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Sterilized Foreign Exchange Market Interventions in a Chartist-Fundamentalist Exchange Rate Model

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Abstract

Sterilized foreign exchange market interventions are commonly dismissed by economists as an ineffective policy instrument. Nevertheless many central banks operating under independently floating exchange rates regimes are often engaged in sales and purchases of foreign exchange in order to manipulate the current value of their currencies. In this paper we argue that the skepticism of many economists can be ascribed to their orientation on fundamental-based, efficient-market exchange rate models. Given their weak empirical support, however, it is unreasonable to evaluate the effectiveness of sterilized foreign exchange interventions against the background of this class of models. Therefore, the purpose of this paper is to investigate the effectiveness of sterilized foreign exchange market interventions on the basis of a more suitable model. Using a chartist-fundamentalist model we show that central banks can influence exchange rates by using sterilized interventions. In particular, turning points occur earlier and exchange rate misalignments are substantially reduced.

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1 Introduction

The use of official foreign exchange market interventions as a policy tool for affecting exchange rates is often subject to controversial disputes. Many opponents assert that official interventions are ineffective in changing exchange rates substantially. In practice, however, central banks are frequently engaged in sales and purchases of foreign exchange.

The effectiveness of interventions is usually evaluated on the basis of three intervention channels: the monetary channel for non-sterilized interventions, the portfolio-balance channel and the signaling channel for sterilized interventions. All of these channels explain the impact of foreign exchange market interventions on the exchange rate using some variant of the asset pricing model of the exchange rate. Especially, the empirical evidence of the portfolio-balance and the signaling channel is rather mixed. However, this result cannot be simply ascribed to the ineffectiveness of central bank interventions, but moreover to the empirical failure of the underlying exchange rate model. Until today, economists do not possess a reasonable model based on macroeconomic fundamentals that can explain exchange rate movements over different time periods.

From our point of view, it is therefore important to evaluate the effectiveness of interventions against the background of a reasonable exchange rate model. In recent years a new class of exchange rate models based on heterogeneous expectations has emerged. One particular specification is known as the chartists-fundamentalists (c&f) model in which two different kinds of expectations are responsible for exchange rate dynamics. Thereby, the c&f model is able to capture observable exchange rate movements rather well.

The purpose of our paper is to integrate the impact of central bank interventions in a c&f model. We show that due to interventions turning points in the exchange rate series occur earlier and exchange rate misalignments are substantially reduced. The remaining part of the study is as follows. In the next section we give a critical review of traditional intervention channels. Section 3 is concerned with the integration of sterilized foreign exchange market interventions in a c&f model. We first discuss the c&f model and subsequently calibrate it. In the next step central bank interventions are incorporated, so that we are able to analyze their impact on exchange rates for various intervention strategies. The paper closes with a short conclusion and an outlook on future research issues.

2   A critical review of traditional intervention channels

2.1   Interventions in the asset pricing model of the exchange rate

The question how exchange rates are affected by central bank interventions in the foreign exchange market is closely related to the question how exchange rates are determined in general. The traditional intervention channels are based on variants of the asset pricing model of the exchange rate according to which the (log of the) spot rate s_t is determined by the present discounted sum of current and expected future (log of) economic fundamentals x_t (Mussa, 1990):

$$s_t = \frac{1}{1+\alpha} \sum_{j=0}^{\infty} \left(\frac{\alpha}{1+\alpha} \right)^j E_t \left[x_{t+j} | \Omega_t \right]. \tag{1}$$

In this kind of models expectations E_t are formed rationally on the basis of the information set Ω_t available at time t. The coefficient $\alpha/(1-\alpha)$ represents the discount factor. In order to specify the fundamentals entering the exchange rate model, for the purpose of the present paper it is convenient to focus on the basic arbitrage condition which is at the core of all exchange rate models, namely the uncovered interest parity (UIP) condition:

$$i_t - i_t^f = E_t \left[s_{t+1} | \Omega_t \right] - s_t + rp_t , \tag{2}$$

where i_t and i_t^f denote the domestic and the foreign nominal interest rate, and rp_t is the risk premium required by risk averse international investors for holding risky assets. Solving equation (2) for s_t yields the following asset price equation of the exchange rate:

$$s_t = \sum_{j=0}^{\infty} E_t \left[i_{t+j}^f - i_{t+j} + rp_{t+j} | \Omega_t \right]. \tag{3}$$

With equation (3) at hand the traditional intervention channels can be easily explained (see Dominguez and Frankel, 1993, Edison, 1993, and Sarno and Taylor, 2001a, for comprehensive overviews). Non-sterilized foreign exchange market interventions involve a one-for-one change in the central bank's net foreign assets and the monetary base. The change in base money leads to a change in the short-term interest rate i_t, and hence to a modified exchange rate path. Since this type of intervention simply is a variant of a central bank's interest rate policy that can be distinguished from conventional open market operations only in the type of asset being exchanged for base money, the underlying intervention channel is called the *monetary channel*. However, central banks that operate under flexible exchange rates are predominantly engaged in sterilized foreign exchange market interventions which leave the primary monetary policy instrument i_t unaffected. According to the *portfolio-balance channel* sterilized interventions change the relative stock of foreign to domestic assets which is held by the international investors. As risk averse asset holders are not indifferent to the currency composition of their portfolios, such a change alters the risk premium rp_t that is required by the investors for holding the risky portfolio. The *signaling channel* by contrast explicitly exploits the asset price nature of the exchange rate. Sterilized interventions are assumed to provide some fundamental news to the investors

which induce them to alter their expectations about the future course of monetary policy, as measured by $E_t i_{t+k}$ for any $k > 0$.

The perceived usefulness of interventions as a monetary policy tool crucially depends on whether interventions are sterilized or not. On the one hand, the effectiveness of interventions through the monetary channel under flexible exchange rates is rarely questioned. Many authors argue like Marston (1988, p. 97): "There is virtually unanimous agreement among economists that non-sterilized intervention can affect exchange rates, just as more conventionally defined monetary policy can undoubtedly affect exchange rates" (see also Edison, 1993, p. 8, and Sarno and Taylor, 2001a, p. 841, for similar statements). On the other hand, most economists share a profound skepticism with regard to sterilized interventions which stems from the apparent empirical failure of the portfolio-balance channel and the signaling channel. Dominguez (2003, p. 1), for example, summarizes the empirical literature as follows: "(…) neither of these channels is easily reconciled with the empirical evidence, which suggests that sometimes intervention works and sometimes it does not." In the 1980s most studies investigated the portfolio-balance channel. While researchers typically concluded that risk premia exist and that they vary through time, they have not succeeded in relating these changes to relative asset supplies. With near unanimity, they have found the relationship to be either statistically insignificant or quantitatively unimportant. In the case of significant evidence, the effects on the exchange rate were too weak in order to attribute any importance to this channel. Because of the release of high frequency data and the publication of official intervention data the empirical focus shifted to the signaling channel in the 1990s. The most popular approach was to directly estimate the news character of current intervention on the exchange rate. Based on equation (1) one can derive the following estimation equation according to which changes in the spot rate Δs_t are assumed to occur in response to fundamental news x_t and to unexpected intervention activity I_t:

$$\Delta s_t = \alpha_0 + \alpha_1 x_t + \alpha_2 I_t + \varepsilon_t. \tag{4}$$

Thus, the basic technique of this approach is to directly estimate the influence of current interventions on exchange rate changes, over and above the contribution of the current fundamental. Empirical studies are, however, far from conclusive. Depending on the underlying sub-period and the intervening central bank, coefficients of the intervention variable are sometimes correctly signed and significant, sometimes insignificant, and sometimes significant and wrongly signed (for a summary of the empirical studies on the portfolio-balance channel and the signaling channel see the abovementioned overview articles).

2.2 A criticism of the underlying exchange rate models

The consensus view of economists on the effectiveness of non-sterilized and sterilized interventions reflects their belief in exchange rate models that rely on a fully efficient foreign exchange market in which the current exchange rate reflects all the relevant fundamental information available.

