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The Exchange Rate under Target Zones

Theory and Evidence on the Finnish Markka

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ABSTRACT: The study contains a collection of essays investigating various aspects of the Finnish experience with maintaining a currency band in the period from 1987 to 1991. It draws upon the recent theory of target zones models of exchange rate dynamics. The empirical evidence presented in Chapter Two suggests that the official exchange rate band of the Finnish markka has suffered from a serious lack of credibility during the period under investigation. Chapter Three focuses on the relevant macroeconomic fundamentals as potential reasons behind the lack of credibility in the currency band. According to the results some of the fundamentals have had an effect on the formation of devaluation expectations. Chapter Four examines the role of the risk premium in the explanation of the differential between domestic and foreign interest rates. The results suggest that uncovered interest rate parity is a workable hypothesis in the case of Finland once the perceived devaluation risk has been taken into account. Chapter Five, in turn, addresses the problem of the pricing of currency options in a regime where the movements of the exchange are limited to a currency band, and where the band itself is subject to realignment risk. The option pricing problem is analyzed with a simulation model.

KEY WORDS: Foreign exchange markets, target zone models, devaluation risk, currency options

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TIIVISTELMÄ: Tutkimus koostuu joukosta esseitä, joissa on tarkasteltu Suomen kokemuksia valuuttajärjestelmästä, jossa valuuttakurssin vaihtelut on rajoitettu ennalta asetettuihin vaihteluväleihin. Työssä sovelletaan uutta teoreettista lähestymistapaa valuuttakurssidynamiikkaan. Tutkimuksessa esitetty empiirinen evidenssi viittaa siihen, että Suomen markan virallinen valuuttaputki on tutkimusperiodin aikana ajoittain ollut epäuskottava. Luvussa kaksi on uskottavuuden puutetta mitattu olettamalla, että avoin korkopariteetti on voimassa. Luku kolme kiinnittää huomiota makrotaloudellisiin perustekijöihin puutteellisen uskottavuuden potentiaalisina aiheuttajina. Tulosten mukaan näillä tekijöillä on ollut merkitystä devalvaatio-odotusten syntymiselle. Neljännessä luvussa pohditaan riskipreemion merkitystä korkoerolle koti- ja ulkomaisten korkojen välillä. Riskipreemion suuruutta arvioidaan ottamalla huomioon devalvaatioriskin olemassaolo. Tulosten mukaan kattamaton korkopariteetti on käyttökelpoinen oletus myös Suomen olosuhteissa. Luvussa viisi käsitellään valuuttaoptioiden hinnoitteluongelmaa tilanteessa, jossa kurssi vaihtelu on rajoitettu tiettyihin rajoihin ja jossa vaihteluvälin pysyvyyteen liittyy epävarmuutta. Ongelmaa tarkastellaan simulaatiomallin avulla.

ASIASANAT: Valuuttamarkkinat, valuuttaputki, devalvaatioriski, valuuttaoptiot

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The idea to investigate empirically the Finnish exchange rate regime with the use of the recent theory was evolved during years spent working with questions of risks incorporated in exchange rates and interest rates of the Finnish markka at the Research Department of the Union Bank of Finland.

A prerequisite for this work was the Union Bank of Finland's Doctoral Program, which enabled me to undertake full time research for sufficiently long periods of time, which I highly appreciate. While being on leave from my normal duties, the Research Institute of the Finnish Economy, my former long-standing employer offered me excellent research facilities and a stimulating atmosphere. I wish to express my gratitude to ETLA for this opportunity.

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Laura Vajanne

Contents

1 The exchange rate under target zones: background and summary of the study

1.1 Introduction

This thesis contains a collection of essays which study different aspects of Finnish experience from maintaining a currency band from 1987 to 1991. The period from 1987 onwards starts a new era in the Finnish financial system because exchange rate controls had already been to large extend relaxed and domestic money markets deregulated. This environment with free capital mobility and a properly functioning money market creates a possibility to investigate and interpret the recent history under a new framework which has emerged in international monetary economics, called the theory of target zones. Underlying the research is the idea to investigate the consequences of the agreements whereby national monetary authorities' attempt to keep their exchange rates within currency bands or target zones. The Exchange Rate Mechanism of the European Monetary System is and the Nordic countries' unilateral exchange rate pegs were arrangements that fulfil the characteristics of target zones.

The traditional theoretical literature on exchange rate regimes did not distinguish narrow target zones from completely fixed exchange rates. Fixed exchange rate regimes have traditionally been modelled as consisting of a completely fixed and credible exchange rate, with free capital mobility resulting in zero differentials between home and foreign interest rates and in a complete loss of monetary autonomy for small open economies.

This framework has proved inadequate for a number of relevant issues addressed by the target zone system. In particular, there is no convincing empirical evidence which would reveal interest rates equalization. Thus, it seems that the exchange rate variability, even when limited to a credible band must be taken into account.

Exchange rate target zones have been the subject of intensive research in recent years.[1] After some earlier work on exchange rate target zones such as Williamson (1985) and Frenkel and Goldstein (1986), the recent work took off with Paul Krugman's target zone model. This paper, first circulated in 1988 and published in 1991 has become the standard target zone model and the starting point for almost all the research that followed.

Krugman started from the presumption that the exchange rate, like any other asset price depends on both some current fundamentals and expectations of future values of the exchange rate.

The fundamental is assumed to consist of two components: one component, velocity is exogenous to the central bank and stochastic; the other component, money supply, is controlled by the central bank and changed by interventions. By controlling the money supply, the central bank can control the aggregate fundamental and thus the exchange rate: when the currency is weak, the central bank can reduce the money supply (intervening either by selling bonds in an open market operation or selling foreign currency reserves in a foreign exchange intervention) in order to strengthen the currency and *vice versa* when the currency is strong. In exchange rate target zone, the central bank controls the money supply to keep the exchange rate within a pre-specified band around a central parity.

The Krugman model has two crucial assumptions. First, the exchange rate target zone is *perfectly credible*, in the sense that market agents believe that the lower and upper edges of the band will remain fixed forever, and that the exchange rate will forever stay within the band. In other words the realignment risk is assumed to be zero. Second, the target zone is defended with *marginal interventions* only. That is, the money supply is held constant and no interventions at all occur as long as the exchange rate is interior of the exchange rate band.

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[1]An excellent interpretation of research on exchange rate target zones is provided by Svensson (1992b).

To get an explicit solution to the model, the stochastic process for the exogenous component of the fundamental, velocity, must also be specified. In Krugman's model the velocity is assumed to be a Brownian motion without the drift so that its realized sample paths are continuous over time and do not include discrete jumps. In addition, changes in the variable over any fixed time interval are distributed as a normal random variable with a zero mean and a variance that is proportional to the time interval's length. The assumption of a Brownian motion implies that the free-float exchange rate will also be a Brownian motion and equal to the fundamental.

In terms of the standard, fully credible, target zone model including the assumption of the Brownian motion about the velocity, the target zone exchange rate can be expressed as a function of the aggregate fundamental, the target zone exchange rate function.

Compared to the free-float exchange rate function there are two main results to be derived from the Krugman's model. The first main result is that the slope of the target zone exchange rate function is less than one at all times. This result is called the "honeymoon effect". The reason for this inherent stabilization of the target zone is that a weak currency implies expectations of future interventions to reduce the money supply and strengthen the currency, and expectations of a future appreciation leads to an immediate current strengthening of the currency. In this case the exchange rate is less than rate predicted by the current fundamental alone, because an expected currency appreciation is taken into account.

An important issue in modelling exchange rate dynamics under a target zone regime is thus the role of expectations. The existence of a band constrains possible future paths of the exchange rate; exchange markets, knowing this, should behave differently than they would if there were no target zone. Thus the existence of a band should affect exchange rate behavior even when the exchange rate is inside the band and the zone is not actively being defended. So the honeymoon effect means that a perfectly credible target zone is inherently stabilizing: the expectations of future intervention make the exchange rate more stable than the underlying fundamental.

The other main result from the Krugman's model is that the slope of the target zone exchange rate function flattens to a slope of zero at the edges of the band. This result is called "smooth pasting" condition, a concept familiar from option-pricing theory (see *e.g.* Merton, 1973 and more recently Dixit, 1992.) The smooth-pasting result implies that the relationship between the exchange rate and fundamental determinant of the exchange rate is non-linear, with more pronounced non-linearity close to the boundaries of the target zone. The non-linearity is due to infinitesimal foreign exchange interventions at the edges of the band that are preventing the fundamental from driving the exchange rate outside the band.

The basic target zone model has a number of testable implications. The existence of non-linearities in a target zone context has been studied by several authors. Meese and Rose (1990) investigated some EMS currencies and the results showed no strong evidence of non-linearities. Diebold and Nason (1990) reached the same conclusion for some EMS currencies but with a different method. Flood, Rose and Mathieson (1990) could not either find any clear evidence of non-linearities in EMS data. Lindberg and Söderlind (1991) found only slight evidence of non-linearities for the Swedish krona during periods when the exchange rate was close to the target zone boundaries.

Moreover, the Krugman model implies, when the uncovered interest rate parity is assumed, as shown by Svensson (1991c) that the relation between the interest rate differential and the exchange rate is negative, and weaker for longer maturities. This important empirical relation between the interest rate differential and exchange rate has also been investigated intensively. The empirical evidence rejects, however, the deterministic relation between the interest rate differentials and exchange rates. Flood, Rose and Mathieson (1990) find no clear pattern in the correlation between the interest rate differential and the exchange rate for the EMS currencies. Svensson (1991d) studies the Swedish krona and the interest rate differential for different maturities and finds negative correlations, with smaller absolute values for longer terms, which is in line with the theory. On the other hand, Lindberg and Söderlind (1991) get the opposite result for the Swedish data, using a somewhat different and longer sample as Svensson. They find positive correlations, which increase with longer terms. Kontulainen, Lehmussaari and Suvanto (1990) provide similar evidence from Finnish data as Svensson exept that the absolute value of the correlation is increasing with maturity.

All in all, the empirical evidence of the predictions from the basic target zone model is rather weak. The support for non-linearities is slight, and the empirical evidence on the correlation sign remains mixed. In addition, the fit between theory and data is far from perfect, and a strongly serially correlated component is left unexplained in the relationship between exchange rate and interest rate differentials.

A rapidly growing theoretical and empirical research has arisen since the basic model was proposed to improve the basic target zone model, and the analysis of target zones has been extended in various directions.

One of the most central questions in the development of these "second generation" target zone models has proved to be the assumption of the credibility of the exchange rate band. To get a better fit for the data, models that incorporate devaluation (or revaluation) risk have been proposed by *eg*. Bertola and Caballero (1990), Bertola and Svensson (1991) and Weber (1992). Also the other crucial assumption that the authorities intervene only when the fundamental reaches the edge of the band has been considered and a model incorporating monetary authorities' intervention within the currency bands has been proposed by Delgado and Dumas (1992). A recent attempt to unite both stochastic devaluation risk and intramarginal interventions is proposed by Lindberg and Söderlind (1992).

This thesis focuses on four different questions, which all broadly fit into the framework of target zones. The first question, which is the theme of *chapter 2*, is, if the Finnish data is qualitatively consistent with the basic target zone model. It will be shown in the course of the study that the Finnish markka exchange rate band suffered from serious lack of credibility during the period under investigation and it is argued that the lack of the crediblity makes the results from the basic target zone model at least questionable. An attempt to measure this imperfect credibility is done in the latter part of this chapter. The second question, the theme of *chapter 3*, focuses on the relevant macroeconomic variables behind the devaluation expectations measured in chapter 2. In *chapter 4*, the question of how much of the excess returns observed in the Finnish forward exchange rate market can be attributed to a potential risk premium and how much is due to an *ex post* forecast bias caused by unrealized devaluation expectations under the sample is considered. The existence of a risk premium is especially important in the connection of target zone literature since the models rely on uncovered interest rate arbitrage and thus disregard the risk premium. *Chapter 5* focuses on the last question addressed in the thesis, that is, how devaluation expectations affect the pricing of foreign currency options when the exchange rate is constrained by a target zone.

Thus the main contribution of this thesis consists of a detailed empirical analysis of the Finnish exhange rate regime, with the use of the most recent theory. The contribution is important for at least two reasons. First, a detailed empirical analysis of the Finnish exchange rate regime adds to the knowledge about similar exchange rate regimes for other countries and improves the understanding of actual working of both the Finnish and other countries' exchange rate arrangements. Second, since the empirical analysis relies on the most recent theory, the empirical analysis is to some extent a test of this theory. This adds to the theoretical understanding of fixed exchange rate regimes with bands.

1.2 Outline and main results of the thesis

The period under examination in this thesis is January 1987 - May 1991. During this period the external value of the Finnish markka was defined in terms of a currency index, which included the currencies of the Finland's most important trading partners. The end of the research period is the change in the peg of markka at the beginning of June 1991. Markka was unilateraly pegged to the theoretical ecu (European Currency Unit) on June 6, 1991.

