Central Bank Intervention and Risk Premia in Foreign Exchange Markets: Evidence of Daily Effects: Switzerland 1986 – 1995☆

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Abstract

Since the Plaza Meeting in September 1985, G-10 central banks have intervened in foreign exchange markets in a manner and scale unprecedented in the post Bretton Woods era. Using official daily data on interventions by the Swiss National Bank, this paper evaluates the effectiveness of these interventions and examines their impact on exchange rate risk premia, as defined by deviations from interest rate parity. My results suggests that intervention (via its effect on the risk premium) may be responsible for the frequently observed failure of foreign exchange market efficiency models and for their poor out-of-sample forecasting performance

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1. Introduction

Official intervention in foreign exchange markets occurs when the monetary authorities buy or sell foreign exchange, normally against their own currency and in order to affect the exchange rate. Since the Plaza Meeting in September 1985, central banks of the major industrial countries have intervened in foreign exchange markets in a manner and scale unprecedented in the post Bretton Woods era. Not only did the subsequent years see central banks of industrial countries unilaterally move toward larger scale foreign exchange market intervention, but central banks frequently co-ordinate their intervention operations. Although the current regime is ostensibly one in which rates are permitted to float, central banks intervene to influence the level of exchange rates as well as to reduce the rates' volatility. Recent developments in South East Asia highlight that central bankers still strongly believe that interventions indeed have the desired effect and that they are economically important.[1]

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[1] Hong Kong's monetary authority are left with an estimated US$ 14bn hole in the reserves after heavily intervening in the markets to defend the HK$ (Financial Times, August 28 1998). It is not clear at this time, however, to what extent these operations were sterilised so as to have no direct impact on monetary aggregates.

A more general interest in discerning the effects of intervention results from the potential significance of this activity as a *policy instrument*. The academic literature is predicated on the distinction between intervention operations that are sterilised and those that are allowed to affect the money supply. It is widely accepted among economists that intervention which changes the monetary base has an effect on the exchange rate via interest rates. Non-sterilised intervention, therefore, forms part of monetary policy and cannot used to target exchange rates independently. Much less consensus exists with regard to the role of *sterilised* intervention as an independent policy instrument. Sterilised intervention occurs when the authorities - simultaneously or with a very short lag - take action to offset or "sterilise" the effects of the resulting change in official foreign asset holdings on the domestic monetary base. Therefore, if sterilised intervention can influence exchange rates, then policy makers have a *third* instrument (in addition to monetary and fiscal policy) with which to achieve their targets.

In theory, sterilised intervention can affect the foreign exchange rate either through its impact on relative asset supplies (*portfolio balance channel*) or by altering expectations of market participants (*signalling channel*). Because these channels differ in their policy implications, recent studies have attempted to distinguish between them.[2] If intervention operates through the portfolio balance channel, the shift in relative supplies of assets denominated in different currencies is all that matters. If the signalling channel is operative, it is probably because the central bank has inside information about monetary policy that it is able to communicate to the market. Most empirical studies have been unable to produce any evidence of quantitatively significant effects of sterilised intervention on exchange rates via the portfolio channel. Evidence of a signalling role is somewhat stronger; however, disentangling the two effects is difficult.

In this paper, I use official daily data on interventions by the Swiss National Bank[3] to test for the presence of both portfolio balance and signalling effects of intervention on exchange rate risk premia, as defined by deviations from interest rate parity (UIP). I focus on the period of 1986 through 1995, when intervention was relatively widely used as a policy instrument. In using high-frequency data to capture the relationship among intervention, volatility, and excess returns, I follow a recent trend in the intervention literature (see Osterberg, 1997) which combines *two previously distinct aspects* of the foreign exchange market; namely the role of time-varying risk premia in the forward foreign exchange market and the degree of sterilised central bank intervention. *This research suggests that intervention (via its effect on the risk premium) may be responsible for the frequent failure of foreign exchange market efficiency models and for their poor out-of sample forecasting performance*.[4] Intervention may influence

[2]Only if the portfolio balance channel is effective can sterilised intervention be considered an independent policy tool.
[3]The tests presented in my paper were made possible by special access granted by the Swiss National Bank to their daily intervention data. The agreement with the SNB requires that I do not use this data for purposes other than my paper.
[4]Taylor (1995) provides a comprehensive summary on foreign exchange rate models and forecasting performance.

the risk premium in exchange rates as well as the level of exchange rates. Although reducing exchange rate volatility is a somewhat different objective than influencing the level of exchange rates, intervention for this purpose may indirectly influence the level of exchange rates. This is because changes in volatility may influence the risk premium that investors require in their return on foreign exchange.

Most recent studies on exchange rate determination give the risk premium a prominent role. This can be traced partly to the failure of earlier theories that did not explicitly consider risk. The presence of a risk premium can explain a divergence of the rates of return between domestic and foreign assets, measured in the same currency; that is, a violation of uncovered interest rate parity.

Unfortunately, there is no consensus on how to model the risk premium in foreign exchange markets. A widely used approach is to analyse the relationship between forward rated and spot rates. Hodrick (1989), for example, relates the forward premium to conditional means and variances of market fundamentals. Osterberg (1997) utilises this framework to show how central bank intervention can affect both the level of the exchange rates and the risk premium. One major disadvantage to approaches that relate the risk premium to fundamentals is that they do not permit testing with high-frequency data.[5] However the method used in this paper, which analyses realised excess returns suggested by the uncovered interest parity condition, can be applied to *daily data*. A number of previous studies (Loopesko (1984), Dominguez and Frankel (1993); Dominguez and Frenkel (1993), and Humpage and Osterberg (1990, 1992) have taken this approach using U.S. intervention data. This paper differs by using official intervention data of the Swiss National Bank (SNB) covering a more recent period of interventions.

One of the most noteworthy statistical findings in exchange rate economics to date has been the tendency for changes in exchange rates to be uncorrelated, but with fat-tailed distributions (leptokurtosis). There are distinct periods of high or low variance, so that volatility appears in clusters. In the case of forward markets for foreign exchange, rejection of efficiency can conceivably be explained by a risk premium, which may be related to time-varying heteroscedasticity. In line with Humpage and Osterberg (1990, 1992), I take advantage of recent advances in modelling conditional variances in asset returns using GARCH (generalised autoregressive heteroscedasticity), particularly as applied to exchange rates.

The plan for the rest of the paper is as follows. In the next chapter, I discuss the role of a risk premium in the market for foreign exchange and give an overview of the related empirical literature. Chapter three describes the formal channels between intervention and exchange rates. The theory is followed by an outline of the previous relevant work in this area. Chapter four describes the recent intervention activity of the Swiss National Bank in some detail, while chapter five outlines the details of the model to be estimated and summarises the data. In chapter six I report the results of estimating the

[5]Most macroeconomic indicators of fundamental variables such as the retail price index or monetary aggregates are only published on a monthly basis.

intervention-risk premium relation. The paper ends with a brief conclusion.

2. Risk Premia in Foreign Exchange Rates

The view that widely and frequently traded asset prices should reflect all available information is one of the most widely held tenets in economics and finance. Because foreign exchange markets are world-wide in scope and volume and almost non-stop in operation, the large number of tests of exchange market efficiency is not surprising.[6] Most empirical studies, however, report results which are *unfavourable* to a simple notion of market efficiency. It is often found that the forward rate on foreign exchange predicts the *wrong direction* of movement for the spot rate. Thus, regressions of ex post changes on appropriate interest differentials typically seem to imply that the high-interest rate currency tends to appreciate: a phenomenon that is often referred to as the "*forward discount puzzle*". This rejection of efficiency of the forward markets for foreign exchange can conceivably be explained by a risk premium, which, as is indicated above, may be related to time-varying conditional heteroscedasticity.

2.1. Speculative Efficiency in Forex Markets

In an efficient speculative market, prices should fully reflect information available to market participants and it should be impossible for a trader to earn excess returns to speculation. In its simplest form, the efficient market hypothesis (EMH) can be reduced to a *joint hypothesis* that foreign exchange market participants have a) rational expectations and are b) risk neutral. However, the EMH can be modified to allow for risk, in which case it then becomes a joint hypothesis of a model of equilibrium returns which admits risk premia and rational expectations.

2.1.1. Some Basic Relationships

Applied to the foreign exchange market, the first component of the EMH refers to the assumed equilibrium condition. This equilibrium condition is often interpreted as referring to the uncovered interest rate parity condition (UIP):[7]

$$\Delta s^e_{t+k} = i_t - i^*_t, \tag{1}$$

where $\Delta s^e_{t+k} \equiv s^e_{t+k} - s_t$ is the expected change in the spot rate in period $t + k$, and i_t, i^*_t are the nominal interest rates on domestic and foreign securities.[8] This implies that the expected foreign exchange gain

[6]In 1992, the *daily* volume of global foreign exchange transactions was approximately $1 trillion. This makes international currency flows about 100 times larger than trade flows (Hallwood and MacDonald, 1994).

[7]Here, "uncovered" refers to the fact that the risk posed by uncertainty about the future exchange rate has not been "covered" through use of a forward contract. In covered interest parity (CIP), Δs^e_{t+k} in 1 is replaced by the forward premium Φ_t in equation 2.2a. The CIP should hold independently of agent's risk preferences.

[8]Unless stated otherwise, I always use the European definition of the exchange rate which expresses domestic currency per unit of foreign currency. The lower case notation of variables always indicates logarithms.

from holding one currency rather than another (i.e. the expected change in the exchange rate) must be offset by the opportunity cost of holding funds in this currency rather than the other (i.e. the interest rate differential).

Alternatively, the equilibrium condition may be expressed in terms of the relationship between the forward rate and the expected spot rate. It may be written in the following way:

$$\Delta f_t^{t+k} = s_{t+k}^e + \rho_t, \tag{2.2a}$$

where f_t^{t+k} denotes the forward rate contract defined in period t, maturing in $t + k$ and s_{t+k}^e denotes the expected spot rate for period $t + k$. ρ_t is a potential (time-varying) risk premium and may be more precisely defined as containing a constant and time-varying component. By subtracting st form both sides, equation 2.2a may be more conveniently expressed in terms of the forward premium:

$$\Delta\Phi_t^{t+k} = s_{t+k}^e + \rho_t, \tag{2.2b}$$

where $\Phi^t \equiv f_t - s_t$ is the forward premium and $\Delta s_{t+k}^e \equiv s_{t+k}^e - s_t$ is the expected change in the future spot rate.[9]

The *rational expectations* leg of the joint hypothesis may be summarised by the equation:

$$\begin{aligned} \Delta s_{t+k} &= \Delta s_{t+k}^e + \mu_{t+k}, & (2.3a) \\ \Delta s_{t+k}^e &= E\left(\Delta s_{t+k} | \Omega_t\right), & (2.3b) \end{aligned}$$

where $\Delta s_{t+k} \equiv s_{t+k} - s_t$ is the actual change in the exchange rate and Ω_t is the information set on which agents base their expectations. If agents are rational, μ_{t+k} should be a random forecast error, orthogonal, or uncorrelated to the information set.

On using equations 2.2b and 2.3a, allowing for a risk premium, the EMH can be expressed as follows:

$$\Delta\Phi_t = \Delta s_{t+k} + \rho_t + \epsilon_{t+k}, \tag{2.4a}$$

where $\epsilon_{t+k} = -\mu_{t+k}$ of equation 2.3a. This simply states that the forward premium should equal the sum of the exchange rate change, a risk premium and a rational expectations error. Equation 2.4a makes clear why, as is frequently documented, the forward premium is a poor predictor of the future change in the exchange rate: a wedge is driven between the forward premium and future change in the spot rate,

[9] As seen in the introduction to this chapter, this term is sometimes also referred to as forward discount (e.g. in the "forward discount puzzle"). The choice is essentially arbitrary, because a premium is just a negative discount.

if there is a lot of news impacting the forward market and/or if there are substantial time-varying risk premia. Therefore, on using equation 2.4a, the forward-rate forecast error, $s_{t+k} - f_t$, can be decomposed into a risk premium and a forecast error

$$\Delta s_{t+k} - f_t = \rho_t + \epsilon_{t+k}. \tag{2.4b}$$

2.1.2. Tests of the Efficient Market Hypothesis

In the empirical literature, the EMH is usually assessed by implementing a two-step strategy. The first stage involves testing whether the forward exchange premium is an unbiased predictor of the corresponding exchange rate change. This can be tested by estimating a regression equation of the form:[10]

$$\Delta s_{t+k} = \alpha\rho_t + \beta\Phi_t + \nu_{t+k}. \tag{2.5}$$

If agents are indeed *risk neutral* (which implies $\rho_t = 0$) and have rational expectations, we should expect $\alpha = 0$, $\beta = 1$ and the error term ν_{t+k} be equal to a white noise process. The vast majority of researchers who test 2.5 take this to be the null hypothesis. If agents are risk averse, however, then a significant constant term in equation 2.5 could reflect a constant risk premium, and a *significant deviation of* β *from 1 could reflect a time-varying risk premium*. Furthermore, it is often argued that under rationality, the error term in 2.5 is expected to be independent and identically distributed (i.i.d); thus finding non-i.i.d. errors is indicative of irrationality. But in the presence of heteroscedasticity – a common feature of financial markets – the error terms may have a changing variance from period to period and therefore cannot be expected to be identically distributed. The existence of heteroscedasticity, therefore, does not conflict with the rational processing.