On the one hand, the hypothesized connection of the exchange rate movements with movements in some fundamental determinants is of major importance for the discussion of the monetary channel and portfolio-balance channel. Using the weak empirical results in favor of the portfolio-balance channel as evidence against the effectiveness of sterilized foreign exchange market interventions would only be a valid argumentation if the portfolio-balance model of exchange rate determination is a convincing

exchange rate theory. By the same token, the unanimous acceptance of the monetary channel of interventions requires an empirically stable relationship between the monetary policy instrument and exchange rates.

On the other hand, the efficient market hypothesis – which is central for the signaling channel – becomes most evident if one takes a closer look at the underlying estimation techniques. Each econometric model such as the one given by equation (4), which can be derived from an asset price model of the exchange rate like equation (1), involves a joint hypothesis: the efficiency of the foreign exchange market and the effectiveness of the intervention policy. The former enters equation (4) through an application of the rational expectations approach, which simply takes ex post changes in the exchange rate as an unbiased measure of expected exchange rate changes. Most economists who argue that their results indicate that interventions cannot be viewed as an effective policy tool assume that the foreign exchange market efficiently maps new information into prices. From this point of view it is perfectly consistent to investigate the immediate effects of interventions on the exchange rate by using daily or intra-daily data. However, if one rejects the efficient markets hypothesis, it is not reasonable to draw any conclusions concerning the effectiveness of interventions on the basis of models that basically rely on this assumption.

The empirical evidence suggests that both assumptions – fundamental based determination of exchange rates and efficient foreign exchange markets – have to be rejected. Under the catch phrase 'disconnect puzzle' many caveats to a fundamental based determination of exchange rates are summarized. First, Messe and Rogoff (1983) have shown that fundamental exchange rate models perform less accurately than forecasts that do not rely on macroeconomic fundamentals at all. This holds true even under the assumption that market participants perfectly anticipate the future path of macroeconomic fundamentals. Second, Flood and Rose (1995) point out that the observable volatility of exchange rates increased in the post Bretton Woods area although the variability of macroeconomic fundamentals does not change very much across exchange rate regimes. This finding is essential as it suggests that fundamental based exchange rate models are unlikely to explain changes in the exchange rate. Third, Goldberg and Frydman (2001) and De Grauwe and Vansteenkiste (2001) report evidence for unstable coefficients in fundamental exchange rate models. With regard to the efficient market hypothesis, empirical evidence also advises skepticism. In efficient markets price movements are only due to the occurrence of new information about fundamentals. However, much of the daily spot exchange rate changes can not be associated with such news (see e.g. Galati and Ho, 2001). Furthermore, the results of studies analyzing survey expectations indicate that the assumption of rational expectations seems to be unsustainable (Bofinger and Schmidt, 2003). The efficient market hypothesis also implies that the current exchange rate should incorporate all information contained in past exchange rates, so that the extrapolation of past prices as it is suggested by technical analysis is futile. However, many studies report that the use of simple technical analysis tools can generate substantial profits (see Levich and Thomas, 1993, and Okunev and White, 2003). In this context we should also refer to another stylized fact of international economics which contradicts the view of fundamental based exchange rate determination and efficient functioning of foreign exchange markets. As Engel and Hamilton (1990) have demonstrated freely floating exchange rates tend to move in long trends. However, these trends can not be related to

macroeconomic fundamentals and may be responsible for the substantial profits related to the usage of technical analysis.

To sum up, there is a huge amount of evidence that fundamentals-based exchange rate theories that rely on the efficient market hypothesis fail. In our view, it is therefore unfair to conclude that foreign exchange market interventions are an inefficient instrument when tested on the basis of empirically unsustainable exchange rate models.

2.3   High trading volumes and foreign exchange market interventions

Another argument typically raised against the effectiveness of foreign exchange market interventions, in particular along the lines of the portfolio-balance channel, is the high daily trading volume that can be observed in the foreign exchange market. Again, there is an important inconsistency when dismissing interventions for this reason. As has been pronounced by Frankel and Froot (1990, p. 92) trading volumes are incompatible with standard macroeconomic exchange rate models: "When a new piece of information becomes available, if all investors process the information in the same way and are otherwise identical, no trading needs to take place. The price of the asset should simply jump to its new value." Thus, macroeconomic models implicitly assume that private demand for and supply of foreign exchange results from agents who all have access to the same information set and who all proceed the information in the same way by building homogeneous expectations. Moreover, these models assume a Walrasian auctioneer who collects preliminary customer orders and who uses them to find the market-clearing price. Accordingly, the auctioneer's price adjustment is immediate and no trading needs to occur in transition. Frankel and Froot (1990, p. 92) continue: "To explain the volume of trading, some heterogeneity of investors is required."

And indeed, the foreign exchange market is characterized by a high degree of heterogeneity which basically occurs on two levels. First, the foreign exchange market is organized by a market maker system in which a single order submitted by a private agent leads to a multiple of turnover in the interdealer market (i.e. the market in which only market makers deal with each other), simply due to this specific pricing mechanism that gradually turns the initially private information of the market maker that has been contacted by the agent into public information (see Sarno and Taylor, 2001b, for an overview article about the 'microstructure' of the foreign exchange market). Second, the way private agents process information and form expectations deviates in many respects from the homogeneity assumption underlying the rational expectations paradigm. This second level will be at the core of the following analysis.

In our view it is therefore important to take into account the institutional dimension of the foreign exchange market. Comparing the amount of a central bank's sale or purchase of foreign exchange with the daily gross turnover in the foreign exchange market can be very misleading as it ignores the fact that roughly 60 per cent of this turnover is due to the market maker principle. Thus, a single intervention also produces a multitude of subsequent trades, and its possible impact on the exchange rate therefore has to be assessed on these grounds (Bofinger, 2000).

3 An alternative intervention channel – the coordination channel

The objective of this section is to integrate foreign exchange market interventions in a realistic exchange rate model. We choose a c&f model because it captures important characteristics of the actual exchange rate dynamics. In particular, the c&f model allows for long swings that are disconnected from fundamentals. Moreover, it considers heterogeneous expectations which is undoubtedly a more realistic description of reality. Finally, this framework enables us to incorporate important institutional aspects of the foreign exchange market.

3.1 The chartist-fundamentalist exchange rate model

The class of c&f models goes back to Frankel and Froot (1990), and has been enhanced among others by De Grauwe and Dewachter (1993), Frenkel (1997), Grimaldi and De Grauwe (2003) and Westerhoff (2003). Basically, c&f models can be assigned to the noise trader approach propagated by Shleifer and Summers (1990). Within the noise trader framework heterogeneous expectations are introduced to capture the observable dynamics of exchange rates more appropriately. Usually, two different kinds of expectations formation are considered: the first one can be assigned as 'fundamental' expectations as they are guided by the fundamental value of the exchange rate. The second kind of expectations is often denoted as 'irrational'. These expectations are based on noisy information which are worthless with regard to the fundamental value. Black (1986) introduced the term noise for this worthless information and concludes that "people sometimes trade on noise as if it were information" (Black, 1986, p. 529). The introduction of 'irrational' expectations in exchange rate models allows for modeling deviations of the actual exchange rate from its fundamental value.