The organization of this thesis is as follows. *Chapter 2* introduces the concepts under which target zone models operate and reviews selectively recent literature on target zone models and empirical results obtained on the basis of the models. In the second part of the chapter devaluation expectations for the Finnish markka are estimated for the sample period using a framework suggested by Bertola and Svensson (1991). The results show that a "naive" estimate of devaluation expectations, the interest rate differential between interest rates on domestic and foreign-currency denominated deposits and bonds, is potentially misleading because interest rate differentials are also affected by expected exchange rate movements inside the band. The reason such an adjustment is important is that the exchange rate within the band displays mean reversion causing expected rates of depreciation inside the band to be about the same magnitude as the interest rate differential.

The main result from chapter 2 is that the unilateral exchange rate target zone for the markka has not deemed credible by the market participants during the sample period. The later experiment with the unilateral ecu-peg had exactly the same problems. In addition, the clear difference between the EMS exchange rates and the FIM exchange rate band is that there was no improvement in the credibility of the FIM exchange rate band which has been found among some EMS currencies, see *eg*. Frankel and Phillips (1991), Rose and Svensson (1991) and Svensson (1991a). However, the results for the Swedish krona showed a similar lack of credibility, see Lindberg, Svensson and Söderlind (1991).

The second question, the theme of *chapter 3*, focuses on the relevant macroeconomic fundamentals related to the devaluation expectations estimated in previous chapter. The issue is how devaluation expectations depend on the state of the economy as desrcibed by a set macroeconomic variables. As a start finding these relevant macroeconomic fundamentals driving devaluation expectations, the monetary approach as an illustrative framework is discussed.[2]

Nevertheless, since a devaluation entails a tacit decision by a central bank or a government under the target zone regime, the principal question is what decision rule the private sector thinks the central bank or government is following when targeting the exchange rate. The theories that come closest to this type of question setting can be found under the framework of the so-called escape clauses in economic policy and the speculative attack literature. However, since there is not any systematic theory for a decision rule of the central bank, the ideas from these theories can be seen only as indicative when searching the linkage between devaluation expectations held by actors in financial markets and the relevant set of macrovariables determining theses expectations.

The results of this chapter indicate that it is possible to find a statistical relationship between some macroeconomic variables and devaluation expectations under the sample period. The unemployment rate has a significant positive effect on devaluation expectations, and the annual growth rate of GDP, foreign exchange reserves and improvment in the current account have significant negative effects.

In *chapter 4*, we seek to answer the question of how much of the excess returns observed in the Finnish forward exchange rate market can be attributed to a potential risk premium and how much is due to an *ex post* forecast bias caused by unrealized devaluation expectations under the sample. The role of a risk premium is an important question in target zone models since the approach relies on uncovered interest parity, which implies that it is possible to disregard the risk premium between home and foreign bonds.

An expression for the risk premium using the model introduced by Svensson (1992a) is presented. Svensson's model, in contrast to the previous literature, takes the exchange rate's heteroscedasticity within the band as well as a separate

[2]The moneraty approach is the common background in most of the theoretical and empirical studies of the target zone models. *E.g.* Bertola and Caballero (1990), Flood and Garber (1989), Froot and Obstfeld (1991) and Krugman (1991) use the monetary model.

devaluation risk into account. In terms of this model the upper boundary of the risk premium for the Finnish markka is approximated.

It turns out that for a target zone such as the Finnish exchange rate band, the risk premium appears to be small especially in relation to devaluation expectations. Thus the uncovered interest rate parity seems to be a sufficiently close approximation also for the FIM exchange rate.

The alternative approach to explaining the apparent *ex post* failure of uncovered interest parity is that there has been a systematic difference between the observed return differentials and their expected values. This situation would arise when the probability distribution is asymmetric and includes a small probability of a very large change in the value of exchange rate. The phenomenon is called the "peso problem".[3] The peso problem arises thus, when a potential change in the current regime has a significant influence over the expected value of the exchange rate, but when this change does not take place over some relevant length of time.

The problem is particulary relevant for exchange rates within the exchange rate bands with a realignment risk. The sample distribution may not be representative of the underlying distribution of the error term, unless the sample includes a large number of realignments. The period under investigation in this study is characterized with highly time-varying devaluation expectations of the Finnish markka. Since there were no devaluations in the period examined, it fulfils the characteristics of a typical peso problem.

Thus, in contrast to earlier research into the forward exchange bias, which has ignored the risk of changing regimes, it is argued that this risk should be seriously considered as a determinant of the forward exchange rate bias. A simple model is build to explain the interest rate differentials with taking this potential change in the current regime into account. The empirical results support

[3]The peso problem in connection with exchange rate market was investigated *eg.* by Krasker (1980) and Lizondo (1983). The phenomenon has been called the "peso problem" because it was initially associated with the persistent expectation of a devaluation in the Mexican peso market.

the hypothesis that devaluation expectations affect the interest rate differentials. The message is in this chapter is that empirical economic models of the forward bias within target zones should explicitly incorporate devaluation risk as an explanatory variable.

Chapter 5 focuses on the last question addressed in the thesis, that is, how do devaluation expectations affect the pricing of foreign currency options when the exchange rate is constrained by a target zone. A simulation model to price currency options on a constrained currency index with devaluation risk is developed. Simulations of the underlying exchange rate movements allow us to study in detail how certain properties of the currency band will affect the pricing of currency options.

In this paper, contrary to previous pricing models of options, which allow jumps in the price of the underlying instrument like Cox and Ross (1976), Cox, Ross and Rubinstein (1979), and Merton (1976), we are interested in the effects of allowing the exchange rate movements within the band and the probability of a jump to be mutually dependent as compared to the assumption of the independence of these two stochastic processes. It is shown that this dependence has significant effects on the valuation of a currency option.

Our results indicate that the expected change in the exchange rate in the independent case will produce unrealistic outcomes. It turns out that these unrealistic outcomes are avoided if the occurrence of re- or devaluations depends on the location within the band, given a realistic set of parameter values.

The largest difference in the call option values produced by the two models are for out-of-the-money options close to the lower border. The constant probability of an upward jump will drive up the option price in the independent case. In our dependent case it will be driven down by a relatively high probability of a downward jump. The smallest difference was observed for in-the-money options. Even in that case a difference of 25 % at its maximum was observed for the 90-day option. Thus, whether independence between the jump and the location within the band is assumed or not is of considerable importance for the pricing of an option on the index.

Finally, when the option values based on our simulation experiments were compared with the option prices calculated with the widely used Garman and Kohlhagen model (1983), it turned out that the Garman and Kohlhagen model gave rise to over- as well as underestimation. When the simulated standard deviation was used in the Garman and Kohlhagen model, the prices generally were above the simulated values, but when jumps were disregarded in the standard deviation the reverse turned out to be true. Once again the out-of-the-money options exhibited the most notable differences.

This chapter is based on a joint paper written together with Tom Berglund and Staffan Ringbom. The simulation model was jointly planned by the three of us. It was programmed by Staffan Ringbom. The analysis of the results was done as a joint project. I did the preliminary screening of the literature, performed the simulation runs and wrote a preliminary draft of the paper.

1.3 Concluding remarks

The research performed in this thesis conveys several tentative results, which can be extended in various directions. Two challenging problems in particular remain for future empirical studies of Finnish markka exchange rate under the target zone. The first is the presence of the restriction imposed by the target zone on the exchange rate. Since rational agents should include the announced band as part of their information set, it is important for the econometrician to explicitly take that into account. This could be done, for instance, along the lines suggested by Chen and Giovannini (1992a), where a modified estimation method taking into account the restrictions the band limits impose is presented. The second prevailing problem has to do with the difficulty in estimating the exchange rate distribution. Since the distribution varies with the intervention policies assumed, and since the theoretical models have closed form solutions for only a few simplified policy rules, it is difficult to estimate a distribution corresponding to the true underlying policy and model structure.

In addition to these econometric problems, there are many interesting questions connected to the exchange rates within target zones, which have been beyond the scope of this research. For instance, questions like the monetary independence in exchange rate regimes with finite bands, the problem of the exchange rate overvaluation or undervaluation and how credibility problems associated with exchange rate bands affect to the overall macroeconomic performance of a country are of great interest. These questions are possible to analyze using an analytical framework which draws on recent development in macroeconomics emphasizing the strategic aspects of the interdependence between the behavior of private forward-looking agents and centralized policymakers in the spirit of Barro and Gordon (1983). Such concepts like time-inconsistency, the learning about the change in regime and the "escape clauses" are just few examples of working tools in this research field.

2 Testing target zone credibility: theory and Finnish data

2.1 Introduction

This chapter provides a study of the Finnish experiences from maintaining the currency band during January 1987 - May 1991. During this period the Bank of Finland unilaterally defended a fixed exchange rate regime in which the markka was allowed to fluctuate in a band defined in terms of a basket of foreign currencies. The band width was since November 30, 1988 $\pm$ 3 per cent, before that it was $\pm$ 2.25, and on one occasion during this period, on March 17, 1989 the markka was revalued by 4 per cent.

The first part of the chapter discusses whether the Finnish data is qualitatively consistent with the basic target zone model (Krugman, 1991). Distributional implications of the basic model to exchange rates and interest rate differential as well the relationship between the interest rate differential and the exchange rate implied by the model are considered.

Under the assumption of perfect credibility no realignments are expected to occur, and the expected rate of currency depreciation is equivalent as the expected rate of currency depreciation within the band. This expected rate of currency depreciation is negatively related to the exchange rate in the Krugman model. Under the assumption of uncovered interest rate parity the Krugman model thus predicts a negative deterministic relation between the interest rate differential and the exchange rate.

The second part of this chapter extends the analysis by relaxing the assumption of perfect credibility and allows a stochastic time-varying devaluation risk along the lines suggested by Bertola and Svensson (1991).[1] It is shown within the context of this theoretical "second generation" target zone model that there is no longer any general implication for the relationship between the exchange rate and its expected rate of change when the stochastic, time-varying devaluation risk is incorporated. However, if the probability of realignment is non-zero but fairly stable, the analysis yields the standard prediction of a negative correlation between the exchange rate and its expected rate of change and thus also with interest rate differentials. On the other hand, if the realignment probability is highly variable, a positive correlation might emerge. It can be shown with the theoretical model that a change in the perceived probability of a realignment is reflected in the overall expected rate of change of the exchange rate, but it also moves the current level of the exchange rate in the same direction. The pattern of covariation between these variables thus depends on the relative variability of the probability of realignment.

An interesting question is whether the lack of credibility, *ie.* a non-zero realignment risk, is by some means quantifiable. Bertola and Svensson have suggested an empirical procedure to measure the devaluation risk and employing this method we estimate the devaluation expectations for the Finnish markka. The key idea in the empirical method is to extract devaluation expectations by adjusting interest rate differentials for expected rates of depreciation of the exchange rate within the band. The adjustment is nontrivial if exchange rates within the band display mean reversion rather than random walk (unit root) behaviour. The Bertola-Svensson method has been implemented to estimate devaluation expectations for EMS-currencies by Frankel and Phillips (1991), Rose and Svensson (1991), and Svensson (1991a), and for the Swedish krona by Lindberg, Svensson and Söderlind (1991).

The remainder of the chapter is organized as follows. Section 2.2 selectively reviews the theoretical concepts and empirical findings of the first generation target zone models. Next some details on the Finnish exchange rate band and the

[1]For alternative empirical approaches to target zone credibility see for instance Bartolini and Bodnar (1992), Bertola and Caballero (1990), Chen and Giovannini (1992b) and Weber (1992). Edin and Vredin (1991) and Holden and Vikøren (1992) have examined devaluation expectations of the Nordic countires.

interest rate differentials during the period investigated are presented. The Finnish evidence is then summarized in terms of the basic model. In section 2.3 the key elements of the theoretical Bertola-Svensson model are introduced and the empirical method for extracting implicit devaluation expectations from data on exchange rates and interest rate differentials is explained. The devaluation expectations for the Finnish markka are then estimated and the results are presented at the end of this section. Section 2.4 concludes the chapter.

2.2 The basic target zone model

2.2.1 Theoretical concepts

The basic components of target zone models, which originated in the work of Krugman (1991), may be characterized as follows[2].

We start with the asset-pricing relationship for the exchange rate:

(2.1) $$e(t) = f(t) + \alpha E_t[de(t)|\phi(t)]/dt, \qquad \alpha > 0.$$

where $e(t)$ is the logarithm of the spot exchange rate at time t (measured as units of the domestic domestic currency per unit of foreign currency or a basket of foreign currencies). It is determined by the fundamental $f(t)$ and the expected change in the exchange rate through the parameter α. The term $E_t(\cdot|\cdot)$ is the conditional expectations operator, conditioned on current information $\phi(t)$, which includes the current value of fundamentals, $f(t)$, as well as any explicit or implicit restrictions the authorities have placed on the future evolution of fundamentals.

