement for the announced band to be fully credible. Prolonged misalignments are generated when traders find forecasts based on past movements in the exchange rate more profitable than forecasts based on underlying economic conditions. Intervention can be successful because it reverses this situation. Indeed, this is exemplified by the Japanese experience: since intervention proved quite successful despite the absence of a announced band for the exchange rate.

### 4.4.2 The efficiency of Japanese intervention operations in the 1990's

The distributions illustrated in figure (4.7) may be used to calculate the ex-ante probability that actual intervention operations by the Japanese authorities would result in a reversal of trend in the exchange rate[11] These probabilities are illustrated in figure (4.8), together with actual intervention operations and the estimated deviation from fundamentals when the intervention took place.

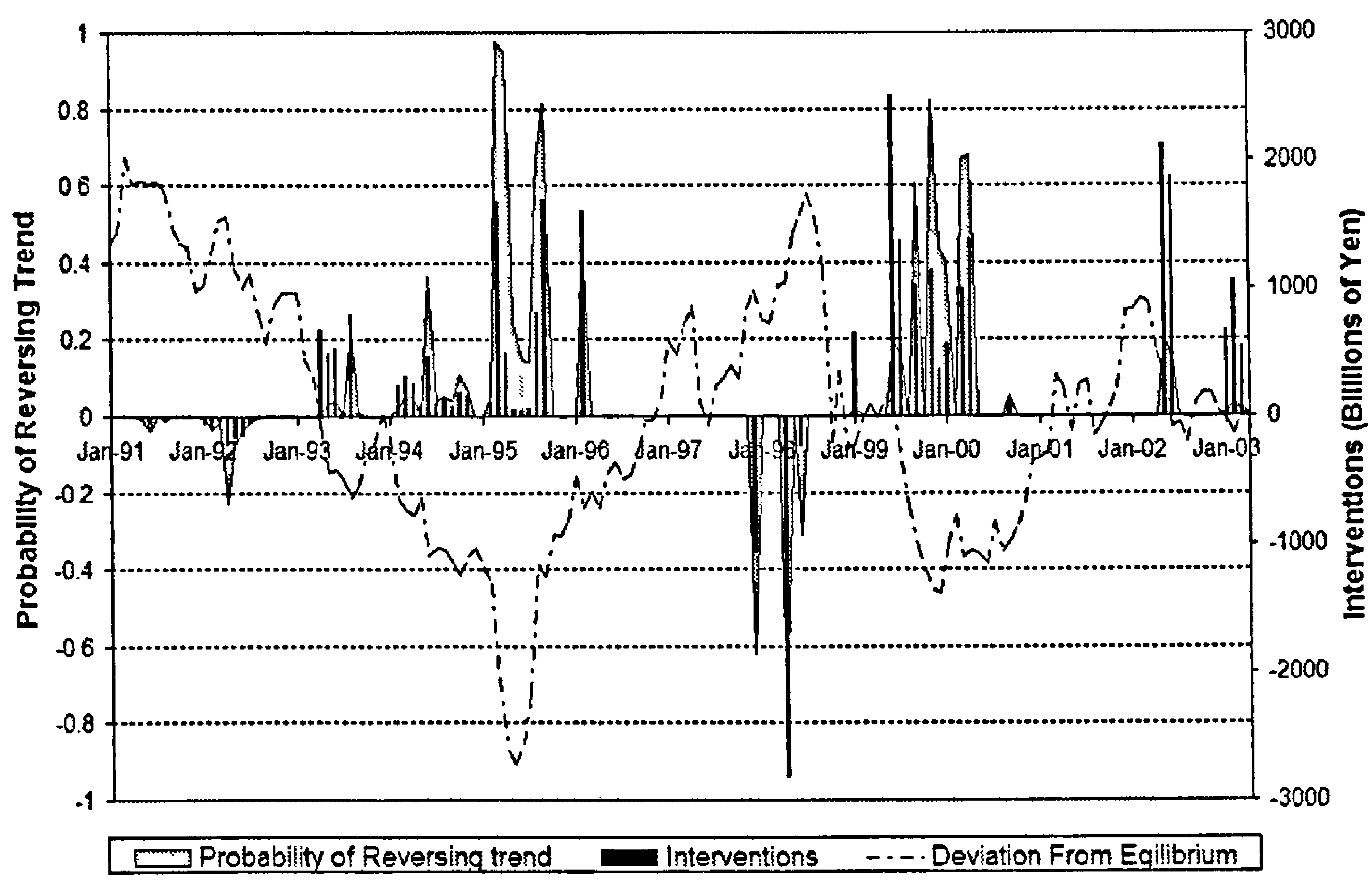



Figure 4.8: Probability of Actual Interventions Inducing Turning Points

The figure highlights how the efficiency of interventions by the Japanese monetary authorities has varied with the period in which they occurred. In particular, it lends further support to the results of Ito (2002), who finds that interventions conducted when Eisuke Sakakibara was Director General

[11]While the analysis presented here focuses on the probability that intervention will *reverse* the trend in the exchange rate, there is also evidence (e.g. Ito (2002)) that intervention is used to reinforce stabilizing trends in the exchange rate. Clearly this type of intervention could be considerably smaller and yet remain effective.

of the International Finance Bureau at the MOF. Referring to his book (Sakakibara (2000)), Ito details how intervention policy under Sakakibara was distinctively different from that of his predecessor. Specifically, interventions became much less frequent, and were considerably larger than before. Ito's results indicate that, in contrast to his predecessor, intervention under Sakakibara was successful in producing the authorities desired effects on the yen. Figure (4.8) illustrates a sharp contrast in the probability of intervention being effective between the periods when Sakakibara was in office at the MOF from 1995 to 1999, and the periods prior to him taking up his position and after he had left. For example, the interventions carried out during September 1995, when both the estimated deviation from fundamentals and the size of intervention were large , are estimated to have a relatively large probability of success (approximately 80%). Prior to 1995, the probability of intervention being effective never exceeded 38%, and was often considerably smaller. Similarly, the results indicate that interventions after April 2000 have had less than 20% chance of changing the trend in the exchange rate.

It is interesting to note that the model identifies many interventions as having a significant effect on the path of the exchange rate, even in case where they do not seem to effect the trend in the short run. These can be interpreted as instances when, although interventions apparently failed to 'burst bubbles', the movement of the exchange rate away from fundamentals would have been more pronounced in their absence. This is because even if the intervention fails to prompt enough traders to switch to the fundamentalist strategy to burst the bubble, it will nevertheless result in a reduction of the mass of traders on the chartist strategy, thereby reducing the force of the trend away from equilibrium. Furthermore, even if the intervention fails to result in the exchange rate bubble bursting immediately, it may still prove effective in prompting a medium-run collapse of the bubble at significantly lower levels of the exchange rate than would have been the case had the authorities not intervened. To see why this is the case, recall that in the medium run the proportion of traders employing the chartist strategy inevitably falls as the exchange rate moves further from equilibrium. An intervention operation by the authorities has the effect of reducing still further the proportion of traders using the chartist rule. Although the intervention will only be successful in bursting the bubble if it is large enough to prompt enough traders to switch to the fundamentalist strategy to result in a move toward equilibrium in the exchange rate. However, even if the size of the intervention is insufficient to result in the bubble bursting right away, the weight of traders using the chartist strategy will still be somewhat reduced, which will have two key consequences. Firstly, the rate at which the exchange rate is moving away from equilibrium may be substantially reduced. Secondly, if the reduction in the mass of traders on the chartist strategy persists (i.e. traders who switched to the fundamentalist strategy following the intervention do not switch back to the chartist strategy one the authorities stop intervening), then, as the bubble grows further, a relatively smaller proportion of traders is required to endogenously switch to the fundamentalist strategy in order for the bubble to collapse. This implies that even if the intervention is unsuccessful in the short run, it may well result in the collapse of the bubble in the medium run at substantially smaller deviations from fundamentals than would have been the case had the authorities failed to intervene.

This delayed effect of intervention may be clarified, and a fuller picture of the actual effect of intervention operations gained, by simulating the path of the exchange rate subject to the realized sequence of shocks in the absence of intervention by the authorities. The simulated path of the exchange rate in the absence of intervention is compared with the actual path in figure (4.9).

Figure (4.9) clearly illustrates how intervention by the Japanese authorities has been successful in reducing medium run volatility in the exchange

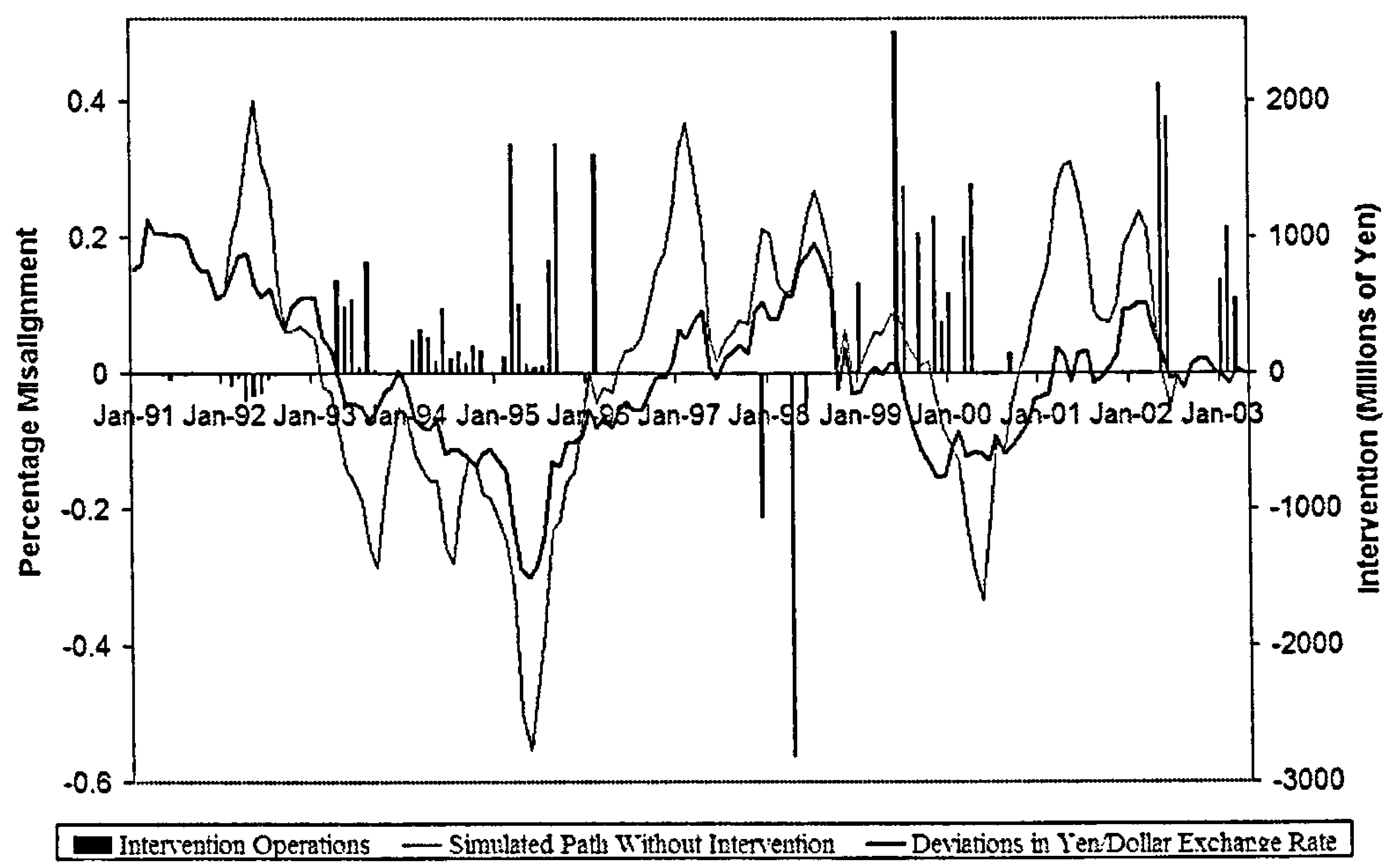



Figure 4.9: Simulated Path of Exchange Rate in Absence of Intervention

rate. While many interventions apparently failed to *reverse* the trend of the exchange rate away from equilibrium, the figure illustrates how they were effective in *reducing the strength* of the trend. Intervention by the authorities thus seems to be have been highly successful in limiting erratic and persistent movements in the exchange rate created by herding behaviour amongst market participants.

## 4.5 Conclusion

Recent work on the presence of noise traders and chartists in the foreign exchange market suggests that the large and persistent swings evident in G3 exchange rates have little relation to movements in economic fundamentals. In order to limit the negative effects of these misalignments on competitiveness, inflation, and financial stability, foreign exchange intervention by, for example, the Japanese monetary authorities, is often used to reduce the severity of such swings. The central hypothesis of this paper is that such interventions can be successful by reducing the profitability of destabilizing trading strategies, thereby inducing market participants to base their forecasts on economic fundamentals. It has been shown how even when interventions are sporadic in nature they can significantly alter the path of the exchange rate in the medium term, effectively bursting bubbles in the exchange rate.

Drawing on twelve years of data on Japanese interventions, there is significant empirical support for the model. Even when intervention by the Japanese authorities has apparently failed to burst bubbles in the exchange rate in the short run, simulations of the model suggest that interventions have often led to the collapse of bubbles somewhat earlier than would have been the case in the absence of intervention. Furthermore, we have provided estimates of the ex ante probability that interventions of a given size will be effective in bursting bubbles. For these results to provide an operational guide to the authorities on the size actual interventions clearly requires modeling at daily or higher frequencies. However, they do provide an indication of the likely efficiency of interventions in the medium term.

The emphasis in this paper has been on limiting exchange rate *misalignments* brought about by the use of backward looking trading strategies. The exchange rate fluctuations studied are generated and corrected in an endogenous manner by traders' selection of forecasting rule. This provides an explanation for the market's own tendency to correct extreme misalignments. One implication of this framework is that it provides an explanation for the rather mixed evidence on the efficacy of intervention in the literature. It was found that traders' high sensitivity to differences in the profitability between competing strategies allows intervention to be effective in reducing misalignments, even when it is of insufficient size to generate portfolio balance effects capable of influencing the equilibrium exchange rate. It is possible that the failure of many studies to differentiate between these effects has resulted in indeterminate results.

From the perspective of the monetary authorities, the mechanisms underlying the type of misalignment studied here can be harnessed to increase the efficiency of intervention operations. At larger misalignments a greater proportion of traders base their forecasts on fundamentals. As a result, a smaller quantity of intervention is required to tip the balance and achieve a 'critical mass' of traders who forecast a shift in the exchange rate to levels in line with economic fundamentals. In this way, intervention is seen to become more efficient as the size of misalignment increases. On the other hand, this implies that the efficiency of sterilized intervention is greatly reduced close to equilibrium. Based on these results, one can conclude that the optimal policy regime for the use of sterilized intervention would resemble a target zone.

While this paper has focused on the role of heterogenous expectations in explaining exchange rate fluctuations and the role of sterilized intervention, an alternative explanation could draw on the role of asymmetric information between market participants [12]. Further work could assess the role of intervention in such a framework. This would also enable an assessment of the role of aural intervention by the authorities in controlling exchange rate fluctuations.

[12]See, for example Abreu and Brunnermeier (2003)

## 4.6 Appendix: Computation of Size of Effective Interventions

The method for computation of the quantity of intervention necessary to burst a bubble is based on the calculation of nonlinear impulse response functions as described by Koop, Pesaran and Potter (1996).

Impulse response functions trace the effect of a one-off shock on the forecast of variables in a given model. The response of a variable following a shock must be compared to a baseline 'no shock' scenario. An 'generalized' impulse response function (GIR) of a variable $X$ can be expressed (using Koop et al's notation) as

$$GIR_X(n, v_t, \omega_{t-1}) = E[X_{t+n}|v_t, \omega_{t-1}] - E[X_{t+n}|\omega_{t-1}], \qquad n = 0, 1, \ldots \tag{4.16}$$

where $n$ is the forecast horizon, $v_t$ is the shock generating the response, $\omega_{t-1}$ is the 'history' or initial values in the model, and $E[\cdot]$ is the expectations operator.

For the purposes of the calculation, an 'effective' intervention is defined as one which reverses the trend of the exchange rate relative to the 'no shock' forecast.

First define the trend indicator variable $\iota_t$ as

$$\iota_t = \begin{cases} 1 & \text{if } X_t > 0 \text{ and } E[X_{t+1} - X_t|\omega_{t-1}] > 0 \\ -1 & \text{if } X_t < 0 \text{ and } E[X_{t+1} - X_t|\omega_{t-1}] < 0 \\ 0 & \text{otherwise} \end{cases} \tag{4.17}$$

so that $\iota_t = 1$ when the baseline forecast of $X_t$ follow a positive bubble path, and $\iota_t = -1$ when the baseline forecast of $X_t$ follows a negative bubble path. Let the level of exchange rate above which a single intervention of magnitude $\Delta$ is triggered be denoted by $\tau$. Then, conditional on $\tau$, an intervention at time $t$ of magnitude $\Delta$ is identified as 'effective' by the indicator variable $\mathcal{I}$:

$$\mathcal{I}(\Delta, \tau) = \begin{cases} 1 & \text{if } \iota \times E[X_{t+1} - X_t|\vartheta_t, \omega_{t-1}] < 0 \\ 0 & \text{otherwise.} \end{cases} \tag{4.18}$$

Thus following an effective intervention an increasing trend in the baseline forecast becomes decreasing in the shocked forecast, while a decreasing trend in the baseline forecast becomes increasing in the shocked forecast.