Basically, the foreign exchange market can be described as a decentralized multiple-dealer market. Trading in foreign exchange market is dominated by two different groups of financial agents. The first group is comprised of all agents who act as customers in the market (e.g. fund managers, hedge funds, exporting and importing firms etc.). They buy and sell currencies according to the needs of their business activities. As customers' demand and supply usually do not match, a second group of agents is needed to take up the excess demand of customers. In foreign exchange markets these agents are called market makers. Market makers ensure that all customer buying and selling orders are fulfilled instantaneously. Farmer and Joshi (2002) show that in markets, which are organized by this principle, prices evolve according to the following price impact function:

$$s_{t+1} = s_t + \alpha \, ed_t . \tag{5}$$

According to equation (5), the change in the (log) exchange rate s from period t to t+1 arises from the excess demand in period t. The factor α can be interpreted as the elasticity of the (net) order size with respect to the exchange rate change. The cause of excess demand are the trading decisions of foreign exchange market customers. Within our model, we distinguish two different kinds of customers:

- Financial investors such as fund managers are concerned with professional investment purposes. To account for both fundamental and 'irrational' trading behavior we assume that financial investors base their investment decisions either on fundamental trading rules or on trading rules resulting from technical analysis. The fundamental trading rule can be concretized as a function of the fundamental

value of the exchange rate and the actual spot rate. The rationale for this trading rule is that the actual spot rate may diverge from its fundamental value for a certain amount of time but it will back up towards its fundamental value over time. Thus, financial investors using a fundamental trading rule try to profit from buying a certain currency if they think it is undervalued and selling it if they think it is overvalued. The fundamental trading rule is given by

$$d_t^f = \gamma\left(f_t - s_t\right),$$
(6)

where γ is a positive parameter that determines the speed of the expected adjustment and f_t represents the (log) fundamental exchange rate. In our model we assume that that the fundamental exchange rate is exogenous. Trading based on technical analysis is represented by the following trend chasing trading rule

$$d_t^c = \beta\left(s_t - \frac{1}{n}\sum_{i=1}^{n} s_{t-i}\right),$$
(7)

where β is a positive model parameter which accounts for the degree of extrapolation. This trading rule reflects a simple n-day moving average rule that is often used by practitioners. The rationale for this trading rule will be discussed in detail in Section 3.2 below.

- Liquidity traders trade in foreign exchange markets due to their liquidity requirements, i.e. they do not trade in foreign exchange markets due to investment objectives but for payment transactions arising from their ordinary business activities (imports and exports). It is assumed that their demand is purely random, i.e. ξ_t^l follows an IID white noise process.

After the introduction of all relevant foreign exchange market participants, we now can summarize the total excess demand of customers as follows:

$$ed_t = m\,d_t^c + \left(1-m\right)d_t^f + \xi_t^l,$$
(8)

where m measures the degree of which investment decisions are taken on the basis of technical analysis.

In contrast to the papers by Frankel and Froot (1990), De Grauwe and Dewachter (1993), Grimaldi and De Grauwe (2003) and Westerhoff (2003) the parameter m is kept constant in this paper, implying a strictly linear model. While a linear model produces some time series charateristics that are clearly at odds with the stylized facts, the main advantage is that it remains simple and analytically tractable so that standard solution methods can be applied (see also Frenkel, 1997, for a similar approach). This approach enables us to determine optimum intervention strategies in a linear-quadratic framework which is a major purpose of the paper. Nevertheless, we will come back to this point in our outlook for future research at the end of the paper.

3.2   Discussion of the c&f exchange rate model

This section deals with an empirical justification for the introduction of non-fundamental trading practices into an exchange rate model. Hereunto, we draw from the results of interviews conducted with foreign exchange market participants. One of the first who questioned traders were Taylor and Allan (1992). Their results indicate that large parts of foreign exchange traders rest their expectations formation upon technical analysis – at least in the short and medium-run. More recently, Cheung et al. (2000), Cheung

and Wong (2000) and Cheung and Chinn (2001) systematically analyzed the British, Asian and American foreign exchange markets by using questionnaires. Their results with respect to the importance of 'irrational' factors determining the expectations formation of market participants are summarized in Table 1. Obviously, market participants think unanimously that irrational factors play a key role in the determination of exchange rates in the short and medium-run, but also in the long-run some 'irrational' influences are suggested.

Table 1: Relative importance of fundamental and irrational factors for the determination of exchange rates♥

		Intraday	Medium-run (≤ 6 months)	Long-run (> 6 months)
UK Foreign Exchange Market (Cheung et al., 2000)	Rational fundamental factors	0.6%	31.4%	82.5%
	Irrational non-fundamental factors	97.7%	67.2%	15.4%
Asian Foreign exchange markets♣ (Cheung and Wong, 2000)	Rational fundamental factors	0.7%	32.2%	79.6%
	Irrational non-fundamental factors	99.3%	67.8%	20.4%
US Foreign exchange market (Cheung and Chinn, 2001)	Rational fundamental factors	0.8%	32.1%	87.4%
	Irrational non-fundamental factors	98.6%	66.8%	9.4%

♣ Values represent the average of the three Asian trading centers Hong Kong, Tokyo, and Singapore
♥ The relevant question in the survey is: select the single most important factor that determines exchange rate movements (see e.g. Cheung et al., 2000, p. 21).

A persuasive theoretical rationale for the introduction of 'irrational' trading practices is recently given by the literature on Behavioral Economics. Within this literature the concept of economic rationality which is at the core of basically all traditional exchange rate models is seriously queried. An essential implication of economic rationality is that agents are able to process all available information using the 'right' economic model. That is, agents do not suffer from any cognitive limitations. This implication appears against the background of psychological evidence to be pretty unrealistic as psychological research shows that agents must make inferences under limited time, limited knowledge and limited computational capacities. Consequently, they are not able to determine an exact rational solution, as the economic theory usually supposes (Gigerenzer, 1997).

Against the background of limited cognitive resources, psychologists have investigated the processes through which agents reach their decisions. Their results suggest that agents tend to use simple heuristics to reduce the complexity of the decision situation. A simple heuristics is thereby defined as a simple rule of thumb, which allows quick and efficient decisions even under high uncertainty (Fiedler and Bless, 2001). Gigerenzer and Todd (1999) have shown that there are many heuristics that provide a reasonable compromise between economic rationality and an efficient use of scarce human cognitive resources. However, there are also circumstances where simple heuristics lead to systematically biased judgments (Tversky and Kahneman, 1999).

In the context of foreign exchange markets, technical analysis can be interpreted as a simple heuristics that allows each individual market participant to easily reach an investment decision (Goldberg, 1997,

Goldberg and von Nitzsch, 2001). The purpose of technical analysis is to extract information about future rates from past realization. Thus, it is an attempt to exploit recurring and predictable patterns in exchange rates. Pring (2003, p.2) describes the main objective of technical analysis as follows: "the technical approach to investment is essentially a reflection of the idea that the [...] market moves in trends which are determined by the changing attitudes of investors to a variety of economic, monetary, and psychological forces. The art of technical analysis, for it is an art, is to identify changes in such trends at an early stage and to maintain an investment posture until a reversal of that trend is indicated." In foreign exchange markets, technical analysis can be seen as a widespread tool used by practitioners when forming expectations about future exchange rates. Table 2 summarizes the relative importance of technical analysis according to the studies of Menkhoff (1998), Cheung and Chinn (2001) and Gehrig and Menkhoff (2004). All three studies show that technical analysis is a prominent tool for the expectation formation of foreign exchange market participants.

Table 2: The importance of technical analysis in foreign exchange markets

	Technical analysis	Fundamental analysis	Order flow	Other
Menkhoff (1998)	37.2%	44.9	17.9	--
Cheung and Chinn (2001)	30%	25%	22%	23%
Gehrig and Menkhoff (2004)	35.8%	29.4%	17.4%	17.4%

A key characteristic of simple heuristics is their usefulness for a wide range of applications. For technical analysis this requirement seems to be fulfilled as many empirical studies have shown that technical trading rules are profitable. Okunev and White (2003) analyze the profitability of momentum-based strategies in various foreign exchange markets. Their results indicate that the potential exists for investors to generate excess returns by adapting a simple moving average rule. This finding is robust to the time periods under consideration, the base currency of reference and the benchmark of comparison. Similar results for the profitability of technical analysis in foreign exchange markets are also reported by e.g. Neely (1997) and Chang and Osler (1999).

Some researches, however, ascribe the profitability of technical analysis merely to central bank interventions in foreign exchange markets (see e.g. LeBaron, 1999). They argue that monetary authorities are willing to take losses on their trading as their objectives are to maintain orderly market conditions and not to make profits. Thus, the profitability of technical analysis may represent a transfer from central banks to technical traders (see Szakmary and Mathur, 1997). In this context, Neely (1998) shows that central bank interventions are generally against the position taken by technical traders who guess the sign of excess return right so that interventions seems to be unprofitable at least in the short-run. However, this argumentation appears to be more than equivocal. On the one hand, trading rules also generate excess profits in other asset markets such as e.g. stock markets where no official interventions occur (see e.g. Jegadeesh and Titman, 1993, 2001). On the other hand, the empirical results of Neely (2002) advise that central bank interventions respond to exchange rate trends which are responsible for the profitability of technical trading rules. Furthermore, empirical studies on the profitability of central bank interventions reveal that in the long-run interventions generate substantial profits for monetary authorities (see e.g.