The second stage in testing the EMH involves testing whether the forward rate forecast error is orthogonal, or uncorrelated, to information available to agents at the time they form their expectations. Such an orthogonality test can be conducted by estimating a regression equation of the form:

$$f_t^{t+k} - s_t = \Gamma X_t + \omega_{t+k}, \tag{2.6}$$

X_t is a $l \times k$ row vector, contains variables thought to make up the information set Ω_t available to agents,

[10]Regression relationships involving exchange rates are normally expressed in logarithms in order to circumvent the so-called "Siegel (1972) paradox". It states that, even in the absence of risk aversion, one cannot have, simultaneously, an unbiased expectation of the CHF/$ and the $/CHF rate as $1/E(S \neq E(1/E)$. Because of Jensen's inequality, expected nominal profits must exist. Traditionally the divergence of the forward rate from the expected future spot rate is attributed to a time-varying risk premium rather than Jensen's inequality. However, Sibert (1989) points out that resulting errors from doing so may not be inconsequential.

Γ is a $k \times l$ row vector of parameters and ω_{t+k} is an error term. The null hypothesis is that Γ should be equal to zero. If this condition is violated then information available to agents at time t has remained unexploited.

2.2. *Evidence on the Efficiency of ForEx Markets*

A variety of studies have tested equation 2.5, using a great number of currencies and time periods for the recent floating period. They generally report results which are unfavourable to the unbiasedness hypothesis. A typical study is by Cumby and Obstfeld (1981) who test the uncovered interest parity (UIP), while assuming informational efficiency. They strongly reject the UIP and find that deviations from it are highly autocorrelated and "do not behave like expectational errors" (p.702). Similarly, Fama (1984) reports a significantly negative point estimate for β and, while maintaining rational expectations, concludes that most of the time variation of forward rates can be explained by a risk premium. Indeed, in a survey of the exchange risk premium literature, Froot and Thaler (1990) find that it seems to be a stylised fact of the forward premium that estimates of β are generally closer to minus unity than plus unity. This phenomenon is called the *forward discount puzzle*.

However, the observation that currencies of countries with high interest rates often appreciate is, of course, a direct result of standard models of exchange rate determination as, for example, proposed by Mundell and Fleming or Dornbusch (1987). The forward discount puzzle is not inconsistent with those models as the UIP is a behavioural, rather than a determining relation between interest rates and the exchange rate.

Tests of equation 2.6 may be divided into two groups depending on whether they are testing for (using Fama's terminology) weak-form or semi-strong-form efficiency. Weak-form tests include only lagged forecast errors in the conditioning information set, whereas semi-strong tests include information additional to lagged forecast errors in the information set.

Weak-form tests have been conducted by, among many others, Geweke and Feige (1979) and Hansen and Hodrick (1980). These studies use a variety of different sample periods, mostly the recent float or the inter-war float, different currencies and different estimation techniques. Most of these test reject the simple EMH without being able to identify the origin of the rejection.

Given the rejections of the null hypothesis reported when researchers test for weak-form efficiency, it is not surprising that semi-strong-form test results are even less favourable to the EMH. Using a statistical procedure which is valid under heteroscedasticity, Hsieh (1988) reports regressions similar to 2.6 where the variables in trader's information set include past values of the own lagged forecast errors and the lagged forecast errors from other foreign exchange markets. He finds that the current period forecast errors are correlated with the variables in the information set (i.e. $\Gamma \neq 0$), thus providing "the strongest rejection of the simple efficiency hypothesis thus far" (p.174).

In conclusion, there is overwhelming empirical evidence of a resounding rejection of the EMH. As indicated above, researchers have broadly sought to explain such rejection in two ways. The first, and most relevant for this paper, is to argue that investors are risk-averse and therefore the (time-varying) risk premium ρ_t is non-zero. Secondly, great efforts have been made to explain the rejection in terms of a failure of the expectations component of the joint hypothesis. Most notably, Froot and Frankel (1989) use survey data on foreign exchange rate expectations in order to decompose the forward discount bias into portions attributable to risk and expectational errors. They reject Fama's (1984) claim that the risk premium is more variable than expected depreciation. While some evidence of a constant risk premium is found, Froot and Frankel provide robust evidence that the forward discount bias is due to systematic expectational errors. This cannot itself shed light on whether the expectational errors are generated by learning, peso problems[11], or by market inefficiency; furthermore, evidence suggests that neither learning nor peso problems offer complete explanations of the facts. Flood and Rose (1996), for example, use realignments in the European Monetary System to quantify the peso problem and find that forward discount puzzle does no not appear to result from it. Rather, the deviations from UIP appear to vary in a way which is dependent upon the exchange rate regime or upon a risk premium. The puzzle seems to vanish for fixed exchange rate regimes.

However, as this paper is trying to establish whether central bank intervention plays any role in explaining a time-varying risk premium in the foreign exchange market, I follow the related literature by imposing the assumption that agents form their expectation rationally rather than investigating it.

3. Modelling the Risk Premium

3.1. Theory

The previous discussion has shown that empirical evidence favouring the existence of a risk premium is indirect. Violation of the UIP and rejection of unbiasedness in the forward market both suggest that a risk premium may exist. If foreign exchange market participants are indeed risk averse, the uncovered parity condition 1 may be distorted by a risk premium ρ_t, because agents demand a higher rate of return than the interest differential in return for the risk of holding a foreign currency. Thus, arbitrage will ensure that the interest rate cost of holding foreign currency is just equal to the expected gain from holding foreign currency plus a risk premium:

[11]The peso problem is referred to situations when market anticipations of an event which does not occur (or not sufficiently frequently) in a sample lead to small-sample bias in regressions. This problem was first pointed out by Krasker (1980) when during the early 1970s the markets' expectations of a substantial devaluation in the Mexican peso failed to materialise for a long time; the peso did not devalue until 1976.

$$\Delta s^e_{t+k} + \rho_t = i_t - i^*_t. \tag{3.7}$$

Unfortunately, there is no consensus regarding the appropriate theoretical framework for analysing foreign exchange-rate risk premia. Lucas's (1982) intertemporal, dynamic, two-country model implies that risk premia should be related both to preferences and to the stochastic behaviour of the "driving processes", such as monetary policy and output. Building on this model, Hodrick (1989) relates the forward premium to conditional means and variances of market fundamentals, such as monetary policy, government spending, and income growth. Osterberg (1997) extends this model further to specify the mechanism through which central bank intervention impacts the risk premium. He shows that the risk premium is a function of the conditional variance of the intervention variable as well as the conditional variances of fundamentals.

Other models of the risk premium include the intertemporal capital asset pricing model (Mark, 1985; Giovannini and Jorion, 1989) which suggests that risk premia should be related to covariances among asset returns. The consumption-based capital asset pricing model (Mark, 1985; Cumby and Obstfeld, 1981; Hodrick, 1989), has specific implications for the covariation between asset returns and intertemporal marginal rates of substitution in utility. More precisely, in this model, investors are assumed to maximise discounted expected utility of consumption subject to sequential budget constraints. The first-order conditions require that the conditional covariance of the marginal rate of substitution of consumption and the real return from investing in an asset equals zero. Exploiting this relationship in an open economy environment, the risk premium of forward foreign exchange is seen to be proportional to the conditional covariance of the excess return on foreign exchange speculation and the marginal rate of substitution of money. Thus, the time variation of the risk premium can be explained through the time variation of this conditional covariance.

3.2. Evidence

Because of the theoretical relationship between risk and second moments of asset price distributions researchers generally use an approach which tests for the risk premium as a function of the variance of forecast errors or exchange rate movements. In this vein, the most popular methods utilises autoregressive conditional heteroscedasticity (ARCH) or one of its many variants.[12]

Domowitz and Hakkio (1993) were the first to apply this class of models to the forward foreign exchange market. They impose restrictions on the model of the representative agent presented above and investigate the existence of a risk premium based on the conditional variance of forward market

[12]The literature on models of changing volatility is enormous and growing constantly. See Bollerslev (1986, 1990) for comprehensive surveys on this subject.

forecast errors, as defined in equation 2.4a. While finding some evidence of ARCH effects, they are unable to reject the null hypothesis of no risk premium for all the currencies investigated. Their findings offer limited support for the conditional variance of the exchange rate forecast error being an important sole determinant of the risk premium. The authors suggest that an alternative approach be considered where the risk premium depends on the conditional second moments of exogenous variables such as, for example, relative money supplies or output. As noted above, the theoretical framework for this approach was established by Lucas' intertemporal asset pricing model where the risk premium is due to consumption risk, as measured by the conditional covariance of the gains in the foreign exchange market and the marginal rate of substitution of money.

Kaminski and Lewis (1996) attempt to capture such effects by investigating the existence of a time-varying risk premium in the foreign exchange market using both Lucas' model and an ARCH-in-Mean model. They re-estimate the Domowitz and Hakkio equations in a multivariate context. Whilst they find evidence of a non-zero risk premium in foreign exchange rates, they reject the restrictions imposed by the intertemporal asset pricing model.

Similarly, a number of studies who look at asset prices in the context of a closed economy also conclude that the models investigated fail to provide an adequate description of the time variation in risk premia (e.g. Cumby, 1988; Giovannini and Jorion, 1989). Mark (1985), though, argues that it is premature to abandon the risk premium interpretation of the bias of the forward rate as a predictor of the future spot rate. Specifying a single-beta CAPM for the pricing of forward foreign exchange contracts, he allows the betas to be specified as ARCH processes in order to accommodate for time variation as well as sign variation of the risk premium in the forward foreign exchange market. Unlike Kaminski and Peruga, he cannot reject the restrictions imposed by the asset pricing model used. His evidence, thus, supports the idea that deviations of the forward exchange rate from the expected future spot rate are due to a risk premium and not due to irrationality among market participants.

In summing up, a fair assessment of the literature would be to say that most studies provide at most *limited evidence for the existence of a time varying premium*. In view of this evidence yet unwilling to consign the risk premium to the dustbin, various authors have suggested that policy shifts may be related to specific changes in the stochastic process that generates exchange rates.[13] Consequently, a change central bank behaviour may affect the forward foreign exchange risk premium. In the context of my paper, it is precisely such questions about exogenous processes and policy shifts which provide a motive for examining the impact of intervention on the risk premium.

[13] Lastrapes (1989) uses ARCH to examine how shifts in U.S. monetary policy regimes may help to explain exchange rate volatility. He concludes that monetary policy can affect the mean and variance of exchange rates and that the persistence of volatility decreases once regime shifts are accounted for.

4. Central Bank Intervention: Theory and Evidence

In the 1960s, when all major industrialised countries had currencies that were convertible into foreign currency at a fixed exchange rate, intervention was not viewed as a discretionary policy instrument available in the governments' policy tool kits. Rather, it was a passive act in which governments were thought to have no choice. (Non-sterilised) interventions had to be used - with different degrees of success - to realign deviations from the exchange rates' central parity.

With the breakdown of the Bretton Woods system in 1973 and the subsequent transition to a floating rate regime, the role of intervention changed drastically.[14] As external constraints on domestic policy had fallen away, central bankers were hopeful that intervention could be used effectively as an independent policy instrument. But soon concerns about the rigidity experienced under a fixed rate system gave way to concerns about volatility under a floating regime. Throughout the latter part of the 1970s, the major industrialised countries intervened frequently and heavily in the foreign exchange markets, and at certain times accorded exchange rate considerations a high priority in the conduct of domestic economic policy.

By the early 1980s, however, the prevailing consensus among economists, policy makers, and foreign exchange practitioners alike appeared to be that intervention, particularly sterilised intervention, could have at most very small and transitory effects on the exchange rate. In June 1982, motivated by recent experiences, participants at the Versailles Economic Summit commissioned an official Working Group on Exchange Market intervention to study the efficacy of government intervention in foreign exchange markets. The Working Group's report[15] concludes that "sterilised intervention did not appear to have constituted an effective instrument in the face of persistent market pressures [...] and the authorities found supportive domestic monetary policy adjustments [...] to be indispensable" (p.72).

Yet at the Plaza Meeting in September 1985, with monetarist beliefs by now firmly in place in most Western economies, central bankers from the G-5 countries agreed to intervene in the foreign exchange markets with the aim to stop the US$'s continued rise.[16] The Plaza Agreement marks the beginning of a new era of central bank intervention. To date, most central banks continue to use sterilised intervention in their exchange rate policy.[17] In a comprehensive review on the foreign exchange policy over the years since Plaza, Catte, Galli, and Rebbechini (1994) suggest that both isolated and co-ordinated intervention

[14] Dominguez and Frankel (1993); Dominguez and Frenkel (1993) provide an detailed account of the history of official intervention over the period of the recent floating rate regime.

[15] The report is commonly referred to as the "Jurgenson report", named after the Working Group's presiding chairman, Philippe Jurgenson, then Deputy Director of the Treasury for International Affairs at the French Ministry of Finance.

[16] The Group of Five (G-5) countries are France, Germany, Japan, the United Kingdom, and the United States. The Group of Seven (G-7) countries consists of the G-5 plus Canada and Italy; the Group of Ten (G-10), of the G-7 plus Belgium, the Netherlands, and Sweden.

[17] Although neither the Federal Reserve System, the Bundesbank nor the Swiss National Bank have intervened in the foreign exchange markets since August 1995, the policy has not been officially abdicated by either the United States, Germany, or Switzerland.

by the central banks of G-10 countries have coincided with changes in the trend of the exchange rates of the major currencies. These developments are reflected in the emergence of a new strand of empirical investigations that has tried to assess whether sterilised intervention may actually influence exchange rates.