Due to the nonlinear nature of the model, the response of the variables to shocks must be conditioned on a given initial history. Furthermore, the effects of future shocks to the variables must be drawn from some distribution and averaged out over a large number of draws. In order to deal with these complications, the effects of interventions must be computed by simulating the model, for which the following algorithm is used.

The model is assumed to be known, so that sampling variability is ignored. Baseline forecasts are computed for $q$ periods, and a single shock to the intervention variable $\vartheta_t$ of size $\Delta$ occurs in period $i < q$ such that $|E[X_{i-1}|\omega_{t-1}]| < \tau < |E[X_i|\omega_{t-1}]|$ and $\iota \neq 0$.

1. Pick an intervention threshold $\tau$.

2. Take an initial history $\omega_{t-1}^r$ from the actual values of the variable $X$ at a given date.

3. Take a sequence of shocks $v_{t+n}^b$, $n = 0, \ldots, q$,where the shocks are drawn with replacement from the estimated residuals of the model.

4. Given $\omega^r$ and $v_{t+n}^b$, simulate the evolution of $x_{t+n}$ over $q+1$ periods. Denote the resulting baseline path $X_{t+n}(\omega_{t-1}^r, v_{t+n}^b)$, $n = 0, \ldots, q$.

5. From the baseline forecast, choose a date $i$ such that $|E[X_{i-1}|\omega_{t-1}]| < \tau < |E[X_i|\omega_{t-1}]|$ and $\iota_i \neq 0$. Then set $\vartheta_t = \iota_i \times \Delta^j$ for $t = i$, and $\vartheta_t = 0$ for $t \neq i$. Simulate the evolution of $X_{t+n}$ over $q+1$ periods and denote the resulting path $X_{t+n}(\vartheta_t, \omega_{t-1}^r, v_{t+n}^b)$, $n = 0, \ldots, q$.

6. Calculate

$$\mathcal{I}(\Delta^j, \tau) = \begin{cases} 1 & \text{if } \iota \times E[X_{t+1} - X_t|\vartheta_t, \omega_{t-1}] < 0 \\ 0 & \text{otherwise.} \end{cases}$$

7. Repeat step 5 $J$ times, and denote the smallest value of $\Delta$ such that $\mathcal{I}(\Delta^j, \tau) = 1$ by $\Delta^{b,r}_{min}(\tau)$.

8. Repeat steps 3 to 7 B times to obtain the distribution of effective interventions conditional on initial histories from $[\Delta^{1,r}_{min}(\tau), \ldots, \Delta^{B,r}_{min}(\tau)]$.

9. Repeat steps 2 to 8 R times, and average the distributions obtained over initial histories to obtain distributions of effective intervention conditional only on the threshold $\tau$

In this paper, in step 1 $\tau$ ranged from 0.05 to 0.3 in steps of 0.01. R was set to 30, using the first set of 30 observations from the data, and B was set to 1000. Figure (4.7) in the main text plots the 25%, 60% and 70% percentiles of the distributions thus obtained against the threshold value $\tau$.

# Part II

# Financial Innovation and Stability in the International Financial System

# Chapter 5

# Introduction

The number and variety of types of financial contracts has increased rapidly over the past twenty five years, and continues to grow. One area of innovation in particular which has seen remarkable growth is that of derivative contracts: financial contracts which derive their value from the price of some other, underlying asset.

The implications of the rapid growth in derivatives markets have been hotly debated, with regular calls to increase their regulation and slow the pace of their growth. At its heart, the controversy surrounding derivatives stems from leverage they provide: derivatives transactions allow investors to take a large price position in the market while committing only a small amount of capital. This ability to take high leveraged positions in markets has lead to their widespread use not only for hedging purposes (reducing the risk resulting from the potential future movements in a market variable), but also for speculation (placing a bet on the future direction of a market variable)[1].

In theory the low-cost hedge provided by derivatives should increase the robustness of financial markets by facilitating risk-sharing, and hence reduce frictions and increase efficiency. However, at the same time their use has been closely associated with several episodes of severe stress in the international financial system. Recent examples of this double-edged nature of derivatives usage are provided by the contrast between the turmoil following the near collapse of the Long Term Capital Management (LTCM) hedge fund in 1998, and the relatively muted impact on the real economy of the collapse in the NASDAQ stock index in 2000.

LTCM widely used financial derivatives to achieve an extremely high degree of leverage[2]. The principal trading strategy it used is known as 'convergence arbitrage', whereby pairs of securities are identified which should theoreti-

[1]Leverage makes it cheaper for hedgers to hedge, but it also makes it cheaper to speculate. Instead of buying \$1 million of Treasury bonds or \$1 million of stock, an investor can buy futures contracts on \$1 million of the bonds or stocks with only a few thousand dollars of capital committed as margin (the capital commitment is even smaller in the over-the-counter derivatives markets). The returns from holding the stocks or bonds will be the same as holding the futures on the stocks or bonds. This allows an investor to earn a much higher rate of return on their capital by taking on a much larger amount of risk.

[2]At the beginning of the 1998, LTCM had capital of \$4.8 billion, a portfolio of \$200 billion (borrowing capacity in terms of leverage) and derivatives with a notional value of $\$1,250$ billion.

cally trade at the same price, and if there is a current divergence in their market prices, bets are placed on them moving together. In the case of LTCM, bets were taken on convergence between liquid treasury bonds and more complex instruments that commanded a credit or liquidity premium, these bets were enacted by using derivatives know as interest rate swaps[3]. Furthermore, because LTCM was largely unregulated it was able these put these interest rate swaps at the market rate for no initial margin - an essential part of its strategy. This meant it was able to borrow 100% of the value of any top-grade collateral, and with that cash buy more securities and post them as collateral for further borrowing: in theory allowing it to leverage itself to infinity.

In August 1998 Russia declared its intention to restructure all official debt obligations falling due at the end of 1999, and imposed a 90-day moratorium on the repayment of private external debt[4] This led to a 'flight to quality[5]' in international bond markets and subsequent large jumps in spreads on corporate and emerging market bonds. This sudden increase in corporate bond spreads worked strongly against the assumptions behind LTCM's trading

[3]An interest rate swap amounts to an agreement for two parties to exchange the interest rate payments from two different securities without exchanging the underlying debt.

[4]Kharas, Pinto, and Ulatov (2001) provide a discussion of the Russian crisis.

[5]In this case with large scale sales of low graded and emerging market debt and purchases of e.g. US treasury bonds.

strategy[6]. Jorion (2000) documents that between the end of December 1997 and the end of August 1998, LTCM lost more than 50 percent of its capital, and increased its assets-to-capital ratio from 28-1 to 55-1.

The position of LTCM was made more difficult by the fact that many other hedge funds were following similar convergence arbitrage strategies. After the Russian default and the flight to quality, LTCM tried to liquidate part of its portfolio to meet its cash needs. However, other hedge funds were facing similar problems to LTCM and attempting to make similar trades. This exacerbated the situation, causing liquidity spreads to be even higher than they would otherwise have been, reinforcing the flight to quality.

During this period of extreme volatility, the U.S. Federal Reserve cut interest rates aggressively in three steps between the 29th of September and the 17th of November, 1998. This sharp easing in U.S. monetary policy was in part motivated by growing concerns that the U.S. economy was on the verge of experiencing a liquidity crash as corporate bond spreads in the U.S., as well as in other countries, had risen to exceptionally high levels, dramatically increasing the cost of financing for corporations. The potential systemic effects of LTCM, and other large hedge fund collapses, and

[6]Although LTCM did not have large exposures to Russian debt itself, the flight to quality resulted in large increases in spreads between liquid and illiquid securities.

the consequent implications for the U.S. economy as a whole, prompted the New York Federal Reserve to organize a bailout of LTCM by encouraging 14 banks to invest in the hedge fund.

The LTCM episode highlights how the growth in usage of derivatives can create substantial risks for the international financial system. However, the insulating effects of their use for hedging have received somewhat less attention. One high-profile example of the positive effects of derivatives was the apparent ease with which the U.S. economy recovered following the collapse of so called 'New Economy' technology stocks in 2000 – 2001.

The late 1990's saw a surge in business investment in the U.S., much of which was linked to computers and information technology. During these years, measured productivity growth picked up, inflation remained low, and the unemployment rate declined. Such observations were often cited as evidence of a permanent structural change - one that portended faster trend growth in the years ahead. Widespread belief in the so-called "new economy" caused investors to bid up stock prices to unprecedented levels relative to earnings (see, for example Lansing (2002)).

It is now clear that the investment boom of the late 1990s was overdone. Firms vastly overspent in acquiring new technology and in building new productive capacity - with an attendant increase in employee headcount -

in an effort to satisfy a level of demand for their products that proved to be unsustainable. A recent study by Gordon (2003) documents the many transitory factors that boosted the demand for technology products during the late 1990s. These include: (1) telecom industry deregulation that led to the creation of new firms, each demanding large amounts of equipment to build communication networks, (2) the need to replace computers in order to run a new generation of software starting with Windows 95, (3) the one-time invention of the world wide web, (4) the surge in equipment and software demand from the now defunct dot-coms, and (5) a compressed PC replacement cycle heading into Y2K.

This extraordinary burst of investment during the late 1990s coincided with the emergence of a major speculative bubble in the U.S. stock market - itself fueled by the very same optimistic projections about the future. In a recent paper, Caballero and M.L. (2002) present the view that the stock market bubble and the investment boom were mutually reinforcing phenomena. In particular, rapidly rising stock prices provided firms with a low-cost source of funds from which to finance their investment projects. The resulting surge in capital accumulation served to increase measured productivity growth which, in turn, appeared to justify the enormous run-up in stock prices.

Following the bursting of the NASDAQ bubble beginning in March 2000, an estimated 8 trillion dollars of wealth was wiped out. Based on the experience of similar events in the past, one would expect the welfare costs of a shock of this size to be dramatic. However, the actual effects of the bursting of the tech bubble seem to have been rather limited (see, for example, Lansing (2003)), to the extent that the role of derivatives in enhancing the robustness of the U.S. financial system in the face of such a large shock was celebrated by the Chairman of the U.S. Federal reserve, Alan Greenspan in an address to the U.K. Treasury in 2002. An important source of resilience singled out by the Fed Chairman was the widespread use of financial derivatives.

While the LTCM debacle has provoked a raft of research which highlights the risks posed to the financial system by the widespread use of derivatives (see amongst others, on Financial Markets (1999), and Kharas, Pinto, and Ulatov (2001) and Kumar and Persaud (2001)), less work has been undertaken to examine the extent to which their usage can insulate the real economy from financial and monetary shocks. This part of my thesis examines these issues in some detail. The next chapter begins by examining the theoretical channels by which financial shocks can impact the real economy, focusing on the role of credit market frictions in amplifying the real effects of these shocks. A simple model is then presented which both provides a rational for the growth in derivatives usage - in particular interest rate swaps

- and their role in reducing frictions, allowing credit markets to function more efficiently so that the impact of financial shocks on the real economy is reduced.

The subsequent chapter addresses the empirical evidence regarding the role of swaps in lessening the impact of monetary policy. The empirical literature on the importance of credit market frictions is surveyed, as is the evidence on the role of derivatives in reducing frictions at the disaggregated level. New aggregate level evidence is then presented for the U.S., drawing on a hitherto unexploited data set from the U.S. Office of the Comptroller of the Currency (OCC), on aggregate derivatives usage. The findings indicate some qualified support for the theory that exponential growth in the usage of interest rate swaps has resulted in a reduction in the impact of interest rate shocks on the real economy.

# Chapter 6

# Corporate use of interest rate swaps and the monetary transmission mechanism

## 6.1 Introduction

The aim of this chapter is to examine the implications of financial innovation, in particular the growth in use of derivatives contracts, for the linkages between the real and financial sides of the economy.

In the complete absence of frictions the economy should display the 'classical dichotomy' (Modigliani (1963), Patinkin (1965)); where real variables such as output, consumption, and the real interest rate are determined independently of nominal financial variables such as asset prices, nominal interest rates and financial asset demand and supply factors. In practice however, there are a wide range of frictions present in the economy which can lead financial developments to have real consequences, at least in the short-run. For example, inertia in wages,prices and inflation can lead to dependencies of consumption on financial factors through wealth effects, and dependencies of investment on financial developments can occur via cost-of-capital effects.

In addition to these 'traditional' channels of monetary transmission, more recent work has examined the consequences for the real sector of developments in credit markets. One important feature of these markets which has been emphasized in the literature is their response to the presence of informational asymmetries between borrowers and lenders which can drive a wedge between the cost of internal and external financial of investment projects. In this case, a rise in interest rates may have a much stronger contractionary impact on the economy if balance sheets are already weak, introducing the possibility that nonlinearities in the impact of monetary policy may be important. The potential for amplification of the impact of monetary shocks in this manner has lead this channel of monetary transmission to be termed the 'financial accelerator'.

While the theoretical foundation of amplification of shocks through the financial accelerator is based on underlying agency problems, recent work has shown that the most popular type of derivatives contract, the interest rate swap, is desirable precisely because it mitigates this cost. If true, the aggregate impact should be a weakening of the financial accelerator due to the recent increase in usage of these contracts.

The use of swaps has grown rapidly in recent years, helped along partly by financial deregulation and reflected in the success of the financial industry in designing a great variety of OTC and exchange-traded contracts. The overall scale of interest rate hedging policies implemented by non-financial firms seems to be substantial. The 1995 BIS survey on global derivatives markets reports a global gross market value of OTC interest rate contracts equal to \$647 billion as of end-March 1995, while the notional amount outstanding in OTC and exchange-based markets for interest rate contracts was about \$36 trillion. The latest BIS survey reports gross market values of about \$5.3 trillion for OTC interest rate derivatives as of end of December 2004 and \$187 trillion of notional amounts outstanding in the combined markets for interest rate derivatives. With 16.1% of the gross market values and 13.3% of the respective notional amounts falling to non-financial customers, this suggests that a maximum of one sixth of the interest rate derivatives outstanding at that time were potentially held for corporate hedging purposes.

While the likely sensitivity of the financial accelerator to financial innovation has been discussed in the literature (see, for example Krishnamurthy

(2003)), to my knowledge there has been no attempt to explicitly model the role of interest rate swaps in this regard. In addition, several studies examine the evidence for agency-cost reduction effects of swaps at firm level. However there are no studies that I am aware of that look at evidence of an impact at the aggregate level.

This chapter begins by examining the nature of the derivatives markets which have developed over the last twenty years. Evidence is presented that the most widespread of all derivatives contracts are interest rate swaps. Section one begins by presenting some stylized facts describing derivatives markets in general, and swaps markets in particular. The leading theories which account for the use of this kind of financial instrument are then examined in some detail. In section two, the discussion moves onto the question of how developments in financial markets may impact on the real economy, in particular output and employment. Particular emphasis is given to the role of the credit channel of monetary transmission, whereby agency problems between debtors and lenders lead borrowers to be credit constrained, with the amount they can borrow being dependent on their net worth.

The third section then introduces interest rate swaps into a model with credit constrained firms. It is demonstrated how the agency problems which amplify the propagation of financial shocks to the real economy are also a key motivating factor for the use of interest rates swaps. I.e. it is desirable for a firm to enter into a swap precisely because this kind of contract can mitigate higher costs of borrowing associated with asymmetric information between lender and borrower. As a result, the agency cost reduction achieved by the usage of interest rate swaps can counteract the amplification of financial shocks caused by information asymmetries. In this way, the model demonstrates how a increase in the 'completeness' of financial markets leads the economy closer to the 'classical dichotomy', which in the extreme case describe a condition where developments in financial markets have no impact on the real economy.

## 6.2 The usage of interest rate swaps

The rapid growth of the market for financial derivatives in recent years has spurred considerable controversy over the economic rationale for these instruments. Many observers have expressed alarm over the growth and size of the market, arguing that such instruments threaten the stability of financial markets, a fear which was confirmed by the market turmoil following the near collapse of the Long Term Capital Management hedge fund in the wake of the Russian default in 1998.

Unlike standard financial contracts which are traded on exchanges, the majority of derivatives contracts are traded over the counter. The over-the-counter (OTC) market is comprised of a group of dealers, consisting of major international commercial and investment banks, who communicate offers to buy and sell contracts over telecommunications networks. OTC dealers intermediate cash flows between different customers, acting as middlemen for each transaction. These dealers act as market makers who quote bid and asked prices at which they stand ready to either buy or sell an contract before a customer for the other half of the transaction can be found.

The dramatic growth in the global usage of derivative contracts is most broadly captured by surveys conducted by the Bank for International Settlements[1](BIS). According to these statistics, the notional amounts outstanding[2] of OTC derivatives accounted for a fairly constant proportion of total (OTC plus exchange-traded) derivatives, being 82% in 1995 and 81% in 2004.

The lions share of growth in the OTC market can be attributed to interest rate derivatives, whose growth in turn is dominated by the increase in

[1]The BIS releases statistics from both its Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity, and its Semi-Annual Regular OTC Derivatives Market Statistics.

[2]The size of the payments exchanged by the counterparties under a derivatives contract is based on some stipulated notional principal amount, which itself is not paid or received.