This model of exchange rate determination is consistent with the flexible-price monetary model under free floating and full capital mobility. Parameter α represents the semi-elasticity of money demand with respect to the nominal

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[2]For more details, see also Froot and Obstfeld (1991).

interest rate.[3]

Using a monetary model, we can define the fundamental as

$$(2.2) \qquad f(t) = m(t) + v(t),$$

where $m(t)$ is the logarithm of the money supply, which is the intervention variable of the authorities, and $v(t)$ represents positive shocks to the velocity of money *ie.* negative shocks to money demand. A positivc shock to the money supply or a negative shock to money demand leads to a temporary money market disequilibrium which quickly disappears as market operators exchange domestic for foreign money. The exchange rate rises (the domestic currency depreciates) and the domestic price level climbs as a result, which restores the equilibrium in the money market.

Velocity is thus an exogenous stochastic process whereas the money supply is a stochastic process under direct control by a monetary authority.

The simplest characterization of the behaviour of the fundamental is to assume that it follows a continuous Brownian motion with or without a drift:

$$(2.3) \qquad df(t) = \eta_f \, dt + \sigma_f \, dW(t).$$

If $\eta_f \neq 0$, the process exhibits drift, *ie.* the fundamental has a constant rate of change and the variance σ_f^2. Otherwise it is driven by random shocks represented by $dW(t)$, where $W(t)$ is a standard Wiener process with $E[dW(t)]=0$ and $E[dW(t)^2]=dt$.

If speculative bubbles are ruled out, the rational-expectations assumption leads

[3]There are also other possible interpretations for the asset pricing relationship of (2.1). See *e.g.* Blanchard and Fisher (1989, 214-217).

to a equilibrium exchange rate path that satisfies (2.1).[4]

This saddle-path solution has the integral representation:

$$(2.4) \qquad e(t) = \alpha^{-1} \int_t^{\infty} exp[(t-s)/\alpha]\ E_t[(f(s)\,|\,\phi(t)]ds.$$

The current exchange rate depends alone on the present discounted value of expected future fundamentals (the discount rate is $1/\alpha$).

The solution of (2.4) depends on whether or not the monetary authorities are willing to influence the exhange rate by affecting the fundamental through changes in the money supply. Under a free float, the authorities are assumed never to intervene in order to offset shocks to velocity ($dm=0;\ df=dv$). Accordingly, under a free float the saddle-path solution to (2.4) is simply:

$$(2.5) \qquad e(t) = f(t) + \alpha\eta_f\,.$$

This solution implies a constant expected instantaneous rate of change for $e(t)$, which is equal to that of $f(t)$, if there is no drift in the fundamental.

However, in the target zone regime free floating is limited to a given range. An intervention is, by definition, a policy measure which affects the $m(t)$ component of the fundamental. The target zone for the exchange rate implies that the range of the fluctuations of the fundamental is restricted by offsetting changes in $m(t)$. By this policy rule, the stochastic process described by equation (2.3) becomes a regulated Brownian motion. In other words, central band interventions are undertaken to prevent the fundamental from moving outside a pre-specified band for the fundamental implying also well-specified bound for the exchange rate. In the following the lower bound of the fundamental is denoted with f^L and the upper bound with f^U and the bounds for the exchange rate as e^L and e^U.

---

[4]Ruling out bubbles seems reasonable in this connection, since the exchange rate is restricted to a target zone. In particular, since $\alpha > 0$ in the present model, the expected value of a bubble would grow indefinitely.

In order to derive the solution under a target zone we have to obtain the general solution for $e(t)$. Let the observable process $e(t)$ be a non-linear twice continuously differentiable function of the fundamental:

(2.6) $$e(t) = G[f(t)].$$

In order to find a solution for equation (2.6) it is possible to use a two-step approach. First, the family of functions of the form $e(t) = G[f(t)]$ that satisfy the equlibrium condition (2.1) so long as the fundamentals evolve according to (2.3) is characterized. Second, the member of this family that satisfies the appropriate boundary conditions is derived.

Using equation (2.1) and Ito's lemma the expected rate of depreciation may be expressed as:

(2.7) $$E_t[de(t)|\phi(t)]/dt = \eta_f G'f(t) + \tfrac{1}{2}\sigma^2_f G''f(t).$$

Combining (2.1) and (2.7) results in a functional equation for the exchange rate:

(2.8) $$G[f(t)] = f(t) + \alpha\eta_f G'f(t) + \tfrac{1}{2}\sigma^2_f \alpha G''f(t).$$

This second order differential equation has, as shown in Froot and Obsfeld (1991), the general stationary solution:

(2.9a) $$G[f(t)] = f(t) + \alpha\eta_f + A_1 exp(\lambda_1 f(t)) + A_2 exp(\lambda_2 f(t)),$$

where $\lambda_1 > 0$ and $\lambda_2 < 0$ are roots to the characteristic equation in λ,

(2.9b) $$(\alpha\sigma^2_f /2)\lambda^2 + \alpha\eta_f \lambda - 1 = 0,$$

and where the constants A_1 and A_2 are determined by the boundary conditions $G(f^U)$ and $G(f^L)$ satisfied by the exchange rate $e(t)$ at the time of intervention:

(2.9c) $$A_1 = \frac{exp(\lambda_2 f^L) - exp(\lambda_2 f^U)}{\lambda_1 exp(\lambda_1 f^U + \lambda_2 f^L) - \lambda_1 exp(\lambda_1 f^L + \lambda_2 f^U)}$$

$$A_2 = \frac{exp(\lambda_1 f^U) - exp(\lambda_1 f^L)}{\lambda_1 exp(\lambda_1 f^U + \lambda_2 f^L) - \lambda_1 exp(\lambda_1 f^L + \lambda_2 f^U)}$$

These '*smooth pasting*' conditions[5], derived from equation (2.9a) for $G'(f^L)= G'(f^U)=0$, ensure that $e[f(t)]$ is flat at the boundary of the fundamentals band and tangent to the boundaries of the implied exchange rate band in Krugman's model of infinitesimal marginal intervention.[6]

The solution obtained gives the familiar S-shaped relationship between the exchange rate and the fundamentals. The presence of bounds on the exchange rate implies that even when they are not binding they influence the exchange rate via expectations and drag it towards the middle of the band. Algebraically this "bias due to the band" is represented by the exponential terms in (2.9a). It is important to note that the solution assumes that the band is known to the agents and does not vary over time.

As Froot and Obstfeld (1991) emphasize, this infinitesimal character of the marginal interventions implies that the exchange rate is never expected to jump in response to interventions. If such a jump were allowed to occur, risk neutral investors would face an arbitrage opportunity as the fundamentals approach the point of intervention.[7]

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[5]These conditions are sometimes called '*value matching*' conditions in the literature as in Dumas (1991), who points out that the term '*smooth pasting*' usually is applied in the context of intertemporal maximization problems involving the costly regulation of state variables that follow a Brownian motion.

[6]Krugman also extended the analysis to an imperfectly credible target zone regime, where the regime collapses once and for all to a free float with a given probability when the exchange rate reaches the edge of its band.

[7]Flood and Garber (1989) show that this no-jump requirement also provides boundary conditions for more general intervention policies, such as finite intervention strictly in the interior of the band.

As shown by Weber (1991), we can identify two types of settings of A_1 and A_2 which are relevant in the context of fully credible target zone models:

(i) Completely ruling out speculative bubbles and ignoring the existence of a target zone ($A_1=A_2=0$) results in a linear relationship between the exchange rate and its fundamentals. This basically is the free float solution in which exchange rates are driven by a random walk.

(ii) In perfectly credible target zones 'smooth pasting' ensures $A_1<0$ and $A_2>0$, and the relationship between the exchange rate and its fundamental has the S-shape, which reflects Krugman's "honeymoon effect": the existence of a perfectly credible fundamentals band gives rise to speculative bubbles which stabilize the behaviour of the exchange rates within the edges of a narrower band. This result holds for all credible target zones, whether with or without intramarginal interventions.[8]

Interest rate differentials

In the same manner as the current exchange rate can be expressed as a function of the current fundamental, the future exchange rate can be expressed as a function of the future fundamental[9].

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[8]In imperfectly credible target zones policy-makers have the option to either fight the parity or to initiate a realignment. Bertola and Caballero (1990) show that in this case the constants A_1 and A_2 depend, among other things, on the relative probabilities of these mutually exclusive events. In particular, they demonstrate that smooth pasting ($A_1<0$, $A_2>0$) only occurs if at the boundary of the fundamental bands the realignment probability is small, $p < 1/2$, whilst $p = 1/2$ leads to the free float solution ($A_1=A_2=0$). Finally, in a non-credible target zone, $p > 1/2$, speculation is destabilizing ($A_1>0$, $A_2<0$) and the relationship between the exchange rate and its fundamentals has an inverted S-shape. The implications of imperfect credibility are discussed later in *section 2.3*.

[9]For more details, see Svensson (1991d).

Assuming uncovered interest rate parity[10], the interest rate differential for an arbitrary term to maturity of τ is accordingly

$$(2.10) \qquad i(f,t;\tau) - i^*(t;\tau) = \frac{E[e(f(t+\tau)) \mid f(t)=f] - e(f)}{\tau},$$

where $i^*(t;\tau)$ is the foreign nominal interest rate or a basket of foreign rates on a pure discount foreign currency bond purchased at time t, with term to maturity τ, (that is maturing at time $t+\tau$), $\tau \geq 0$. These foreign interest rates are exogenous for a small open economy. The function $i(f,t;\tau)$ denotes the nominal interest rate on a home currency pure discount bond, purchased at time t with the fundamental $f(t)$ equal to f, and maturing at time $t+\tau$, $\tau \geq 0$.[11]

In other words, uncovered interest rate parity states that the interest rate differential equals the expected change in the log of the exchange rate (the expected depreciation until maturity) divided by the term to maturity.

Since the exchange rate and the fundamental are Markov processes, the right-hand side of (2.10) depends only on the level of the fundamental at time of purchase, f, and the term τ, not on the time of purchase of the bond, t. Therefore the interest rate differential, the left-hand side of (2.10), which will be denoted by $\delta(f;\tau)$, also depends only on f and τ. Since both sides of (2.10) are independent of the purchase time, we can set the purchase time equal to zero and define the interest rate differential as

$$(2.11a) \qquad \delta(f;\tau) = \frac{E[e(f(\tau)) \mid f(0)=f] - e(f)}{\tau}, \qquad \tau > 0.$$

The interest rate differential for instantaneous bonds, $\delta(f;0)$, will then be given by

[10]The discussion about the justification of the use of uncovered interest rate parity assumption is presented in *chapter 4*.

[11]The approximation $ln(1+i(t,\tau)) \approx i(t,\tau)$ etc. is used.

(2.11b) $$\delta(f;0) = \lim_{\tau \to 0} \delta(f;\tau) = E[de(f(t))]/dt.$$

The instantaneous interest rate differential equals the expected rate of change, the drift, of the exchange rate.

The interest rate differential for very long maturities approaches zero, since the numerator on the right-hand side is bounded,

(2.11c) $$\delta(f;\infty) = \lim_{\tau \to \infty} \delta(f;\tau) = 0.$$

Under a free float, the interest rate differential is equal to the constant expected rate of change of the exchange rate, the expected depreciation of the home currency, and it is independent of the term to maturity and the fundamental.

Under the target zone, for a term to maturity of zero, the instantaneous interest rate differential is by (2.11b) and (2.1)

(2.12) $$\delta(f;0) = [e(f) - f] / \alpha.$$

The instantaneous interest rate differential $\delta(f;0)$ coincides with the drift of the exchange rate and the expected instantaneous depreciation of the currency and it is easy to compute according to (2.12). The properties of the instantaneous interest rate differential are extensively examined in Svensson (1991c). It is decreasing in the fundamental. In the lower part of the fundamental, where the currency is strong, expectations of future interventions to increase the money supply imply expectations of a depreciation of the currency and hence a positive interest rate differential. Conversely, in the upper part of the fundamental with a weak currency, expectations of future interventions to reduce the money supply imply expectations of an appreciation and a negative interest rate differential. The instantaneous interest rate differential does not fulfill the smooth pasting conditions.

For positive terms it is more difficult to compute the interest rate differentials in (2.11a). The first step in calculating $\delta(f,\tau)$ is to find a function for the expected exchange rate at $t+\tau$

$$(2.13) \qquad h(f;\tau) = E[e(f(\tau)) \mid f(0)=f].$$

This is difficult since the exchange rate is a complicated nonlinear heteroskedastic stochastic process, with variable drift and instantaneous standard deviation. By applying the similar kind of smooth pasting condition as above the expected exchange rate can be expressed as a function of the current fundamental and the term.[12] The relationship has an S-shaped form similar to that of the relationship between the current fundamental and the current spot rate. The relationship becomes flatter and more linear as the term increases and it is horizontal for a finite term.