Leahy, 1995, Sweeney, 2000, Saacke, 2002, and Ito, 2002). Thus, it would be reasonable for investors to trade in accordance with central banks instead of taking the opposite position.

The crucial point in the context of intervention effectiveness is the considered time horizon. If the objective of central bank interventions is to break existing trends it may take longer to realize this change. This suggestion is supported by the empirical findings of Saacke (2002) who shows that profitability only occurs in the longer-run (after 26 days positive impact, statistically significant after 330 days), meaning that in the short-run the response of exchange rates to interventions is either insignificant or has the wrong sign. However, in the longer-run his results indicate that exchange rates tend to move in a manner consistent with the central bank's intentions. This result is in line with previous findings suggesting that in the longer-run central bank interventions affect exchange rates in the desired direction, but that in the short-run the central bank is likely to experience losses (see e.g. Goodhart and Hesse, 1993).

3.3 Calibration of the baseline c&f exchange rate model

In this section we choose appropriate model parameters for a daily exchange rate model. Even though c&f models already enjoy a great popularity, there is yet no convincing econometric work that we could rely on. Our calibration is therefore mainly based on plausibility considerations. We assume that the relative weight of chartism m in the financial investor's decision process is constant and equal to 0.5. This roughly reflects the survey results summarized in Table 2. The chartists extrapolate the exchange rate according to a 50-day moving average so that $n = 50$. The fundamental exchange rate is assumed to follow a near-random walk

$$f_{t+1} = 0.99f_t + \xi_{t+1}^f .$$
(9)

We excluded a pure random walk to maintain the stationarity of the model's variables which is a crucial prerequisite for the applicability of the numerical algorithms used below. For simplicity we set the scaling factor α equal to one.

For the choice of the parameters β and γ we took the following criteria into account. First, the exchange rate process should be stable. As a general rule, the higher the impact of chartists (the lower the impact of fundamentalists) on the exchange rate, i.e. the higher β (the lower γ), the more unstable the evolution of the exchange rate, i.e. the more persistent the misalignments. Second, the exchange rate should oscillate around the fundamental exchange rate after a single shock so as to get endogenous 'swings'. Here the rule is that the higher the impact of both, chartists and fundamentalists, on the exchange rate, the higher the frequency with which the exchange rate oscillates. Figure 1 summarizes these results. Parameter combinations above the dashed oscillation frontier lead to an exchange rate process that oscillates around its fundamental value. Parameter combinations below the solid stability frontier lead to a stable exchange rate process. The final choice of β and γ is somewhat arbitrary. We set $\beta = 0.07$ and $\gamma = 0.006$, because this parameter combination produced 'realistic' simulated exchange rate time series (see Figure 2 and Figure 3).

Figure 1: Regions of stability and oscillation (logarithmic scale)
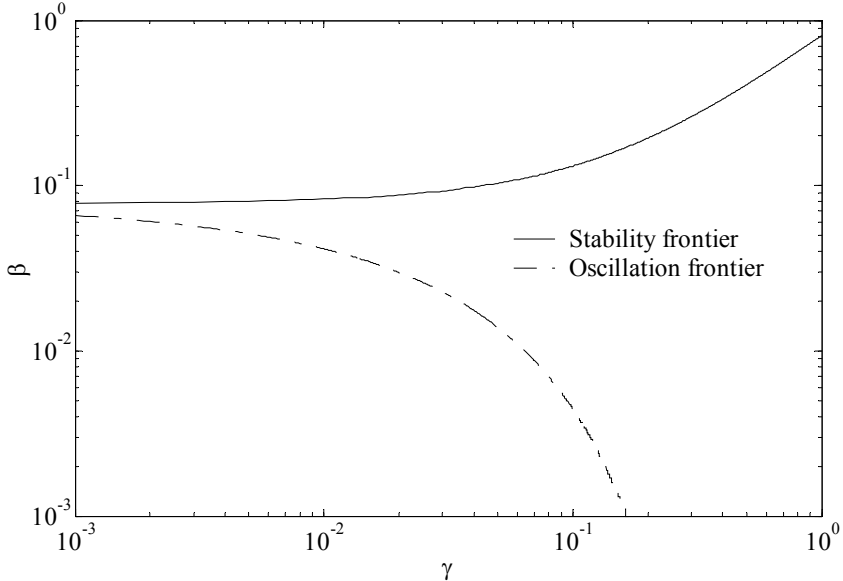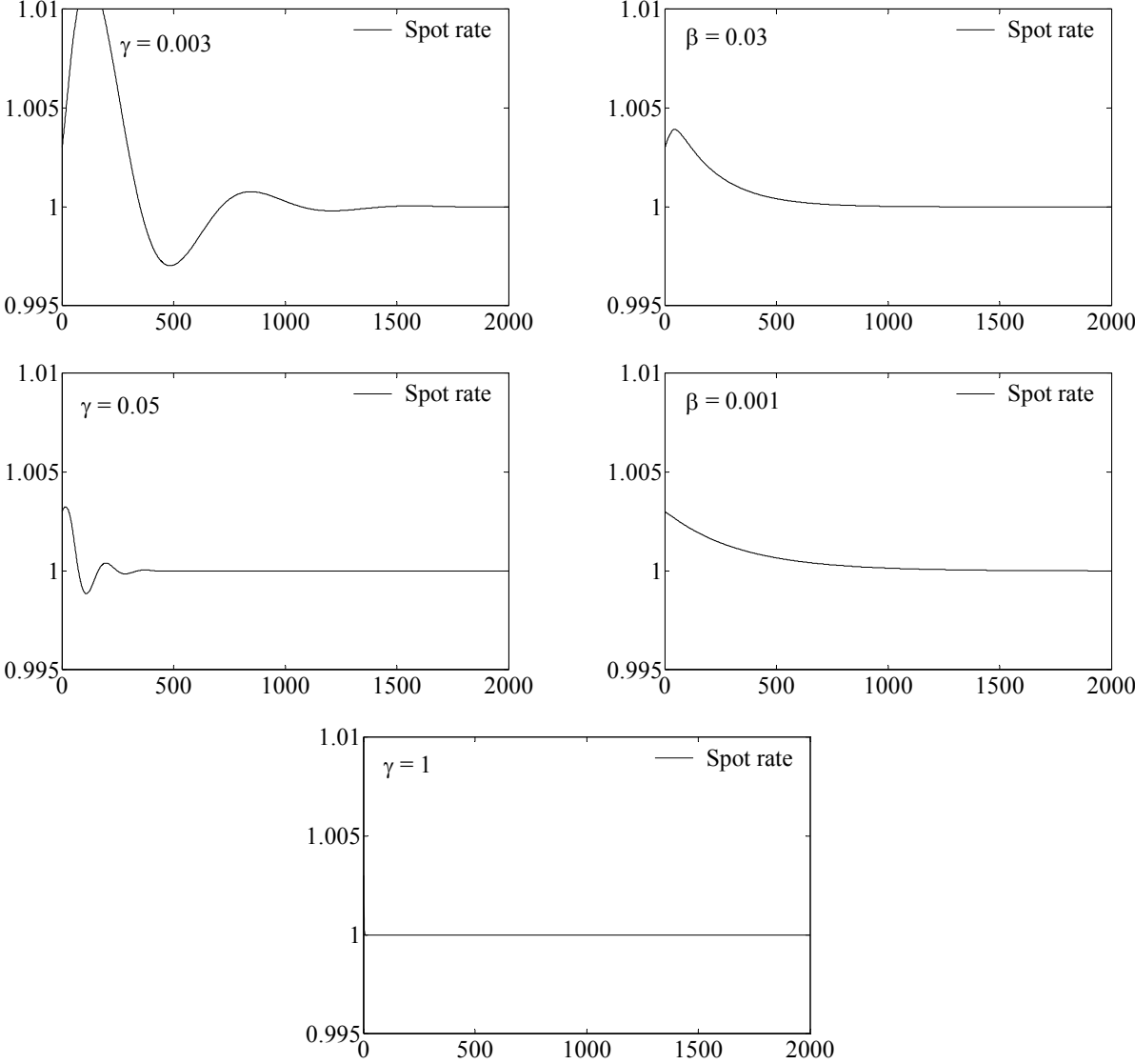