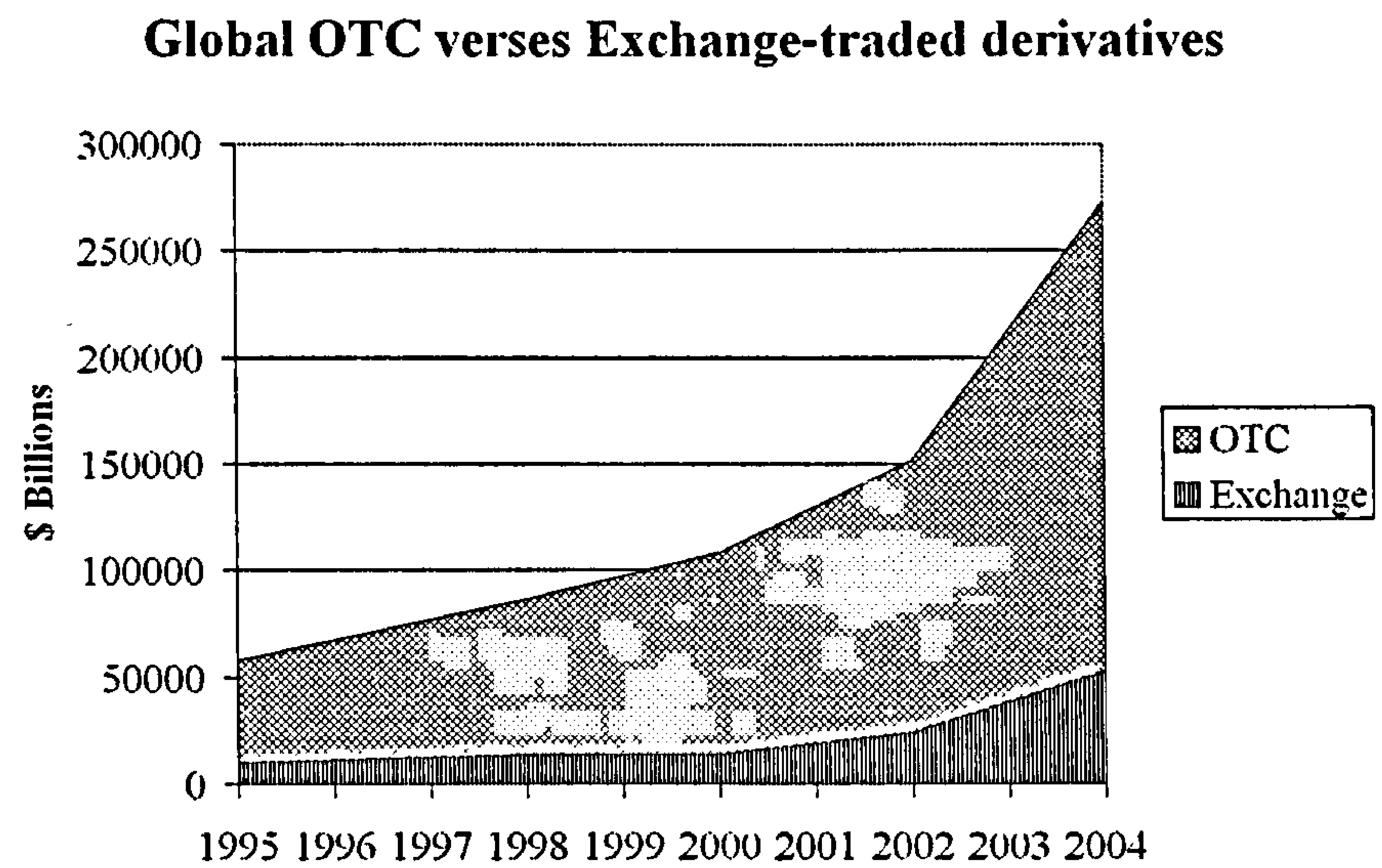



Figure 6.1: Outstanding amounts of Exchange traded versus OTC derivatives.

outstanding interest rate swap contracts; as indicated by figures (6.1) and (6.2) respectively.

An interest rate swap is a contractual agreement between two parties to exchange a series of interest rate payments without exchanging the underlying debt. The most common type of interest rate swap is the fixed/floating swap in which a fixed-rate payer promises to make periodic payments based on a fixed interest rate to a floating-rate payer, who in turn agrees to make variable payments indexed to some short-term interest rate. In this way, an interest rate swap essentially transforms variable interest rate debt into fixed rate debt.

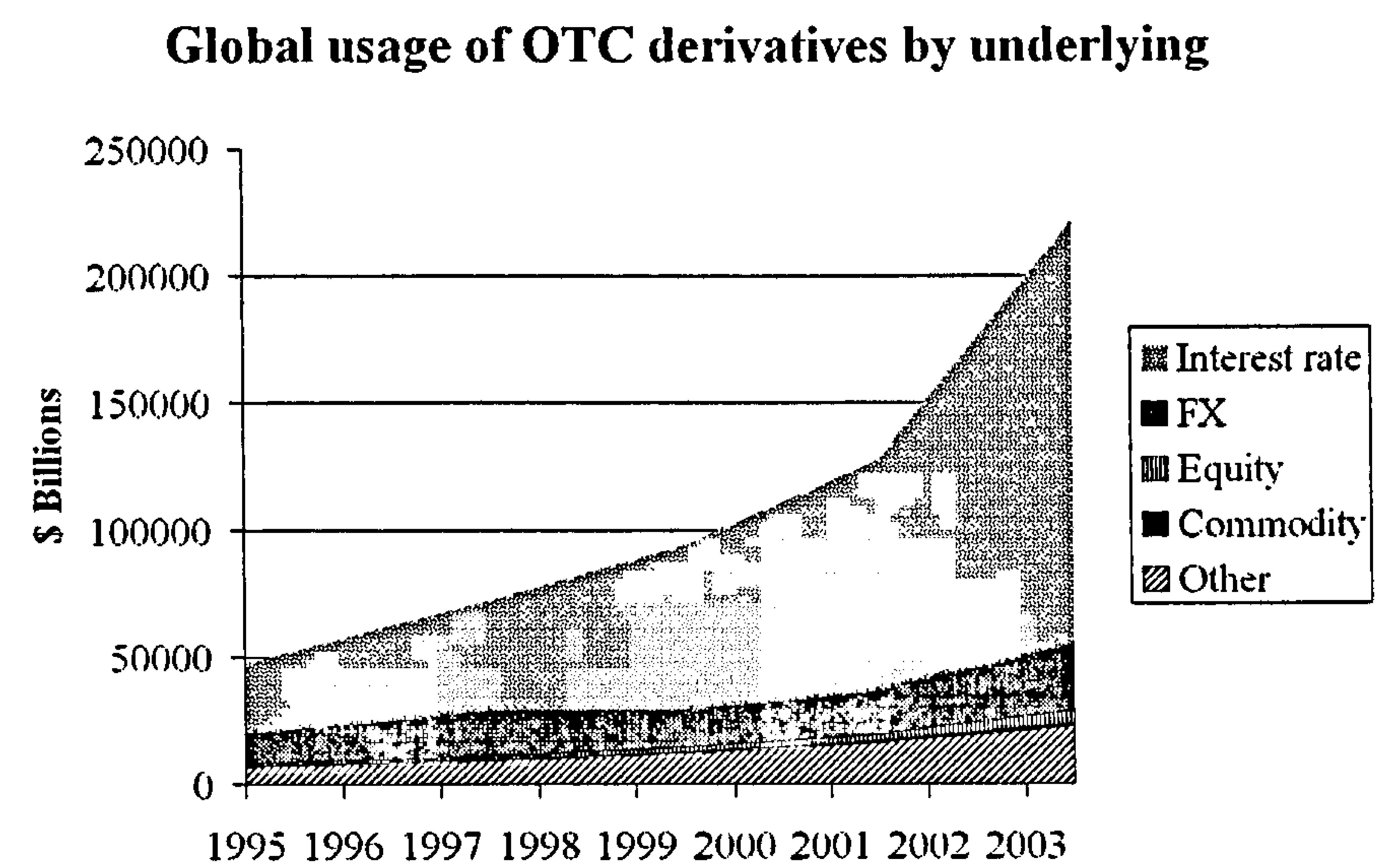



Figure 6.2: Breakdown of OTC derivative usage by type of underlying instrument.

Because swap dealers act as intermediaries, a swap customer need be concerned only with the financial condition of the dealer and not with the creditworthiness of the other ultimate counterparty to the agreement. Counterparty credit risk refers to the risk that a counterparty to an interest rate swap will default when the agreement has value to the other party. Managing the credit risk associated with swap transactions requires credit-evaluation skills similar to those commonly associated with bank lending. As a result, commercial banks, which have traditionally specialized in credit-risk evaluation and have the capital reserves necessary to support credit-risk management, have come to dominate the market for interest rate swaps (Smith, Smithson, and Wakeman (1986)). The discussion that fol-

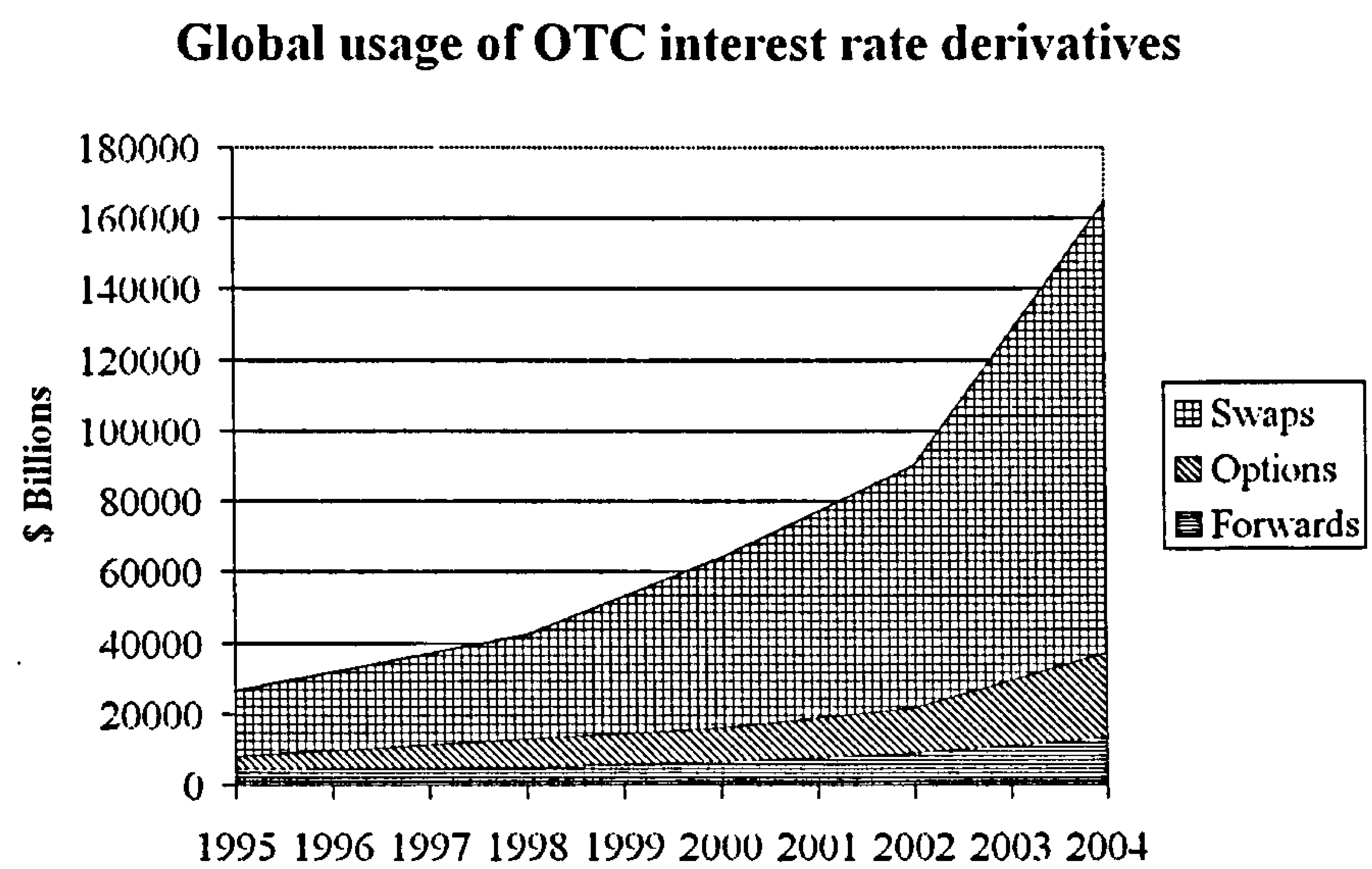



Figure 6.3: Breakdown of OTC interest rate derivative usage by type of contract.

lows largely abstracts from counterparty credit risk and the role of swap dealers. In addition, the description of interest rate swaps is stylized and omits many market conventions and other details so as to focus on the fundamental economic features of swap transactions. For a more detailed description of interest rate swaps and other interest rate derivatives, see Kuprianov (1994). Burghardt, Belton, Luce, and McVey. (1991) and Marshall and Kapner (1993) provide more comprehensive treatments.

The growth and development of the interest rate swap market has been surveyed by Kuprianov (1993) who also provides a description of swap dealers, swap market conventions, and swap transactions. Smith et al. (1988)

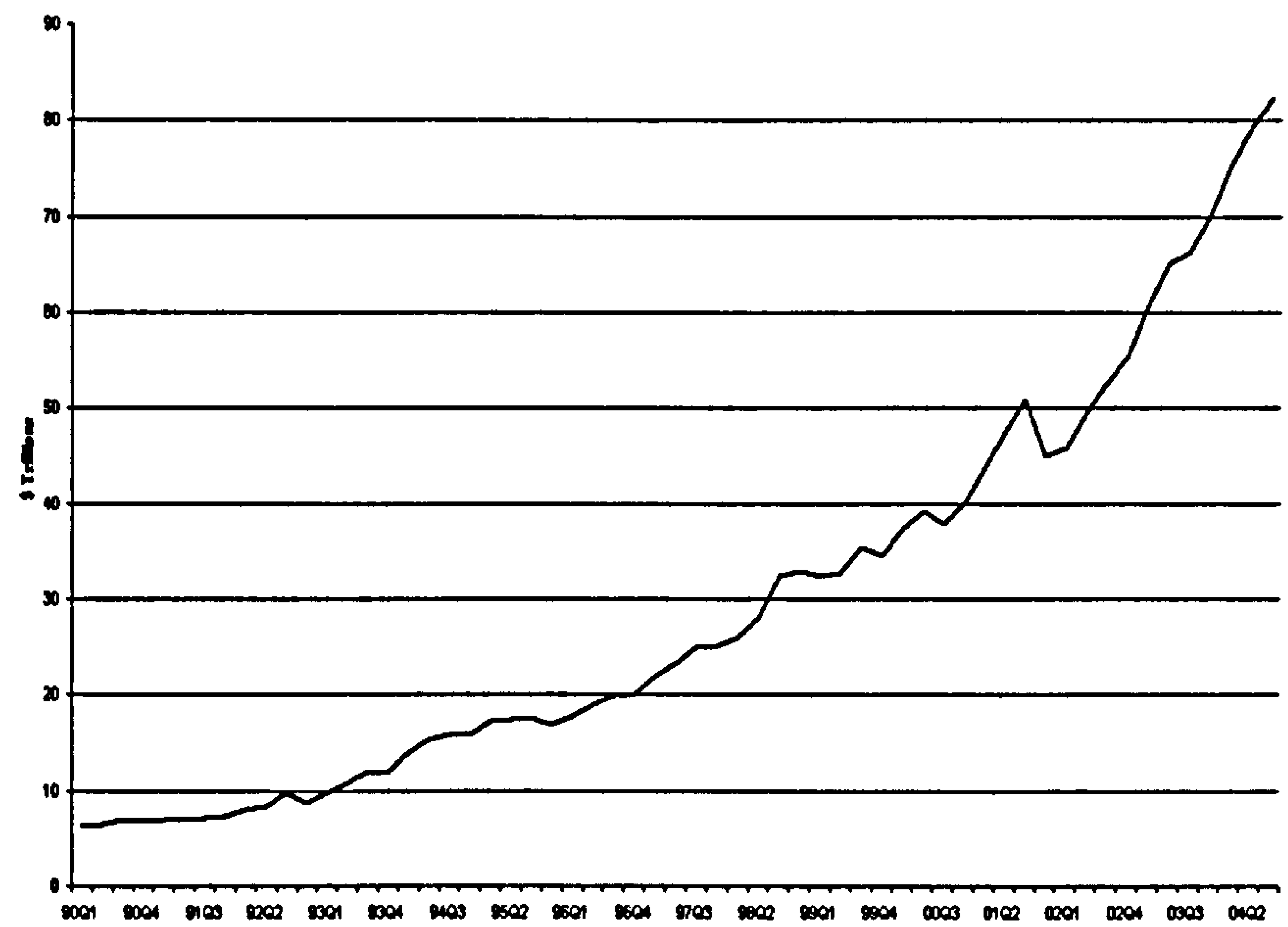


Figure 6.4: Total outstanding OTC interest rate swaps, notional amounts.

demonstrate the methods that financial managers can use in order for interest rate swaps to hedge interest rate exposure. The increased use of interest rate swaps as a hedging tool has helped the swap markets grow. Hedging has a cost to the firm and offers benefits to the firm. However, it is difficult to measure and analyze the cost benefit effects of interest rate swaps from publicly available financial statements. A survey by Bodnar, Hoyt, and Marston (1995) finds that swap contracts are the most common interest rate derivative contract used and indicates that more firms swap floating-rate for fixed-rate debt than fixed-rate for floating-rate, although both are common. This survey is also consistent with Fenn, Post, and Sharpe (2002) which finds that 58% of their sample firms were on the pay-fixed side of the swap.

### 6.2.1 Accounting for growth in interest rate swap usage

The rapid growth of the swaps market in recent years strongly suggests that market participants must perceive significant benefits associated with their use. While it is generally accepted that the ultimate gain from their use is a reduction in funding costs, the sources of this cost reduction are yet to be fully understood. Financial economists have proposed a number of different hypotheses, amongst which the key rationales are: comparative borrowing advantages, the mispricing of credit risk, information signaling, obtaining an optimal debt level, and agency cost reduction.