Given the behaviour of the expected maturity exchange rate $h(f;\tau)$, it is straightforward to compute the interest rate differential for positive terms as

$$(2.14) \qquad \delta(f;\tau) = \frac{h(f;\tau) - e(f),}{\tau} \qquad for\ \tau>0.$$

In contrast to the instantaneous interest rate differential, interest rate differentials for a positive term to maturity fulfill now the smooth pasting conditions. For positive terms to maturity the interest rate differential curves are flatter than for a term of zero, except for very short terms and in the middle of the band.
Because the exchange rate is bound to remain inside the (fully credible) band, the interest rate differential approaches zero as the term τ approaches infinity. In addition, the relationship between the current exchange rate and the interest rate differential is negative and becomes flatter as the term increases.

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[12]Svensson (1991d) shows that the function defined by (2.13) will be the solution to a so-called parabolic partial differential equation with derivative boundary conditions similar to those in equations (2.9): (2.13)' $h(f;\tau) = \eta h'(f;\tau) + ½\sigma^2 h''(f;\tau), f^L \leq f \leq f^U, \tau\geq 0$, with initial values given by $h[f(t),0] = e(f), f^L \leq f \leq f^U$, and the boundary conditions $h'(f^L;\tau) = 0$ and $h'(f^U;\tau) = 0, \tau\geq 0$.

A constant devaluation risk

So far the target zone exchange rate regime has been assumed to be perfectly credible. This assumption is clearly against the real world target zone evidence, since almost all exchange rate bands have been shifted now and then. It is, however, possible even in terms of the basic target zone model to model devaluations or revaluations. Following Svensson (1991d), the simplest way is to assume that devaluations are reoccuring with a given constant probability, regardless of where the exchange rate lies in the band.[13] This will allow a simple analytic solution of the exchange rate equation, which is analogical to Krugman's solution of fully credible exchange rate band.

It is assumed that devaluations are occuring according to a Poisson process $N(t)$ with a constant parameter $\nu>0$, meaning that during the interval dt the process will experience at least one jump equivalent to unity with a probability of νdt. The probability of no jump is $(1-\nu dt)$.

A devaluation is modelled as a simultaneous shift of the same magnitude g in the lower and upper bounds for the fundamental as well as in the money supply. Then a devaluation maintains the fundamental's position relative to the fundamental band.

The exchange rate is thus a function of the current fundamental which depends on the number of devaluations. The upper and lower bounds change according to

$$(2.15) \qquad df^L = gdN \quad \text{and} \quad df^U = gdN,$$

where dN is unity with probability νdt and zero with probability $(1-\nu dt)$. The equation (2.9a) is now given by

$$(2.16) \quad \tilde{e}[f(t),N] = f(t) + \alpha\eta_f + \alpha\nu g + A_1 exp[\lambda_1(f(t)-gN)] + A_2 exp[\lambda_2(f(t)-gN)],$$

[13]In *section 2.3* a stochastic variability on the likelihood and size of devaluation is analyzed.

and the interest rate differential, given by (2.14) is now also a function of devaluations (N),

$$\text{(2.17)} \qquad \delta(f,N;\tau) = \frac{h(f-gN;\tau) + \nu g\tau - e(f-gN)}{\tau}$$

$$= \delta(f-gN;\tau) + \nu g.$$

Hence, with a devaluation risk the only modification of the interest rate differentials is that a constant equal to the rate of expected devaluation, νg, is added to each term. Otherwise, the interest rate differentials depend on the term and the fundamental relative to the current fundamental band without any devaluation risk. In particular, for very long terms the interest rate differential does not approach zero but rather the rate of expected devaluation,

$$\text{(2.18)} \qquad \delta(f,N;\infty) = \nu g.$$

2.2.2 Empirical implications

The standard target zone model has a number of important implications. Summarizing the results above the most important testable implications are:

(i) The exchange rate is a non-linear function (S-shaped) of the fundamental and the slope is always less than one (the "honeymoon effect").

(ii) The exchange rate distribution inside the band is U-shaped, with a higher density at the edges of the band.

(iii) The conditional standard deviation of the exchange rate as a function of the exchange rate is shaped like an inverted U. That is, most of the variability should be observable in the middle of the band.

(iv) The interest rate differential should be a negative function of the current exchange rate.

(v) The term structure of the interest fluctuations should be decreasing in the term. The longer the horizon the smaller the interest rate differentials, assuming there is no drift in the fundamentals.

(vi) The estimate of the constant indicates whether there is any devaluation risk.

The non-linear relationship between the exchange rate and the fundamental implies that, while the fundamental is evenly distributed between the limits of the fundamental band, the exchange rate is more often near the edges of the band than in the middle. The asymptotic distribution of the exchange rate should, therefore, be bimodal, *ie*. U-shaped. As the exchange rate's responsiveness to the fundamental is decreasing towards the edges of the band, it follows, that the instantaneous standard deviation of the exchange rate decreases to zero at the edges of the band. The relation between the interest rate differential and the exchange rate is negative and weaker for longer maturites, because the interest rate differential is less resposive to the exchange rate for longer terms.[14] The sixth implication is made under the assumption of zero fundamental drift.

Recently there have been a number of attempts to test empirically these implications of the basic target zone model. The most stringest test using an observable proxy of the exchange rate fundamentals is performed by Flood, Rose and Mathieson (1990).[15] They studied the currencies of the six long-term participants in the Exchange Rate Mechanism of EMS using daily data. They divided the total sample (1979-1989) into 13 sub-periods corresponding to realignments in the EMS. Applying graphical methods they were able to find only a few non-linearities in the samples. Parametric tests for non-linearities

[14]The variability of the exchange rate and the interest rate differential are discussed in detail in Svensson (1991c).

[15]The proxy they use is simply : $f(t)=e(t)-\alpha[i(t)-i^*(t)]$, where the uncovered interest rate parity is assumed.

produced mixed outcomes as well. They concluded that non-linear models did not forecast exchange rate developments within the EMS better than linear models. Finally they reported both negative and positive correlations between the interest rate differential (with two days to maturity) and the exchange rate. The components left unexplained by nonlinear models were highly serially correlated, and in many cases, so large as to raise serious doubts on empirical validity of target zone models. Lindberg and Söderlind (1991) also refuted the basic target zone model on daily data for the Swedish krona.

Meese and Rose (1990) tested for the presence of non-linearities in exchange rate equations subject to a target zone, as characterized by the exponential terms in (2.9a). They tested the hypothesis that a linear model performs as well as a general non-linear alternative, the latter being estimated non-parametrically, and found only weak evidence on non-linearities. Similar results are also obtained by Diebold and Nason (1990).

A different approach was taken by Pesaran and Samiei (1991). They analysed the role of expectations and the implied non-linearities in the determination of Deutsche mark / French franc exchange rate in a discrete-time target zone model. Their empirical findings stress the importance of a proper treatment of expectations formation within a target zone regime, and also highlight the relevance of expectations in keeping the exchange rate within the band. When the information on the band is taken into account, it implies significant non-linear effects.

Another way of testing the implications of target zone models is to focus on the distributional and time series properties of observable exchange rates without quantifying a measure of the exchange rate fundamentals. As noted in the introduction, Svensson (1991d) found that Swedish data was broadly consistent with the prediction of his model, where the assumptions of infitesimal marginal interventions and a constant devaluation risk were made. But the evidence was rather weak, because the fit between theory and data was far from convincing, and a strongly serially correlated component was left unexplained in the relationship between the exchange rate and interest rate differentials.

Kontulainen, Lehmussaari and Suvanto (1990) provided similar evidence for Finnish data.

To check if the Finnish data is qualitatively consistent with the preditictions of the basic target zone model, the properties of the Finnish exchange rate and interest rate differential data is analyzed in the next section. We also update the test on the relation between the exchange rate and interest rate differential done by Kontulainen *et al.* focussing on the period January 1987 - May 1991 thus lengthening the data by about two years (daily observations). Our more recent results can be contrasted to the earlier results, which were in some sense still favourable to basic hypotheses of the first generation target zone model.

2.2.3 The Finnish evidence

Descriptive analysis

Finland has had a fixed but adjustable exchange rate system for the entire postwar period. During the Bretton Woods era the markka was pegged to the US dollar. With the collapse of the Bretton Woods system in 1973, the Bank of Finland started to peg the currency to a trade-weighted currency basket. The 1977 Currency Act formalized the unilateral basket-pegging system and introduced an explicit currency band. Since 1977 the peg has been altered twice. In 1984, the Soviet ruble was removed from the basket and thereafter the calculation of the trade-weighted index was based only on convertible currencies. At the same time the arithmetic index formula was replaced by a geometric index. In June 1991 the earlier peg was replaced by a unilateral peg to the theoretical ecu.[16]

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[16]For more details of the Finnish currency band, see Puro (1978) and (1984), Lehmussaari (1991) and Åkerholm (1992).

Although the exchange rate regime has remained formally unchanged for most of the postwar period, the role of the exchange rate and exchange rate policy have undergone profound changes. As long as capital mobility and the domestic financial markets were tightly regulated, capital movements were slow to react to changes in monetary tightness at home relative to that abroad. As a result, monetary policy had a considerable degree of autonomy, and, in addition, the exchange rate could be used as an independent instrument of economic policy. During the period of tight regulation, which in Finland lasted longer than in most OECD countries, the interest rate policy was geared mainly toward demand management and structural objectives, whereas the decisions on exchange rate policy were based mainly on the maintenance of competitiveness of the export sector.

The beginning of 1987 was chosen as a starting point in this study because approximately at that time genuine domestic money markets started to operate in Finland. The exchange rate controls had already to a large extent been relaxed and domestic money markets deregulated. This environment with free capital mobility and a properly functioning money market creates the possibility to investigate and interpret the history under the framework of the theory of target zones. Our data ends at the beginning of June 1991, when the trade weighted peg was replaced by a peg to the ecu.[17]

The data is divided in two sub-periods ("regimes"), the break-off point being the revaluation of the markka on March 17, 1989 by 4 per cent. Both periods thus have about 550 observations.

The exchange rate $e(t)$ is defined as the logarithmic percentage deviation of the currency index from the midpoint of the official band. The interest rate differential $\delta(t,\tau)$ for the term τ (1, 3, 6, and 12 months) is measured as the difference between the annualized domestic rate and the basket-weighted average of foreign Euro-currency interest rates. The width of the official band was $\pm$3 % starting on November 30, 1988. Before that the width of the band was $\pm$2,25%.

[17]Practically all estimations in this thesis were undertaken already during 1991.

Figure 2.1 shows the exchange rate and the interest rate differentials for the whole sample from January 2, 1987 to May 31, 1991. There are a few points worth noting in the diagram.

First, the interest rate differentials were always positive. Second, the exchange rate was almost all the time in the lower (stronger) half of the band. Third, there are periods when the exchange rate and the interest rate differentials seem to move in opposite directions as predicted by the basic target zone model, but is not uncommon that they move to same direction either. One characteristic feature for the Finnish data is that there are periods when the interest rate differentials have reached a remarkably high level. On these occassions, devaluation rumors have circulated and capital outflows have occurred.

Figure 2.1 Interest rate differentials (%) and the exchange rate (%-deviation from the midpoint)