Figure 2: Responses to a one s.d. liquidity trader shock for varying model parameters

Concerning the variances of the shock processes we proceeded as follows. Shocks resulting from liquidity traders are modeled as white noise processes with $\mathrm{Var}\left[\xi_t^l\right]=\left(0.003\right)^2$. The higher we set the variance, the more pronounced the oscillations around the fundamental value (see Figure 3 and Figure 4). For the calibration of $\mathrm{Var}\left[\xi_t^l\right]$ we tried to take into account the stylized fact that the turnover resulting from this kind of foreign exchange market activity accounts for roughly 50 % of the customer transactions in the foreign exchange market (see Table 3 below). This figure was calculated as the average absolute value of liquidity traders' demand in a stochastic simulation of the model over 100000 periods. Shocks resulting from the fundamental exchange rate (the so-called unpredictable news) are also modeled as a white noise process. In contrast to the liquidity trader shocks, however, the variance of the unpredictable news has very little impact on the course of the spot exchange rate, at least as long as we modeled the fundamental exchange rate as a process that exhibits much less volatility than the spot rate. We somewhat arbitrarily set $\mathrm{Var}\left[\xi_t^f\right]=\left(0.001\right)^2$.

Figure 3: Model simulations
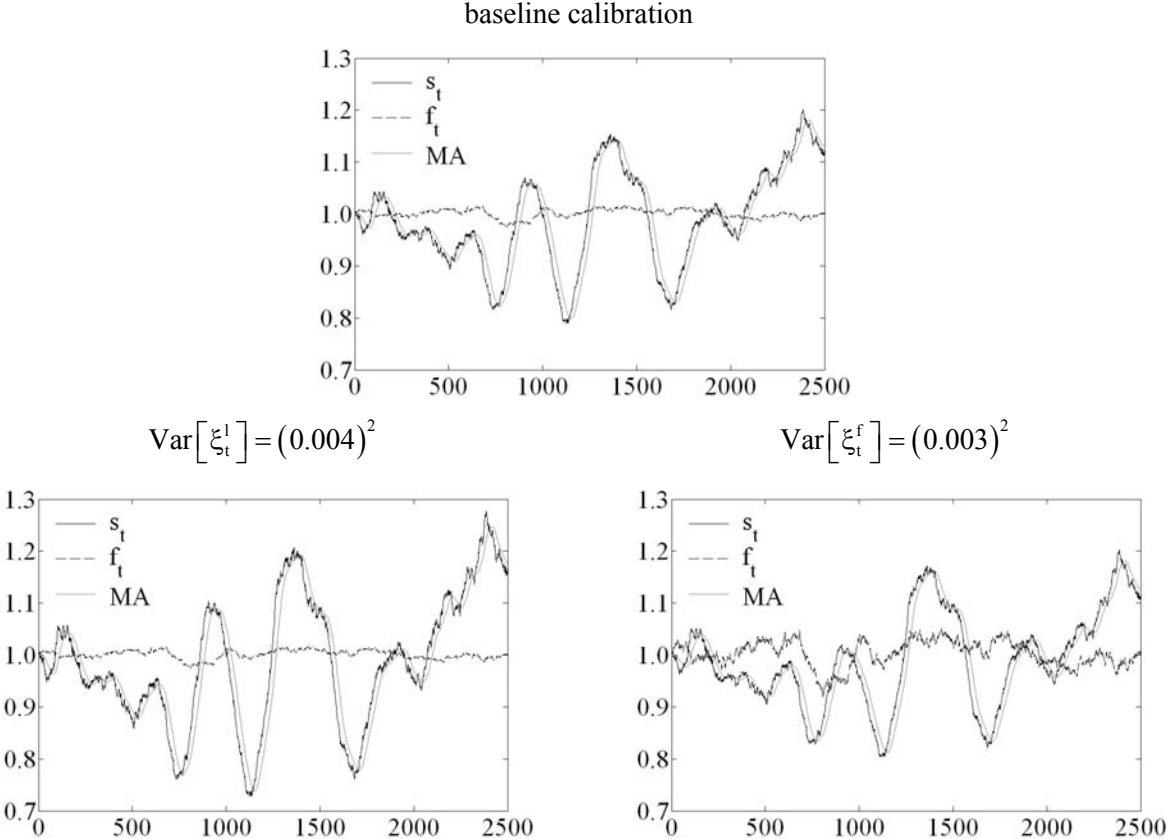
Note: By assuming that 250 days correspond to one year, the depicted time horizon is 10 years.

Figure 4: Impulse-responses for different shock sizes

response to a one s.d. liquidity trader shock

response to a one s.d. fundamental shock

response to a 0.004 liquidity trader shock

response to a 0.003 fundamental shock
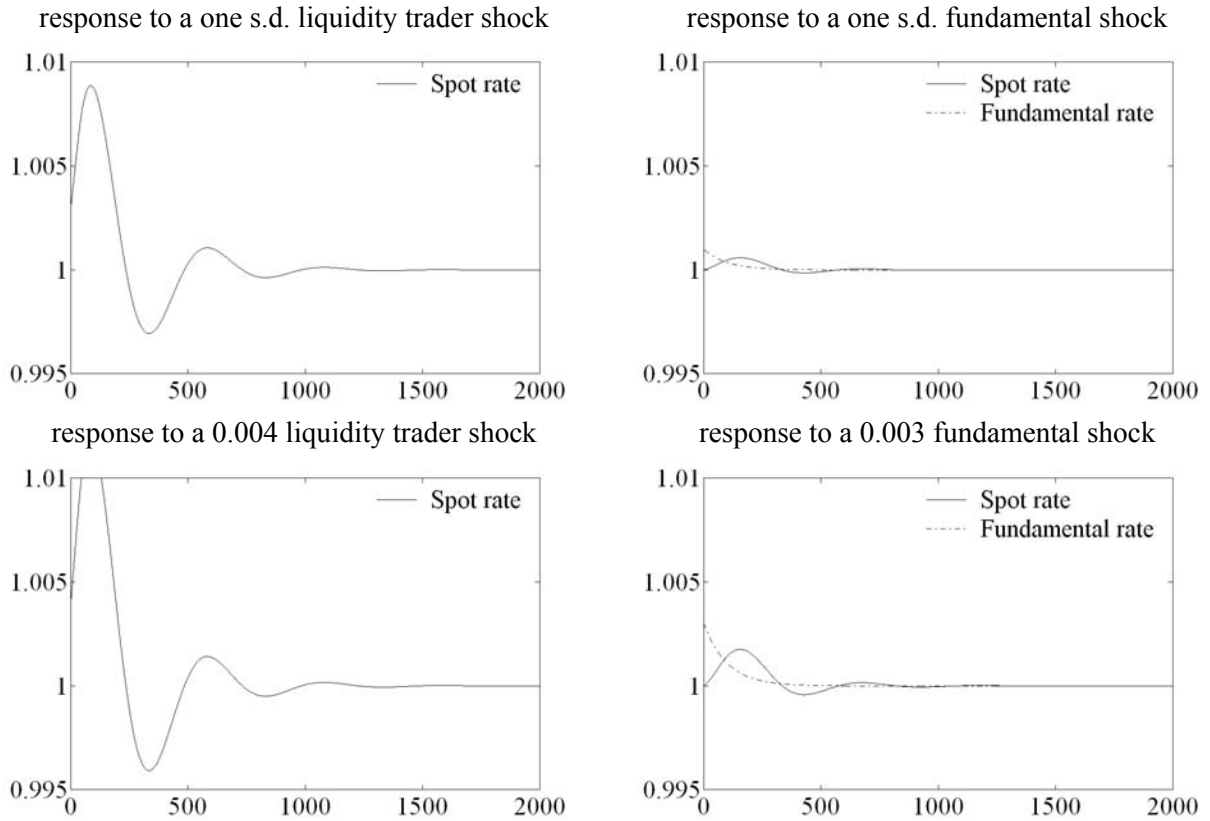
3.4 Interventions in the chartist-fundamentalist model

A central bank that buys and sells foreign exchange enters the model as an additional customer in the foreign exchange market. The excess demand is then defined as the weighted sum of chartist and fundamentalist demand, plus the central bank's foreign exchange market intervention, plus the demand of liquidity traders:

$$ed_t = m\, d_t^c + (1-m)\, d_t^f + I_t + \xi_t^l, \tag{10}$$

where I_t measures the central bank's demand for foreign exchange. The sterilization of interventions is broadly defined. Sterilized interventions do not only leave the short-term interest rate unaffected, but also all kinds of fundamental determinants of the exchange rate (which, for example, could be the risk premium if one believes in uncovered interest parity). For this reason there is no need to further specify a model of how the fundamental exchange rate is determined.