#### Comparative advantage

Perhaps the best known explanation of the benefits of interest rate swaps is based on the principle of comparative advantage. In international trade theory, the principle of comparative advantage explains the economic rationale for international trade by showing how different countries facing different opportunity costs in the production of different goods can benefit from free trade with other countries. In the context of borrowing cost reduction, Bicksler and Chen (1995) observe how the comparative advantage principal can be applied to differential information in different markets, institutional restrictions, and transactions costs. They note that these frictions may create some market imperfections and the presence of comparative advantages among different borrowers in these markets (p. 646). These market imperfections, according to Bicksler and Chen, provide the economic rationale for interest rate swaps.

However, the comparative advantage explanation for interest rate swap usage is not without problems. For example, Smith, Smithson, and Wakeman (1986), Smith, Smithson, and Wakeman (1988) observe that much of the apparent savings from the use of swaps can be attributed to the absence of a prepayment option on generic swaps. Fixed-rate bonds typically carry a prepayment option that allows the borrower to call and refund a debt issue should market interest rates fall. The cost of this option is incorporated into the interest rate the firm is required to pay on such bonds. In contrast, the generic interest rate swap carries no such prepayment option. Early termination of a swap agreement requires the value of the contract to be marked to market, with any remaining amounts to be paid in full. A borrower can buy a callable swap, which permits early termination, but must pay an additional premium for this option. Thus, to be fair, the cost of actual long-term debt should be compared to the cost of callable synthetic fixed-rate financing, which would reduce the measured cost advantage resulting from the use of interest rate swaps.

### Mispricing credit risk

The mispricing of credit risk is also offered as another theoretical explanation for interest rate swaps (e.g., Smith et al., 1988; Arak et al., 1988; Wall and Pringle, 1989; Litzenberger, 1992). The methods used by floating- and fixed-rate lenders to evaluate credit risk may lead to credit risk mispricing. However, Sun et al. (1993) empirical test results suggest that the market does price credit risk. The Duffie and Huang (1996) swap valuation model demonstrates that credit risk asymmetry results in only a few basis points of notional principal. They find that a spread of 100 basis points due to credit risk results in less than a basis point in the coupon swap market. The market price of credit risk is very small. If market price of risk is small, then higher risk firms benefit more from an interest rate swap compared to lower risk firms.

The comparative advantage principle has also been combined with the notion of mispricing of credit risk to explain the benefits of using swaps. All firms pay a credit-quality premium over the risk-free rate when they issue debt securities. These credit-quality premiums grow larger as the maturity of the debt increases. Thus, firm A might pay a credit risk premium of 50 basis points over the risk-free rate on its short-term debt obligations, the credit-quality premium it is required to pay on longer-term debt, say ten-year bonds, might rise to 100 basis points. Not surprisingly, firms with good credit ratings pay lower risk premiums than firms with lower credit ratings. Moreover, the credit-quality premium rises faster with maturity for poorer credits than for good credits. Thus, if firm B has a poorer credit rating than firm A, it might pay a credit-risk premium of 100 basis points on its short-term debt while finding it necessary to pay 250 basis points over the risk-free rate to issue long-term bonds. The quality spread between the interest rate paid by the lower-rated firm and that paid by the higher-rated firm is only 50 basis points in the short-term debt market, but rises to 150 basis points at longer maturities. The quality-spread differential, the difference in the quality spread at two different maturities, is 100 basis points in this example. Firm A has an absolute cost advantage in raising funds in either the short- or long-term debt markets, but firm B has a comparative advantage in raising funds in short-term debt markets.

While intuitively appealing, the evidence on this theory is not compelling. For example, Smith, Smithson, and Wakeman (1986), Smith, Smithson, and Wakeman (1988) argue that observed behavior in the swap market is not consistent with classic financial arbitrage of the type described by proponents of the comparative advantage rationale. The use of interest rate swaps to arbitrage quality-spread differentials, they argue, should increase the demand for short-term loans among firms with poor credit ratings while reducing demand for overpriced long-term loans. Eventually, such a process should reduce quality-spread differentials and therefore reduce demand for interest rate swaps. In fact, Bicksler and Chen (1995) did report evidence of declining quality-spread differentials as interest rate swaps came into widespread use. But trading activity in interest rate swaps has shown no sign of abating even as quality-spread differentials have declined. On the contrary, as described above the market for interest rate swaps has grown exponentially since the early 1980s.

### Information signalling

Information signaling due to asymmetric information can lead firms to be active in the swaps markets. Arak, Estrella, Goodman, and Silver (1988), Wall and Pringle (1989) and Titman (1992) hypothesize that if a firm possesses information about itself that will lower its risk premium in the credit markets in the future, but it wants to borrow at a fixed rate now, it can benefit from the use of interest rate swaps. The firm would borrow short term, then use interest rate swaps to obtain fixed rate borrowing that it needs to lower its financing costs. After the information is revealed in the market, and the firm receives a credit rating upgrade, the firm benefits from lower interest rates. However, previous studies show that there is no statistically significant stock price reaction to the announcement of rating upgrades and the reactions do not differ by initial credit rating (Hand, Holthausen, and Leftwich (1992); Nayar and Rozeff (1994)).

### Obtaining an optimal debt level

Interest rate swaps can be used to address capital structure situations. A firm could adjust its long-term debt structure up or down to reach and to maintain its optimal level, according to Wall and Pringle (1989) and Smith, Smithson, and Wakeman (1988). A firm that borrows long term to obtain a fixed rate could find itself committed to a level of debt that may not be optimal over the length of the loan. Then the firm can swap some fixed-rate debt for floating rate. On the other hand, using interest rate swaps, a firm can borrow short term to maintain an optimal debt level on its books and swap for a more cost effective fixed-rate debt.

In summarizing the theoretical arguments about interest rate swaps, Litzenberger (1992) makes several observations: (1) interest rate swaps are not redundant financial products, (2) interest rate swaps do not display the volatile cyclical behavior evidenced by corporate bond spreads, and (3) firms do not pay-up to do swaps with highly rated counterparties. These three characteristics cannot all be explained by any one theory or any combination of the theories given above. Litzenberger notes that credit rating differences have no observable impact on swap spreads, which implies that fixed/floating interest rate swaps are mispriced, although Duffie and Huang (1996) believe this can be attributed to very small values. Furthermore, Litzenberger theorizes that the growth in the use of swaps may also be attributed to their usefulness in signaling events favorable to the firm, although no empirical test of the impact of signaling with interest rate swaps has been done.

### Agency cost reduction

Perhaps the most important alternative theory to those based on comparative advantage is based on the swaps' potential for reduction of agency costs[3]. As defined by Jensen and Meckling (1976), an agency relationship is a contract under which one or more persons (the principal(s)) engage another person (the agent) to perform some service on their behalf which

[3]See, inter alia Wall (1989); Arak, Estrella, Goodman, and Silver (1988); and Titman (1992)

involves delegating some decision making authority to the agent (p. 308). If principals could always costlessly monitor the behavior of their agents, they could ensure that agents would always act in their best interests. Monitoring the behavior of agents is costly, however, and requires principals to expend resources. Thus, the agent might be required to incur certain bonding expenditures. Finally, if principals cannot ensure that agents will always act in their best interests despite monitoring and bonding, there may be some deadweight residual loss. Jensen and Meckling define agency costs as the sum of these expenditures. They show that debt finance can reduce overall agency costs for a firm, but their analysis does not consider the problem of interest rate volatility and the question of whether a firm should issue short-term or long-term debt, issues which lie at the heart of the usage of interest rate swaps.

Wall (1989) emphasized the role of agency costs in providing incentives for firms to use swaps. He argues that the existence of agency costs is one reason why quality spreads widen with debt maturity. This is because while established firms with good credit ratings and access to low-cost credit have incentives to limit risks, newer and smaller firms do not have the same incentives. Like Loeys (1985), Wall gives special emphasis to the influence creditors can exercise over borrowers when renegotiating short-term loans.

Wall was among the first to observe that synthetic fixed-rate financing obtained through the use of swaps carries different incentives for borrowers than actual fixed-rate financing. To understand why this might be so, notice that the interest rate lenders charge a borrower when renewing a short-term loan can change for two reasons: (1) a change in market interest rates or (2) a change in the firm-specific credit-quality risk premium. Interest rate swaps compensate the borrower only for changes in market rates, and not for changes in the short-term quality spread. Thus the total cost of synthetic fixed-rate financing is given by the swap fixed rate plus the quality spread between the rate the firm pays on its short-term debt and the swap floating-rate index. A firm that chooses synthetic fixed-rate financing faces the risk that the quality spread might rise if lenders realize that management has increased the firms riskiness. In extreme cases, the firm might even find itself unable to roll over its outstanding short-term debt and be forced into bankruptcy proceedings.

Capital markets fear that high-risk firms may borrow long term at fixed rates and then engage in asset substitution. Therefore, high-risk firms pay a premium for long-term fixed rates. A high-risk firm borrowing short term will reduce these agency costs because short-term borrowing increases monitoring and reduces the risk of asset substitution. A high-risk firm can reduce its agency costs and obtain fixed-rate terms by borrowing short-term and swapping for fixed rates. A reduction of agency costs will not necessarily result in a credit ratings upgrade, but could materially benefit the firm through credit risk improvement.

Walls (1989) rationale for interest rate swaps lies with the observation that synthetic fixed-rate financing should discourage management from pursuing risky investment strategies. According to this argument, interest rate swaps lower funding costs by controlling the adverse incentives a firms management might have to increase the risk assumed by the firm to the detriment of creditors. Thus, interest rate swaps do make it possible for firms to reduce financing costs in Walls theory. But the savings attributable to the use of swaps result from lower agency costs and do not constitute arbitrage in the sense that term is normally understood.

In addition to providing a rationale for the use of swaps, agency costs have also been highlighted as a potentially important friction which can lead shocks originating in the financial markets to impact the real economy. We turn to this literature in the next section.

## 6.3 The credit view of monetary policy transmission

In this section, the corporate finance foundations of monetary transmission are explored to understand how the usage of derivatives may alter the impact of monetary policy on output. Specifically, we follow the recent literature on the so-called credit view of monetary transmission.

In the previous section, the only sources of financing available to the firm were either long-term or short-term debt. In this section the menu is extended to allow for internal financing of investment projects. In the credit view of monetary policy, by emphasizing a combination of market imperfections such as informational frictions and portfolio balance effects, theory suggests that the state of a firms balance sheet has implications for its ability to obtain external finance. Policy-induced interest rate changes will, therefore, not only work through the traditional interest rate effect, but will also be reinforced by balance sheet effects. The existence of informational frictions thereby creates a separate channel for policy transmission. By virtue of this financial accelerator or, focusing on monetary transmission, 'broad credit channel', seemingly small changes in interest rates can have a large impact on real variables.

The concept of the financial accelerator derives from informational asymmetries in the credit markets, which drive a wedge between the costs of external and internal finance. In the early literature, the Modigliani and Miller (1958) theorem states that financial structure is irrelevant to corporate investment decisions. More recent research, however, has questioned the assumption of perfect substitutability of external and internal funds by pointing to the existence of capital market imperfections. The most common argument posits that asymmetric information and problems of contract enforcement lead to the emergence of agency costs, thereby driving a wedge between the cost of external and internal finance. As outside investors require a premium for unobservable or uncontractable risks, external finance becomes more costly than internal finance.

In such a situation, internally generated funds enable firms to reduce their demand for costly external finance. Hence, a fall in a borrowers net worth or cash flow raises the demand for external finance and subsequently reduces investment. Given that negative shocks affect cash flow individually, the effect of an initial shock to the economy may be amplified. Small shocks might therefore create large cycles, hence the term financial accelerator. A contractionary monetary policy shock now reduces investment spending through the traditional cost-of-capital effect and, given that changes in interest rates affect corporate cash flows, lowers a firms cash flow and its ability to borrow. Consequently, monetary policy impulses are reinforced by cash flow effects.

Examples of a theoretical link between balance sheet positions and investment appear, amongst others, in Bernanke and Gertler (1990) and Calomiris and Hubbard (1990). Both papers predict that borrowers investment decisions will be excessively sensitive to current cash flow: A rise (fall) in cash flow strengthens (weakens) the firms balance sheet and thus lowers (increases) the cost of capital. It is, hence, possible to rationalize income accelerator effects on investment. Fazzari, Hubbard, and Petersen (1988) provide empirical support for these various propositions. They conduct a time series and cross-sectional analysis of a broad class of firms. Their main result is that investment is significantly more sensitive to current firm cash flow than a frictionless model would predict.

The informational asymmetries which are at the heart of these models of the monetary transmission mechanism create incentives for corporate risk management strategies based on interest rate derivatives such as swaps. Hence, broad credit channel effects may be minimize, thereby reducing the impact of interest rate changes to the pure cost-of-capital (interest rate) effect. This suggests that financial derivatives may have quite a strong impact on this specific transmission channel. This study thus contrasts with the analysis of Romer and Romer (1993), who argue that: [...] it is difficult to see how recent financial market innovations could have significantly affected this component of the transmission mechanism [ie the financial accelerator or broad credit channel].

In the next section these ideas are stated more formally and a theoretical model is developed to demonstrate the impact of interest rate swap usage on the credit channel of monetary policy.

## 6.4 Interest rate swaps and the credit channel of monetary transmission

In this section a model of the financial gains from interest swap usage, due to Li and Mao (2003), is extended to allow for internal financing of investment projects in order to directly model the impact of swaps on the financial accelerator.

Earlier theories of interest rate swaps emphasize firms's choice between commercial paper and long-term fixed-rate debt. As described in section (6.2) a key feature of the these models is that firms can benefit from their constantly changing credit quality by rolling over short-term debts at frequent intervals. However the disadvantage of short-term debts is that they expose firms to interest rate fluctuations. Interest rate swaps allow firms to benefit from borrowing short-term debts and avoid the associated interest rate risk. The existing theories provide important insights on interest rate swaps, but also have certain limitations. For example, by focusing on debt maturities, they can only explain the combination of short-term loans and interest rate swaps, but cannot explain why firms choose to borrow long-term floating-rate loans and enter interest rate swaps.

Li and Mao's (2003) extend work by Holmström and Tirole (1997) to develop a model of interest rate swaps which is based on the difference between bank loans and public debts. Their framework captures important features of the agency cost/information asymmetry argument by allowing for banks that are good at discerning the credit quality of their borrowers, and in addition, that restrictive covenants of bank loans are another important way to mitigate agency costs[4]. If the borrower's credit quality deteriorates significantly, banks can demand their money back and effectively accelerate the maturity of the debt. Thus, the distinction between long-term and short-term bank loans is not important for mitigating agency problems; restrictive covenants make bank loans short term with respect to their credit risk regardless of their stated maturity. While restrictive covenants of bank

[4]See for example Diamond (1984); Leland and Pyle (1977); Ramakrishnan and Thakor (1984)

loans help reduce agency costs, banks have natural disadvantages in bearing interest rate risk due to their floating liabilities. A firm that wants a fixed-rate loan can borrow a floating-rate loan from a bank and enter an interest rate swap to hedge the interest rate risk.

In models of the financial accelerator discussed in section (6.3), the effects of financial shocks on the real economy are amplified because agency costs drive a wedge between the costs of internal and external financing. This in turn makes firms' ability to fund investment dependant on their balance sheets. The impact of interest rate swaps on this mechanism is explored by extending Li and Mao's model to allow for internal financing, drawing on work by Gertler and Hubbard (1989). In this framework it is shown how the use of interest swap can reduce the magnitude of wedge between internal and external financing, and thus at the aggregate level mitigate the amplification effects of the financial accelerator.

### 6.4.1 Model

The model is partial equilibrium in nature, and consists of two periods, and three dates: $t = 0, 1, 2$. There are three types of firms: Good, Super Good, and Bad, all assumed to be risk neutral; and two types of available project, Risky and Safe.

The key source of heterogeneity between firms lies in the different production technologies which ar available to them. Although both of the available technologies require the use of a single input $x_t$. The safe project's return is deterministic and is given by:

$$y^S_{t+1} = g(x_t). \tag{6.1}$$

For the Risky project two possible states, "good" and "bad", are realized after the investment decision is made:

$$y^R_{t+1} = \begin{cases} b(x_t) & \text{with probability } p, \\ \alpha b(x_t) & \text{with probability } (1-p) \text{ and } 0 < \alpha < 1. \end{cases} \tag{6.2}$$

The expected return for the risky project is thus

$$B = pb(x) + \alpha(1-p)b(x). \tag{6.3}$$

The production technologies are assumed to be twice continuously differentiable, strictly increasing, and strictly concave. They satisfy the following constraints:

$$g(0) = b(0) = 0; \qquad g'(0) = b'(0) = \infty, \tag{6.4}$$

and

$$g'(x) > B'(x); \qquad g''(x) < B''(x) < 0. \tag{6.5}$$

Whereas Good firms have both types of project available Bad firms only have access to the risky project. Thus the Bad firms are 'bad' in the sense that they only have access to limited technology. These two types of firm exist in proportions:

$$f_G + f_B = 1. \tag{6.6}$$

The remaining type of firm, Super Good firms, have one project with extremely high net present value, and are default free. The Good and the Bad firms in the model represent medium-sized, middle-rated firms with different qualities, while the firms the Super Good firm represents are highly rated, publicly known firms.

The Good and Bad firms start at period $t = 0$ with an exogenous endowment of net worth, $N$. Firm's borrowing is given by:

$$D(x) = x - N, \tag{6.7}$$

so that investment is partially financed internally using the firm's cash flow, as well as externally by borrowing money. The up-front investment for either project is financed at time $t = 0$ by a loan at the risk-free rate which must be repaid at time $t = 2$.