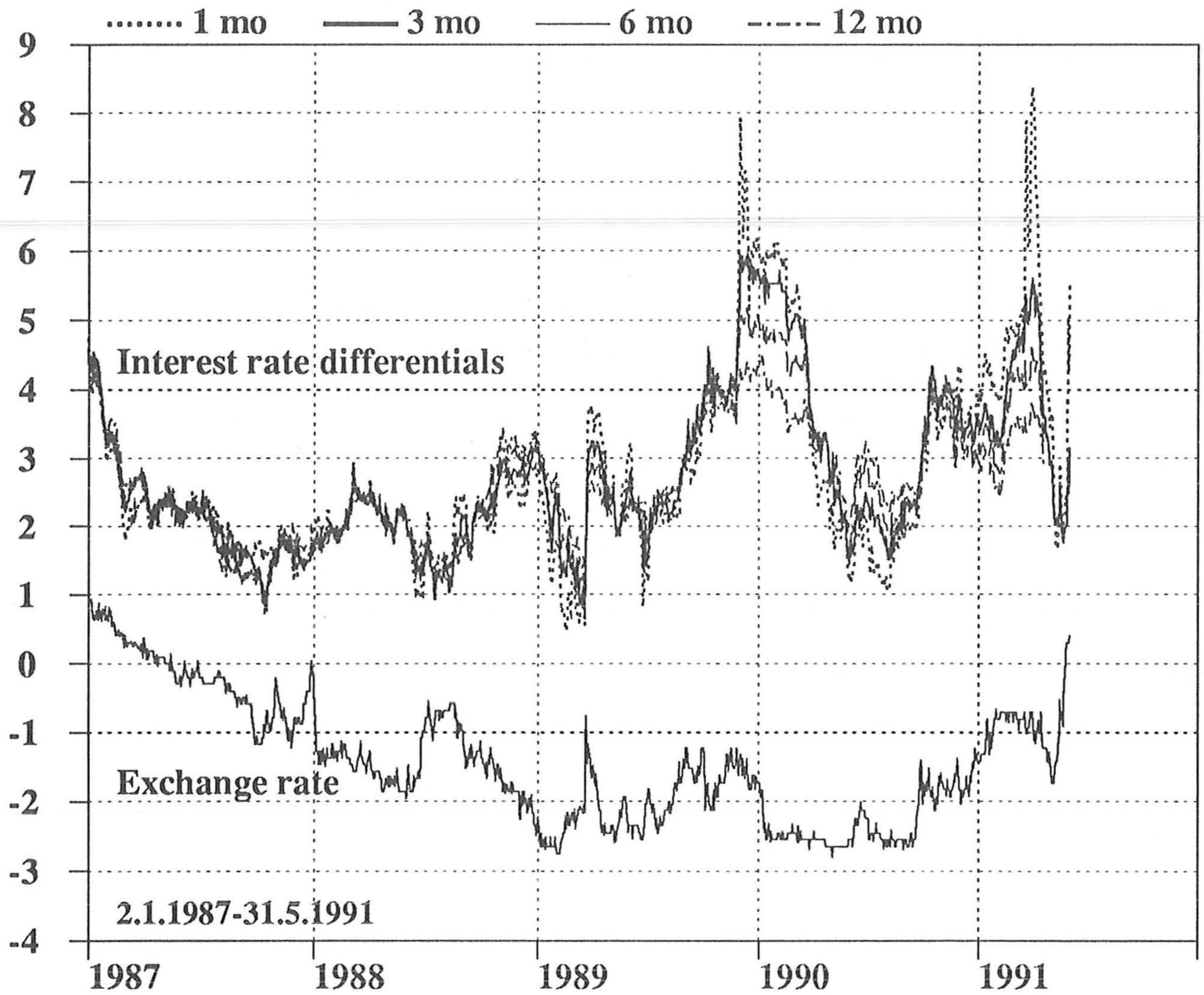


Table 2.1 a-b gives the summary statistics for the data. According to the basic target zone model, the mean of the interest rate differentials is zero in the absence of any devaluation risk. In the data, we see that the mean is positive and between 2 - 3.5 for all interest rate differentials, alerting us to the possibility of a devaluation risk.

According to the target zone theory, the band for each interest rate differential should be decreasing in the term. In the data, *table 2.1* shows that the interest rate differentials' minimum is increasing in the term, and that the maximum is decreasing in the term. Hence, the interest rate differential bands defined this way are indeed decreasing in the term. Furthermore, the unconditional standard deviation of the interest rate differential should decrease with the maturity. According to the data this happens in the second sub-period. In addition, according to *table 2.1*, the interest rate differentials are almost all positively skewed. The reason for the skewness might be that there are short periods of

Table 2.1 (a) **Summary statistics**

(2.1.87 - 17.3.89)

Variable	Mean	Std.dev	Min	Max	Skew.	Kurtosis
e	-1.10	0.89	-2.89	0.95	0.07	-0.78
$\delta(1)$	2.08	0.64	0.48	4.76	0.75	2.46
$\delta(3)$	2.12	0.66	0.73	4.57	0.92	1.68
$\delta(6)$	2.12	0.70	0.72	4.50	0.90	0.97
$\delta(12)$	2.20	0.67	0.95	4.23	0.77	0.15

Table 2.1 (b) **Summary statistics**

(20.3.89 - 24.5.91)

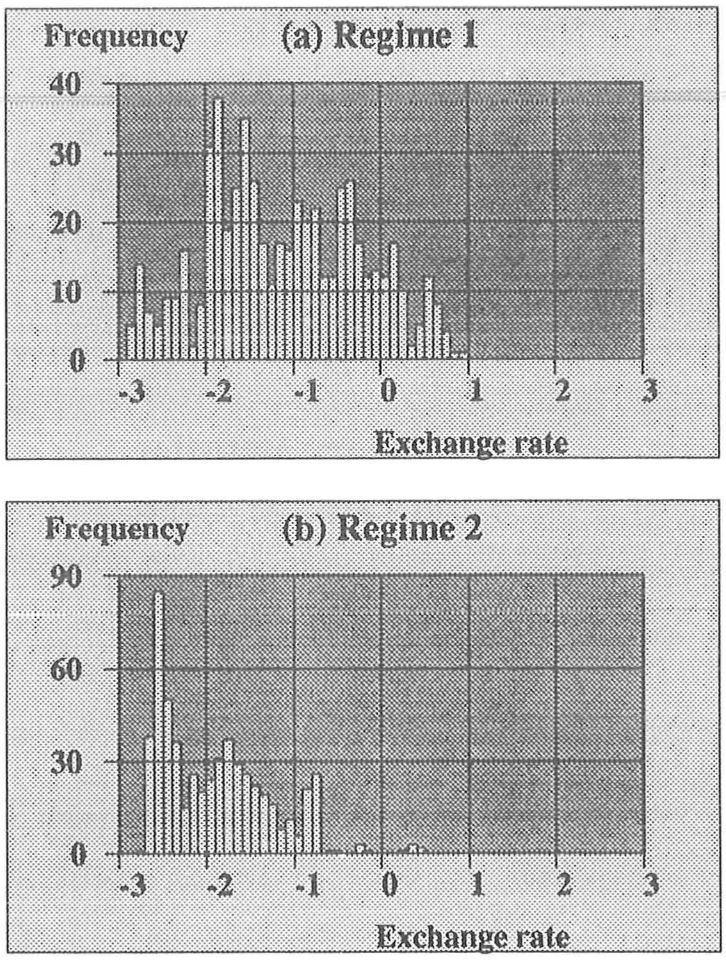
Variable	Mean	Std.dev	Min	Max	Skew.	Kurtosis
e	-1.90	0.60	-2.75	-0.20	0.55	-0.76
$\delta(1)$	3.48	1.55	0.82	8.38	0.64	-0.16
$\delta(3)$	3.40	1.19	1.38	5.92	0.44	-0.86
$\delta(6)$	3.25	0.91	1.56	5.17	0.28	-1.05
$\delta(12)$	3.07	0.65	1.67	4.47	0.14	-0.98

high devaluation expectations combined with clustering of observations with relatively low interest rate differentials.

Moreover, according to *table 2.1* the exchange rate shows no excess kurtosis at all, rather the opposite (the kurtosis is negative). In terms of the model, this implies that the fundamental process might be mean reverting. It can also be noted from *table 2.1*, that during the second sub-period, the exchange rate is clearly skewed. This could possibly be explained by an implicit band in the lower part of the official band during the period after the revaluation in March 1989 until the end of 1990, which the market participants believe has been in use.

Considering the exchange rate the theory predicts, as stated in prediction (ii), that the frequency distributions of the exchange rate should be U-shaped. In practice, these are not as illustrated in *figures 2.2a -b.*

Figure 2.2. **The distribution of exchange rate (%-deviation from the midpoint)**



In *table 2.2 a-b* correlations between the exchange rate and interest rate differentials are shown. According to *table 2.2*, the correlations are positive for both sub-periods. They are all statistically significant except for the coefficient of 12 months in regime 1. Positive correlations are clearly contradictional to the theoretical predictions.

These positive correlations can be contrasted to the negative correlations found by Kontulainen *et.al.* (1990) for Finnish data and by Svensson (1991d) for Swedish data. The periods under examination in these studies have been chosen intentionally to characterize fairly small and stable interest rate differentials, and thus the periods reflect high credibility of the exchange rate bands. The latter observation is especially true for the Swedish data.

Table 2.2 (a) **Correlation coefficients**
(2.1.87 - 17.3.89)

Variable	e	$\delta(1)$	$\delta(3)$	$\delta(6)$	$\delta(12)$
e	1.00				
$\delta(1)$	0.40	1.00			
$\delta(3)$	0.27	0.93	1.00		
$\delta(6)$	0.17	0.85	0.97	1.00	
$\delta(12)$	0.07	0.76	0.92	0.98	1.00

Table 2.2 (b) **Correlation coefficients**
(20.3.89 - 24.5.91)

Variable	e	$\delta(1)$	$\delta(3)$	$\delta(6)$	$\delta(12)$
e	1.00				
$\delta(1)$	0.44	1.00			
$\delta(3)$	0.32	0.96	1.00		
$\delta(6)$	0.26	0.89	0.98	1.00	
$\delta(12)$	0.17	0.76	0.89	0.96	1.00

Thus, expanding the data until the middle of 1991 and also including the nine first months of 1987, reverses the results from the Finnish data so that statistically significant positive correlations dominate the relationship between the exchange rate and interest rate differentials. The same type of positive correlations have been found by Lindberg and Söderlind (1991) for Swedish daily data and by Frankel and Phillips (1991) for monthly EMS data.

Estimation results

To more explicitly test the relationship between the interest rate differential and exchange rate, we have estimated the following linear approximation of the basic model (*cf.* iv-vi in section 2.2.2) as suggested by Svensson (1991,d)

$$(2.19) \qquad \delta(t;\tau) = a(\tau) + b(\tau)e(t) + \varepsilon(t;\tau).$$

According to the theory, the coefficients $b(\tau)$ are negative and increasing in the term to maturity in absolute terms. Absent fundamental drift and no interventions when the exchange rate is inside the band, the constants $a(\tau)$ should be zero if there is no devaluation risk. We take the error terms $\varepsilon(t,\tau)$ to have zero mean, but the error terms are not uncorrelated with the exchange rate, because exchange rates and interest rate differentials are endogenous and simultaneously determined. Then it is appropriate to use lagged variables as instruments for the exchange rate. We have used two lags of exchange rates and 3-month interest rate differentials as instruments for the exchange rate. Two lags worked fine in *e.g.* Svensson (1991d) and the results were not sensitive to different combinations of instrumental variables.

In addition to simultaneous-problems we have to consider that the errors are serially correlated and likely heteroskedastic, too. Therefore, we have applied the Hansen (1982) and White (1980) technique with 15 lags[18] in calculating the standard errors in order to allow for both serial correlation and heteroskedasticity in the error terms. Also a dummy-variable was set for the widening of the band

[18]The number of lags was selected by searching for the level where the increase of lags did not effect the standard errors any more.

in November, 1988, but it turned out to be statistically insignificant, so these results are not reported.

The results from the regressions are reported in *table 2.3a-b*. The estimates of the constants are all significantly positive. According to *figure 2.1*, the exchange rate fluctuated in the lower half of the official band during the whole period considered. Until the revaluation in March 1989 it seems that there has been a general tendency towards appreciation of the currency which is consistent with the interpretation that there was negative drift in the fundamentals calling for a currency appreciation. For instance, the terms-of-trade were constantly improving. Since March 1989 the exchange rate has been fairly evenly distributed in the lower part of the band, which is not inconsistent with a zero fundamental drift. Thus the estimates of the constants pre-1989 are the sum of the devaluation risk and the drift effect. If the latter term is negative, the perceived devaluation risk is higher than what was indicated in the estimated intercepts.

The fact that the exchange rate never went into the upper half of the band raises the possibility that the Bank of Finland actually defended an implicit band inside the official band, the middle point being around -2 per cent instead of zero. The implicit band seems to have been in use during the period starting in March 1989 until the end of 1990. Then the relevant estimate of the average devaluation risk is not the intercept in the middle of the official band, at a zero exchange rate, but the level of the regression lines in the middle of the inofficial band, for the exchange rate equal to -2 per cent.[19]

Under the maintained hypothesis of zero fundamental drift or a negative fundamental risk, we can therefore reject the hypothesis of no devaluation risk. But the estimates of the coefficients for the exchange rate are all of the wrong sign in terms of the theory, although they mostly are not statistically significant. The interpretation of constant devaluation expectations will thus be ruled out with these results.

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[19]These questions are discussed more thoroughly in Kontulainen *et al.*(1990).

Table 2.3 (a) **Regressions on (2.19)**
(2.1.87 - 17.3.89)

(1)	(2)	(3)	(4)	(5)	(6)
Depend.var	Const.	Coeff.	R^2	DW	AR(1)
δ(1)	2.35** (.22)	0.28 (.17)	0.16	0.06	0.9723
δ(3)	2.31** (.26)	0.20 (.19)	0.07	0.03	0.9834
δ(6)	2.25** (.29)	0.13 (.20)	0.03	0.02	0.9888
δ(12)	2.25** (.29)	0.05 (.20)	0.01	0.01	0.9929

Table 2.3 (b) **Regressions on (2.19)**
(20.3.89 - 24.5.91)

(1)	(2)	(3)	(4)	(5)	(6)
Depend.var	Const.	Coeff.	R^2	DW	AR(1)
δ(1)	5.56** (.86)	1.10* (.47)	0.19	0.06	0.9726
δ(3)	4.54** (.64)	0.61 (.37)	0.10	0.02	0.9889
δ(6)	3.97** (.49)	0.38 (.28)	0.07	0.03	0.9874
δ(12)	3.39** (.36)	0.17 (.18)	0.03	0.03	0.9839

Hansen-White standard errors are given in parentheses. The number of nonzero autocorrelations of the errors has been set to 15. Two lags of exchange rates and 3-month interest rate differentials have been used as intruments for the exchange rate. Columns (4), (5) and (6) have been computed from the residuals $\delta - \tilde{a} - \tilde{b}e$, where $\tilde{a}$ and $\tilde{b}$ are the estimates from the instrumental-variable estimation and δ and e are the actual observations. Column (6) shows the estimate of the first autocorrelation of the error terms. A * denotes significance on a 5 per cent level and ** on a 1 per cent level. The number of observations is 564 in the first and 550 in the second period.