Surveying this literature, Edison (1993) points out some common problems of empirical studies on central bank intervention. First, the literature somewhat fragmented which makes it difficult to explain why results differ from study to study, a problem that is particularly acute in the recent literature on the signalling effect. A second problem, which is rarely stated explicitly, is the great difficulty economists still have defining a reliable framework to model the behaviour of the exchange rates. Furthermore, the intervention literature is plagued by the lack of data on actual amounts of intervention. As most central banks are reluctant to release these figures, researchers have had to rely on imperfect proxies. However, the Swiss National Bank is an exception, which has enabled me to use the most accurate intervention data in this paper.[18]

4.1. Definition and Mechanics of Sterilised Intervention

Sterilised intervention in exchange markets leaves the monetary liabilities of both home and foreign authorities unchanged. An intervention operation is thus the analytical equivalent of a trade with the public of securities denominated in foreign currency. As a result there is a change in the relative sizes of the net stocks of securities denominated in different currencies that are available to the public to hold. In the following I will follow a *narrow definition of sterilised intervention* which, as reported by Adams and Henderson (1983), embraces purchases and sales by central banks of foreign exchange against domestic currency only. Broader definitions of intervention involve customer transactions, directed borrowing and lending, and capital controls.[19]

Official intervention in the foreign exchange market has the direct effect of altering the balance sheet of the central bank, and possibly of other government agencies.[20] When foreign exchange intervention is not sterilised, it can affect exchange rates by changing the stock of high-powered (or base) money, a change that leads to adjustments in broader monetary aggregates, in interest rates, and in market

[18] Another exception is the Federal Reserve Board; since the early 1990s it releases details of daily U.S. interventions in the Federal Reserve Bulletin, once each quarter. These reports cover only interventions intended to influence foreign exchange market conditions. The Federal Reserve may also do operations on behalf of other central banks, acting as their agent. This data, however, is not made publicly available. I am grateful to Steven Malin at the Federal Reserve Bank of New York for pointing this out to me.

[19] Customer transactions are described in more detail in the following sections below.

[20] In Switzerland, this does not occur because authority for both monetary and foreign exchange policy lies with the Swiss National Bank. Unlike in United States and Japan, the Swiss Treasury does not hold an account for intervention purposes at the SNB. In the U.S., all official exchange market transactions are conducted by the Federal Reserve Bank of New York, which maintains one account for the Treasury and one for the Federal Reserve System, whereas in Japan, the Bank of Japan conducts interventions as fiscal agent on behalf of the Ministry of Finance.

expectations about future price level inflation. A stylised balance sheet for the Swiss National Bank (SNB) would show its net asset holdings - consisting of net foreign assets (NFA_t) and net domestic assets (NDA_t) - equal to its monetary liabilities (B_t), the Swiss monetary base:

$$NFA_t \uparrow + NDA_t = B_t \uparrow . \tag{4.8}$$

A non-sterilised SNB purchase of a \$10 million bank deposit at Swiss franc (hereafter CHF) 1.5 per U.S. dollar (hereafter US\$), say, alters the central bank's balance sheet by raising NFA_t (on the asset side) and B_t (on the liability side), both by CHF 15 million. The corresponding change in the private sector's balance sheet is the mirror image of this one: a CHF 15 million rise in Swiss high-powered money holdings, and a CHF 15 million decline in holdings of dollar deposits.

The SNB could sterilise this intervention's expansionary effect on the money base through several types of offsetting operation, for example, a CHF 15 million open market sale of CHF-denominated domestic government securities. This additional operation would reduce the SNB's net domestic assets (NDA_t) and its monetary liabilities, both by CHF 15 million:

$$NFA_t \uparrow + NDA_t \Downarrow = B_t \uparrow\Downarrow . \tag{4.9}$$

Taken together, the two SNB actions - intervention plus sterilisation - would leave the public with unchanged holdings of high-powered money, but with a higher stock of interest-bearing CHF assets and a correspondingly lower stock of interest-bearing US\$ assets. In this sense, sterilised intervention is a "pure" change in the relative stocks of national currency bonds held by the public.

4.2. Channels of Influence for Intervention

The theory has focused on sterilised intervention largely for two reasons. First, the effects of unsterilised intervention may be indistinguishable from those of monetary policy. Second, most large industrialised nations (including Switzerland) claim that intervention is sterilised.

In his treatise on economic policy, Tinbergen (1952) shows that in order to achieve N policy goals, at least N independent policy instruments are required. Thus, in a world of N countries and N policy instruments (the individual countries' monetary policies), it is only by accident that N domestic objectives and $N - 1$ exchange rate targets can simultaneously be attained in the short run. Unless $N - 1$ additional policy instruments are available, conflicts between internal and external balance are bound to arise, as they have done continually in recent years (Obstfeld, 1983, 1990). Sterilised foreign exchange intervention furnishes $N - 1$ additional policy tools with the potential to be useful complements to monetary policies. These $N - 1$ additional tools are pure changes in the relative stocks of national currency bonds held in private portfolios, such as described above. Moreover, determining the effectiveness of intervention has also implications for other policies; if bonds differing only in currency denomination are perfect substitutes, not only is intervention ineffective but also fiscal policy may be only of limited effectiveness. This is a well-documented reality of small open economies with flexible exchange rates.

A major difficulty in evaluating intervention is to identify empirically the channels, if any, through which intervention has significant, lasting effects on exchange rates. The following section describes the channels through which intervention may be operative.

4.2.1. The Portfolio Balance Channel

Theory. The portfolio balance theory states that investors diversify their holdings among domestic and foreign interest-bearing assets. Further, it assumes that it makes a difference if a nation's assets are on the balance sheet of the government or the public. Thus, *Ricardian equivalence* - a situation referred to when the public are fully anticipating and internalising the fact that current government debt will be serviced by future taxation - does not prevail. Or, to use Barro's (1972) terminology, government bonds are assumed to be net wealth. If government bonds are not net wealth, however, it follows that changes in their relative composition have no effect on the foreign exchange markets equilibrium and intervention is ineffective. The breakdown of the Ricardian equivalence is a strong assumption, as there is little empirical evidence to substantiate it. (Dominguez and Frankel, 1993, p.1357) write "it [the Ricardian equivalence] is the sort of proposition that one would like to test rather than impose".

Even if it is not granted that government bonds are net wealth, a second line of argument for the operation of intervention through the portfolio balance channel is the view that investors are risk averse. Consequently, they consider domestic and foreign currency assets as imperfect substitutes. In this scenario, the expected returns on domestic and foreign currency assets are not equal; they differ by the foreign exchange risk premium, which depends on the covariances of returns and on relative supplies.[21] Thus, investors will allocate their portfolios to balance exchange rate risk against expected rates of return.

Rather than formally presenting a portfolio balance model, it shall suffice for the purposes of this paper to briefly describe the mechanism by which changes in the relative supply of bonds affect the exchange rate.[22] As demonstrated in section 3.2, the quantity of domestic bonds changes when monetary authorities are sterilising an intervention in the foreign exchange markets. For example, a rise in the supply of domestic bonds requires a rise in demand for domestic bonds.[23] Assuming that income, wealth, and exchange rate expectations are fixed in the short run, the rise in demand can be achieved

[21] More precisely, depending on the portfolio balance model employed, the covariance with the market portfolio (CAPM models), consumption (Consumption CAPM models), or the MRS (general asset pricing models).

[22] A good review of the myriad of portfolio balance models can be found in Taylor (1995).

[23] As shown in equation 4.9, this sterilises the effects of a purchase of foreign currency.

by a rise in domestic interest rates, by a depreciation of the domestic currency, or by a fall in foreign interest rates. With interest rates determined in the money markets, it is the exchange rate that must change. This is the portfolio balance effect of sterilised intervention. Its strength depends on the degree of substitutability between domestic and foreign bonds.

The empirical implementation of the portfolio balance models in the intervention literature broadly follows two approaches. In a direct approach, a few studies estimate the relevant asset demand equations directly. In doing so, the focus is on the relative changes in asset supplies following sterilised intervention.[24] However, because reliable data on income and wealth are notoriously hard to come by, most studies use an indirect method. This approach defines the risk premium, in a similar fashion to equation 1, as the expected deviation from uncovered interest parity (UIP):[25]

$$(1 + i_t^*)\, E\,(S_{t+1}) - (1 + i_t) \equiv \rho_t. \tag{4.10}$$

Because a sterilised intervention implies a change in the relative supply of domestic and foreign assets, the risk premium changes.

Modern empirical work recognises that any test concerning the behaviour of the risk premium is necessarily a test of the joint hypothesis on the degree of asset substitutability and expectations formation. However, the above discussion has not specified how expectations are formed. It is assumed that investors have rational expectations, using all publicly available information. Furthermore, the portfolio balance model represents only one strand of the literature modelling the risk premium (cf. section 2.2). As I have pointed out, a great number of studies testing the same joint hypothesis focus on the question of market efficiency rather than intervention. In general, these studies do not ask explicitly whether sterilised intervention is effective. Rather, they use a finance perspective to test alternative explanations of why the joint hypothesis fails.

Econometric estimates of the relationship between the exchange rate level and interventions are often plagued by simultaneity bias. This problem arises because exchange rates and asset supplies may be determined simultaneously. In this case, it is inappropriate to use the level of the exchange rate as the dependant variable, as any potentially significant coefficients would be incorrectly signed.[26]

Evidence. To avoid the simultaneity bias, a number of more recent studies have instead approached the portfolio channel by estimating the effects of intervention on the risk premium. This is done by imposing

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[24] It is important to note that this approach requires a much broader intervention definition than I am using here (cf. Section 3.1. and also Adams and Henderson, 1983).

[25] As noted by Obstfeld (1983), the statement that UIP fails to hold is not the same as the statement that sterilised intervention is effective in moving exchange rates. This point ties in with the discussion of alternative explanations for deviations from UIP in section 3.

[26] See, for instance, the results reported by (Dominguez and Frenkel, 1993, pp. 126-28).

rational expectations and regressing *ex post* excess returns on a cumulative intervention variable or some broader relative asset supply measure.

A typical study is Rogoff (1984); the existence of a portfolio balance effect is investigated using the relative supplies of assets denominated in U.S. and Canadian dollars over the 1973–1980 period. As effects of sterilised intervention may be quite short lived, Rogoff uses weekly data to construct more powerful tests. Despite uncovering the presence of a time-varying risk premium, he concludes that it cannot be affected by sterilised intervention.

Loopesko (1984) examines the joint hypothesis of perfect asset substitutability and exchange market efficiency. Her study analyses the effect of sterilised intervention using daily data on US$ exchange rates against the currencies of the other G-7 countries from 1974 to 1984. Although the joint hypothesis is rejected, in about half the cases, Loopesko finds that lagged cumulated intervention is significant, which leads her to conclude that sterilised intervention may have an impact on exchange rates through a portfolio channel, however short-lived.

Ghosh (1992) follows a different strategy. He uses monthly data for the US$/DM exchange rate for the 1980 to 1988 period and estimates both a monetary model and a portfolio model. Controlling for expectations of future monetary policy (i.e. the signalling effect), his portfolio model uses the supply of assets denominated in US$ and DM. The model is found to explain deviations of the exchange rate from the value implied by the monetary model. Ghosh concludes that there is a statistically significant portfolio effect on the exchange rate but that it is weak.

Another possibility to test for a portfolio effect is to use survey data on exchange rates rather than ex post changes in the expected rate to get a measure of the risk premium. This approach is applied by Dominguez and Frenkel (1993) who use survey data on one-month and three-month ahead US$/DM risk premia. Using Federal Reserve and Bundesbank data between 1982 and 1988, regressions are run with the risk premium as the dependent variable, interventions, the variance of exchange rates, and a minimum variance portfolio are the explanatory variables. Dominguez and Frankel find the strongest evidence to date of significant effects of intervention on exchange rates via the portfolio effect. In order to examine whether the operations by a smaller central bank are equally as effective, they use intervention data form the Swiss National Bank.[27] However, their findings indicate that the portfolio effect on the exchange rates is only statistically significant when Federal Reserve and SNB interventions are combined. They conclude that as long as interest rate differentials do not fully absorb the impact of intervention on risk premia, the results indicate that foreign exchange interventions operating through the portfolio channel matter.

[27] Apart from Zurlinden (1996), this study represents an exception in working with Swiss intervention data. As such, the work of Dominguez and Frankel constitutes a major contributing factor of the motivation for this paper.

Surveying the literature on the portfolio channel, Edison (1993) finds that, regardless of how the tests are specified, studies using data from the 1970s find little evidence of portfolio balance effects. Some of the studies using data from the 1980s have been more successful in establishing statistically significant effects on excess returns. More importantly, many of the authors who do find some effects point out that the estimated elasticity is too small to be of any practical importance to policy makers. For instance, (Ghosh, 1992, p. 219) reports that "the mean of the outstanding dollar assets is roughly $1,365bn . . ., so intervention in the order of $13bn would be required to move the $/DM rate by 0.15 to 0.35 percent".