The risk free rate in the first period is zero, and in the second period is a random variable which can take on two possible values, $R_H$ and $R_L$, with $R_H > R_L$. The probability that the high interest rate occurs is $\pi$. The risk-free interest rate $R$ satisfies:

$$\frac{1}{R} = \frac{\pi}{R_H} + \frac{1-\pi}{R_L}, \tag{6.8}$$

which rules out arbitrage opportunities.

It is assumed that the random processes governing the outcomes of the interest rate and the output from the risky project are independent, and furthermore that the following restrictions apply:

$$b'(x) > R_H > g'(x) > B'(x) > R > R_L > \alpha b'(x). \tag{6.9}$$

This set of restrictions implies the following:

1. The safe project has higher NPV than the risky project, since $g'(x) > B'(x)$.

2. The risky project has positive expected NPV, since $B'(x) > R$.

3. The good firm is subject to default risk if it borrows a floating rate loan, since $g'(x) < R_H$.

4. The bad firm is always subject to default risk whether it borrows a fixed or floating rate loan since $R > \alpha b'(x)$ and $R_L > \alpha b'(x)$.

Finally it is assumed that there is an exogenous fixed cost $\Omega$ associated with bankruptcy of either firm.

There are two types of lenders in the economy, banks and private investors. Due to their expertise in credit analysis and large number of investments in small firms, banks are able to actively monitor loan agreements, although they charge a cost $c$ for their monitoring service. However since bank's liabilities are sensitive to interest rate volatility they prefer to lend either short term or floating rate loans. Because of this, they charge a premium $S$ for bearing the interest rate risk associated with long-term fixed rate loans. Private investors on the other hand, are unable to identify ex ante whether or not a firm has access to the superior 'safe' technology. They are therefore subject to an asymmetric information problem which leads to agency costs and ultimately financial accelerator effects on investment.

In the analysis that follows, we focus on the financing problem facing the manager of the good firm. While similar results can be derived for the bad firm (see Li and Mao (2003)), this does not affect the results derived in this paper. Therefore for ease of exposition these are not discussed here. In the sections following we consider the (good) firm's investment decision when it obtains 1) fixed rate financing from public investors, 2) fixed rate financing from a bank, and 3) floating rate financing from a bank.

### 6.4.2 Optimal investment decision: Private investor financed

When borrowing from the public investors, the goal of the manager of the good firm is twofold. Firstly she must choose whether to invest in the Safe or the Risky project, and secondly she must choose the amount to borrow for investment purposes. However, these decisions are constrained by the terms of the loan contract offered by the investors. From their point of view, there are two key conditions which the terms of the contract need to satisfy. Firstly they must be reassured that investment in the firm yields a return which is at least as good as investing at the risk-free rate. Secondly they will wish to set the terms of the contract to ensure that all firms that are able to will invest in the safe project. We now discuss these issues in more detail.

The key feature of the problem facing the firm when borrowing from public investors is the presence of asymmetric information. Suppose, as alluded to earlier, that the public investors are unable to identify whether an individual borrower is a good or a bad firm. This assumption reflects the difficulties small-scale investors face in identifying the credit risk of a potential borrower given there limited resources for credit analysis. Given this asymmetric information problem, both the good and bad firms will be pooled together and charged an additional premium above the risk-free rate. The public bondholders are aware of the proportions of good and bad firms in the economy as a whole ($f_G$ and $f_B$), and as such they are able to calculate the riskiness of their loans on aggregate, and hence set the terms of the contract optimally. However, it is possible that some of the good firms, having obtained financing at a preferential interest rate, cheat and divert funds to invest in the risky project. To prevent this occurring, the private investors therefore structure the loan contract to prevent this happening. To avoid this, the private investors specify the terms of the contract such that the good firm will always prefer to invest in the safe project.

The contract specifies a quantity borrowed, $B(x) = x - N$, a payment $P_g$ to the intermediary in the event that the Risky project yields the "good" output level, $b(x)$, and a payment $P_b$ in the event that the risky project yields the "bad" output level $\alpha b(x)$. The features of the contract are chosen to ensure the financial intermediary receives an expected return equal to the opportunity cost of its funds, the gross risk-free rate times the quantity borrowed. The contract payments must therefore satisfy

$$f_B(pP_g + (1-p)P_b) + f_G P_g = RD(x). \tag{6.10}$$

However, the amount that Bad firms can credibly commit to pay should the bad state occur is limited by their available assets. This implies the following limited liability constraint on the optimal contract

$$P_b \leq \alpha b(x). \tag{6.11}$$

Similarly, the amount that good firms can credibly commit to pay is limited by the return on the safe project, so that

$$P_g \leq g(x). \tag{6.12}$$

Finally, to ensure that all good firms invest in the safe project, financial intermediaries will set the terms of the loan contract so that the present value of the expected payoff from investing in the safe project is at least as high as that from the risky project. I.e.

$$E\left\{\frac{g(x) - P_g}{\widetilde{R}}\right\} \geq E\left\{\frac{\max[\widetilde{B}(x) - P_g, 0]}{\widetilde{R}}\right\} - \frac{\Omega}{R} Pr\{\widetilde{B}(x) < P_g\}. \tag{6.13}$$

Note that (6.13) implies that the firm's incentive to cheat and invest in the risky project is increasing in the degree of leverage (and hence decreasing in net worth), and decreasing in the cost of financial distress. To see this, let $\Delta$ represent the present value of the difference between the expected payoff from the risky and safe projects:

$$\Delta = (1-p)P_g - (1-p)\Omega + pb(x) - g(x). \tag{6.14}$$

Then,

$$\frac{\partial \Delta}{\partial P_g} = \frac{(1-p)}{R} > 0, \qquad \text{and,} \qquad \frac{\partial \Delta}{\partial \Omega} = -\frac{(1-p)}{R} < 0. \tag{6.15}$$

If the above constraint were not satisfied, the private investors would charge all firms a risk premium, $d_1$ which solves

$$\frac{E\{\min[\tilde{B}, R + d_1]\}}{R} = D(x), \tag{6.16}$$

yielding,

$$d_1 = \frac{(1-p)(R - \alpha b(x))}{p}. \tag{6.17}$$

If, on the other-hand, the firms can be trusted to commit sufficient internal funds so that (6.13) holds, the private investors only require a risk premium which solves

$$\frac{f_b E\{\min[\tilde{B}, R + d_2]\} + f_g \min[g(x), R + d_2]}{R} = D(x), \tag{6.18}$$

yielding

$$d_2 = \frac{f_b(1-p)(rD(x) - \alpha b(x))}{(1-(1-p)f_b)}, \tag{6.19}$$

which together satisfy $d_1 > d_2$. The private investors are therefore assumed to set the terms of the contract such that (6.13) holds, and charge a risk premium $d_2$ given by (6.19).

This implies that

$$(1-p)P_g - (1-p)\Omega + pb(x) - g(x) \leq 0. \tag{6.20}$$

Under these conditions, the good firm chooses an amount of $x^*$ to invest so as to maximize the present value of the expected payoff from the safe project:

$$\max_x \frac{1}{R}(g(x) - D(x)). \tag{6.21}$$

Following Gertler and Hubbard (1989), we assume the limited liability constraint (6.11) is binding. Combining constraints (6.10)-(6.20), together with equation (6.7) then yields

$$f_B(1-p)\alpha b(x) + \Omega(pf_B + f_G) + \frac{(g(x) - pb(x))}{(1-p)}(pf_B + f_G) - R(x-N) \geq 0. \tag{6.22}$$

It is important to note the role of firm's net worth, $N$, in determining whether or not this constraint is binding. From (6.22) it is clear that as $N$ decreases and leverage rises, for a given level of $x$ there is some critical value of $N$, $N^*$, such that (6.22) must hold with equality.

The good firm now maximizes its objective function (6.21) subject to the constraint (6.22). There are two general solutions to this contracting problem. In the first case, internal funds (i.e. net worth) will be high enough to ensure that (6.22) is non-binding. In this case investment demand will adjust to the optimal level $x^*$ which is the solution to the f.o.c:

$$g'(x^*) = R \tag{6.23}$$

In such a case, the internally generated share of funds is high enough to reduce the underlying asymmetric information problem in a way that is sufficient to support the optimal volume of investment. Finance and investment decisions will thus be independent, as under the condition of the Modigliani-Miller (MM) theorem (Modigliani and Miller (1958)).

However, the situation will be quite different if (6.22) binds with equality. In this case, financing and investment decisions will be mutually interdependent. As long as the firm's cash flow is too low, (6.22) will hold with equality and investment will be restricted to a level lower the MM optimum. In particular, solving the constrained optimization problem when (6.22) yields the suboptimal level of equilibrium investment, $x$ such that

$$g'(x^*) < g'(x), \tag{6.24}$$

which implies that

$$x^* > x. \tag{6.25}$$

This is the problem of 'underinvestment' resulting from informational frictions in the credit market. The extent of the underlying agency problem is given by the default premium charged by the private investors, $d_2$ given in equation (6.19). This has the effect of driving a wedge between the cost of internal finance and external finance. For a given gross interest rate and the optimal level of investment, the critical level for the firm's flow of internal finance, $N^*$, can be defined by

$$N^* = x^* - \frac{1}{R}(f_B(1-p)\alpha b(x^*) + \Omega(pf_B + f_G) + \frac{(g(x^*) - pb(x^*))}{(1-p)}(pf_B + f_G)). \tag{6.26}$$

For any flow of internal finance lower than the critical $N^*$, equation (6.22) will bind with equality. The relative values of $R$ and $N^*$ thus determine the firm's feasible volume of investment. That is, the firm's investment demand is now implicitly defined by equation (6.22) and may be written in the following form:

$$x_t^d = \begin{cases} h(R_t) & \text{for } N_t > N_t^*, \\ h(R_t, N_t) & \text{for } N_t < N_t^*. \end{cases} \tag{6.27}$$

In addition, the present value the Good firm gets at $t = 0$ is given by

$$PV_{PI}^{fx} = \begin{cases} \frac{1}{R}(g(x^*) - B(x^*) - d_1) & \text{for } N_t > N_t^*, \\ \frac{1}{R}(g(x) - B(x)) - d_2) & \text{for } N_t \leq N_t^*. \end{cases} \tag{6.28}$$

For firms that are low on cash flow, i.e. with $N < N^*$, a reduction of the firm's income reduces the share of own funds devoted to the investment project, thereby increasing the underlying agency problem. As a result, feasible investment will fall. Hence the scale of investment plans is determined not only by traditional factors, i.e. investing up to the point where marginal cost equals marginal benefit, but also by the resources available internally.

The financial accelerator has strong implications for the functioning of the monetary transmission mechanism. Given that firm investment is a function of internally generated funds, as standard theory and evidence suggest, cash flow and market interest rates being negatively correlated, a credit channel effect arises. An increase in interest rates will affect investment spending not only by changing the cost of capital. In addition, cash flow will decrease and therefore enhance the impact of a given change in interest rates.

This is what Oliner and Rudebusch (1996) call the 'broad credit channel' and what is otherwise termed the 'balance sheet channel' of monetary transmission. In such a model, monetary policy, that is a change in interest rates, exhibits a direct as well as an indirect effect. The direct effect of a change in the cost of capital is thus reinforced by an indirect effect which operates though the interest rates' impact on cash flow. It is this effect which is at the heart of the "balance sheet channel" of monetary transmission. Given that a firm's cash flow declines when interest rates rise, the decline in cash flow will enhance the depressing impact of interest rates on corporate investment spending[5].

### 6.4.3 Optimal investment decision: Bank financed

Public investors are not the only source of investment financing available to the firms. They can avoid paying the agency cost faced when their cash flow is below $N^*$ by borrowing instead from a bank. Bank's expertise in credit analysis and close relationships with their borrowers means that they are able to correctly differentiate the Good firms from the Bad. However the costs of collecting and analyzing this information means that they charge firms a cost, $c$, for this service. It is also assumed that the bank is able to monitor borrowers perfectly. While this assumption abstracts from many details of the actual relationship between the bank and its borrower, it simplifies the analysis greatly. We follow Li and Mao (2003) in assuming that the covenants of the bank loan specify that the firm can only borrow from them to invest in the safe project. Implicitly, following Diamond (1991), the covenant is specified in such a way that, were the bank to discover that the firm had chosen the risky project, it would liquidate the loan early yielding the bank the present value of the quantity borrowed, and the firm nothing.

[5]See Mishkin (1996) and Bernanke and Gertler (1995) for details.

Due to the floating-rate liabilities of banks, they would prefer to lend either at fixed rates for short-term, or at floating interest rates. Therefore, if the firm wishes to borrow a fixed rate loan from the bank it will be charged an additional interest rate risk premium $S$, in addition to the monitoring cost, $c$.

Since the firm can avoid the agency problem altogether by borrowing from the bank, it's investment decision in this case is not influenced by it's cash-flow. This leads it to invest at the MM optimal level $x^*$. The net present value of the project to the firm when borrowing at a fixed rate from the bank is thus

$$PV_B^{fx} = \frac{1}{R}(g(x^*) - D(x^*) - c - S). \tag{6.29}$$

Alternatively, the firm may choose to borrow a floating rate loan from the bank. However in this case, since $g'(x) < R_H$, the firm will be subject to default risk in the event of a realization of the high interest rate. The bank will therefore charge the firm a default risk premium, $d_3$ which solves

$$E\left\{\frac{\min[g(x^*), (\tilde{R} + d_3)D(x^*)]}{\tilde{R}}\right\} = 1 + \frac{c}{R}, \tag{6.30}$$

yielding

$$d_3 = \frac{\pi(R_H - g(x))R_L}{(1-\pi)R_H} + \frac{R_L c}{(1-\pi)R}. \tag{6.31}$$

In this case the present value the firm gets at $t = 0$ is given by the present value of the firm's equity minus the expected cost of financial distress, i.e.

$$PV_B^{fl} = \frac{1}{R}(g(x^*) - D(x^*) - c - \pi\Omega). \tag{6.32}$$

Given the present value of the firms' investment under the various financing options, in the next section we turn to an analysis of the conditions under which the will lead the firm to choose any given one of the various available options. In addition we will examine the implications of the model for financial accelerator effects on the evolution of the business cycle.

### 6.4.4 Firm's choice of financing and the financial accelerator.

Given the economy described in the previous sections the firm's choice of financing source, and the potential for financial accelerator effects, will depend on the costs of the various frictions present. In addition, the choice of lender will also be affected by the state of the firms cash flow available for internal financing. The good firm must choose the source of financing from the following: borrow a fixed rate loan from public investors, and get $PV_{PI}^{fx}$; borrow a fixed rate loan from the bank and get $PV_{B}^{fx}$; or borrow a floating rate loan from the bank and get $PV_{PI}^{fl}$.

In equilibrium, the firm compares the net present value of these financing options, given by equations (6.28), (6.29) and (6.32). In general, it will borrow from the public investors if the cost of the bank loan, which equals $R^{-1}(c+S)$ for the fixed-rate, or $R^{-1}(c+\pi\Omega)$ for the floating rate loan, exceeds the benefit of distinguishing itself from the bad firm. I.e. the firm will always borrow from the public investors if

$$d_2(f_B) < \frac{1}{R} min(c+S, c+\pi\Omega). \tag{6.33}$$

However, in this case the firms' investment will be constrained below its optimal level if it's net worth is lower than the critical level $N^*$. In addition, a rise in net worth allows the firm to increase investment towards the optimal level, $x^*$, since it permits an increase in investment without a consummate increase in the degree of leverage. There are two important information frictions in this economy: a) the public investors are unable to differentiate the good firms from the bad, and b) there is a risk that good firms will cheat and redirect funds to invest in the risky project. The key problem is that the firm's incentive to invest in the risky project depends positively on the degree of leverage. Hence additional net worth makes it feasible to invest more without violating the incentive constraint.

The dependence of the level of investment on net worth when condition (6.33) holds implies that the economy will exhibit financial accelerator effects when faced with a shock to interest rates. For example, an increase in policy interest rates should reduce the value of firms' assets (e.g. equity holdings), implying a fall in their net worth. In the case where firms' leverage ratio is at the threshold level $D^*$, firms will be forced to reduce investment to prevent violation of the incentive compatibility constraint. This reduction in investment will be over and above the traditional cost-of-capital effect on investment, i.e. the financial accelerator amplifies the effect of the shock on output.

### 6.4.5 The role of interest rate swaps

The firm prefers to borrow from the public investors because of the cost of bearing either interest rate risk or credit risk when borrowing from the bank. At an aggregate level, this implies the impact of interest rate shocks on output may be amplified via a financial accelerator mechanism. However, it is possible for the firm to lessen the costs of borrowing from the bank by utilizing interest rate swap contracts. Swaps can facilitate this by enabling the transformation of floating rate debt into fixed rate debt.

Assume that in the swap contract, either the good firm or the bank hedges its interest rate risk by paying $R - d_s$ to the super-good firm in exchange for receiving $\tilde{R}$, where $d_S$ is the swap spread, and is assumed to satisfy $d_S \in (0, g'(x) - R - c]$. The super-good firm is willing to enter into this contract since in doing so it obtains floating rate financing for its investment at rate of $\tilde{R} - d_S$, which is lower than the risk-free rate.