As seen from the results, a dominating proportion of the total variability of the interest rate differentials remains unexplained by the exchange rate. A rather reasonable interpretation of these results could be that the serially correlated error terms reflect serially correlated devaluation risks. The estimates of the constants are then averages of these time-varying devaluation risks.

2.2.4 Summary

Taken together, the facts from the previous section imply that the predictions from the basic target zone model are also refuted for Finnish data. Most important, interest rate differentials are positively correlated with the exchange rate, which clearly stands in contradiction with the theory assuming a credible band. Also, the distribution of exchange rate suggests that fundamentals might be mean reverting.

There are at least three possibilities to extend the analysis of the relationship between the exchange rate and interest rate differentials under target zones.

One way could be of course to move towards nonlinear estimation to see, if the nonlinearities increase the fit between the basic target zone theory and data. However, experiments using nonlinear estimation have so far not been very promising as shown for instance by Flood, Rose and Mathieson (1990) for EMS data and also by Lindberg and Söderlind (1991) for Swedish data. In these studies there is roughly no evidence at all about the nonlinearities.

One of the weaknesses of the basic target zone model is obviously the assumption that the authorities intervene only when the fundamental reaches the edge of the band. There is substantial empirical evidence that movements of exchange rates within the the band display strong mean reversion, which may be caused, *inter alia*, by intramarginal interventions. As a matter of fact, intramarginal interventions are quite common in real world target zones.[20]

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[20]After the 1987 Basle/Nyborg Agreement, *eg*. the ERM participants moved to more flexible operational practices by accepting wider use of intramarginal interventions.

These findings have led to the development of target zone models that take intramarginal interventions into account. The implementation of potentially plausible intervention rule is, however, constrained by the fact that it is difficult, if not impossible, to find a closed form solution similar to equation (2.9) when the fundamental follows more complicated processes. As shown by Delgado and Dumas (1992), and Froot and Obstfeld (1991), such a solution can, however, be found in the case where the fundamental follows a mean reverting process. This mean reverting policy rule reduces the non-linearity (S-shape) in the relationship between the fundamental and the exchange rate and the exchange rate becomes unimodal around the reversion point (*cf.* Lindberg and Söderlind, 1992).

However, allowing the fundamental to follow a mean reverting process may not work out the empirical evidence found, that is, the positive correlation between the exchange rate and interest rate differential. The assumed negative correlation is a result from the other crucial presumption behind the basic target zone model, *ie.* the band is fully credible or at least the prevailing devaluation risk is stable over time. Thus an obvious extension to this basic model is to incorporate a time-varying devaluation risk into the model.

This is done in the following in the framework suggested by Bertola and Svensson (1991), where stochastic fluctuations in the size and/or in likelihood of devaluations are incorporated into the framework.[21] In the model, exchange rates and interest rate differentials are influenced by the current rate of expected devaluation on the one hand, and by the character of the stochastic process it follows over time on the other.

[21]See footnote 1 for other empirical devaluation models.

2.3 Modelling imperfectly credible target zones

2.3.1 Key elements of the Bertola-Svensson model

This section briefly describes the key elements of the Bertola-Svensson (1991) model in terms of the model reviewed in the previous section. Since Bertola and Svensson provide a full theoretical treatment and the technical details of the model, we refer for more detail to the original research paper.

In the previous section it was assumed that the devaluations were reoccuring according to a Poisson process with a constant probability ($\nu > 0$) meaning that during the interval dt the process will experience at least one jump equivalent to unity with a probability of νdt. This gave us a simple analytic solution of the exchange rate where the exchange rate is a function of the current fundamental depending on the number of devaluations.

The only modification of a devaluation risk to interest rate differentials was that a constant equal to the rate of expected devaluation νg was added to each term (equation 2.17).

To see the impact of allowing for stochastic variability on the likelihood and size of devaluations we need some new definitions.

As a starting point we again use equation (2.1), where the exchange rate was assumed to be a function of the fundamental and its own expected rate change in continuous time.

First, we define the process $c(t)$, which is the (log of) central parity. It is a jump process; it jumps at realignments and is constant between realignments.

Next, let

$$(2.20) \qquad e(t) \equiv x(t) + c(t), \;\; f(t) \equiv f(t) + c(t),$$

where $x(t) \equiv e(t)-c(t)$ denotes the exchange rate's log deviation from central parity and $f(t) \equiv f(t)-c(t)$ denotes the fundamental's deviation from central parity. When a devaluation occurs, the upper and lower boundaries of the exchange rate fluctuation band are redefined and the central parity, the exchange rate and the fundamental undergo a discrete change.

Then we denote the size of the exchange rate jump if a devaluation occurs at time t with $z(t)$. It is convenient to assume that $z(t) = dc$, which means that the jump in the exchange rate is equal to that in central parity so that thc cxchange rate's position within the band is unchanged by a realignment, although this need not to be the case.

A devaluation resulting in a exchange rate jump of a random size $z(t)$ occurs with a probability of $\nu(t)dt$ in a time interval of infinitesimal length dt, while no devaluation occurs with probability $1 - \nu(t)dt$. Because risk neutrality and instantaneous equilibrium are assumed as before, only the expected size of the exchange rate jump associated with a realigment in the next instant has a bearing on exchange rate determination. An expected rate of the devaluation process $g(t)$ is then defined as

(2.21) $$g(t) = (1/dt)(\nu(t)E_t[z(t)]dt) = \nu(t)Z(t),$$

where $Z(t) = E_t[z(t)]$.

If either or both of $Z(t)$ and $\nu(t)$ fluctuate stocastically over time, so does $g(t)$. In the Bertola-Svensson framework it is assumed that $g(t)$ follows a Brownian motion process, allowing a possibly nonzero correlation between its increments and those driving the process of the fundamentals $f(t)$.

Ruling out bubbles, the exchange rate and the expected rate of depreciation can then be written for given parameters and given target zone boundaries as functions of the two state variables, f and g. The presence of multiple state variables would typically make it difficult or even impossible to solve a nonlinear forward-looking model. In this case, the equation (2.1) and the presence of target zone limits for exchange rate fluctuations impose strong restrictions on the joint probability distribution of exchange rates and expected depreciation rates and, consequently, on the shape of the function. In this model, the expected depreciation rate is the sum of two components: the expected depreciation rate within the band, denoted $E_t[dx]/dt$, and the expected rate of devaluation, $g(t)$. Thus we can write

(2.22) $$E_t[de(t)]/dt = E_t[dx(t)]/dt + g(t).$$

Substitution (2.22) into (2.1), together with (2.20), allows us to write

(2.23) $$\begin{aligned} e(f,g) &= f(t) + \alpha g(t) + \alpha E_t[dx(t)]/dt \\ &= f(t) + \alpha g(t) + \alpha E_t[dx(t)]/dt + c(t) \\ &= x(f,g) + c(t), \end{aligned}$$

where $x(t)$ hence depends only on f and g. We can then define the new state variable

(2.24) $$k(t) \equiv f(t) + \alpha g(t)$$

and note that, by assumption $k(t)$ is a Brownian motion process with differential

(2.25) $$dk(t) = \eta dt + \sigma dW(t), \text{ where}$$

$$\eta \equiv \eta_f + \alpha\eta_g \quad and \; \sigma \equiv \sqrt{\sigma_f^2 + \alpha^2\sigma_g^{\,2} + 2\alpha\rho\sigma_f\sigma_g}\,,$$

so η is the instantaneous total mean drift, σ^2 is the variance and ρ is the possibly nonzero correlation between the processes of the fundamental and devaluation.

Thus the exchange rate determination is reduced to a single state variable problem, and we can write (2.23) as

(2.26) $$\begin{aligned} x(f,g) &= (f(t) + \alpha g(t)) + \alpha E_t[dx(t)]/dt \\ &= k(t) + \alpha E_t[dx(t)]/dt. \end{aligned}$$

Now, equation (2.26) has the same form as (2.1). The solution for (2.26) will be identical to the Krugman solution to (2.1) except that the exchange rate within the band $x(t)$ and the now composite fundamental $k(t)$ have been replaced the total exchange rate $e(t)$ and the fundamental $f(t)$ in (2.1).

Bertola and Svensson also derive the implications of stochastic devaluation risk for the instantaneous interest rate differentials and for the term structure of interest rate differentials. In particular, they study the correlation between exchange rates and interest rate differentials.

It turns out that almost any pattern of exchange rate and instantaneous interest rate differential observation can result when both the fundamentals and the expected rate of depreciation fluctuate over time. If the relative variablity of the expected rate of devaluation g is low to that of the fundamental, most of the variablity of the state variable k is due to variations in the fundamental f and the analysis yields the standard prediction of a negative correlation between $e(t)$ and $E_t[de(t)/dt]$ and thus also with interest rate differentials. If instead the relative variability of the expected devaluation is high, most of the variability of the state variable k (and hence of the exchange rate) is due to variations in g. The increase in g spurs a rise in the exchange rate as well and a positive correlation between exchange rates and interest rate differentials might emerge.

To clarify the above argument, the instantaneous covariance between the exchange rate and the instantaneous interest rate differential ($\sigma_{e\delta}$) can be written as

$$(2.27) \qquad \sigma_{e\delta} = ((\sigma_f^2 + \alpha^2\sigma_g^2 + 2\alpha\rho\sigma_f\sigma_g)\delta'(k) + \rho\sigma_f\sigma_g + \alpha\sigma_g^2)x'(k).$$

If $\sigma_g = 0$, this reduces to $\sigma_{e\delta} = \sigma_f^2\ \delta'(k)\ x'(k) < 0$. Conversely, if $\sigma_f = 0$, we have $\sigma_{e\delta} = \alpha(\alpha\delta'(k)+1)\ x'(k)\sigma_g^2 = \alpha\sigma_g^2(x'(k))^2 > 0$.[22]

[22]This holds since that the exchange rate is increasing in the fundamental ($x'(k) > 0$) and the interest rate differential for a zero expected rate of devaluation is decreasing in the fundamental ($\delta'(k) < 0$).

Bertola and Svensson argue that this might explain some of the apparent inconsistencies in the empirical literature discussed previously. The relative variablity of the expected rate of devaluation has been low during those periods the negative correlaton between interest rate differentials and exchange rates has been observed.

In addition to these results concerning implications of the devaluation risk for the instantaneous interest rate differentials Bertola and Svensson also investigate the implications for the finite-maturity interest rate differentials as well for the shape of the differential yield curves. They show that with regard to the correlation between interest rate differentials and the exchange rate the sensitivity of the interest rate differentials to the exchange rate for given levels of $g(t)$ decreases with longer maturities. For instance, if the exchange rate is positively correlated with $g(t)$, it is possible that the correlation between interest rate differentials and exchange rates is negative or slightly positive for short maturities, positive for intermediate maturities, and close to zero for longer maturities.

As a summary, we can conclude that while a good 'fit' of a target zone model does not require perfect credibility of the band, it does require that the devaluation risk has to be fairly stable over the sample period. In the Bertola-Svensson framework, credibility is imperfect, and furthermore the devaluation risk is time-varying; there is then no general implication for the relationship between the exchange's rate position within the band and its expected rate of change. Even though the expected rate of currency depreciation within the band is negatively correlated with the exchange rate within the band, depending upon how the expected rate of realignment fluctuates over time and is correlated with the exchange rate, any correlation pattern between the interest rate differential and exchange rate is possible.

2.3.2 Inferring devaluation risk from target zone data

In the model of Bertola and Svensson, exchange rates and interest rate differentials are endogenous and jointly determined by fluctuations in fundamentals and devaluation risks. The parameters could be estimated in a variety of ways. However, it is also possible to infer devaluation risk from the target zone data using an empirical method suggested by Bertola and Svensson without actually testing the model. Before turning to the data, we briefly outline this method we also are going to use to investigate the Finnish data.

The analysis relies once again on the assumption of uncovered interest rate parity, which implies that the interest rates differential reflects the total expected rate of exchange rate depreciation. If the uncovered interest rate parity holds, we can split the total expected rate of depreciation of a currency into two components: the expected rate of depreciation of the currency within the exchange rate band, and the expected rate of devaluation. Given an estimate of the expected rate of depreciation within the currency band, an estimate of the expected rate of devaluation can be found by subtracting the estimate of the expected rate of depreciation within the band from the interest rate differential.