Following theoretical intervention studies (see e.g. Almekinders, 1995), interventions are modeled in terms of an intervention response function

$$I_t = Fy_t, \tag{11}$$

where y_t is a column vector of state variables, and F defines a row vector containing the response coefficients. The structure of F will be determined in accordance with typical central bank behavior. According to Jurgensen (1983) widely used strategies for the implementation of foreign exchange market interventions are exchange rate targeting and leaning-against-the-wind. A central bank that follows an

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exchange rate targeting rule intervenes in the foreign exchange market if the exchange rate deviates from its fundamental value. Under a leaning-against-the-wind strategy the central bank does not refer to any specific target value, such as the fundamental exchange rate. It simply intervenes in a way to counter past exchange rate movements (see Almekinders and Eijffinger, 1996, for this definition).

For the evaluation of intervention policies we have to specify an objective function. In dynamic models this objective is usually expressed by an intertemporal loss function

$$J_0 = E_0 \left[\sum_{t=0}^{\infty} \delta^t \text{Loss}_t \right] \tag{12}$$

where we defined the period loss as

$$\text{Loss}_t = \text{Var}\left[\text{mis}_t \right] + \lambda \text{Var}\left[I_t \right], \tag{13}$$

with a weight $\lambda \geq 0$ and a discount factor $0 < \delta \leq 1$. Using this formulation we assume that the central bank is concerned with the misalignment mis_t of the exchange rate (which is defined as the percentage deviation of the spot exchange rate from its fundamental value, $s_t - f_t$), but that it also faces a cost when using its intervention instrument.

The rationale for including these costs is twofold. First, the central bank faces a 'hard budget constraint' as the sales of foreign exchange cannot exceed the central bank's stock of foreign exchange reserves. The inclusion of the amount of intervention in the loss function therefore limits the average amount of intervention so that the probability of reaching the constraint is very low. It can be shown that the (non-linear) constraint that the intervention volume must be below a certain threshold in every period can be replaced with a (linear) constraint upon its variability (Woodford, 2003, Chapter 6).

Second, there are also costs of interventions which are related to being detected by the market. In general, foreign exchange market interventions are not publicly announced and are conducted secretly; details of the intervention are sometimes published after the intervention took place, but with a time lag of several weeks (see Chiu, 2003, for a survey of actual central bank practices). While under the traditional intervention channels (in particular the signaling channel) the secrecy of interventions appears to be puzzling, it can be explained quite well in a c&f model. As has already been noted by Hung (1997), the channel by which interventions influence exchange rates in a model with heterogeneous agents centers around the question of how a central bank is able to alter the behavior of the chartists which are responsible for the misalignment. There is no doubt that a central bank – like any other big player in the market – is able to exert a transitory effect on the exchange rate. But if this transitory effect of intervention causes chartists to revise their position because the current spot rate is much closer to the moving average or even breaks it, the temporary effect will last longer. The higher the amount of intervention, however, the more exceptional the order and the more markets become suspicious. And in the context of financial markets suspicion means that the rules according to which expectations about future exchange rates are formed are likely to change. A typical scenario in response to a foreign exchange market intervention would be a bet against the central bank that is likely to accelerate an already existing trend.

A crucial exercise of our paper concerns the calibration of the objective function. As far as the discount factor is concerned, we are in line with the standard literature by setting $\delta = 1$. The choice of the

weight λ requires a little more consideration. The purpose of the calibration of the loss function was to get an average intervention volume of our central bank that is close to that of the Japanese monetary authorities.[1] The reason for choosing the Bank of Japan as the benchmark is that the bank regularly intervened in the JPY/USD market all over the 1990s and that it publishes the daily intervention data. In the period between April 1991 and June 2003 the average intervention volume was 1.4 billions of USD, if only days are considered on which interventions actually took place (see Figure 5). The relevant market for foreign exchange market interventions is the spot foreign exchange market (Neely, 2001). According to the Bank for International Settlements the average daily customer-initiated foreign exchange market turnover in the JPY/USD spot market roughly amounts to 40 billions of USD (40 % of 100 billions of USD, see Table 3). Thus, the average intervention volume represents about 3.6 % of the average daily customer transactions. For the calibration of λ we now assumed that the central bank implements its intervention according to an optimal reaction function that follows if the central bank minimizes the loss function (12) subject to the c&f model (equations (5), (6), (7) and (10)). The higher we set λ, the lower the average intervention activity of the central bank is which we calculated as the average absolute value of I_t in a stochastic simulation of the model over 100000 periods. For $\lambda = 150000$ we finally got an average intervention activity that amounts to 3.6 % of total turnover.

Table 3: Structure of the Japanese foreign exchange market

	average daily turnover in		interdealer trades	trades with financial customers	trades with non-financial customers
	total FX market	spot FX market			
	in billions of USD		in percent of spot market turnover		
1995	242.0	87.7	62.4%	18.6%	16.6%
1998	266.6	120.5	58.9%	17.1%	24.0%
2001	231.4	80.9	56.6%	28.7%	14.6%

Source: Bank for International Settlements (2002)

Figure 5: Frequency distribution of Japanese interventions (04/1991 – 06/2003)
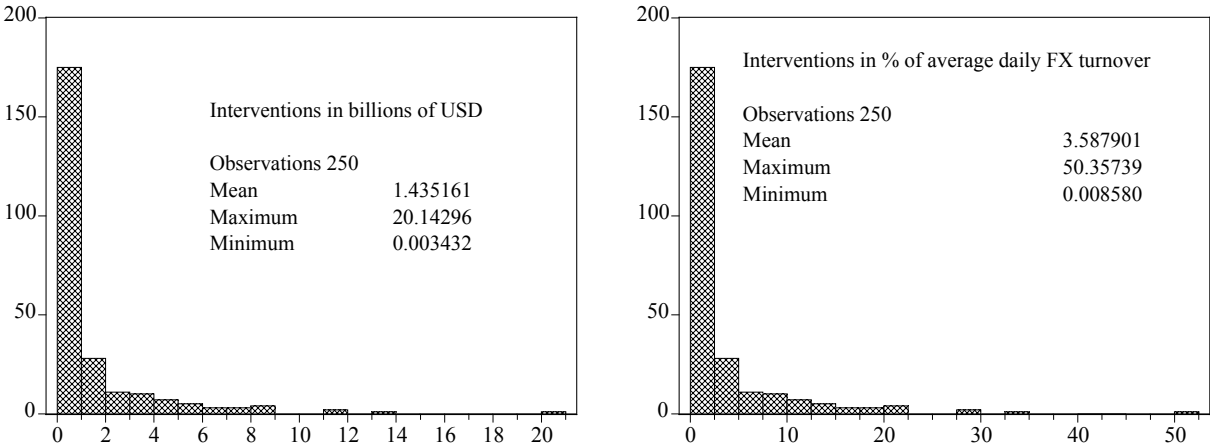
Data source: Homepage of the Japanese Ministry of Finance (http://www.mof.go.jp)

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[1] To be precise, both, the Bank of Japan and the Ministry of Finance are responsible for the conduct of foreign exchange market interventions. For simplicity, we will refer to the Bank of Japan from now an.

The optimum intervention reaction function uses all information available from the exchange rate model. Thus, the central bank buys and sells foreign exchange in response to a function of the weighted average of the entire state vector y_t in which the weights are determined according to a dynamic optimization procedure (see Söderlind, 1999, for details).