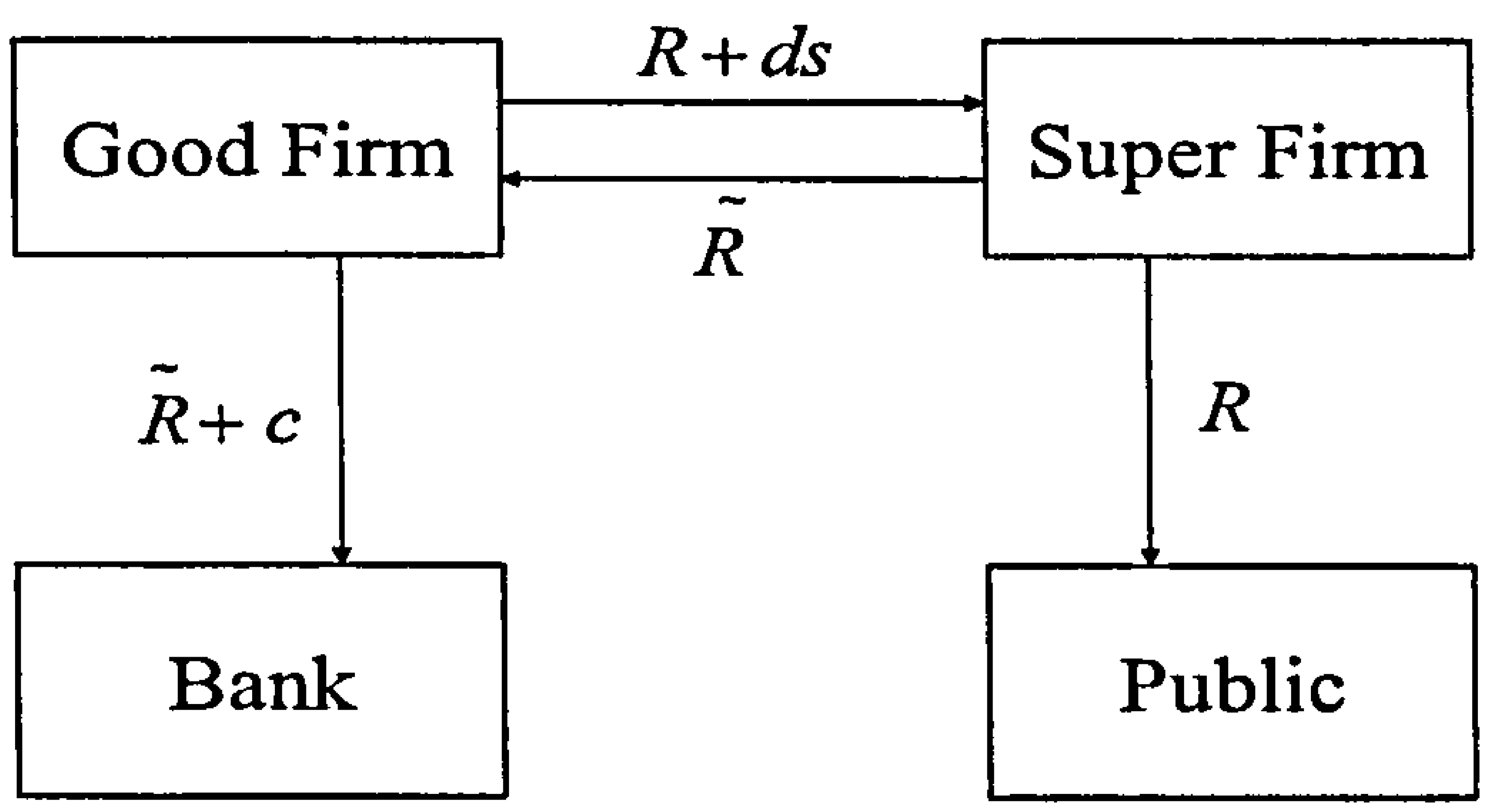



Figure 6.5: Firm enters swap contract with Super Good firm.

Figure (6.5) taken from Li and Mao (2003) illustrates the mechanism by which swaps can reduce firms' borrowing costs when entering directly into

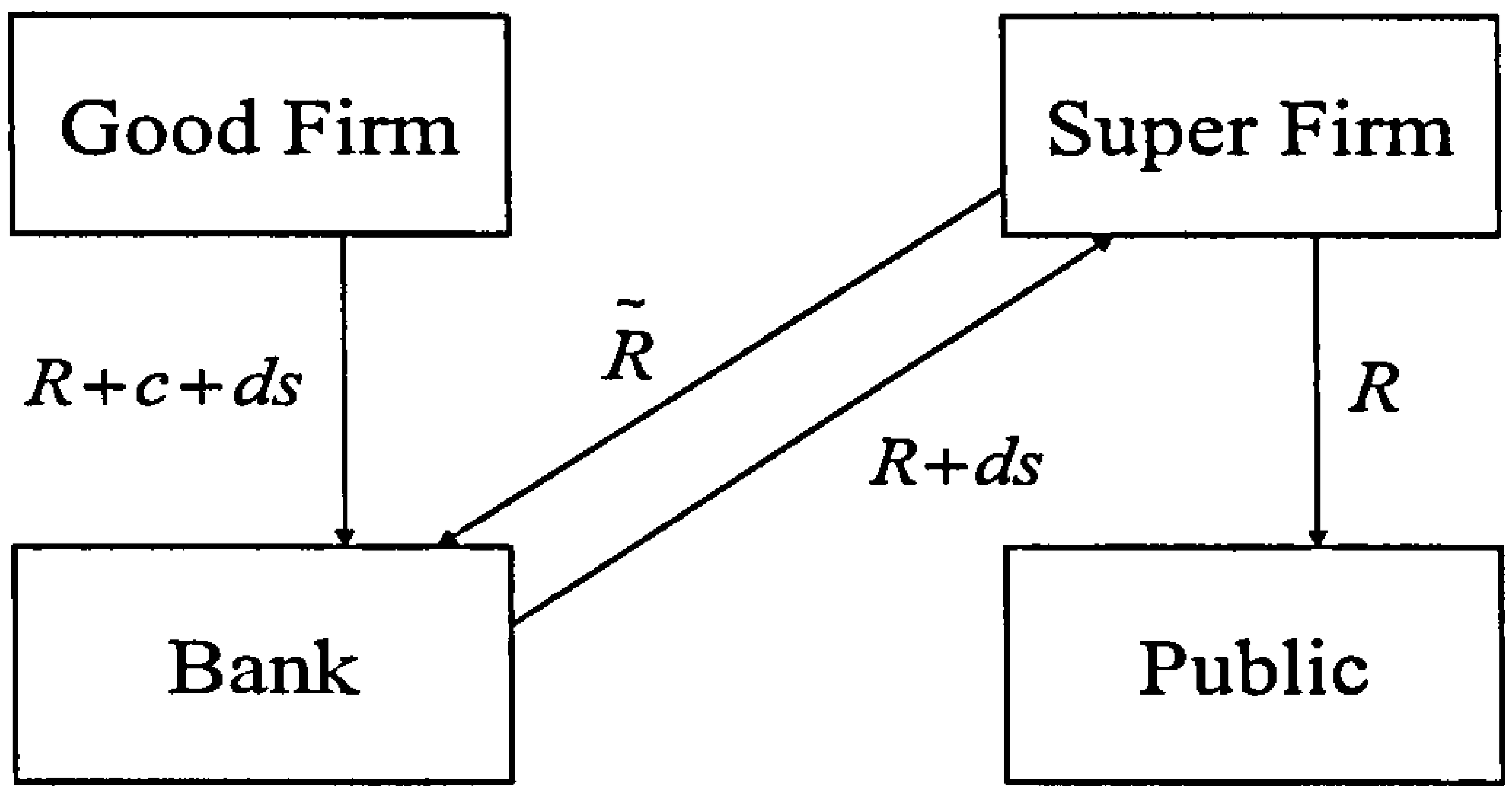



Figure 6.6: Bank enters swap contract with Super Good firm.

a swap contract with the super-good firm. In this case the good firm borrows a floating rate loan from the bank. However in doing so it exposes itself to default risk. It can then hedge its credit risk by entering into a swap contract with the super-good firm. The super-good firm profits by simultaneously borrowing a fixed rate loan from the public investors, thereby receiving a net income equal to the default premium, $d_S$.

The benefits to firms of borrowing cost reduction facilitated by swaps can also be realized even when the firm does not itself directly enter into a swap contract. This case is illustrated in figure (6.6). Here, the firm borrows a fixed rate loan directly from the bank, and the bank hedges its interest rate risk by entering into a swap contract with the super-good firm, and recovers the cost of the swap contract by shifting the swap premium onto the good firms' borrowing costs, charging them $R + C + d_S$. As long as the swap premium, $d_S$ is lower than the interest rate risk premium, $S$, the firm finds its borrowing cost reduced by the introduction of swaps.

This borrowing cost reduction feature of swaps can influence the impact of the financial accelerator. The model developed in the previous section demonstrated how the financial accelerator is engaged by firms borrowing from public investors who are unable to correctly identify firms quality. However, given the cost to the firm of interest rate risk and default risk when borrowing from the bank the firm may still prefer to borrow from the public investors as long as the risk premium charged by the public is lower than the costs of the bank loan, i.e.

$$d_2(f_B) < \frac{1}{R}\min(c + S, c + \pi\Omega). \tag{6.34}$$

At the margin, the introduction of swaps will reduce the cost of borrowing sufficiently to allow some firms to switch from issuing public sector debt, and instead borrow from the bank. In doing so, the link between the firm's investment decision and it's net worth is broken, and hence it's investment is no longer subject to a financial accelerator[6]. In effect, the use of swaps allows the firm to avoid agency costs, which in aggregate has the effect of reducing the financial accelerator.

## 6.5 Conclusion

The high degree of leverage provided by derivatives makes them powerful financial instruments, capable of providing low cost hedging against risk, or the taking of large speculative positions. While the risks to the financial system generated by the use of derivatives for speculation have received close scrutiny, the insulation provided to the system by their use for hedging has received less attention.

In this chapter, a model has been presented which demonstrates how by far the most popular type of derivative contract, the interest rate swap, can enhance the stability of the financial system.

The sensitivity of the real economy to developments in credit markets can be increased by the presence of informational frictions such as agency problems. Shocks to interest rates effect firms' cash flow and collateral, thereby influencing the proportion of their own funds they can commit to financing

[6]Recall that because of the bank's expertise in monitoring firms, it is able to enforce loan covenants which stipulate the good firm may only invest in the safe project, so that it does not suffer from an asymmetric information problem.

investment projects. In the presence of asymmetric information between borrowers and lenders, this can lead lenders to raise the cost of funds. This in turn leads to reductions in investment and ultimately output, in excess of levels predicted by the traditional cost of capital effects.

In this paper it has been shown how the use of interest rate swaps can dampen this amplification mechanism. A principal motivation for firms to use swaps is to reduce borrowing costs by mitigating agency costs. In doing so, the degree of magnification of shocks via the financial accelerator should be reduced, since firms' cost of borrowing should become less dependant on the availability of internal funds.

The use of interest rate swaps has grown dramatically since their introduction in the early 1980s. As increasing numbers of non-financial firms employ swaps to lower borrowing costs, the model developed here implies that financial accelerator effects should be progressively weakened, and interest rate shocks have progressively smaller impacts on the real economy. In the next chapter, these predictions are tested empirically for the U.S., employing a hitherto unexploited data set on the total notional amount outstanding of interest rate swaps since the beginning of the 1990s.

# Chapter 7

# The usage of interest rate swaps and their effect on credit market frictions: empirical evidence

## 7.1 Introduction

This chapter presents some empirical evidence on the central proposition of the previous chapter: that usage of interest rate swaps may have led to a reduction in the impact of U.S. monetary policy shocks. The traditional approach to examining the impact of monetary policy is to employ a vector-autoregression (VAR) model. In this chapter, the effect of the swap usage on monetary transmission is investigated by modeling the coefficients in the VAR as a function of the extent of swap usage. This is accomplished by employing a non-linear, smooth transition VAR model. In addition this study uses a hitherto unexploited data set on activity in U.S. OTC interest rate swaps, provided by the U.S. Office of the Comptroller of the Currency.

The next two sections survey the empirical evidence on the impact of interest rate swap usage, and the empirical evidence on the credit channel of the monetary transmission mechanism respectively.

The following sections introduce the empirical methodology, and the discuss the data set employed in the analysis, after which results from a baseline analysis using a linear vector auto regression (VAR) model are presented. Tests for nonlinearity of the type predicted by the model are then discussed and assessed before developing and implementing the nonlinear framework. The implications of the estimation results are then assessed using generalized impulse response analysis. The final section concludes.

## 7.2 Empirical evidence on the benefits to firms from interest rate swaps

In order for firms to achieve a reduction in borrowing costs with swaps, Wall (1989) emphasizes the case where firms can reduce agency costs by employing a combination of short-term debt and interest rate swaps. Evidence on the financial profiles of the type of firms that use swaps has been described in recent studies. For example, Fenn, Post, and Sharpe (2002) find that swap users are larger and use more short-term debt than non-swap users. They also find that the greater the proportional amount of short-term debt used the larger the notional value of interest rate derivatives employed.

Other implications of Wall's agency cost reduction theory can also be tested empirically. In the literature, many tests examine the prediction that higher risk firms should experience larger benefits from interest rate swaps than lower risk firms. In one of the earliest studies, Wall and Pringle (1989) test theories on interest rate swaps based on information contained in the footnotes of Annual Reports for the year of 1986 and find supporting evidence for agency theory.

Samant (1996), using the 'Compact Disclosure' database from June 16, 1990 to June 15, 1992, also finds evidence that supports the agency theory of Wall (1989) and the information asymmetry explanation of Titman (1992). The results from Samant (1996) show that fixed-rate payers compared to non-swap users have increased profitability, more divergent earnings estimates, higher leverage, and more growth options. In other words, fixed-rate payers face higher agency costs. He also shows that floating rate payers do not have characteristics that are significantly different than non-swap users which demonstrate lower agency costs.

Harper and Wingender (2000) also test the agency theory using the 'Compact Disclosure' database, but for the years of 19861991. With a small sample of 24 observations, they find a significant positive relationship between the risk of the firm and the reduction of agency costs. Their results are consistent with Wall's hypothesis and other theories on swaps.

More recently, Li and Mao (2003) find that fixed-rate swap payers generally have lower credit ratings, higher leverage ratios, higher percentages of long-term floating-rate loans, and are more likely to use bank loans than floating-rate swap payers. On the other hand, they find little differences on debt maturities and percentages of short-term debt between the two groups of swap users, which is not consistent with existing theories.

Generally, the literature suggests there is strong support in the data for Wall's theory in explaining the benefits of interest rate swaps due to increased market discipline and monitoring.

## 7.3 Empirical evidence on the credit channel of monetary policy

The evidence in support of the broad credit channel of monetary policy has been surveyed by, inter alia, Bernanke (1993), Gertler and Gilchrist (1993), Kashap and Stein (1995), Hubbard (1995), and Bernanke, Gertler, and Gilchrist (1996). The last two of these surveys list several implications of the broad credit channel. First, external finance is more expensive for borrowers than internal finance. This greater expense should apply particularly to uncollateralized external finance. Second, because the cost differential between internal and external finance arises from agency costs, the gap should depend inversely on the borrower's net worth. A fall in net worth raises the cost of external finance. Third, adverse shocks to net worth should reduce borrowers' access to finance, thereby reducing their investment, employment, and production levels. In addition, the credit channel also operates when shifts in monetary policy alter either the efficiency of financial markets in matching borrowers and lenders, or to the extent that borrowers face rationing in credit markets so that aggregate spending is influenced by liquidity constraints.

Non-price credit rationing can be characterized as the situation where, at current interest rates, creditworthy borrowers are denied credit even when they are demonstrably able and willing to pay a higher rate of interest. In other words, the situation of non-price credit rationing is characterized by persistent excess demand for credit and a failure of interest rates to adjust to clear the market. (See Stiglitz and Weiss (1981) and Jaffee and Stiglitz (1990)).

One approach to examine the evidence for credit rationing is to estimate demand and supply schedules for bank loans. King (1986) estimated that loan supply is positively related to the volume of deposits, suggesting that banks are liquidity constrained. He also estimated that the loan market is dominated by periods of excess demand (i.e. estimated demand exceeded actual loans in 63 out of 99 observations). On the other hand, however, the estimated loan supply schedule is also upward sloping with respect to the loan rate. This contradicts the hypothesis of credit rationing. It is also unclear whether perhaps the estimates of excess demand fall within normal standard errors of the estimated equations.

Lown (1990), Sofianos, Wachtel, and Melnik (1990), and Morgan (1992) examined the evidence on credit rationing with loan commitment data. Under a loan commitment agreement, a bank promises to issue a borrower a loan up to an agreed amount as long as the borrower satisfies the terms of the contract. Because rationing can only affect firms that do not have such agreements, the percentage of total loans made under commitments should increase in periods of tight credit. Lown (1990) found that the percentage of new loans made under commitment has a significant negative relationship with real output. Hirtle (1990) found that noncommitment loans appear to (weakly) Granger cause output, whereas commitment loans do not. Morgan (1992) confirmed that loans made under commitment track movements in economic activity. Loans not made under loan commitments begin to fall relatively quickly, responding as fast and as sharp as monetary aggregates in response to movements in monetary policy.

It is important to recognize that credit rationing is sufficient but not necessary for a credit channel to exist. A theme of Gertler (1989), Bernanke (1993), Bernanke and Gertler (1989), and shared by the model developed in the previous chapter is that agency costs in credit markets will vary countercyclically; a monetary tightening that raises interest rates and generates a real economic slowdown[1] will cause firm balance sheets to deteriorate, raising agency costs and lowering the efficiency of credit allocation.