Let $\delta(t) = i(t)-i^*(t)$ denote the home country's observable interest rate differential at time t. The uncovered interest rate parity is then expressed over a *finite* time interval Δt as

$$(2.28) \qquad \delta(t,\Delta t) = E_t[\Delta e(t)]/\Delta t,$$

where E_t again denotes expectations conditional upon information available at time t and $\Delta e(t) = e(t+\Delta t)-e(t)$. That is, the interest rate differential reflects the expected average rate of depreciation of the home currency during a time interval corresponding to the maturity.

The total expected rate of depreciation is divided into two components as defined in the previous section: the expected rate of depreciation of the exchange rate within the exchange rate band, and the expected rate of change of the central parity

$$(2.29) \qquad E_t[\Delta e(t)]/\Delta t = E_t[\Delta x(t)]/\Delta t + E_t[\Delta c(t)]/\Delta t.$$

As assumed previously, during the next small time interval Δt the central parity remains constant with a probability of $1 - \nu(t)\Delta t$, whereas it experiences a jump of independent random size $z(t)$ with a probability of $\nu(t)\Delta t$. It follows that the expected change in central parity can be written as

$$(2.30) \qquad \begin{aligned} E_t[\Delta c(t)] &= (1 - \nu(t)\Delta t)*0 + \nu(t)\Delta t E_t[z(t)] \\ &= \nu(t)\mathfrak{z}(t)\Delta t, \end{aligned}$$

where $\mathfrak{z}(t) = E_t[z(t)]$ denotes the expected size of the realignment (positive if a devaluation is expected, negative if a revaluation is expected). Thus the expected rate of realignment is a product of the probability intensity of a realignment (the probability per unit of time) and the expected size of a realignment:

$$(2.31) \qquad E_t[\Delta c(t)]/\Delta t = \nu(t)\mathfrak{z}(t).$$

It is important to notice that the term "devaluation" is used to mean the actual jump in the exchange rate at the time of a realignment, as opposed to "realignment" which denotes the jump of the mid-point of the official band. The size of the devaluation will differ from the size of the realignment if the exchange rate's relative position within the band $x(t)$ changes in conjunction with the realigment.[23]

Now, for simplicity, assume that the position of the exchange rate within the band remains the same immediately before and immediately after a realignment.[24] Remembering that $g(t)$ denotes the expected rate of devaluation,

[23] *E.g.* the exchange rate can be in the upper (weak) half of the band immediately before the realignment and near the lower (strong) edge of the band immediately after a realigment. In that case the size of the devaluation is less than the size of the realignment.

[24] To relax this assumption, see Svensson(1991a).

we may identify the expected rate of devaluation with the expected rate of realignment:

$$(2.32) \qquad g(t) = E_t[\Delta c(t)]/\Delta t.$$

It follows that we may express the expected rate of devaluation as the difference between the interest rate differential and the expected rate of depreciation within the band,

$$(2.33) \qquad g(t) = \delta(t,\Delta t) - E_t[\Delta x(t)]/\Delta t.$$

Equation (2.33) has obvious empirical implications. Even though the expected rate of devaluation is not directly observable, it can be extracted from the data if one forms an estimate of the expected rate of depreciation within the band and then subtracts this estimate from the interest rate differential. So, the interest rate differential as a function of the exchange rate within the band corresponds to the expected rate of depreciation shifted up by the expected rate of devaluation.

As can be seen from expression (2.33), the clue in finding devaluation expectations is the estimation of the expected future exchange rate within the band, $E_t[x(t+\Delta t)]$, which is of course equivalent to the estimation of the expected rate of depereciation within the band $E_t[x(t+\Delta t)-x(t)]/\Delta t$.

2.3.3 Estimation of devaluation expectations[25]

Estimation of Expected Future Exchange Rates within the Band

Lindberg, Svensson and Söderlind (1991) discuss possible assumptions concerning the expected rate of depreciation within the band. Following these authors, it is possible to have at least three alternative simple assumptions about

[25]The tentative results of this section are presented in Pikkarainen and Vajanne (1992), where the credibility of Finland's basket peg exchange rate regime in 1977-1991 is discussed.

the expected rate of depreciation within the band:

(i) The exchange rate within the band is a martingale, *ie.* $E_t x(t+\Delta t) \equiv x(t)$, which implies a zero expected rate of depreciation within the band, $E_t[x(t+\Delta t)-x(t)]/\Delta t \equiv 0$. Then the expected total rate of depreciation in equation (2.29) is equal to the expected rate of realignment. Thus, the interest rate differential can be used as a *direct* quantitative estimate of the expected rate of devaluation.

(a) $g(t) = \delta(t).$

(ii) Market agents have perfect foresight about the exchange rate movements within the band, *ie.* $E_t x(t+\Delta t) \equiv x(t+\Delta t)$, which implies $E_t[x(t+\Delta t)-x(t)]/\Delta t \equiv [x(t+\Delta t)-x(t)]/\Delta t$.

Then the expected rate of devaluation fulfils

(b) $g(t) = \delta(t) - [x(t+\Delta t)-x(t)]/\Delta t,$

and the interest rate differential adjusted for the actual *ex post* rate of depreciation for the band can be used as a quantitative estimate of the expected rate of devaluation.

(iii) The exchange rate within the band reverts to the middle of the band, *ie.* $E_t[x(t+\Delta t)] \equiv 0$, which implies $E_t[x(t+\Delta t)-x(t)]/\Delta t \equiv - x(t)/\Delta t$. The expected rate of depreciation within the band is a decreasing function of the exchange rate within the band and the expected rate of devaluation fulfils

(c) $g(t) = \delta(t) - x(t)/\Delta t,$

and the interest rate differential adjusted for this mean reversion of the exchange rate within the band is a quantitative estimate of the expected rate of realignment.

Empirically, floating exchange rates are normally found to behave like a random walk, a special case of a martingale, see *e.g.* Meese and Rogoff, 1983. However, exchange rates within bands cannot literally be random walks because of the boundaries. It is more natural thus to assume that exchange rates inside the band display mean reversion, which is induced by the exchange rate band as discussed previously. At the lower edge of the band the exchange rate cannot appreciate any further; it can only remain constant or depreciate back into the band. Hence there is a positive expected depreciation. Conversely, at the upper edge of the band, the exchange rate cannot depreciate any further; it can only remain constant or appreciate back into the band. Hence there is negative expected depreciation.

In the Bertola-Svensson model the single determinant of the expected future rate of depreciaton within the band is the current exchange rate within the band, $x(t)$. In addition, although in principle the relation between the expected rate of depreciation within the band and the current exchange rate is non-linear, Bertola and Svensson suggest that a linear approximation may be acceptable for typical parameters. This simple projection model has been estimated *e.g.* in Frankel and Phillips (1991), Rose and Svensson (1991) and Svensson (1991a) for EMS-currencies and in Holden and Vikøren (1992) and in Lindberg, Svensson and Söderlind (1991) for different Nordic currencies.

Thus we decided to estimate the simplest model of the expected rates of depreciation within the band as the following linear regression

$$(2.34) \qquad [x(t+\Delta t)-x(t)] \;/\; \Delta t \;=\; \beta_0 + \beta_1 x(t) + \varepsilon_1(t+\Delta t)$$

where by rational expectations the expected mean of the error terms is assumed to be zero and errors are uncorrelated with the exchange rate. The time interval Δt is set to 1/12 and 3/12 years corresponding to 22 and 66 days. We use the same data as previously. The data is, however, now divided into three subperiods; before and after the revaluation of the markka, on March 17, 1989, as before, plus between October 1, 1987 and December 31, 1990, which characterizes quite a stable period in the exchange rate. The exchange rate fluctuated in a narrow band near the strong edge of the official band and Bank of Finland was not intervening actively during those years.[26] A dummy-variable is set for the widening of the band on November 30, 1988 as well as for the revaluation day on March 17, 1989.

As can be seen from the above expression, the residuals will be serially correlated, which follows from the fact that overlapping time-periods are used[27]. In addition to the "overlapping problem", which arises when the sampling horizon is shorter than the forecasting horizon, the estimation is complicated by possible heteroskedasticity of error terms. We have chosen to use the OLS estimation method, but compute Newey-West (1987) standard errors which allow for heteroskedastic and serially correlated error terms. Since the observations are overlapping by 22 and 66 days, the number of lags in the error covariance matrix are set equal to each maturity.

Using OLS we implicitly assume, however, that the estimated expected future exchange rates within the band are asumptotically normally distributed. Nevertheless, we know that the estimated expected future exchange rate within the band cannot fall outside the exchange rate band and that the conditional distribution is likely to have a non-normal shape within the band.[28] The non-normal distribution may to some extent be taken into account by the heteroskedasticity-consistent estimate of the covariance matrix[29].

Rose and Svensson (1991) consider a number of different estimation methods, functional forms, and explanatory variables for the French franc / Deutsche mark exchange rate. The different cases examined include as explanatory variables the exchange rate within the band as well as its square and its cube, lagged

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[26]A study on the effects of Bank of Finland's interventions to the exchange rate within the band is provided by Lehmussaari, Suvanto and Vajanne, 1992.

[27]For more details on the overlapping problem, see Hansen and Hodrick (1980).

[28]For other possibilities to model the future exchange rate within the band see *e.g.* Chen and Giovannini (1992a) and Rantala (1992). In these models the restrictive implications of the distribution of the exchange rate within the band are avoided.

[29]A detailed discussion of problems connected to the error terms and comparisons of different estimations methods feasible for this type of data is presented in Lindberg *et. al.*(1991).

exchange rates within the band and other ERM cross rates.

Lindberg, Svensson and Söderlind (1991) also estimate the expected future exchange rate with different estimation methods in addition to OLS (with Newey-West standard errors) like recursive least squares (RLS) with a moving window of fixed length, which allows for parameters changing gradually over time. Second, they use GARCH to allow for conditional heteroskedasticity of error terms, with and without a moving average adjustment. Thirdly, they use a nonparametric method, locally weighted regression (LWR), which allows for arbitrary non-linearity. Fourthly, they use an autoregressive method in order to handle the serial correlation of the residuals.

All these results combined indicate that a simple linear regression of realized rates of depreciation within the band on the current exchange rate consistently generates sensible results, whereas more elegant techniques sometimes generate unreasonable results.

Estimating the expected future exchange rate depreciation within the band is equivalent to estimating the expected future exchange rate within the band with an autoregressive model

(2.35) $$x(t+\Delta t) = \mu_0 + \mu_1 x(t) + \varepsilon_2(t+\Delta t)$$

where the coefficients and error term are related by $\mu_0=\beta_0\Delta t$, $\mu_1= \beta_1\Delta t+1$, and $\varepsilon_2(t+\Delta t) = \varepsilon_1(t+\Delta t)\Delta t$.

In terms of equation (2.35) it is possible to see the mean-reversion effect in the data. In the mean-reverting case $0 < \mu_1 < 1$. It should be decreasing when the horizon is lengthed indicating more mean reversion. For sufficiently long maturities the expected rate of depreciation within the band must be approximately zero, since the maximum amount of the depreciation within the band is bounded by the width of the band and then divided by a long maturity. The reversion point is $\mu_0^* = \mu_0/(1-\mu_1)$. This property may result from mean-reversion in the fundamental, which, in turn, may reflect systematic policy rules applied by the authorities. For instance, if the central bank aims at the mid-point of the band ($\mu_0^* = \mu_0 = 0$) and intervenes accordingly, though stochastically, the exchange rate and thereby its expectation tend to move in that directions (cf. Lindberg and Söderlind, 1992). It is important that the intervention point is inside the band. If the exchange rate path is a random walk, which would be assumed in the free floating case, μ_1 would be equal to 1, and the equation would have a unit root. The exchange rate could, in principle, wander beyond the band boundaries, and the expectation could not be anchored to any reversion point. Equation (2.35) is unstable if $\mu_1 > 1$, in which case the expected depreciation could just as easily go beyond the band boundaries.

Table 2.4 a-b shows the result of OLS estimation on (2.35) for Δt set to one and three months for the main two sub-periods. The results are satisfactory in a number of respects. The intercept with respect to exchange rates expected in one month for the first subperiod is -0.26 and for the second subperiod it is -0.48. For the three-month horizon they are in the range from -0.6 to -0.9. The mean reversion captured by the coefficient β is in the range from 0.7 to 0.8 for the one-month horizon and for the three-month horizon the slopes are in the range from 0.5 to 0.7. The slopes are all statistically significant and they also are decreasing in size the longer the forecast horizon considered. The "t-values" for the coefficients being less than unity, however, vary in the range -1.5 to -2.7, which does not allow us to reject the hypothesis of a unit root. (The critical level for the Dickey-Fuller test on a 5 % significance level is -2.87 for this sample size; *cf.* Fuller, 1976, Table 8.5.2.

The computed reversion point of the exchange rate, $\mu^*=\mu_0/(1-\mu_1)$, is in the range of -1.5 to -2.6 per cent (below the mid-point). The widening of the band in 30 November 1988, lowers the reversion point by about 0.75 percentage points, which effect is captured by the dummy. There is a notable decrease in the R^2 in the second subperiod for the three-month horizon. The reason might be that second subperiod is characterized with highly fluctuating expectations of exchange rates within the band compared to the first subperiod.