4.2.2. The Signalling Channel

Theory. The second channel through which sterilised intervention may operate is provided by the signalling theory. It was formally introduced into the intervention literature by Mussa (1981). This theory posits that there is a channel through which sterilised intervention can move exchange rates even when bonds of different currency denomination are perfect substitutes. The volume and direction of intervention may signal new information about economic conditions and future economic policies to the market independently of any other current policy changes. Therefore, intervention's potential role as a signal derives from the assumption that the central bank is understood to have superior or "inside" information about its own future monetary policy intentions. It must be emphasised, however, that if intervention affects exchange rates only through the signal it sends, then it is not a macroeconomic policy instrument in the same sense that monetary and fiscal policy are.[28] It derives its power entirely from its ability to influence market perceptions or expectations about other economic factors.

Apart from verbal announcements[29], sterilised intervention is unique among a monetary authority's policy tools in that it can convey information without directly altering current period real money balances. As mentioned above, other policy instruments such as open market operations, for example, will certainly send signals about future monetary policy, but they will also affect real balances. But if sterilised intervention is to convey a credible signal about in the authorities' future monetary stance, intervention in period t must be followed by some activity of monetary policy in period $t + 1$. In this sense, some economists argue that sterilised intervention is "un-sterilised" in subsequent periods and consequently has "real" effects.

The asset market view of exchange rates stresses that exchange rates display many similarities with other asset prices in well-developed markets; most importantly, frequently traded assets should reflect all available market information. Hence, exchange rates are strongly influenced not only by current

[28]Recall that if sterilised intervention entails a portfolio balance effect, it offers policy makers an independent, third policy instrument (in addition to monetary and fiscal policy).

[29]Stein (1989) presents a "cheap talk" model to explain why under certain conditions (imprecise) verbal announcements by a central bank about future monetary policy intentions will be credible.

events but also by market participants' expectations of future events. This gives expectations about future exchange rates a key role in determining current rates, which can be formalised as:

$$s_t = \text{fund}_t + \alpha \left(E_t s_{t+1} - s_t \right), \tag{4.11a}$$

where s_t is exchange rate at time t, fund_t a fundamental determinant of the currency (e.g. the monetary base) and α is a positive parameter. The saddle path solution to equation 4.11a can be written as

$$s_t = \frac{1}{1+\alpha} E_t \sum_{j=0}^{\infty} \left(\frac{\alpha}{1+\alpha} \right)^j \text{fund}_{t+j}, \tag{4.11b}$$

showing that s_t is the expected present value of future fundamentals.

As indicated above, the basic idea behind the signalling channel is that sterilised interventions convey information about fundamentals for the exchange rate. For example. this information may indicate how the monetary authorities interpret the character and persistence of a real shock and how they will respond with monetary instruments. If a sterilised intervention conveys that kind of information, market participants will revise their expectations of future fundamentals and thus their expectations about future exchange rates. By equation 4.11b, this brings also about a change in the current exchange rate since the exchange rate is a forward looking price.

The signalling argument that makes intervention a pure information transmission mechanism opens up a second potential role for intervention policy: intervention may also be used to *manipulate exchange rate expectations directly*. In contrast to signals about future monetary intentions, in targeting the exchange rate the central bank does not directly bond itself to a particular monetary policy. However, "leaning against the wind" can prove costly to the central bank, if market expectations are not influenced successfully. The degree to which intervention can be manipulative depends on how easily the market is able to spot intervention signals which are inconsistent with market fundamentals. There is some evidence by Neely and Weller (1997) that trading rules which take positions on the *opposite side* of the market from that taken by central banks regularly achieve excess profits. This suggests that intervention may be treated as a signal that the trend being resisted by the authorities will continue.

However, if monetary and foreign exchange policy are under the jurisdiction of different bodies, this gives rise to a potential conflict between the *targeting objective* of intervention and the *information objective*.[30] In the U.S., for example, by law, both the Treasury and the Federal Reserve could intervene alone. There may be, therefore, periods in which the Treasury's exchange rate objectives are at odds with the Federal Reserve's monetary policy objectives. Typically, however, both authorities act together

[30] This is not the case in Switzerland as the SNB is highly independent in central banking terms. Some democratic accountability to the Swiss Government exists via the "Bankenrat", a banking council.

in a co-ordinated manner. In this context, Vitale (1997a) points out that the co-ordination of monetary and foreign exchange intervention is particularly useful in eliminating the problem of overshooting of monetary policy. If prices are sticky, undesired output effects can be mitigated by using intervention to reveal monetary objectives.

Not only must the interventions on average send a true signal about future policy changes in order to establish a credible link between sterilised interventions and future fundamentals, but it is often claimed that for the signalling channel to work properly, market participants must be able to observe the intervention. The general reluctance of central banks to indicate when they are intervening is seen by many as a priori evidence against the signalling channel argument.[31] However, recent work by Vitale (1997b) questions the general opinion that visible intervention should be preferred to secret one. He argues that secrecy of intervention may be desirable to target the value of the exchange rate and shows that it is most effective when concentrated over a short period during which markets are thin.

Given that (1) the central bank is believed to have "inside" information about future policy, and (2) the central bank has the incentive to reveal that information truthfully, central banks may agree to *co-ordinate intervention* operations with other central banks in order to convince the market.[32] Multiple signals will increase the total amount of "inside" information conveyed by intervention operations. Multiple co-ordinated signals will not only increase the importance of any given signal but may also serve to increase the probability that the signal is true. The additional cost of lost reputation among the co-ordinating central banks may serve to further restrain central banks from sending misleading signals.

Similar to the investigation of a portfolio balance effect, there is a direct way to assess the effects of the signalling hypothesis on the exchange rate. This involves looking at the instantaneous relationship between the exchange rate and interventions. However, as in the case of the portfolio balance effect, econometric estimates of this relation will be plagued by *simultaneity bias*.

Evidence. Unlike studies examining the portfolio balance channel, no common model exists among studies examining the signalling channel. Edison (1993) identifies two general approaches. The first group of studies examines the impact of intervention on exchange-rate expectations in the context of a portfolio balance model. The second group assumes that an anticipated change in future monetary policy will alter exchange rate expectations. In this context, it is then asked whether or not intervention actually signals a change in monetary policy. With the surge in models of changing volatility, a third strand of empirical investigations has emerged in recent years. Unlike the other two approaches, most of

[31] An exception with regards to intervention procedures among central banks, the SNB informs market participants whether a certain transaction is an intervention or not.

[32] Of the 113 interventions between 1985 and 1995 the SNB intervened only on 4 occasions on its own (i.e. without either Federal Reserve or Bundesbank). A more detailed presentation of these interventions can be found in table 1 of chapter 4.

these studies implicitly assume that intervention works though the signalling channel and ask whether intervention has an effect on *exchange rate volatility*. Exchange rate volatility can be attributed to either the volatility of market fundamentals, changes in expectations of market participants or speculative bandwagons. The volatility literature views sterilised intervention as a unique policy tool which is able to influence all three.

Impact of Intervention on Exchange-Rate Expectations. A typical study using this approach is Dominguez (1990). She uses the foreign exchange risk premium as the dependent variable and invokes rational expectations to estimate a portfolio balance equation.[33] She then argues that the coefficients on intervention will provide information about the portfolio balance as well as the signalling channel, and, recognising that the two cannot be separated, she emphasises the signalling channel, using actual interventions as explanatory variable. Dominguez tests the signalling channel by examining the US$/DM and US$/¥ exchange rates for the 1985 to 1987 period, which is divided into five subperiods. She finds that the coefficients on both co-ordinated and non co-ordinated intervention are statistically significant and of the correct sign only in the first two subperiods.

In two related studies, Humpage and Osterberg (1990, 1992) examine the relation between day-to-day official intervention and day-to-day exchange rate movements using a similar definition of the risk premium to Dominguez (1990). In line with the vast literature on time-varying risk premia discussed in chapter 2, they model the behaviour of the risk premium using GARCH. Their results only provide limited evidence both the portfolio balance and signalling channel. Unlike Dominguez, they find no evidence that co-ordination of intervention improves its efficacy.

Intervention as a Signal of Future Monetary Policy. The second approach which investigates the effect of intervention as a signal of future monetary policy is used by Klein and Rosengren (1991). Using daily intervention data and discount rate changes, they ask whether intervention signalled changes in monetary policy between the 1985 Plaza Agreement and the 1987 stock market crash. They find that intervention did not precede changes in monetary policy. The curiosum that interventions had a significant effect on the exchange rate in the first part of the sample period is explained by markets having learned that intervention does not serve as a signal of future monetary policy.

The same approach is employed by Kaminski and Lewis (1996) who use data on observations of U.S. intervention from 1985 to 1990 to test whether market participants view intervention as a signal of future changes in monetary policy. The hypothesis that intervention provides no information about future

[33] Mussa (1981) mentions that while this approach is supposed to capture the signalling effect operating through a risk premium, the effects of intervention may come from impacts on foreign exchange rates consistent with uncovered interest parity, i.e. no risk premium.

monetary policy is strongly rejected. However, this evidence can not be used to argue that intervention policy is effective as the signals of future monetary policy are opposite in direction to those implied by the interventions. They also examine the response of US$/DM and US$/¥ exchange rates to news of intervention, dividing the sample between episodes of "correct" and "wrong" signals. This provides some evidence that exchange rates and intervention are correlated with the appropriate sign, depending on the sample period.

Intervention as a Determinant of Exchange Rate Volatility: GARCH models. Baillie and Bollerslev (1992) estimate a target-zone model for the period after 1987, when the G-3 countries agreed at the Louvre Meeting to further co-ordinate their intervention efforts. Jointly estimating an exchange rate and intervention equation, they introduce the use of GARCH models into the intervention literature. Their results suggest that the G-3 reacted to exchange-rate movements in a manner broadly consistent with maintaining target zones. However, they fail to discover any evidence that intervention successfully influenced the subsequent conditional variance of the exchange rate.[34]

Using a similar GARCH model, Dominguez (1993) tests the proposition that intervention by the U.S. and German authorities has influenced the volatility of the US$/DM rate. One of the results of this study is that publicly known intervention decreased daily volatility during the same period (1987-1991) examined by Baillie and Humpage.

This same route of investigating the impact of intervention on the volatility of exchange rates is being followed by number of studies covering different currencies and time periods. Two prominent studies are Almekinders and Eijffinger (1992) who use German data and Lindberg (1994) who uses Swedish data.

In conclusion, the evidence viewed in this section clearly indicates that sterilised intervention can have some, if small, significant effect both the level and the volatility of the exchange rate via the signalling channel.

5. Foreign Exchange Market Intervention in Switzerland

In the mid 1970s, during the early years of the current regime of flexible exchange rates, the Swiss National Bank was among the first and most prominent central banks to intervene heavily in the foreign exchange markets, above all supporting the US$. For the second period of heightened central bank activity, marked by the Plaza Meeting in 1985, however, the SNB could be considered a late entrant as

[34]The use of GARCH as volatility measure with respect to intervention has been criticised in two related papers by Bonser-Neal and Tanner (1995) and Bonser-Neal (1996). It is argued that because GARCH gauges only historic volatility, the implied volatility of foreign exchange options is a more appropriate, forward-looking measure.

it did not intervene until October 1986. Since then the SNB has been active in the foreign exchange markets on over 100 days.

Having discussed mechanics of foreign exchange market intervention in the previous chapter, this chapter provides a detailed illustration of the theory by looking interventions of the Swiss National Bank between 1986 and 1995.[35]

5.1. A Cross Section of the Interventions

Interventions of the Swiss National Bank (hereafter the Bank) are exclusively foreign exchange transactions which the Bank conducts with other (commercial) banks in Switzerland. Whenever the Bank intervenes in the foreign exchange market, the transactions are always conducted with several other banks simultaneously. Furthermore, these banks are informed if a certain transaction serves in fact an intervention purpose. Therefore, the information that the Bank is intervening is quickly dissipated in the market and it can be assumed that market participants generally know when the Bank has intervened. This policy of no secrecy about interventions is rare among the major central banks. As such, it is clearly an argument in favour of interventions working through the signalling channel.[36]

Between 1985 and 1995, all the Bank's recorded interventions are spot transactions and, therefore, do not include either foreign exchange swaps or foreign exchange futures contracts. Swap transactions are used to influence the liquidity in the banking system, whereas for the reporting period the Bank's transactions involving futures were only conducted on behalf of commercial customers. Therefore, both types of transaction did not have any exchange rate policy aims and do not constitute a foreign exchange intervention (cf. definition of intervention in section 3.1). The Bank's biggest customer for foreign exchange transactions is the Swiss Government. Because the Bank almost always purchases foreign currency against US$, there is a constant drain of dollars from its reserves. In order to maintain a certain level of foreign exchange reserves, the Bank must replenish the reserves regularly. This is achieved by either direct spot purchases or sometimes through the Bank for International Settlements (BIS). Thus, the Bank is active in the foreign exchange spot market if it is intervening or restocking its reserves. Testing whether the latter activity actually has a significant, although unintended, effect on the exchange rate, Zurlinden's (1996) results are inconclusive. Though, in line with the narrow definition of intervention used in this paper (cf. section 3.1), I am only concentrating on "policy driven" interventions.

The frequency and volume of the interventions of the Swiss National Bank are summarised in table 1. The Bank generally intervened in the CHF/$ market (101 days) and only on rare occasions in

[35] See Zurlinden (1996) for an overview.