Considerable effort has gone in to testing these theories. The empirical literature, starting with Fazzari, Hubbard, and Petersen (1988), finds that investment and cash flow are usually positively related, even after investment opportunities, represented by Tobins q, are controlled for. For example, Kashap, Lamont, and Stein (1994) find that inventory investment by firms without access to public bond markets appeared to be affected by liquidity constraints. These relationships are stronger for small firms, corporations with low dividend payments, and firms with low credit ratings. That is,

[1]The credit rationing story developed in the previous Chapter only generates real persistence, so that for monetary policy to have an effect on real interest rates there also must be some kind of nominal rigidity (e.g. due to menu costs).

firms which would usually be expected to have less access to the credit markets seem to display a greater sensitivity of investment demand to internal financing.

Other authors, such as Gertler and Gilchrist (1994), Oliner and Rudebusch (1996), and Bernanke, Gertler, and Gilchrist (1996), investigate the monetary policy implications of these theories. Changes in credit conditions are not reflected solely in interest-rate levels. If, as emphasized under the broad credit channel, agency costs worsen during recessions and in response to contractionary monetary policy, then the share of credit going to low-agency-cost borrowers should rise. Because small firms are presumably subject to higher agency costs than are large firms, much of the evidence for a broad credit channel has been sought by looking for differences in the behaviour of large and small firms in the face of monetary contraction.

Empirical evidence based on partially disaggregated US data seems to support this effect. One of the most prominent papers in this area is Gertler and Gilchrist (1994), who document that small firms behave differently than large firms over the business cycle, with small firms being much more sensitive to cyclical fluctuations. Applying the VAR methodology, an empirical study of the comprehensive QFR (Quarterly Financial Report for Manufacturing, Mining, and Trade Corporations) dataset for the United States is used to assess the impulse response functions of corporate sales, inventories and short-term debt. Gertler and Gilchrist use the QFR data to construct series of growth rates for small and large firms. In addition, QFR data on firm size is then used as a proxy for credit market access and the possible importance of informational asymmetries.

The impulse response functions estimated by Gertler and Gilchrist (1994) show that small firms contract substantially, relative to larger ones, in response to tight monetary policy. Shocks have a greater cumulative impact on small than on large firms and the differences are reasonably significant for inventories and short-term debt, though not for sales. The evidence from the QFR data is thus consistent with a differential impact of monetary policy on small firms. Credit market imperfections are relevant to the story, to the extent that they may explain why small firms behave differently from larger ones (Gertler and Gilchrist (1993)).

Oliner and Rudebusch (1996) also assess the role of financial factors by using the OFR data for another study that yields similar results, examining the behaviour of small and large firms around changes in monetary policy. Interest rate increases in response to a monetary contraction lower asset values and hence the value of collateral, increasing the cost of external funds relative to internal funds. Since agency problems are likely to be more severe for small firms than large firms, the linkage between internal sources of funds and investment spending should be particularly strong for small firms after a monetary contraction. Oliner and Rudebusch do find that the impact of cash flow on investment increases for small firms, but not for large firms, when monetary policy tightens.

These studies show that the responses of small and large firms to monetary impulses differ and that the reaction of small firms seems to be more pronounced than the respective response of large firms. This, again, is seen as evidence of the importance of financial propagation mechanisms, i.e. financial accelerator effects for monetary policy and aggregate activity.

## 7.4 An empirical framework for assessing swap's impact on monetary transmission

Perhaps the most striking stylized fact concerning interest rate swaps presented in the previous chapter is the expontential growth in their use. One theoretical implication of the growing importance of corporate hedging is that any differences in the behaviour of small and large firms in response to monetary policy measures should vanish over time. This follows, because small and less mature firms are commonly regarded to be more affected by problems of asymmetric information than larger or more mature ones.

Large firms will usually be able to replace any shortfall in internal funds with some other form of financing during a monetary tightening. However, this possibility might not be available to small firms. Under the conditions of a broad credit channel, small and large firms will hence respond differently to monetary policy shocks.

Froot, Scharfstein, and Stein (1993) argue that the very assumptions that are at the heart of every model featuring broad credit channel effects, namely informational asymmetries, will also create incentives for corporate risk management. According to this theory, firms operating under a financial accelerator will engage in cash flow hedging programmes that engineer their internal cash flows so as to meet their feasible investment needs and to avoid any further deadweight costs induced by underinvestment.

Optimal risk management strategies thus manipulate the interest rate risk exposure of corporate cash flows in an attempt to stabilize agency costs. This, in turn, should diminish any credit channel effect of monetary policy and hence reduce monetary policy transmission to the pure cost-of-capital effect. Given these theoretical results, there should be little room for a sizeable credit channel in the presence of widespread corporate risk management.

The theory developed in chapter 6 produces a number of testable hypotheses. The most important one is that, due to the introduction of interest rate derivatives and the rapid development of their markets, the financial accelerator (broad credit channel) effect in operation should have diminished over time. One should therefore be able to detect an incremental weakening in the monetary transmission process as swap usage has become increasingly widespread.

Recent research seems to point in this direction. Taylor (1995) estimates interest rate elasticities of investment for the US, Germany and Japan with data from two sample periods, one from the early 1970s through 1985 and the other from 1986 through the mid-1990s. A comparison of these two sets of estimates gives an idea of the magnitude of change in the monetary transmission mechanism over time. In the US, the interest rate elasticity of investment has declined. The same is true for real output, which responds differently to monetary policy in the three countries mentioned above. On balance, the monetary transmission mechanism has changed so as to reduce the impact of a given change in short-term interest rates. While this seems to be true for all three countries, the change in the US seems to be larger than the one in Germany and Japan.

The approach taken here employs data on the aggregate use of interest rate swaps in the U.S. since 1990. We augment a standard monetary policy

VAR model to allow for possible effects of aggregate interest rate swap usage on the transmission of monetary shocks. In addition, we allow for possible nonlinear effects due to increased usage of swaps by employing a 'Logistic Smooth Transition VAR (LSTVAR) approach'. The discussion in the previous chapter indicated how swaps may have important effects on the parameters governing, for example, the response of output to changes in interest rates. In general, we would expect that output would respond less strongly to movements in interest rates and inflation of the same magnitude when the use of swaps is widespread.

In addition, another implication of the model presented in chapter 6 is that the demand for swaps should be counter-cyclical. An important prediction of the model is that a fall in net worth during economic downturns leads to an increase in agency costs. This should increase the demand for interest rate swaps to mitigate the increase in borrowing costs. This prediction agues for the inclusion of an equation in the VAR to measure the impact on the growth rate of swaps usage of aggregate economic conditions.

Consider a linear Vector Auto-Regression (VAR) model, written in standard form:

$$X_t = \mu + \sum_{j=1}^{p} \Phi_j X_{t-j} + \epsilon_t, \tag{7.1}$$

The theoretical model developed in the previous chapter predicts that the parameters in equation (7.1) are a function of the 'completeness' of financial markets - which is captured by the state variable $z_{t-d}$. The smooth transition vector autoregression (STVAR) model is

$$X_t = \left(\mu_1 + \sum_{j=1}^{p} \Phi_{1j} X_{t-j}\right)(1 - F(z_{t-d})) + \left(\mu_2 + \sum_{j=1}^{p} \Phi_{2j} X_{t-j}\right) F(z_{t-d} + \epsilon_t \tag{7.2}$$

where $\epsilon_t \sim iid(0, \sigma^2)$, and the parameters of equation (STVAR) shift according to the regime defined in terms of a function of the observable transition variable $z_{t-d}$, where $d$ is a delay parameter. The transition function, $F(z_{t-d})$, is bounded between 0 and 1, so that the range of parameters is $(\mu_1, \mu_1 + \mu_2)$ and $(\Phi_1, \Phi_1 + \Phi_2)$. It is assumed to take the form of the logistic function:

$$F(z_{t-d} : \gamma, d, c) = \{1 + \exp[-\gamma(z_{t-d} - c)/\sigma(z_t)]\}^{-1}, \qquad \gamma > 0 \tag{7.3}$$

The parameter $c$ in this equation represents the threshold around which the dynamics of the model change. In the limit as $(z_t - c)$ approaches plus (minus) infinity, $F(z_{t-d})$ approaches one (zero). The parameter $\gamma$ controls the 'smoothness' with which $F(z_{t-d})$ moves from zero to one as $z_t$ changes. As $\gamma$ approaches zero, $F(z_{t-d})$ converges to a constant, the nonlinear terms become redundant, and the model becomes linear. As $\gamma$ approaches infinity, small changes of $z_t$ around the threshold value $c$ result in abrupt shifts in the parameters of the model, so that the model approximates the threshold autoregression model due to Tong (1990).

### 7.4.1 Specification of the Benchmark Model

In order to gauge the importance of possible nonlinear effects of the recent explosion in swaps usage on the monetary transmission mechanism, we initially specify and estimate a standard linear, unrestricted Vector Auto-Regression (VAR) model given by equation (7.1). In our model, the vector $X_t$ consists of variables capturing growth in real US output, inflation, monetary policy, and growth rate notional amounts outstanding of swaps. The model includes the first differences of the logs of real GDP, the consumer price index, money (M1), and notional amounts outstanding of interest rate swaps for the U.S. reported by the Office of Comptroller of the Currency of Department of Treasury, 1990:Q1 to 2004:Q3, giving a total of 55 observations.

The first three variables are from the International Monetary Fund's IFS data base. The orders of differencing and lag length, $p$, of the liner model are chosen on the basis of conventional specification tests. Each of the series is stationary according to augmented Dickey-Fuller tests.

There is mixed evidence on co-integration: Engle-Granger tests tend to suggest the presence of a co-integrating vector, while Johansen tests tend to reject co-integration. The only choice of a cointegrating vector suggested by theory is given by the 'quantity theory of money'. However, ADF tests conducted on the velocity[2] of M1 in the U.S. indicated it is non-stationary in levels. Since co-integrating relationships by definition can only exist between variables which are integrated of the same order, and no other co-integrating vector would be suggested by theory, the series are assumed not to be co-integrated. While the Schwartz criterion suggests using 3 or 4 lags, the Akaike Criterion suggests four lags. However, due to the constraints imposed by the small sample size, three lags were used in the estimations. This proved to be the smallest lag length such that serial correlation in the residuals of the model was insignificant according to standard tests.

Under the hypothesis that the true data generating process is nonlinear, the

[2]The series for velocity was constructed as the ratio of nominal GDP to M1, using data from the IFS.

techniques described above for determining the specification of the model are not applicable. For the purposes of comparison, the nonlinear model was estimated with the same specification as the benchmark linear model.

### 7.4.2 Testing for nonlinearity

This section details the test employed to find evidence of nonlinearity in the baseline VAR and reports results. The linearity tests are the multivariate versions of the Lagrange multiplier tests due to Granger and Teräsvirta (1993), and described in chapter 3 of this thesis. These tests provide strong evidence against linearity and in favor of the LSTVAR model.

Testing for nonlinearity in the STVAR model using the logistic transition function is equivalent to testing the null hypothesis $H_0 : \gamma = 0$ against the alternative $H_1 : \gamma > 0$ in equation (7.2). Following Luukkonen, Saikkonen, and Terisvirta (1988), linearity testing equation by equation employs a three step procedure based on a first-order Taylor approximation of the transition function around $\gamma = 0$. Consider a $k$-variable VAR with $p$ lags and let $w_t = (x_{1t-1}, x_{1t-2}, \ldots, x_{1t-p}, x_{2t-1}, \ldots, x_{kt-p})$. Assume the switching variable $z_t$ is known. To test linearity equation by equation:

1. Estimate

$$x_{i,j} = \beta_{i,0} + \sum_{j=1}^{pk} \beta_{ij} w_{jt} + u_{it} \tag{7.4}$$

and collect the residuals $\hat{u}_{it}$. Define $SSR_0 = \sum \hat{u}_{it}^2$.

2. Use these residuals to run the regression

$$\hat{u}_{it} = \alpha_{i0} + \sum_{j=1}^{pk} \alpha_{ij} w_{jt} + \sum_{j=1}^{pk} \delta_i z_t w_{jt} + \eta_{it} \tag{7.5}$$

and collect the residuals $\hat{\eta}_{it}$. Define $SSR_1 = \sum \hat{\eta}_{it}^2$.

3. Compute the test statistic $LM = T(SSR_0 SSR_1)/SSR_0$, where T is the number of observations.

Under the null hypothesis, $LM$ is distributed $\chi^2(pk)$. In small samples, the equivalent $F$ statistic is

$$F = \frac{[(SSR_0 - SSR_1)/pk]}{[SSR_0/(T-(2pk+1))]}. \tag{7.6}$$

The model developed in chapter 4 suggests that asymmetry is present simultaneously in all of the equations of the VAR under the alternative hypothesis. Thus the appropriate test of linearity in the system as a whole is a log-likelihood test of the null hypothesis $H_0 : \gamma = 0$ simultaneously in all of the equations.

| LM test for STAR-type nonlinearity | | | | |
|---|---|---|---|---|
| Equation | $y$ | $\pi$ | $m1$ | $Swp$ |
| F-Statistic | 12.50 | 28.69 | 32.518 | 17.645 |
| LR statistic | 143.09 | | | |

Table 7.1: Nonlinearity test equation-by-equation and for whole system

Let $\Omega_0 = \sum \hat{u}_t\hat{u}_t'/T$ and $\Omega_1 = \sum \hat{\eta}_t\hat{\eta}_t'/T$ be the estimated variance-covariance matrices of residuals from the restricted and unrestricted regressions respectively. Then the statistic $LR = T(\log|\Omega_0| - \log|\Omega_1|)$ is asymptotically distributed $\chi^2(pk)$.

Table (7.4.2) reports the results of these linearity tests using the data described in section (7.4.1). The evidence against linearity in the output and outstanding swaps equations is weak for all choices of the delay parameter, while there is consistently strong evidence of nonlinearity in the inflation equation and the money equation in particular. This is consistent with the hypothesis that the primary channel through which the use of swaps influences the monetary transmission mechanism is through the credit channel. The tests for nonlinearity in the system as a whole provide very strong evidence against the null hypothesis in the standard VAR, and in favor of the LSTVAR specification. However, whether this nonlinearity results in economically meaningful effects on monetary policy shocks must be determined by examining the dynamic effects of these shocks in the LSTVAR model.

## 7.5 Estimation Results

The estimation of the model given by equation (7.2) is carried out using a grid search, whereby values of $\gamma$, $c$ and $d$ are fixed and the equation is estimated by equation by equation nonlinear least squares. The log of the determinate of the variance-covariance matrix, $\log|\Omega|$, is then calculated and the process repeated for different values of $\gamma$, $c$ and $d$. The estimates of these parameters that minimize $\log|\Omega|$ are those that are used in the final regressions. One drawback of this method is that standard errors are not computed for $\gamma$, $c$ or $d$. The final estimates are $\gamma = 3.2$, $c = 0$ and $d = 2$. This relatively low value of $\gamma$ indicates a relatively smooth transition from one regime to another, which is consistent with the intuition that increasingly use of interest rate swaps have an incremental effect on the monetary transmission mechanism, as opposed to a sudden transition to another regime which would imply the existence of a 'critical' threshold of swaps usage above which the nature of the monetary transmission mechanism is substantially altered.

Table (7.2) presents results of $F$- tests for the hypothesis that the $\theta$ coefficients in the model are equal to zero in each equation and the system as a whole. These tests also provide strong evidence in favor of our nonlin-

F test for nonlinearity

| Equation | $y$ | $\pi$ | $m1$ | $Swp$ |
|---|---|---|---|---|
| F-Statistic | 32.15 | 24.69 | 49.52 | 19.53 |
| LR statistic | | 63.17 | | |

Table 7.2: F-tests for nonlinear adjustment equation-by-equation and for the whole system

ear model. The null hypothesis of linearity is rejected in all equations at the 5 percent significance level. Linearity for the system as a whole is also rejected.

## 7.6 Calculation of Impulse Response Functions

In this section we outline the procedure used to calculate impulse response functions from the estimated model. These functions trace out the dynamics response one variable to a shock in another variable in the system.

In order to allow for correlation in the error terms across equations, the equation errors of the nonlinear STVAR model are orthogonalized using the Choleski decomposition so that the covariance matrix is diagonal. One disadvantage of impulse response analysis is that it is sensitive to the ordering of the variables in the system, in that different orderings of the variables can lead to different results. To reduce this problem, the ordering needs to be chosen such that the first variable is the only one with a potential contemporaneous impact on the other variables in the system. The second variable then needs to be chosen such that it may have a contemporaneous impact on the other variables in the system, but not the first one, and so on. We impose the ordering $y$, $\pi$, $M1$, $Swp$, so that while shocks to output, inflation and $M1$ may have a contemporaneous impact on the growth of swaps usage, changes in trading volume do not instantaneously impact on the other variables in the system.

In contrast to linear models, shocks occurring in nonlinear models depend on the history of the variables as well as the magnitude of the shocks. In order to deal with these problems, in this paper we calculate generalized impulse response functions as detailed by Koop, Pesaran, and Potter (1996) and D. Van Dijk, Teräsvirta, and Franses (2001).

The impulse response functions are calculated using the following procedure. In order to account for the effects of different initial conditions on the impulse response functions, the data set is split into four sub samples according to the quantity of swaps outstanding, so that impulse responses are calculated for low, medium, high and very high initial levels of trading. The final impulse response functions for each level of trading are calculated by averaging over the impulse responses for every set of initial values within each sub sample. To compute individual impulse responses, shocks for periods 0 to $j$ are drawn with replacement from the residuals of the estimated LSTVAR model. For a given set of initial values of the variables, the shocks are fed through the estimated model to compute baseline forecasts of the variables. The procedure is then repeated using the same initial values and bootstrap draw, but with the shock to the interest rate in period 1 set to one standard error of the nonlinear model. As the shocks pass through the estimated model, a new forecast value is computed. The impulse response function for this set of initial conditions is then calculated as the difference between the dynamic path of each variable under the shock and the baseline dynamic response in the absence of shocks. For each set of initial values, this procedure is repeated one hundred times with different bootstrap draws, and the average taken so that the impulse responses become conditional only on initial values. When averaged over the set of initial conditions for each sub sample of the data, this procedure produces impulse response function for each regime. Thus the impulse response functions for regime 1 are the estimated responses of output and inflation to interest rate shocks when the total amount of swaps outstanding is over \$29.75 billion, regime 2 when trading volume is between \$29.75 and \$17.62 billion, regime 3 for trading volume between \$17.62 and \$10.30 billion, and regime 4 when trading is less than \$10.30 billion.