As has been described in the introduction of section 3.4 central banks usually adopt some more simple intervention strategies, rather than an optimal reaction function. In contrast to the latter a simple intervention rule only uses a small subset of information variables. An exchange rate targeting central bank pursues the following rule:

$$I_t = f^{target}\left(f_t - s_t\right), \tag{14}$$

where $f^{target} > 0$. Thus, it sells foreign exchange when the spot rate exceeds the fundamental exchange rate and it buys foreign exchange when the spot rate is below the fundamental exchange rate. In a daily model the leaning-against-the-wind strategy can have – at least – two dimensions. Depending on the length of the period entering the intervention rule we can distinguish between a moving-average (MA) rule and a smoothing rule. A central bank that follows an MA rule tries to resist an existing medium-term exchange rate trend. It sells foreign exchange when the spot rate is above some moving average line and it buys foreign exchange otherwise:

$$I_t = f^{MA}\left(\frac{1}{k}\sum_{i=1}^{k} s_{t-i} - s_t\right), \tag{15}$$

where $f^{MA} > 0$. By contrast, a central bank that smoothes exchange rates is supposed to resist large short-term (e.g. day-to-day) movements in the exchange rate:

$$I_t = f^{smooth}\left(s_{t-1} - s_t\right), \tag{16}$$

where $f^{smooth} > 0$.

For the determination of the response coefficients we minimized the policy maker's intertemporal loss function, this time, however, on a restricted set of state variables as given by equations (14), (15) and (16) . In other words, for each of the simple intervention rules we calculated the optimum response coefficients f^{target}, f^{MA} and f^{smooth}. For the MA rule we set $n = 50$. The results of the restricted optimization are shown in Table 4. The variance of the misalignment and the loss are expressed in per cent of the outcome that would result if the central bank abstained from any foreign exchange market intervention. The last column shows the performance of the optimum intervention rule. It serves as a theoretical benchmark for the evaluation of the simple intervention rules.

Table 4: Structure and performance of intervention rules in the c&f model

| intervention rule	$\mathrm{Var}\left[\mathrm{mis}_t\right]$[♣]	Loss[♣]	relative average intervention volume[♥]
without intervention	100.00	100.00	0.0 %
targeting rule			
optimized: $\quad I_t = 0.0012\left(f_t - s_t\right)$	66.50	79.62	3.1 %
volume-adjusted: $\quad I_t = 0.0014\left(f_t - s_t\right)$	*61.68*	*79.78*	*3.6 %*
MA rule:			
optimized: $\quad I_t = 0.0041\left(\dfrac{1}{50}\sum\limits_{i=1}^{50} s_{t-i} - s_t\right)$	58.22	73.59	3.1 %
volume-adjusted: $\quad I_t = 0.0049\left(\dfrac{1}{50}\sum\limits_{i=1}^{50} s_{t-i} - s_t\right)$	*53.85*	*74.11*	*3.6 %*
smoothing rule			
optimized: $\quad I_t = 0.019\left(s_{t-1} - s_t\right)$	88.37	93.45	2.0 %
volume-adjusted: $\quad I_t = 0.033\left(s_{t-1} - s_t\right)$	*81.40*	*96.60*	*3.6 %*
optimum intervention rule	*43.96*	*66.81*	*3.6 %*

Notes: [♣] unconditional variances in % of the model without interventions, analytically computed;
         [♥] obtained from stochastic simulations of the model (100000 periods).

Table 4 shows that with relatively small (and above all realistic) intervention volumes the misalignment of the exchange rate can be reduced substantially. There are, however, important differences between the three rules. By dampening the average misalignment to 58 % the MA rule clearly performs best, closely followed by the targeting rule. The smoothing rule, by contrast, does not seem to be very successful. It only reduces the variance of the misalignment to 88 % of the misalignment without intervention. The Table further shows that the relative average intervention volume of the optimized intervention rules is somewhat lower than 3.6 %. For this reason we adjusted the response coefficients in a way to produce this intervention volume (the 'volume-adjusted' row in the Table, written in italics). As all intervention rules become more aggressive the average misalignment of the exchange rate can be further reduced, of course at the cost of a higher loss. This higher loss, in particular for the smoothing rule, results out of the higher variance of the intervention instrument.

Figure 6 depicts the impulse responses with and without foreign exchange market intervention. We focused our analysis on the response to liquidity trader shocks, as these shocks are – in comparison with the fundamental shocks – the driving force of the model. According to the smoothing rule the central bank reacts to a shock in the exchange rate with a huge sale of about 0.69 billion USD in period 1, which is admittedly not discernible in the figure. However, afterwards only minor intervention activities are observed. Overall, interventions according to the smoothing rule induce a reduction of the exchange rate amplitude by dampening exchange rate changes. Compared to the three other interventions rules the total effect of interventions appears to be small. This is consistent with the results of Table 4.

Figure 6: Interventions in response to a one s.d. liquidity trader shock
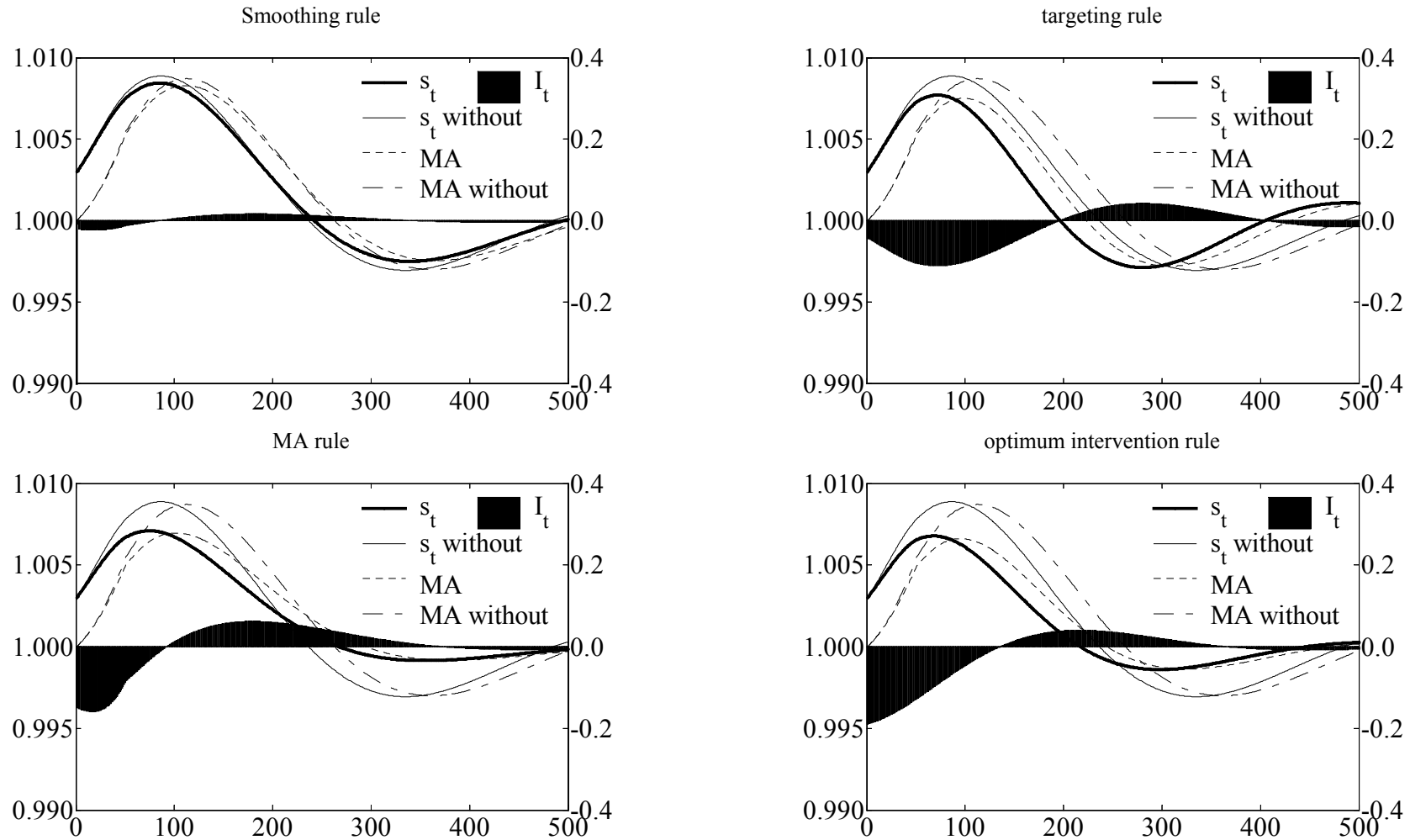
Note: The charts show the intervention response according to the optimized intervention rules. On the right scale we depicted the scaled intervention volume. When the central bank follows the optimal intervention rule that results for $\lambda = 150000$, the average daily turnover due to fundamentalists', chartists' and liquidity traders' activity is around 0.0033. This figure was obtained by simulating the model with the baseline calibration over a sufficiently long time horizon (e.g. 100000 periods) and by computing the mean of the sum of the absolute values of md_t^c, $(1-m)d_t^f$ and ξ_t^l (because turnover is a gross figure). Given the average daily foreign exchange market turnover in the JPY/USD market, we have to multiply the turnover figures resulting from our model by 12100 so as to get reasonable turnovers when expressed in billions of USD. (Note that the average turnover due to fundamentalists' and chartists' activity would also be around 0.0033 if the central bank abstained from any intervention activity. Thus, there is almost no feedback from central bank trades on private market particpants trades.)