[36] As most other central banks maintain a certain amount of secrecy about their intervention activities, the theoretical argument for a signalling effect has often been criticised. There is some evidence of a different impact of actual and reported interventions Osterberg and Humes (1995).

the CHF/DM market (two days). Furthermore, a small number of interventions were conducted in the US$/¥ (eight days) and US$/DM market (four days).[37] Because the Bank intervened on two days simultaneously in two markets (CHF/$ and CHF/DM), there were a total of 113 days in the reporting period on which the Bank conducted interventions.

[INSERT TABLE 1 ABOUT HERE]

As shown in table 1, most of the Bank's interventions is co-ordinated with the two most active central banks, the Federal Reserve System and the German Bundesbank. The Bank has intervened only on four occasions without either of those two central banks being active. On most occasions, i.e. on 75 days, both the American and German authorities were active on the same day as the Bank. Zurlinden (1996) reports that the Bank always intervened in the same direction as the Federal Reserve and the Bundesbank. Therefore, in line with the signalling hypothesis, the Bank has never sent mixed signals to the market by, say, buying a certain currency while an other central bank was selling the same currency.

In the years between 1986 and 1995, the transaction amounts of the Bank's interventions have varied considerably. Furthermore, during that period, the average intervention amount is only approximately half that of the average Bundesbank intervention (US$119m) and little less than a third of the Federal Reserve's amount (US$210m). It is important to remember the tremendous differences in relative size of those respective economies. If, for example, in line with a monetary model of the economy, the monetary base is selected as point of reference for comparison, the Bank's interventions are proportionally much larger than either the Federal Reserve's or the Bundesbank's.

5.2. The Interventions as a Time Series

The foreign exchange market interventions of the Swiss National Bank are not distributed equally over the reporting period. As mentioned above, the Bank has intervened on a total of 113 days. Of these, 2 days fall on the year 1986, 22 days on 1987, 20 days on 1988, 39 days on 1989, 6 days on 1990, 13 days on 1991, 6 days on 1992, 2 days on 1994 and 3 days on 1995. The Bank did not conduct any interventions in 1993 and intervened in the foreign exchange markets in August 1995 for the last time. Ever since, any effort to influence the exchange rate was undertaken in a non-sterilised manner, e.g. by manipulating monetary aggregates. This change in the Bank's policy stance is in response to a recessionary economic climate in Switzerland. It does not indicate a change in the Bank's view on the appropriateness of sterilised intervention as a policy instrument.[38]

[37] Mr. Zurlinden has pointed out to me that interventions in a specific currency not necessarily imply that they were targeted at the respective foreign exchange rate. For example, on some occasions, the SNB has intervened in the CHF/DM market, although the CHF/$ exchange rate was the intended target.

[38] I am grateful to Mr. Zurlinden for this point.

The development of these interventions over time is illustrated in figures 1 and 2. The figures show the interventions in relation to the relevant exchange rates and interest rates. The volatility of the exchange rate is depicted in figure 3. In all three figures I have split the sample into two 5 year periods. Figures 1 and 2 consist of two separate graphs with the top graph depicting the amount of US$ purchases (+) and sales (-), the point in time and the direction of the Bank's interventions against the CHF/US$ exchange rate. The second graph in each figure shows the three-month Euro-currency interest rates for the CHF as well as the development of the three-month CHF/US$ interest rate differential.[39] Clearly, the Swiss interest rates are strongly dependent on the Bank's monetary policy, while the interest rate differential is also influenced by the Federal Reserve's monetary policy.

[INSERT FIGURES 1 AND 2 ABOUT HERE]

Figures 1 and 2 provide a brief history of the Bank's foreign exchange market interventions from 1986 to 1995. During that period, the first interventions were made in October 1986 when the Bank bought US$ for CHF on two separate days. This marks the end of a three year period in which the Bank had not conducted any interventions. More frequent interventions followed in March 1987 after the G-7 finance ministers had met at the Louvre in Paris. At the Louvre Meeting, participants agreed to stabilise both the DM/US$ and ¥/US$ exchange rates at their existing levels. Although no binding obligations for central bank intervention were made, the frequency of interventions markedly increased thereafter. Despite not being represented at the Louvre, the Bank subsequently participated on a number of co-ordinated interventions.

[INSERT FIGURE 3 ABOUT HERE]

Between March 1987 and early 1989 the Bank conducted several interventions aimed at supporting the US$. These were followed by US$ sales, and in November 1988 two further attempts to strengthen the US$ were made. Thus, in line with most other major central banks, the Bank intervened in both directions. Baillie and Humpage (1992) argue that is therefore possible to make inferences about the level of the US$ rates the central bankers deemed appropriate during that time. They find that the interventions of both the Federal Reserve and the Bundesbank are broadly consistent with maintaining target zones during the first two years after Louvre. However, they do not find any strong evidence that intervention successfully influenced exchange rates in subsequent year. As Figure 1 conveys, these results are visually compatible with developments in Switzerland for the same period.

[39] I am using the three-month interest rates for the graphs only, as they are far less volatile than daily rates. The appropriate *daily* interest rates are used in the estimations.

Between early 1989 and mid 1992, with one exception[40], the Bank only engaged in sales of foreign exchange, thereby attempting to provide support for the CHF and to weaken the US$ respectively. This episode coincided with a period of rising prices in Switzerland and the Bank was intent on keeping a tight their rein on inflation. Figures 1 and 2 show that the development of Swiss interest rates and the CHF/US$ interest differential were in line with the Bank's exchange rate policy aims. While interest rates fell until after the 1987 stock market crash, they began rising at an unprecedented rate, particularly during 1989. At the same time, the interest differential to the US$ shrank drastically, and from the end of 1989 until 1993, Swiss interest rates were above the corresponding U.S. rates.

Compared to the latter half of the 1980s, central bank interventions in the 1990s display different characteristics: the periods of extensive interventions periods during which Federal Reserve and the Bundesbank (and to a lesser extent the Bank itself) intervened almost on a daily basis were became increasingly rare. Between 1992 and 1995 the Bank has only intervened on 11 separate occasions. Furthermore, interventions were not only much more deliberately targeted but also far less co-ordinated. It is during this period that the Bank, unilaterally, conducted its largest interventions. Humpage (1996a,b) offers an explanation for this recent reluctance to intervene. He indicates that although the transaction size increases the probability of an intervention's success, there is some evidence that the random-walk nature of exchange rate movements – rather than the central banks superior information – seems capable of explaining the frequency of success.

6. Empirical Model

Central banks generally are non-specific with respect to the precise aims of intervention, sterilised or not. Nevertheless, it is clear that the broad objective of intervention in foreign exchange markets, similar to (government) intervention in any other market, is to either influence market trends or to reduce uncertainty in the markets. Therefore, the question any empirical test has to investigate is whether central bank intervention has an impact on the level and the volatility of exchange rates.

However, direct econometric tests of the influence of sterilised foreign exchange intervention operations on exchange rates are not feasible for reasons pointed out above. Recapitulating, there does not exist a consensus model of exchange rate determination in which intervention operations can be included to test for significant explanatory power.[41] More importantly, intervention policy and exchange rate movements are potentially simultaneously determined. Therefore, intervention cannot be assumed to be exogenous without giving rise to a simultaneity bias.

[40]The sole intervention supporting the US$ took place shortly before the start of Operation Desert Storm in the Gulf (February 1991) and, as such, was of a political rather than economic motivation.

[41]Despite theoretical advances in the intertemporal general equilibrium framework which allow for intervention (e.g. Osterberg, 1997), empirical models have not made the same progress.

One approach that avoids the potential simultaneity problem examines whether today's observed intervention helps explain the predictable component of ex post excess returns in the foreign exchange market. The empirical model used in this paper is related to this approach which is also found in Loopesko (1984) and Dominguez (1990). Both authors examine the impact of intervention on the exchange risk premia implied by deviations from uncovered interest parity (UIP). This approach allows sterilised intervention to impact on exchange rate risk premia through both the portfolio balance and signalling channel. Humpage and Osterberg (1990, 1992) extend this methodology by modelling the time varying behaviour of the risk premium using generalised autoregressive conditional heteroscedasticity (GARCH). Following their work, I will examine the relation between day-to-day official intervention of the Swiss National Bank and the day-to-day exchange risk premium for the CHF/US$ exchange rate.

6.1. UIP and the Risk Premium

I use the UIP condition, as described in chapter 2, to generate a daily measure of the exchange rate risk premium. This is indicated by equation 6.12:

$$RET_t = \left(1 + i_t \frac{d}{360}\right) - \left(1 + i_t^* \frac{d}{360}\right) \times \frac{E_t[S_{t+1}]}{S_t}, \tag{6.12}$$

where

i_t	: Domestic overnight LIBID rate,
i_t^*	: U.S. Dollar overnight LIBID rate,
d	: Day-count between business days,
S_t	: Spot foreign exchange rate (domestic currency per US$),
$E_t[S_{t+1}]$	: Expected one-period ahead spot rate.

If RET_t equals zero, the UIP holds. Here, the investor does not cover the transaction by selling forward, but instead forms expectations of the spot rate $E_t[S_{t+1}]$ for a one day investment), which is uncertain at the time of the transaction. To generate an empirical measure of RET_t, I need to take account for timing conventions in the foreign exchange markets.

The timing conventions in the spot foreign exchange markets allow for two business days between the contract date and the delivery date (Humpage and Osterberg, 1992). Consequently, the foreign currency transaction must be completed prior to the investment. For instance, consider an investor who expects to invest CHF overnight on day t. This investor could buy CHF on day $t-2$ for delivery on day t. On day $t-1$, he sells the CHF for US$ that are to be delivered on day $t+1$. On day t, he collects the CHF which are invested overnight. Finally, on day $t+1$, the CHF, which he had previously contracted to sell, are withdrawn. As part of this process, the investor forms expectations of the uncertain future spot rate ($E_t[S_{t+1}]$) for a one-day-ahead investment. These timing conventions, together with the assumption that $E_t[S_{t+1}] = S_{t+1}$ imply that

$$RET_t = \left(1 + i_t \frac{d}{360}\right) - \left(1 + i_t^* \frac{d}{360}\right) \times \frac{S_{t-1}}{S_{t-2}},$$
$$= RP_t + FE_t. \tag{6.13}$$

In equation 6.13, the excess returns has been decomposed into a risk premium (RP) and a forecast error (FE). A regression of ex post excess returns RET_t on variables that are in the investor's information set I_t provides a test of the - by now familiar - joint hypothesis that the expected risk premium is zero and that the spot exchange market is informationally efficient. Hence, *assuming informational efficiency*, if the measure of intervention at $t-3$ explains RET_t, this is evidence that intervention influences the risk premium.

However, as Mussa (1990) points out, the potential signalling role of central bank does not rely on the existence of a risk premium.[42] The excess return regression specification as in equation 6.12 is, therefore, restrictive because it only tests whether intervention that provides information about the future relative supply of outside domestic assets influences market expectations by changing the perceived relative riskiness of those assets. If investors are risk neutral and view foreign and domestic assets as perfect substitutes (i.e. UIP holds), then ex post returns RET_t will be uncorrelated with intervention. Nevertheless, the advantage of the excess return regression specification is that it allows intervention to influence expectations both through the portfolio balance and signalling channel.

6.2. Statistical Model

A well documented feature, a stylised fact, of asset return data is that large returns tend to be followed by more larger returns. In other words, the volatility of asset returns appears to be serially correlated. The "clustering" of volatility is clearly present in the ex post CHF/US$ excess returns. This can be seen visually in Figure 4, where the top graph plots the daily excess returns, as measured by variable RET_t, over the entire sample period 1986 to 1995. Whilst individual daily returns vary widely, the lower graphs reveals that they do so within a range which itself changes over time. The range for returns is smaller in the first half of the sample and seems to increase towards the end of the sample.

To capture this serial correlation of volatility, Engle (1982) proposed the class of Autoregressive Conditionally Heteroscedastic (ARCH) models. The success of ARCH models in finance is due to a key characteristic of financial time series data; namely, the first and second moment of the distribution of asset returns are closely linked to the risk-return relation. As such, ARCH models allow for a potential time-variation of risk premia, inter-market links and they can be used to measure the impacts of

[42]Recalling the discussion of the channels of intervention in chapter 3, it is important to note that the existence of a risk premium is imperative for the portfolio balance channel to operate.

regulation to name but a few applications. Consequently, this wide applicability is reflected in a massive proliferation of proposed extensions.[43]

ARCH(p) models write the conditional variance as an AR(p) process, i.e. as a distributional lag of the past squared error terms:

$$\epsilon_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i \epsilon_{t-i}^2. \tag{6.14}$$

A way to model persistent volatility movements without estimating high-order AR processes is the GARCH(p,q) model proposed by Bollerslev, Chou, and Kroner (1992). An extension of Engle's work, it replaces the AR(p) process by an ARMA (p,q) process. In this model the conditional variance equation is now defined as:

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_j \epsilon_{t-j}^2. \tag{6.15}$$

Empirical work reveals that for most applications a simple GARCH(1,1) model is sufficient. For the purposes of this paper, I will make the same assumption without formally testing it. In the GARCH(1,1) the conditional variance equation reads as

$$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \epsilon_{t-1}^2. \tag{6.16}$$

An attractive features of the GARCH(1,1) model is that its *coefficients are straightforward to interpret*. The α coefficient, often referred to as "news" coefficient, measures the extent to which a volatility shock today feeds through into the next period's volatility. The β coefficient, which is referred to as "persistence" coefficient, measures the rate at which the impact of past shocks dies out over time.