## 7.7 Discussion of results

### 7.7.1 Regime Identification

The relationship between the values of the transition function and the quantity of outstanding swaps is reported in Figure (7.1). The figure also illustrates the smoothness of the transition between the low trading volume regime and the high trading volume regime. Increases in trading volume at low levels of trading have a large impact on the transition function, but the size of this impact decreases as the trading volume reaches higher levels. This suggests that the effects of further increases of usage of swaps had little effect on the monetary transmission after the end of 1999, when the total amount of swaps had reached $36 billion.

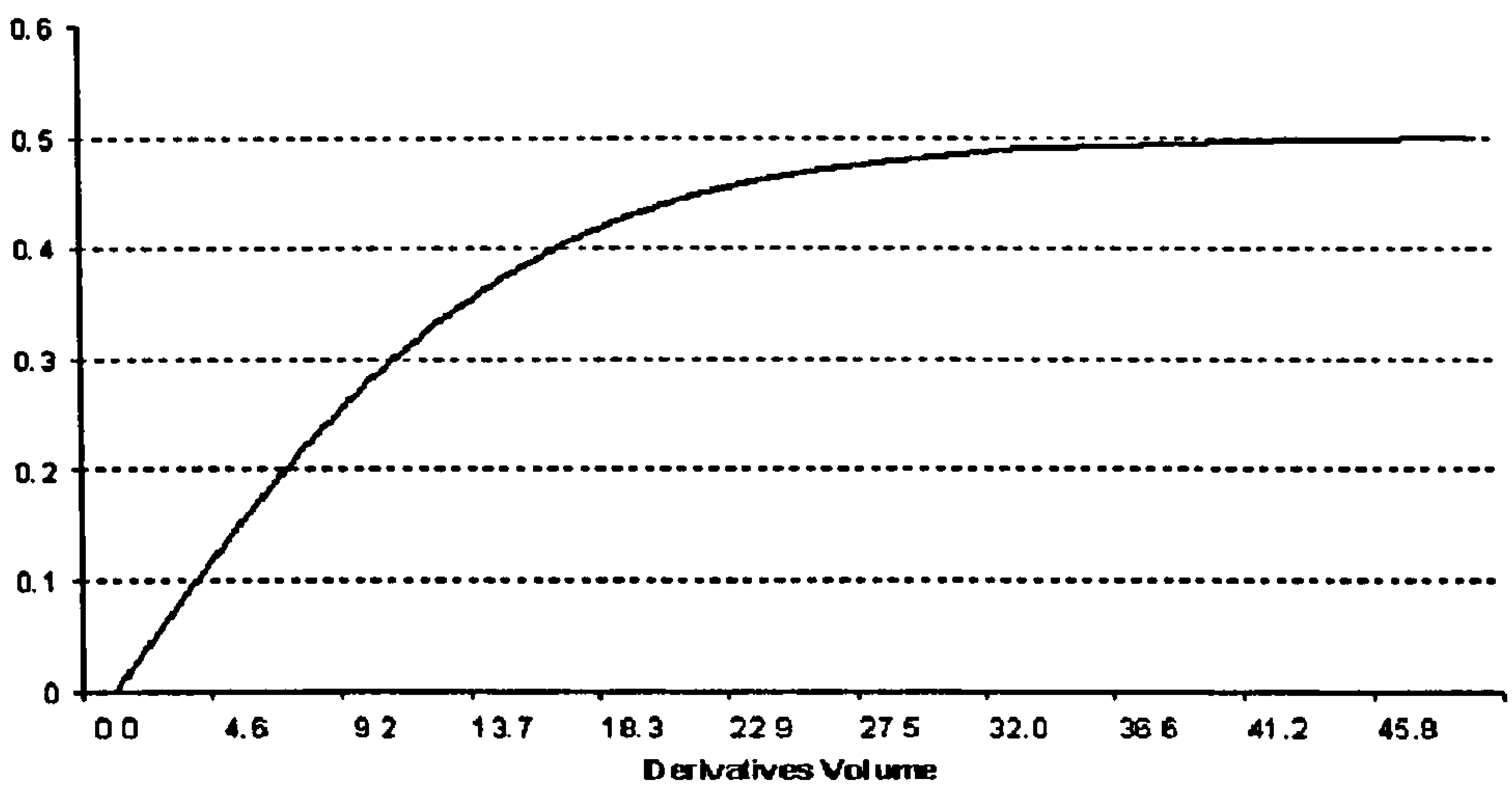



Figure 7.1: Impact of derivatives usage on model coefficients

An alternative representation of the effects of swaps usage is presented in Figure (7.2). Here, the cumulative coefficients on the money supply terms in the output equation of the model are plotted against total amount of swaps outstanding. The figure indicates how higher usage leads to monetary shocks having a reduced effect on output. However, it also emphasizes how, even with prolific usage of swaps, changes in the money supply continue to have an (albeit reduced) effect. While an increased ability to hedge against a variety of risks can reduce frictions in financial markets, speed up the transmission of monetary shock to prices, and insulate firms from adverse effects of shocks, the use of swaps will not affect other market imperfections which can give rise short-run non neutrality of money. Thus while there is evidence that the effect of monetary shocks on output is reduced by a increased usage of swaps, there remains some scope for the use of monetary policy by the authorities.

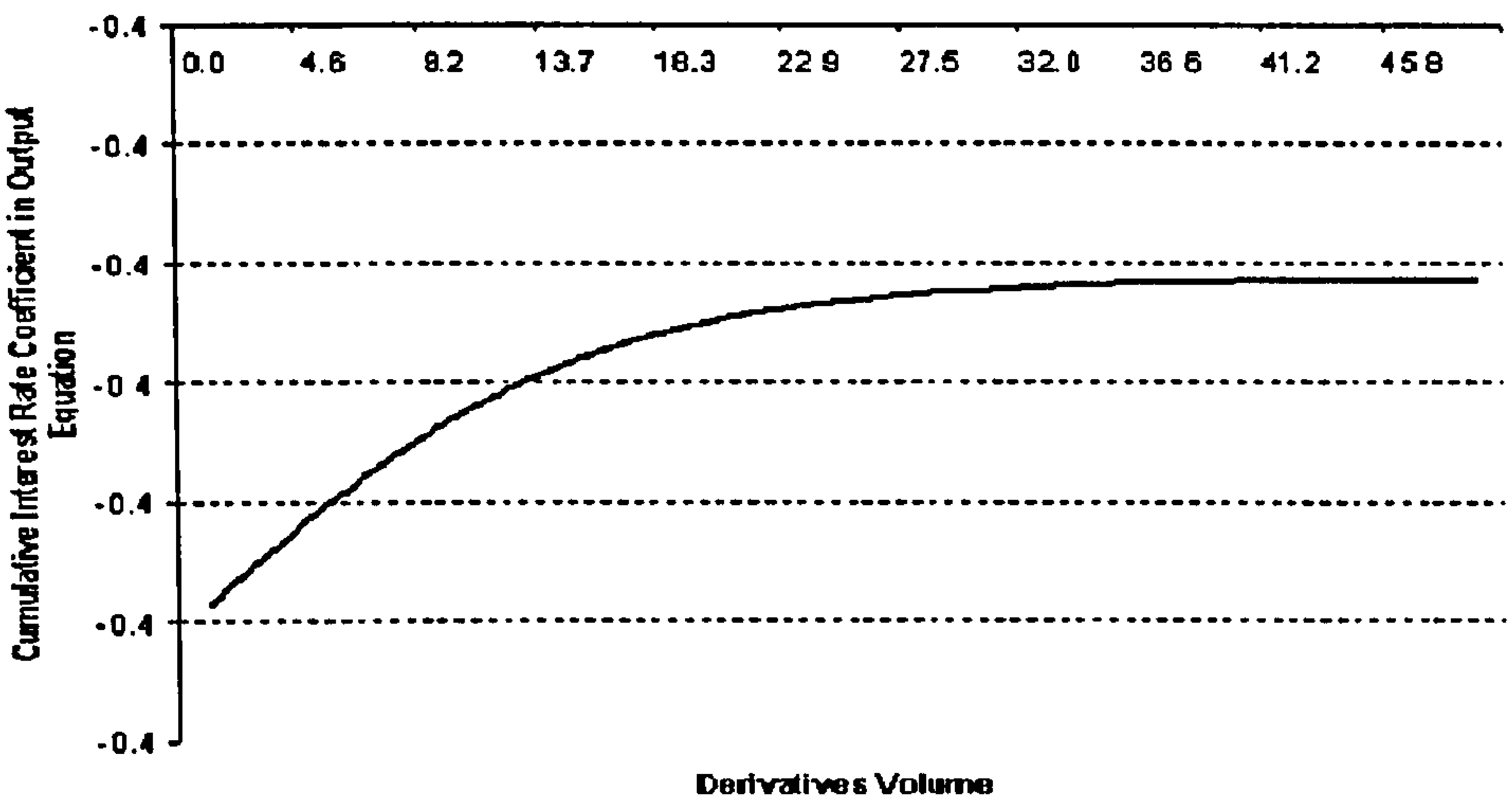



Figure 7.2: The changing impact of monetary shocks due to increased swap usage.

### 7.7.2 Assessing the asymmetric effects of monetary shocks

The nonlinear approach taken in this paper allows us to directly identify the effects of different levels of swaps usage on the dynamic response of the economy to monetary shocks. Within our nonlinear framework, we are able to investigate the impact of shocks conditional on the volume of trading at the time of the shock, and the size/sign of the shock. This approach enables us to address a number of questions. Firstly, do higher levels of swaps usage significantly alter the response of output to monetary shocks? Secondly, does the degree of usage of swaps result in output responding differently to positive versus negative money shocks, and finally is the effect of shocks of different magnitude influenced by the degree of swaps usage?

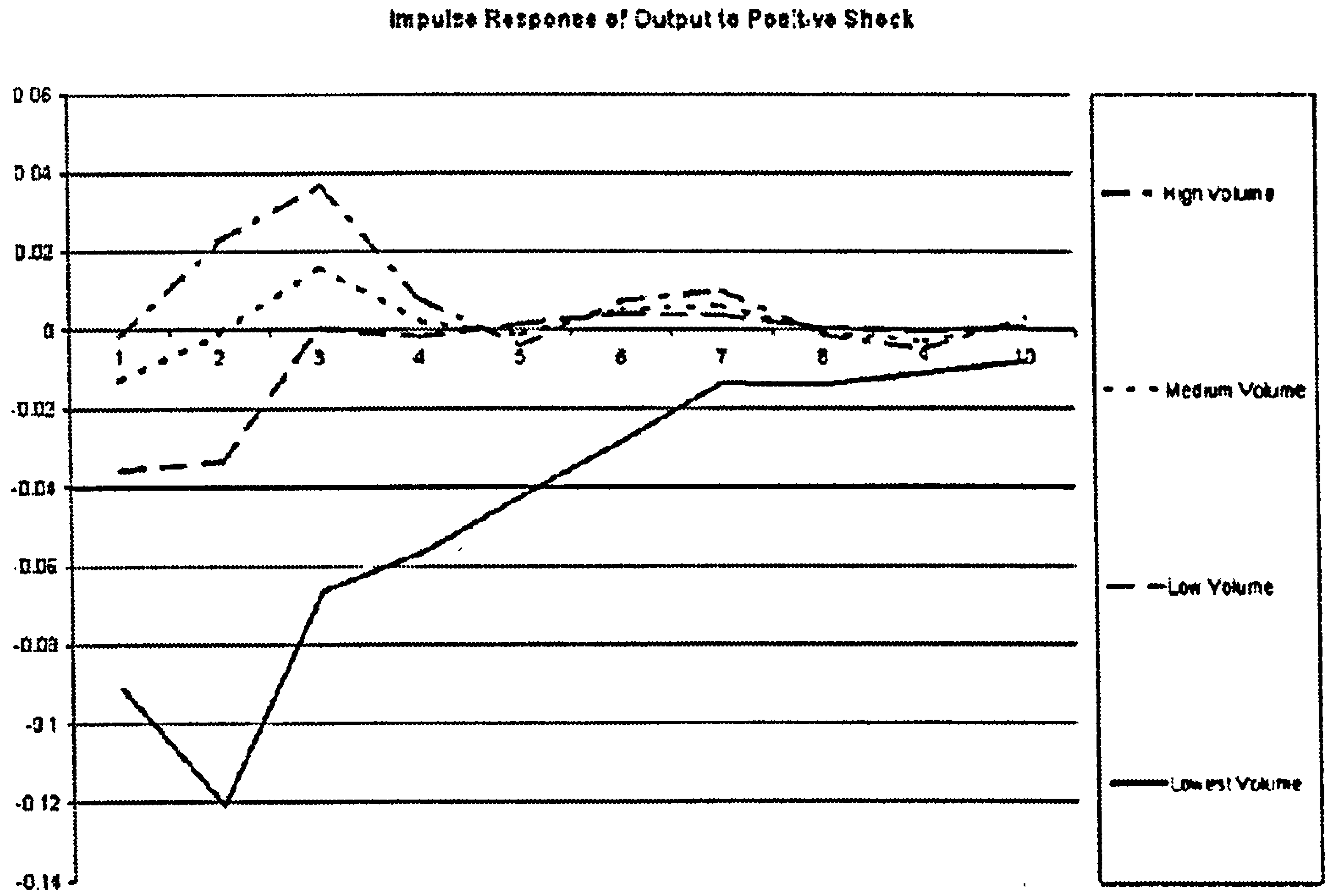



Figure 7.3: Generalized cumulative impulse responses of output growth to a 1 standard deviation shock to M1

Figure (7.3) presents the estimates cumulative response of output growth to a one-time shock to the change in $M1$. The shock is one standard deviation, or 1.53 percent. The graphs can be interpreted as the response of the log level of output to a permanent 1.51 percent increase in the federal funds rate. The response of output growth shocks of one and two standard deviations were computed for comparison. However, there was no evidence of significant asymmetric effects, so the results are not reported here. In addition, there was no evidence of asymmetry in the effects of positive or negative shocks. However, the initial level of swaps usage at the time of the shock has a marked effect on the impulse responses. For the lowest initial levels of swaps usage (less than $10.3 billion), output growth falls strongly in response to a positive interest rate shock. However, as the initial level of trading rises, the estimated initial response of output growth falls rapidly. In addition to the size of the response, higher levels of swaps usage result in output growth responding more slowly to the interest rate shock. Also, when the level of trading is high, the initial effects on output growth die out more rapidly, so that increased use of derivative seems to be associated with a reduction in both size and duration of effect on output.

Finally, we can consider a simple summary measure of the impact of swaps usage on the response of the economy to monetary policy. The impulse response functions in figure (7.3) imply that the impact of unanticipated monetary shocks on output growth has fallen by 60% since 1990 due to the use of interest rate swaps. While these results must clearly be viewed with caution due to the small sample used in this study, they nonetheless paint a striking picture.

## 7.8 Conclusion

This chapter has presented evidence that financial innovation, particularly the introduction and exponential increase in use of interest rate swaps, has brought with it the potential to significantly influence the monetary transmission mechanism in the U.S..

This provides some evidence that as corporate risk management has become more pervasive, the real side of the economy has become more insulated from monetary and financial developments.

There are a number of policy implications of these findings. Firstly, they suggest that the monetary authorities in industrialized countries may need to consider the impact of developments in derivatives markets when formulating monetary policy. For example, there has been considerable recent interest in the causes of the 'great stability': the historically low levels of price and growth volatility observed during the past decade in the G7 countries (excluding Japan). Indeed, consistent with the theory developed and tested in this part of my thesis, the increased usage of derivatives for risk management has been highlighted as a likely contributing factor. In a recent speech, Charles Bean, Chief Economist at the Bank of England, noted: '[A] source of this "Great Stability", ... can be found in the consequences of financial deregulation, innovation and integration. ... . Financial innovation has led to the development of new derivative assets that allow idiosyncratic risk to be diversified more effectively, again making the economy more resilient to shocks.' Bean (2005).

At first sight, the policy conclusions from this analysis may not be comforting, since it seems that monetary authorities in industrial economies have lost some of their punch in pursuing monetary policy. However, it is not clear that the implications are truly that negative. Financial innovation has brought with it many positive elements, such as more efficient markets and better techniques for the management of risk, which must be weighed against any losses in monetary control. Finally, to the extent that markets are functioning more efficiently, they may be performing some of the tasks that were formerly required of the monetary authority. The consequences of financial innovation can hardly be considered negative if they are reflective of a market that is doing its job.

A major limitation of the results presented here is that they are based on a very small sample of data. More conclusive results would require either a considerable longer span of data, or alternatively data at a monthly frequency. As such the impact of derivatives markets and of risk management is not altogether clear, and the results may simply reflect a shortage of relevant data. However, these conclusions should be taken as preliminary and not as definitive. The literature in this field is fairly scant, and there is a clear potential for much further progress, particularly on the empirical side. Moreover, as empirical evidence materializes, there may be a need to revisit the theoretical framework in light of any new results.

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