A central bank that follows a targeting rule sells (buys) foreign exchange if it is overvalued (undervalued) against the fundamental value. By doing so the central bank initially counteracts the existing trend. However, after the trend reversal, the central bank pushes the exchange rate further towards the fundamental value. This intervention strategy results in reduction of the amplitude in the first upward swing. Subsequently the size of the amplitude remains unchanged due to the trend consistent interventions after the trend reversal. Nonetheless, the frequency of the swings is reduced. With regard to the timing of the trend reversal Figure 6 shows that interventions according to the targeting rule lead to an earlier trend reversal compared to the non-intervention situation.

The MA rule and the optimum rule show a quite similar intervention pattern. According to both intervention rules central banks sell foreign exchange when the domestic currency depreciates and buy foreign exchange when the domestic currency appreciates. A closer look at the above charts, however, reveals that under an optimum rule the switch from sales to purchases (and from purchases to sales) lags somewhat behind the turning point of the exchange rate. In other words, the central bank initially leans with the wind and pushes an already existing trend. This behavior cannot only be observed under optimum interventions, but also if the central bank follows an MA rule. The basic difference between the MA and the optimum rule compared to the targeting rule is the fact that according to the former less trend consistent interventions are conducted. Therefore, the MA rule and the optimal rule reduce the amplitude of the impulse response substantially. Like the targeting rule the MA rule and the optimal rule induce an earlier trend reversal compared to the non-intervention situation.

Overall, these results put across that the total effects of a single intervention definitely do not become apparent within a few hours or a day, which is typically the investigated time period in standard time series studies. Furthermore it seems to be rather likely that a sequence of sterilized interventions dampens the amplitude of exchange rate swings and thus reduces the economic costs of exchange rate misalignments. Moreover, a sequence of interventions is likely to forward the breaking of an existing exchange rate trend.

Our results are largely in line with the noise trading channel hypothesis of sterilized foreign exchange market interventions put forward by Hung (1991a, 1991b, 1997). "The hypothesis maintains that (...) central banks can use well-designed intervention strategies to induce noise traders to buy or sell a currency in such a way that the otherwise temporary effect of sterilized intervention is longer-lasting" (Hung, 1997, p. 782). It is uncontested that each sale or purchase of foreign exchange has a temporary effect on the exchange rate, simply by the order flow it creates (see equation (5)). The long-run effectiveness of the intervention then crucially depends on its impact on the expecatation formation process of other market participants. If intervention is conducted secretly chartists are unable to discern the sources of additional demand for or supply of foreign exchange and may incorporate the latest spot rate movement into their trendline analysis. Since chartists put more weight to the most recent exchange rate movement, it is likely that they may interpret the effect of intervention as a first indication of a trend reversal and adjust their position accordingly.

4   Conclusion and outlook for future research

In this paper we have tried to investigate the effectiveness of sterilized foreign exchange market interventions against the background of a chartist-fundamentalist exchange rate model. Our basic result is that central banks can influence exchange rates by the means of sterilized interventions. In particular, turning points of exchange rate swings around the fundamental exchange rate occur earlier and the degree of exchange rate misalignments is substantially reduced. The performance of the intervention policy crucially depends on the strategy with which the policy is implemented. While attempts to counter day-to-day exchange rate movements (a so-called exchange rate smoothing strategy) do not turn out to be very successful, a moving average rule and an exchange rate targeting rule perform relatively well. These results are also confirmed by actual intervention policies. Using a Logit model, Frenkel et al. (2002) investigated the determinants of foreign exchange market interventions of the Bank of Japan. They found that the Japanese authorities followed some variant of a moving average rule and a targeting rule, whereas the smoothing rule turned out to be insignificant.

Of course there is a range of possible extensions and modifications that can and will be considered in future works. A first issue concerns the formulation of the intervention policy. While our model assumes that the central bank intervenes continuously over time, a stylized fact of interventions is that they occur sporadically and in clusters (see Frenkel et al., 2002, for a detailed description of the Japanese intervention policy). Thus, instead of modelling interventions in terms of a policy rule such as (14), (15) or (16), intervention policy could be formulated as a non-linear intervention rule. One way to introduce the non-linearity would be to make the intervention intensity depend quadratically on the distance of the spot rate from the fundamental exchange rate or the moving average. Alternatively, one could define one or several thresholds from which interventions would take place. In the literature on interest rate rules such a policy is known as 'the opportunistic approach' (Orphanides and Wilcox, 2002). Additionally, one could also think of designing an asymmetric intervention response function. Central banks typically prefer to resists an appreciation of their currency since this policy faces no quantitative limits.

The second and maybe more crucial modification that will be performed in the future concerns the underlying exchange rate model. While our model is able to replicate some important stylized facts of actual exchange rate behavior, above all the endogenously generated long swings of the spot exchange rate around the fundamental rate, our simulated exchange rate time series unfortunately exhibit a high degree of autocorrelation in their returns which is clearly in opposition to the stylized facts. As high frequency exchange rate series typically display a unit root (see e.g. Goodhart et al., 1993), exchange rate changes usually appear to be unpredictable in the short-run. In our model the source of the high autocorrelation in returns is the constant 50 % share of chartists who simply extrapolate the past into the future at each point in time. One way to avoid the short-run predictability of exchange rate returns is to render the model non-linear. Grimaldi and De Grauwe (2003), for example, set up a model in which the weight given to chartists and fundamentalists depends on the profitability of the forecasting rules applied by them and the risk associated with their use. In addition to avoiding autocorrelation in the returns, this approach is capable of explaining important anomalies of foreign exchange markets, such as the emergence of bubbles. While our linear model specification always implies a convergence of the spot exchange rate to its fundamental value, irrespective of the initial conditions, a non-linear specification

may result in multiple equilibria. This opens the way for a new role of foreign exchange market interventions. Instead of altering the history of the exchange rate time series (as in the noise trading channel described in this paper), central banks may acts as a coordinator between 'good' and 'bad' equilibria. In the words of Sarno and Taylor (2001a, p. 863): "Publicly announced intervention operations can here be seen as fulfilling a coordinating role in that they may organize the 'smart money' to enter the market at the same time. This route for the effectiveness of intervention might be termed the 'coordination channel'".

Modeling the weights m_t as a time-varying function would therefore allow to model the announcement effects of an intervention explicitly. So far we assumed that our interventions are not announced and conducted secretly. Thus, we concentrated on the power of the central bank to transitorily affect the exchange rate, and by this to influence the trading rule of the chartists. If the intervention rule is well designed, we then got a longer-lasting effect on the exchange rate. In our view the announcement of an intervention could be modeled by making m_t depend on the intervention. If the announcement is credible, the explicit weight of chartists becomes lower, in favor of the fundamentalists' weight.

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