A substantial body of literature suggests that exchange rates are well described by a martingale process and that their first differences are heteroscedastic. The GARCH framework has been utilised to analyse the conditional means and variances of exchange rates with some success.[44] In particular, the usefulness of the conditional student-t distribution in examining daily exchange-rate data has been demonstrated by Hsieh (1989) and Baillie and Bollerslev (1989). Furthermore, Baillie and Bollerslev point out that the ARCH effects diminish with increasing data frequency, and, therefore, are particu-

[43] In their comprehensive review of ARCH models, 1992; 1994 make reference to over 40 such extensions.

[44] An interesting study by West and Cho (1993) evaluates the performance of different models for exchange rate volatility. Estimating how much an investor would pay to use one model rather than another, they find some evidence that GARCH models tend to do best. According to their calculations an investor would be willing to pay between 5 to 200 basis points of wealth to switch to GARCH.

larly prominent in daily data. Hsieh (1988) finds evidence that both day-of-week and holiday dummy variables should be included as explanatory variable in daily exchange rate GARCH models. In this paper, I apply this framework to analyse the conditional mean and variance of the foreign exchange risk premium, measured as deviation from UIP.

Equations 6.17a through 6.17c present the GARCH(1,1) model used:

$$
\begin{aligned}
Y_t &= \boldsymbol{X}_t b + \phi h_t + \epsilon_t, & (6.17a)\\
\epsilon_t | I_{t-1} &\sim t\,(0, h_t, \nu)\,, & (6.17b)\\
h_t &= \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \epsilon_{t-1}^2. & (6.17c)
\end{aligned}
$$

In equation 6.17a, Y_t corresponds to the measured excess return (RET_t), as defined in equation 6.14, and $\boldsymbol{X}_t$ is the vector of explanatory variables, which includes intervention, an intercept, a holiday dummy, and day-of the week dummies. The term ϕh_t allows for the conditional variance to influence the excess return. This GARCH-in-mean specification permits to take account of the risk-return relation.[45] Although I do not present a theoretical model for this effect, it is implied in the intervention literature by models such as that in Osterberg (1989).

Equation 6.17b indicates that the distribution of the error term ϵ_t conditional on the information set I_{t-1} is student-t, with mean zero, variance h_t and ν degrees of freedom. Equation 6.17c shows that I use a GARCH(1,1) model with intercept.

The Swiss National Bank interventions introduced into the model are all dated at $t-3$. Following both Loopesko (1984) and Humpage and Osterberg (1990, 1992), I have cumulated the intervention amounts from the beginning of the sample which is denoted in the tables as $CUMINT$. Intervention calculated in this manner seems roughly consistent with the portfolio balance approach. Recalling from chapter three, the portfolio balance effect of intervention predicts a significant relationship between the relative supply of foreign and domestic assets and the risk premium. Consequently, the test of the impact of cumulative intervention has as its null hypothesis that markets are efficient and no portfolio balance effect exists. Using the variable $CUMINT$ as a proxy for relative asset supplies assumes that investors have accurate information about intervention.

However, even if the null hypothesis is not rejected, it is still possible that intervention matters. The signalling hypothesis suggests that intervention is transmitting information to the market. In order to allow for this possibility, following Dominguez (1990) and Humpage and Osterberg, I am distinguishing between co-ordinated and unilateral intervention without cumulating. These variables are referred to in

[45] The extension of ARCH models to include the variance in the mean equation was first introduced by Engle and Gau (1997). They apply ARCH-M to estimating time-varying risk premia in the term structure of interest rates.

the tables as $COORD$ and $UNILAT$ respectively. Because the signalling effect need not a priori rely on the transactions volume of intervention, the co-ordinated and unilateral intervention variables are also specified as dummy variables, $COORD_d$ and $UNILAT_d$.

6.3. *Data*

The sample period is January 1, 1986 to December 29, 1995, and there are 2608 daily observations, excluding lags. I obtained the exchange rate data form the Zürich market through the Swiss National Bank. The exchange rate data are mid rates (i.e. averages of bid and offer quotes) as of 11 a.m. in Zürich. The interest rate data is obtained from the Bank for International Settlements (BIS) in Basel.[46] Interest rates are bid SPOT-NEXT Eurocurrency deposit rates for the CHF and US$, quoted on a 30/360-day basis, and are recorded 10 a.m. in Basel, one hour prior to the exchange rates. For estimation purposes, they are converted to a daily basis.

The Swiss National Bank also provided the official daily intervention data. The majority of the Bank's interventions are US$ transactions against CHF. Because, as indicated in chapter four, some of the few US$ purchases and sales of DM and Yen were conducted with a specific CHF/US$ target in mind, these interventions are included as well. A more detailed description of the data is relegated to the appendix.

The statistics in Table 2 indicate that skewness and kurtosis are generally significant in the raw daily and the percentage change CHF/US$ data. Very similar non-normal distributional characteristics are found for the daily excess returns. While the Augmented Dickey-Fuller tests for unit roots clearly fail to reject the hypothesis of a unit root in the daily spot rate data, the daily excess return data appear to be stationary. These findings are consistent with the existing literature.

7. Empirical Results

GARCH models are estimated using the maximum likelihood algorithm described in Berndt, Hall, Hall, and Hausmann (1974) which is based on numerical derivatives. The GARCH(1,1) model given by equations (5.6) through to (5.8) is estimated over the full sample period running the time series analysis package TSP. Tables 3 and 4a,b present the parameter estimates from three alternative specifications of the model. To ensure the stability of the results (i.e. that the estimates represent global, rather than local maxima), the parameter estimates were re-entered as starting values in both TSP and Microfit.

In order to examine the sensitivity of the results on the significance of intervention on excess returns for each specification, the model is initially estimated omitting both the daily and holiday dummies as

[46]The agreement with the BIS requires presentation of results in such a way as to maintain the confidentiality of the data.

well as the GARCH-M term (h_t) from the conditional mean equation. The first column of each table shows the results for the estimates of this basic model. Both the sign and significance of the intervention measures appear robust to changes in the specification of the mean equation. Column two of Table 3 shows that, even if included, the conditional variance, h_t, does not enter significantly into the conditional mean equation.

There is a large literature on the day-of-week effects for asset prices. In the context of foreign exchange rates, most studies find some evidence of significant effects, although on different days of the week (see McFarland, Pettit, and Sung, 1982; Hsieh, 1984; Baillie and Bollerslev, 1989). In order to determine which dummy variables to retain for the subsequent equations, likelihood ratio tests are utilised.[47] I find evidence of a significant Monday effect and a slightly less significant Thursday effect in the mean of the CHF/US$ risk premium. The results are presented in columns three to five of Table 3 and columns two to three in Tables 4a and 4b. My findings are similar to those of Humpage and Osterberg (1992) who find both a Thursday and a U.S. holiday effect for the DM/US$. The Thursday effect may reflect the tendency of Swiss monetary policy announcements to fall on this day.[48]

7.1. The Portfolio Balance Channel and Cumulative Intervention

If the portfolio balance channel is operative, the total change in the ratio of foreign to domestic assets should affect the relative portfolios of the investors. In the implementation of equation (5.3), I have calculated the relative risk premium in terms of CHF. Accordingly, because the intervention data is expressed in terms of US$, positive (negative) values represent CHF sales (purchases) by the Swiss National Bank, which, when sterilising the intervention, increases (decreases) the supply of CHF-denominated assets. Therefore, a positive coefficient on $CUMINT$ would be consistent with the portfolio balance approach.

Table 3 indicates that an increase in CHF sales tends to result in significantly increased CHF excess returns. In other words, investors had to be compensated by greater returns to hold the increased supply of CHF-denominated asset. This is consistent with the portfolio balance approach. The significance of the cumulative intervention measure is in agreement with both Loopesko (1984) and Humpage and Osterberg (1990, 1992). However, Humpage and Osterberg find a direction of the effect for U.S. intervention inconsistent with the theory.

[47]The null hypothesis assumes that a specific restriction is valid. The likelihood ratio tests for the "closeness" of the restricted and unrestricted parameters. It follows a χ^2 distribution with the degrees of freedom equal to the number of restrictions imposed.

[48]The Federal Reserve System, the Bundesbank and the Bank of England also hold their monetary policy meetings on Thursdays.

7.2. The Signalling Channel and Co-ordinated vs. Unilateral Intervention

If intervention works through the signalling channel, it is necessary to distinguish between co-ordinated and unilateral intervention. Although there is no agreed upon theory which implies particular signs for the coefficients of COORD and UNILAT, stronger influences are to be expected for the former.

The results in Table 4a suggest that both co-ordinated and unilateral intervention have a significant impact on market expectations about the required excess return. And, as expected, the coefficient on $COORD$ exceeds the coefficient on $UNILAT$. Yet when interventions are implemented as (1,0,-1) dummies in Table 4b, a somewhat different picture emerges. Now only the co-ordinated intervention seems to have a significant effect, while the coefficient for unilateral interventions is insignificant and has also changed sign. The latter results are in line with Dominguez (1990) who finds some evidence that only co-ordinated intervention operations consistently influence longer-term market expectations. Nevertheless, the credibility of a central bank's intervention signal sometimes not only depends on whether intervention is orchestrated or not but also on the size of the intervention itself. The size of an intervention may well influence expectations because, the larger the amount, the greater the potential financial loss monetary authorities would be risking by committing themselves to inconsistent exchange rate targets. As the few unilateral interventions represent the Swiss National Bank's biggest transaction amounts (see Table 1), the specification of interventions as dummy variables may not fully capture the signalling effect.[49]

7.3. Specification Issues

The evidence from my estimations seems to be supportive of the claim that sterilised intervention by the Swiss National Bank was able to influence the risk premium in the CHF/US$ foreign exchange market between 1986 and 1995, operating through both the portfolio balance and the signalling channel. Of course, I cannot claim to have reliably isolated to portfolio balance effect from the possibility that intervention has had a role in signalling new information.

The cumulative intervention measure $CUMINT$ can only act as a proxy for the relative supplies of CHF- and US$-denominated assets. Given that the average SNB intervention amount of US$65m represents only a small fraction of the total value of outstanding CHF assets, it is plausible that my estimates are inconsistent with the elasticity of the risk premium with respect to a change in relative asset supplies. Although the portfolio balance theory states that the identity of the country intervening should *not* matter, different results might be obtained if a measure of U.S. intervention was included in the model. This could prove rather difficult to implement, though, as the Federal Reserve normally only intervenes in either the DM/US$ and ¥/US$ markets.

[49] I am grateful to Bill Osterberg for stressing this point to me.

Furthermore, on re-examining equation (5.3), an other specification complication emerges which may have an impact on the reliability of the GARCH estimates. I have created a measure of daily risk premia using UIP rather than the covered interest rate parity (CIP) in order to avoid the use of overlapping forecast intervals, which, with daily data, would induce high-order serial correlation in the forecast error (FE).[50] However, despite using UIP, it becomes clear that the problem of serial correlation cannot be entirely side-stepped. Because market expectations of future spot rates are *unobservable*, I have to use the actual realisation of $St+1$ instead of its expectation $E_t[S_{t+1}]$. This means that a first order moving average term is introduced into the forecast error (FE_t). The forecast errors now only show no serial correlation after two lags, which violates the implicit assumption that the error terms t in the standard GARCH model are described by an uncorrelated, white noise series.

Whilst it is possible to redress the problem by allowing the MA(1) term to enter the mean equation of the GARCH model, the implementation of this approach inevitably requires more advanced statistical programming using GAUSS.[51] Due to resource and time constraints, this is beyond the scope of this paper. Therefore, further research will be necessary to conclusively establish the validity of the results presented in this paper.

8. Conclusion

Examining the relation between central bank intervention and risk premia in the foreign exchange market, this paper brings together two distinct aspects of the foreign exchange market. It follows a growing strand of empirical research which is investigating whether the increased intervention activity of central banks after the collapse of the Bretton Woods system could be responsible for the well-documented failure of foreign exchange market efficiency models.

I am using official high-frequency data on Swiss central bank intervention and an excess return measure from the UIP condition as proxy for the daily risk premium in the foreign exchange market to test for the presence of portfolio balance and signalling effects of intervention. Taking advantage of developments in statistical models of changing volatility, I am estimating a GARCH(1,1) model of the conditional variance of excess returns.

Although I do not formally disentangle portfolio balance and signalling influences, the estimation results indicate that the interventions of the Swiss National Bank may affect the daily CHF/US$ excess returns through both channels. The operation of a portfolio balance channel not only implies that

[50] When the forecast horizon, k, is longer than the sample frequency, the forecast error will be autocorrelated. More formally, the autocorrelation coefficient at lag j will equal zero only for $j \geq [k] + 1$, where $[k]$ is the largest integer smaller than k. For one-month forward contracts settlement conventions in the foreign exchange markets suggest that $k = 22$ (Baillie and Osterberg (1991)).

[51] The theoretical foundations for ARMA(k,l)-GARCH(1,1) models are laid in Baillie and Bollerslev (1992).

investors view interest-bearing CHF and US$ assets as imperfect substitutes but also suggests that, in addition to fiscal and monetary policy, sterilised interventions furnishes the Swiss monetary authorities with an independent policy instrument. In attempting to distinguish between co-ordinated and unilateral intervention to represent the signalling channel, I find that, independently of the specification of the intervention measures utilised, purchases of US$ which the Swiss National Bank co-ordinates with other central banks increase the excess return on CHF-denominated assets.

However, the presented estimation techniques do not allow for certain specific characteristics of the excess return measure. Consequently, further investigation is necessary to confirm the validity of the results presented here.

I think it is important to note that rather than just providing an explanation for the failure of foreign exchange rate efficiency models, some of the motivations behind the many recent statistical investigations on the impact of intervention are of a different nature; in a number studies, the central bankers themselves argue the case that, intervention in the foreign exchange markets is a prerequisite for allowing the monetary authorities to achieve their domestic objectives, and, consequently, it is not desirable to leave the exchange rate entirely at the mercy of market forces.

In theory at least, however, the acceptance of market-determined, flexible exchange rates should allow the authorities to concentrate on achieving internal balance, allowing the exchange rate to act as buffer to absorb external shocks. Nevertheless, economists agree that there are two main arguments against complete acceptance of freely-floating exchange rates. The first is that if external balance is disturbed not by an external shock but by some internal conditions, the reliance on exchange rate to restore external balance will initially worsen the internal balance. The second argument is that a regime of flexible exchange rates may involve increased variability in rates. There are, therefore, motives for managing the exchange market. And, ultimately, it is these motives that the many empirical tests of the effectiveness of central bank interventions are trying to corroborate.

> "[. . .] whether or not you accept these reasons for official intervention in the exchange market, most countries will in practice seek to manage their rates, whenever exchange-rate movements seem to threaten their objectives. If some countries do this, others will feel defensively compelled to follow, and this provides a case for establishing certain 'rules of the game'." (Goodhart, 1989, p.434).

9. Tables

Table 1: Daily Interventions of the Swiss National Bank, 1986–1995

[a]The number of days of interventions arranged in currencies and size of transaction values does not sum up to the total number of interventions. This is because on certain days the SNB intervened in several currencies. [b] There were a total of 2542 business days in Switzerland between 1986 and 1995. [c] These amounts relate to SNB Interventions only.

	No. days with transaction value in US$ million								
	0 < ≤ 25	25 < ≤ 50	50 < ≤ 100	100 < ≤ 250	250 < ≤ 500	500 < ≤ 1000	No. days[a]	% of total days[b]	Avge. amount
Interventions									
Total	**29**	**45**	**30**	**6**	**1**	**2**	**133**	**4.5%**	**64.9**
According to Currencies									
US$ for CHF	24	41	28	6	1	1	101	4.0%	63.5
US$ for ¥	4	4	0	0	0	0	8	0.3%	30.0
US$ for DEM	1	0	2	1	0	0	4	0.2%	61.3
DEM for CHF	0	0	0	1	1	0	2	0.1%	217.9
According to Participation									
SNB (without Fed and BuBa)	1	0	0	0	1	2	4	0.2%	421.4[c]
SNB and Fed (without BuBa)	5	8	1	0	0	0	14	0.6%	36.4[c]
SNB and Buba (without Fed)	5	5	6	1	0	0	17	0.7%	56.2[c]
SNB, Fed and Buba	18	32	23	5	0	0	78	3.1%	51.1[c]

Table 2: CHF/$ Exchange Rate and Excess Return Statistics

The skewness and kurtosis are normalised so that a value of 0 corresponds to the normal distribution. The Bowman-Shelton test statistic for normality follows a χ^2 distribution with 2 degrees of freedom. The ADF statistic pertains to Augmented Dickey-Fuller unit root regressions which include an intercept but not a trend. † denotes significance at the 95% level, and $*$ denotes significance at the 99% level.

	Jan 1986–Dec 1995	Jan 1986–Dec 1990	Jan 1991–Dec 1995
Sample	(1)	(2)	(3)
Variable	S_t, spot CHF/$ exchange rate at 11 a.m. (GMT+1)		
Mean	1.464	1.554	1.373
Std. deviation	0.175	0.173	0.124
Skewness	0.604*	0.705*	-0.542*
Kurtosis-3	1.069*	0.592*	-0.921*
ADF	-1.117		
Variable	$\Delta(\log S_t)$, daily percentage change in spot CHF/$ exchange rate		
Mean	-0.949E-4	-0.151E-3	-0.408E-4
Std. deviation	0.0035	0.0033	0.0037
Skewness	0.035*	-0.049†	0.091*
Kurtosis-3	2.061*	0.937†	2.763*
ADF	-25.405*		
Variable	RET_t, daily excess returns at 11 a.m. (GMT+1)		
Mean	0.160E-3	0.249E-3	-0.999E-4
Std. deviation	0.0081	00.0079	0.0084
Skewness	-0.038*	-0.031*	0.032*
Kurtosis-3	1.807*	1.547*	2.726*
ADF	-36.515*		

Source: Author's calculations.

Table 3: **The Portfolio Balance Channel**: Influence of Cumulative Interventions

All intervention amounts are in US$ million. The t-statistics appear below coefficient estimates in parenthesis. Bold fonts indicate significance at the 95% level (two sided test). For key to variables see appendix A.

$$RET_t = \omega_0 + \sum_{i=1}^{5} \omega_i D_{i,t} + \omega_6 HOL_t + \psi_1 CUMINT_{t-3} + \phi h_t + \epsilon_t$$
$$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 h_{t-1}$$

		(1)	(2)	(3)	(4)	(5)
		Conditional Mean				
Constant	ω_1	1.802E-04	**3.699E-04**	**3.699E-04**	**5.187E-04**	**6.872E-04**
		(1.1569)	(2.1430)	(2.1437)	(2.5434)	(1.9834)
Monday	ω_1		**-9.617E-04**	**-9.616E-04**	**-1.117E-03**	**-1.289E-03**
			(-2.4694)	(-2.4701)	(-2.7689)	(-2.6276)
Tuesday	ω_2					5.192E-06
						(-0.0106)
Wednesday	ω_3					-5.144E-04
						(-1.0399)
Thursday	ω_4				-5.973E-04	-7.631E-04
					(-1.5390)	(-1.5965)
Friday	ω_5					0
						(0.0000)
Holiday	ω_6				1.433E-04	
						(0.1426)
h_t	ϕ		0			
			(0.0000)			
Intervention						
CUMINT	ψ_1	**1.590E-05**	**1.626E-05**	**1.626E-05**	**1.647E-05**	**1.643E-05**
		(1.9734)	(2.0004)	(2.0011)	(2.0279)	(2.0282)
		Conditional Variance				
	α_0	**2.433E-06**	**2.470E-06**	**2.471E-06**	**2.493E-06**	**2.465E-06**
		(2.3646)	(2.3676)	(2.3660)	(2.4006)	(2.3987)
	α_1	**0.03554**	**0.03589**	**0.03592**	**0.03604**	**0.03630**
		(3.6851)	(3.6941)	(3.6809)	(3.7227)	(3.7356)
	β_1	**0.92710**	**0.92607**	**0.92606**	**0.92558**	**0.92574**
		(42.5922)	(41.9081)	(41.8804)	(42.2953)	(42.5059)
Log-likelihood		8899.69	8896.64	8902.84	8903.97	8904.73
No. of Iterations		10	15	7	8	9

Table 4: **The Portfolio Balance Channel**: Influence of Cumulative Interventions (Dummy Variables)

All intervention amounts are in US$ million. The t-statistics appear below coefficient estimates in parenthesis. Bold fonts indicate significance at the 95% level (two sided test). For key to variables see appendix A.

$$RET_t = \omega_0 + \sum_{i=1}^{5} \omega_i D_{i,t} + \omega_6 HOL_t + \psi_1 CUMINT(d)_{t-3} + \phi h_t + \epsilon_t$$
$$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 h_{t-1}$$

		(1)	(2)	(3)	(4)	(5)
		Conditional Mean				
Constant	ω_1	**1.991E-04**	**3.823E-04**	**3.824E-04**	**5.326E-04**	**7.105E-04**
		(1.2841)	(2.2246)	(2.2240)	(2.6204)	(2.0663)
Monday	ω_1		**-9.305E-04**	**-9.306E-04**	**-1.088E-03**	**-1.268E-03**
			(-2.3922)	(-2.3916)	(-2.6980)	(-2.5956)
Tuesday	ω_2					-2.593E-05
						(-0.0533)
Wednesday	ω_3					-5.201E-04
						(-1.0552)
Thursday	ω_4				**-6.031E-04**	**-7.782E-04**
					(-1.5550)	(-1.6338)
Friday	ω_5					0
						(0.0000)
Holiday	ω_6				1.107E-04	
						(0.1124)
h_t	ϕ		0			
			(0.0000)			
Intervention						
$CUMINT(d)$	ψ_1	**3.166E-03**	**3.146E-03**	**3.146E-03**	**3.161E-03**	**3.155E-03**
		(3.7055)	(3.6811)	(3.6800)	(3.7101)	(3.6974)
		Conditional Variance				
	α_0	**2.494E-06**	**2.532E-06**	**2.532E-06**	**2.550E-06**	**2.515E-06**
		(2.3456)	(2.3442)	(2.3457)	(2.3819)	(2.3753)
	α_1	**0.03631**	**0.03664**	**0.03662**	**0.03677**	**0.03696**
		(3.6657)	(3.6570)	(3.6688)	(3.7060)	(3.7201)
	β_1	**0.92523**	**0.92423**	**0.92423**	**0.92379**	**0.92415**
		(40.8188)	(40.1213)	(40.1451)	(40.6462)	(40.8912)
No. of Iterations		12	13	12	13	14

Table 5: **The Signalling Channel**: Influence of co-ordinated and unilateral Interventions

All intervention amounts are in US$ million. The t-statistics appear below coefficient estimates in parenthesis. Bold fonts indicate significance at the 95% level (two sided test). For key to variables see appendix A.

$$RET_t = \omega_0 + \sum_{i=1}^{5} \omega_i D_{i,t} + \omega_6 HOL_t + \psi_1 COO_{t-3} + \psi_2 UNI_{t-3} + \phi h_t + \epsilon_t$$
$$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 h_{t-1}$$

		(1)	(2)	(3)
		Conditional Mean		
Constant	ω_1	1.863E-04	**3.749E-04**	**5.203E-04**
		(1.2006)	(2.1782)	(2.5545)
Monday	ω_1		**-9.554E-04**	**-1.108E-03**
			(-2.4568)	(2.7467)
Thursday	ω_4			-5.838E-04
				(-1.5045)
Intervention				
COORD	ψ_1	**4.462E-05**	**4.476E-05**	**4.474E-05**
		(2.4718)	(2.4795)	(2.4858)
UNILAT	ψ_2	**5.008E-06**	**5.321E-06**	**5.577E-06**
		(2.0071)	(2.1064)	(2.1876)
		Conditional Variance		
	α_0	**2.491E-06**	**2.534E-06**	**2.554E-06**
		(2.3192)	(2.3230)	(2.3617)
	α_1	**0.03545**	**0.03585**	**0.03596**
		(3.6067)	(3.6023)	(3.6499)
	β_1	**0.92618**	**0.09250**	**0.92459**
		(40.6694)	(39.9667)	(40.4845)
Log-likelihood		8903.01	8906.12	8907.03
No. of Iterations		8	9	9

Table 6: **The Signalling Channel**: Influence of co-ordinated and unilateral Interventions (Dummy Variables)

All intervention amounts are in US$ million. The t-statistics appear below coefficient estimates in parenthesis. Bold fonts indicate significance at the 95% level (two sided test). For key to variables see appendix A.

$$RET_t = \omega_0 + \sum_{i=1}^{5} \omega_i D_{i,t} + \omega_6 HOL_t + \psi_1 COO(d)_{t-3} + \psi_2 UNI(d)_{t-3} + \phi h_t + \epsilon_t$$
$$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 h_{t-1}$$

		(1)	(2)	(3)
		Conditional Mean		
Constant	ω_1	1.945E-04	**3.761E-04**	**5.233E-04**
		(1.2549)	(2.1880)	(2.5743)
Monday	ω_1		**-9.213E-04**	**-1.076E-03**
			(-2.3687)	(-2.6675)
Thursday	ω_4			-5.899E-04
				((-1.5198)
Intervention				
COORD(*d*)	ψ_1	**3.339E-03**	**3.311E-03**	**3.319E-03**
		(3.8536)	(3.8183)	(3.8399)
UNILAT(*d*)	ψ_2	-1.447E-03	-1.304E-03	-1.135E-03
		(-0.3904)	(-0.3505)	(-0.3026)
		Conditional Variance		
	α_0	**2.493E-06**	**2.531E-06**	**2.549E-06**
		(2.3470)	(2.3468)	(2.3831)
	α_1	**0.03664**	**0.03697**	**0.03707**
		(3.6574)	(3.6496)	(3.6975)
	β_1	**0.92490**	**0.92391**	**0.92350**
		(40.6585)	(39.9988)	(40.5097)
Log-likelihood		8906.69	8909.59	8910.44
No. of Iterations		9	12	13

10. Figures

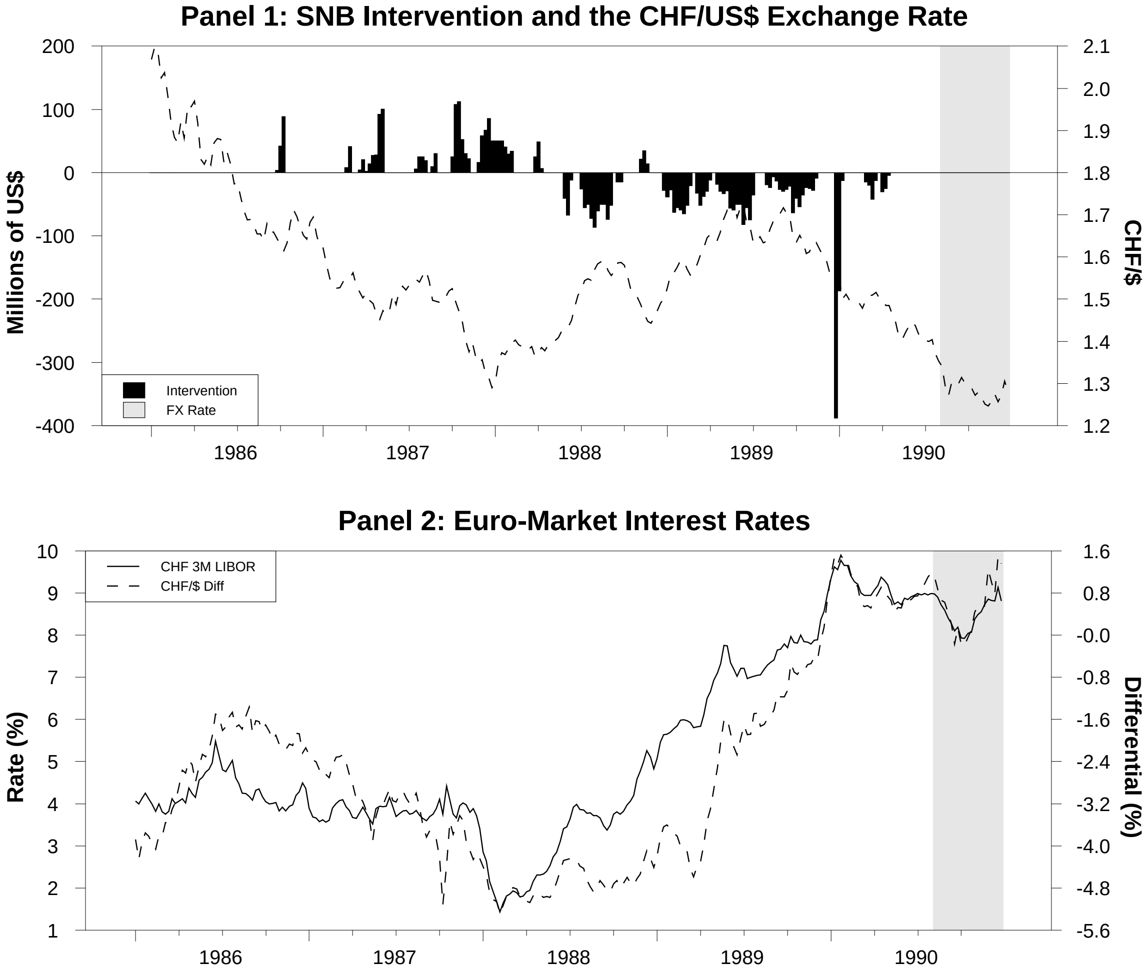

Figure 1: SNB Interventions, FX Rates and Interest Rates, 1985–1990

(i) Panel 1 displays the SNB's daily interventions in CHF/$ along with the evolution of the targeted exchange rate. (ii) The 3-month Swiss franc LIBOR rate and the differential to the dollar rate is shown in panel 2. Shaded areas in the graphs indicate recessions. For the United States, recessions are defined according to the NBER's Business Cycle Dating Committee methodology. For Switzerland, recessions are defined in terms of a fall of (seasonally adjusted) GDP over the course of al least two consecutive quarters.
Source: Swiss National Bank, Datastream.

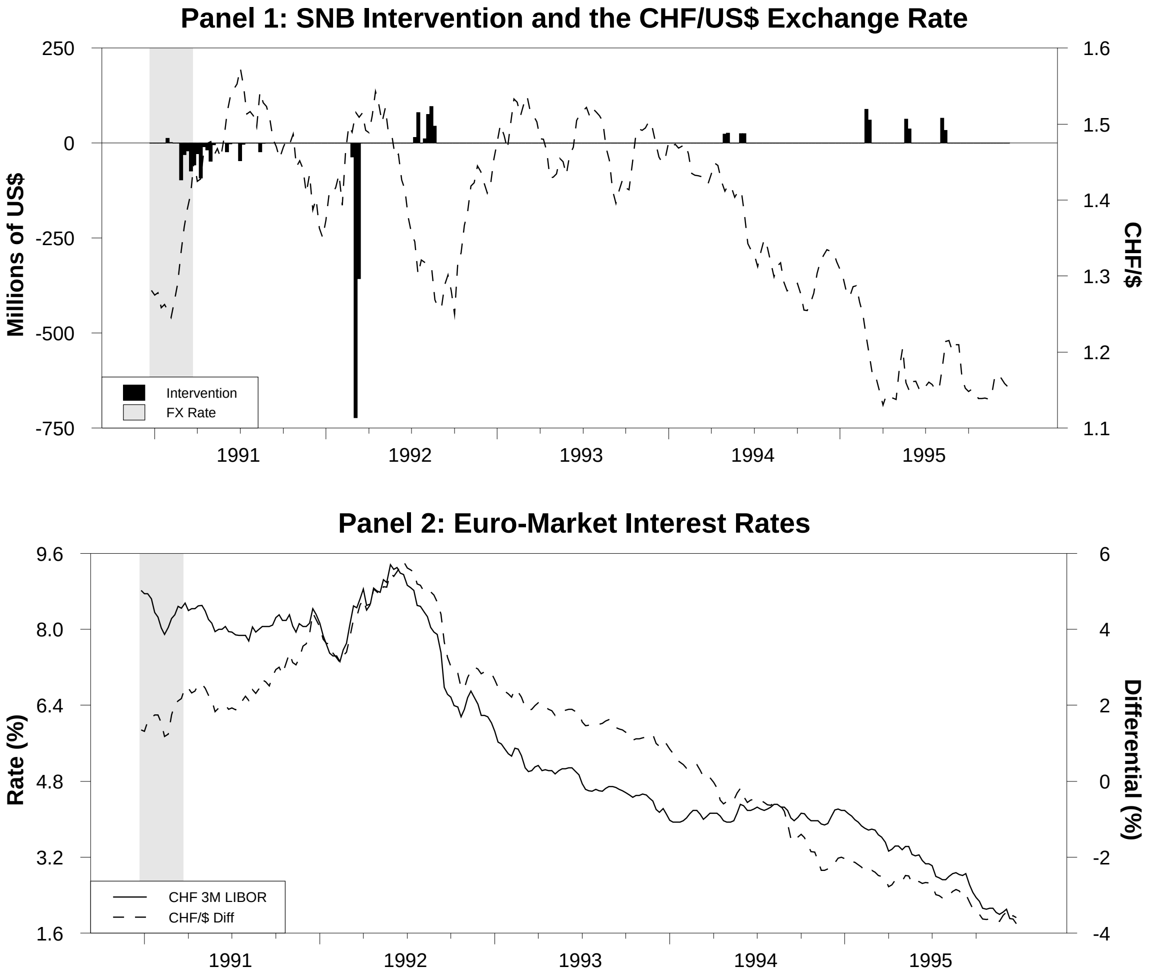

Figure 2: SNB Interventions, FX Rates and Interest Rates, 1991–1996

(i) Panel 1 displays the SNB's daily interventions in CHF/$ along with the evolution of the targeted exchange rate. (ii) The 3-month Swiss franc LIBOR rate and the differential to the dollar rate is shown in panel 2. Shaded areas in the graphs indicate recessions.
Source: Swiss National Bank, Datastream.

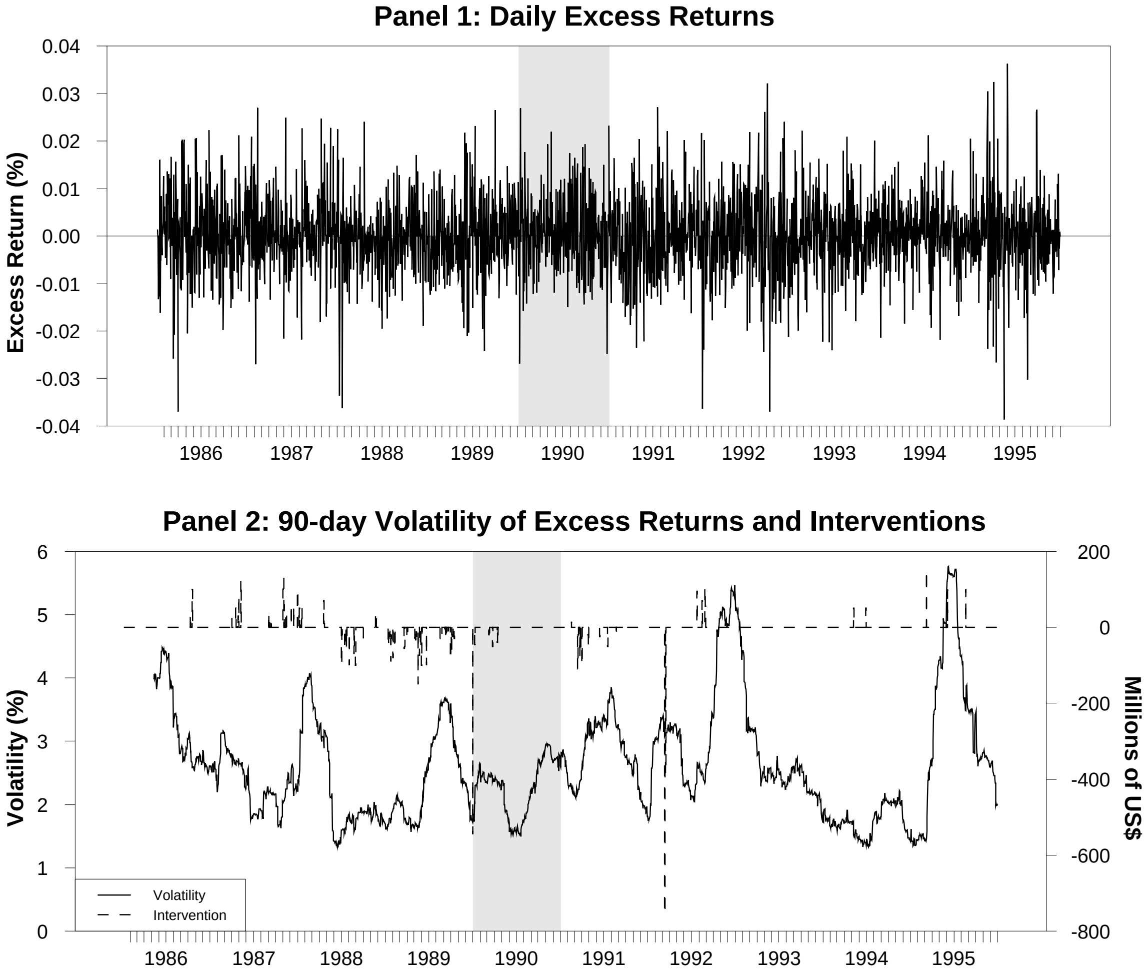

Figure 3: Deviations from UIP and SNB Interventions, 1985–1996

(i) Panel 1 displays the daily excess returns as defined as a risk premium associated with deviations from the Uncovered Interest Parity. (ii) The Swiss National Bank's daily interventions in CHF/$ are plotted against the evolution of the 90-day volatility of the risk premium in panel 2. Shaded areas indicate recessions.
Source: Swiss National Bank, Author's calculations.

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Appendix A. Data Description

I use the following data series either to estimate the model or to construct the variables. The data set contains 2608 observations beginning on January 1, 1986. I estimate all of the models beginning at the first observation.

Both the detailed construction of the variables and the variables used for estimation purposes are contained in the following files:

- `SNBVars.fit`: Microfit file,
- `SNBVars.dat`: ASCII Data file

These files are available from the author upon request.

Appendix B. Overview of Variables

The two files contain the cleaned data for the following variables, each column representing one variable: RET, $CUMINT$, $COORD$, $UNILAT$, $COORD(d)$, $UNILAT(d)$, MON, TUE, WED, THU, FRI, HOL.

Exchange Rate S_t is the CHF/US$ Spot Exchange Rate recorded daily at 11 a.m. (GMT+1) by the Swiss National Bank in Zürich.

Interest Rates The interest rates series are the (annualised) bid SPOT-NEXT Eurocurrency deposit rates for the CHF and the US$ recorded daily at 10 a.m. (GMT+1) by the Bank for International Settlements in Basel.

Intervention Variables

$CUMINT$ Cumulative interventions of the Swiss National Bank in millions of US$. Positive (negative) values of the intervention data represent dollar purchases (sales). See also Figures 2a,b.

$COORD$ Co-ordinated interventions of the Swiss National Bank in millions of US$.

$UNILAT$ Unilateral interventions of the Swiss National Bank in millions of US$.

$COORD(d)$ Co-ordinated interventions as (1,0,-1) dummy variable.

$UNILAT(d)$ Unilateral interventions as (1,0,-1) dummy variable.

Dummy Variables

MON Dummy variable equal to 1 on Mondays.

WED Dummy variable equal to 1 on Wednesdays.

THU Dummy variable equal to 1 on Thursdays.

FRI Dummy variable equal to 1 on Fridays.

HOL Dummy variable equal to 1 on the day after a Swiss holiday. On Swiss holidays, interest rate or exchange rate data were either missing or incomplete. There were 84 Swiss holidays in the sample period.