Table 2.4. Expected Future Exchange Rate within the Band

(a) Period 2.1.87 - 17.3.1989

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depend.var.	Const.	Coeff.	D1	μ*	R^2	σ	DW
x(t+22)	**-0.26****	**0.82****	**-0.20**	**-1.45**	0.81	0.37	0.13
	(0.06)	(0.07)	(0.25)	**-2.56D**			
x(t+66)	**-0.60****	**0.71****	**-0.10**	**-2.09**	0.53	0.52	0.06
	(0.11)	(0.19)	(0.38)	**-2.44D**			

(b) Period 20.3.89 - 15.5.1991

	(1)	(2)	(3)	(4)	(5)	(6)
Depend. var.	Const.	Coeff.	μ*	R^2	σ	DW
x(t+22)	**-0.48****	**0.74****	**-1.87**	0.53	0.40	0.14
	(0.22)	(0.09)				
x(t+66)	**-0.87**	**0.50***	**-1.72**	0.17	0.55	0.06
	(0.55)	(0.22)				

(c) Period 1.10.87 - 31.12.1990

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depend. var.	Const.	Coeff.	D1	μ*	R^2	σ	DW
x(t+22)	**-0.63****	**0.56****	**-0.28**	**-1.43**	0.54	0.41	0.13
	(0.15)	(0.12)	(0.17)	**-2.05D**			
x(t+66)	**-1.43****	**0.13**	**-0.38**	**-1.64**	0.22	0.48	0.07
	(0.19)	(0.20)	(0.39)	**-2.08D**			

OLS on (2.35) with Newey-West standard errors within parentheses (lags equal to each maturity). D1 is the dummy for the widening of the band. μ* is the computed reversion point without and with the dummy. σ is the standard deviation of the residuals. A * denotes significance on a 5 per cent level and ** on a 1 per cent level.

These results of the two main sub-periods can be compared to the third, overlapping period, which results are shown in *table 2.4 c*. Since the revaluation dummy did not have any effect, the estimation results are reported without the dummy. This period is characterized by rather stable development in the sense that the exchange rate stayed almost all the time in a narrow band (about $\pm$ 0.75 per cent) near the strong edge of the band. The results are reasonable in this case too. The computed reversion point lies in range to -1.5 to -2 per cent, and the slopes show clear mean reversion towards the reversion point.

According to the results it appears that as regards the recent Finnish exchange rate target zone, the current level of the exchange rate gives a reasonable linear prediction of its own future change. As a further check, we also estimated some alternative specifications.

First, the square and cube of the exchange rate were added to the basic equation to capture non-linearities in the relationship between expected future and the current exchange rate. Second, the lagged values (5 lags) of the exchange rate were included. Furthermore, the interest rate differential was included.[30] However, these variables did not improve the simple linear approximation, while the new terms added were statistically not different from zero.

In addition, we also estimated models for the unofficial band which the Bank of Finland used after the revaluation in March 1989 until the end of 1990. The limits of this implicit band within the official band were deemed to be 96.5 and 98.0. The results of these estimations were not very different from those for the official band; the intercepts shifted towards zero but the slopes remain about the same.

Hence we decided to use the estimation results of equation 2.34 to calculate the expected future exchange rate and thereby the expected rate of depreciation.

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[30]In Bertola-Svensson model the assumption that the current exchange rate is the only determinant of the expected rate of depreciation within the band requires the assumption of constant parameters of the exogenous stochastic processes of the fundamental and the interest rate differential. If that assumption does not hold, the interest rate differential may also affect the expected rate of depreciation within the band.

The expected future exchange rate with 95 per cent confidence intervals is depicted in *figure 2.3*. As shown in *figure 2.3,* the estimated expected future exchange rate is always within the band. Furthermore, an important issue is to examine whether confidence intervals for expected future exchange rate always fall within the exchange rate band. If this is not the case, the estimation method may have to be modified to explicitly take into account the restrictions the band limits impose, for instance along the line suggested by Chen and Giovannini (1992a).[31] In our case this seems to be the case except only for some shorter periods and even in these cases the lower interval follows the lower border of the band quite closely.

The estimated expected rates of depreciation within the band, conditional there being no realignment, are now easily calculated according to expression (2.34)

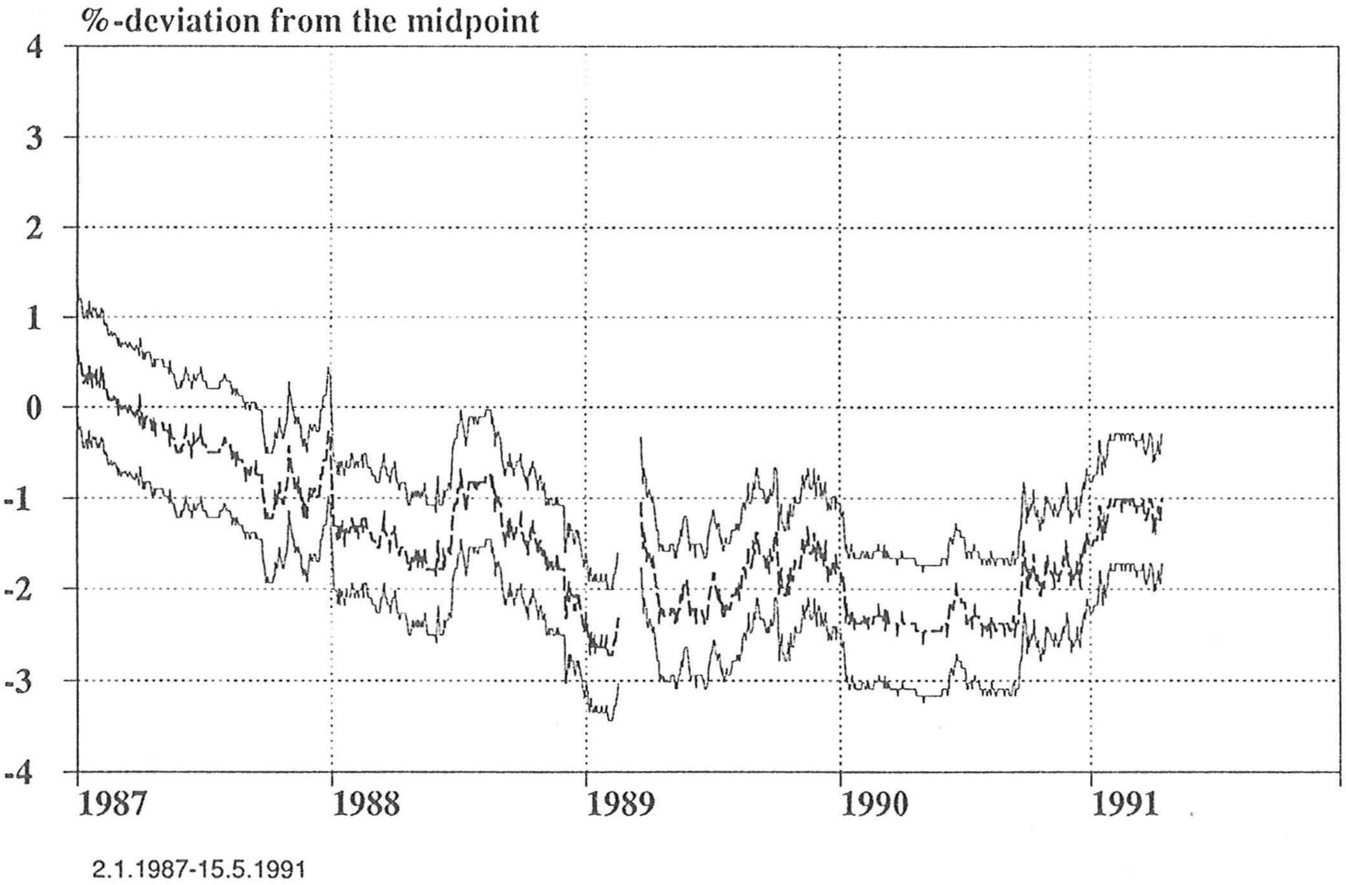
$$(2.36) \qquad \hat{E}_t[x(t+\Delta t)-x(t)] \,/\, \Delta t = [\hat{\mu}_0 + (\hat{\mu}_1-1)x(t)]/\Delta t,$$

where a hat (^) denotes estimates of the parameters μ_0 and μ_1 in 2.35.

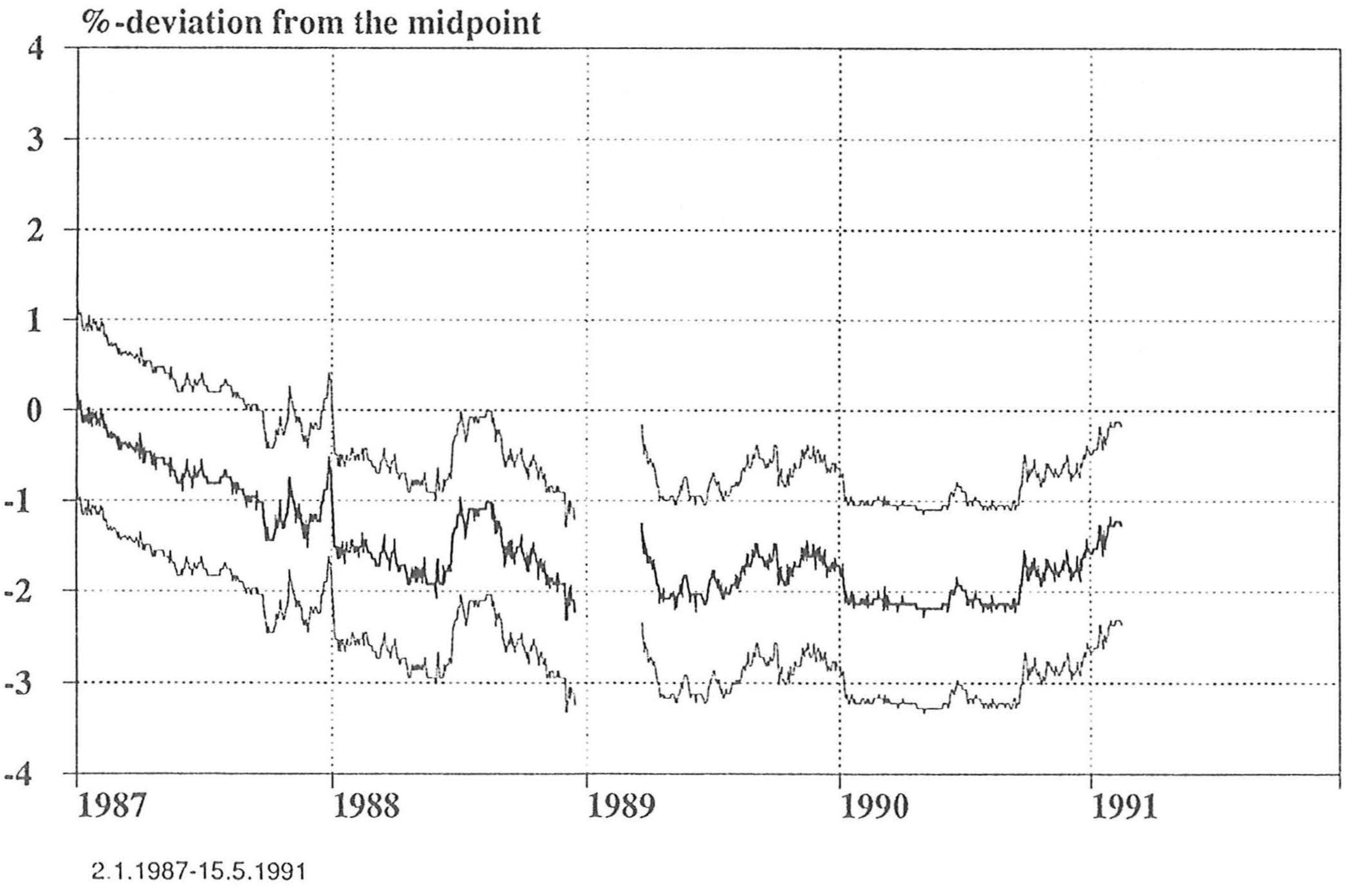
Comparing our results to those estimated for the EMS currencies in Svensson (1991a) and to those estimated for the Swedish krona in Lindberg *et al.* (1991). the estimated slopes for the expected rate of depreciation within the band are rather similar in magnitude for Finnish, Swedish and EMS exchange rates. The feature that the markka has been almost all the time near the strong edge of the band indicating a high negative intercept is not found in the EMS data (*vis à vis* D-mark), where the intercepts are typically positive. The estimated coefficients in Frankel and Phillips (1991) for monthly data are clearly smaller in size, but in all cases they are negative as were our estimates.

[31]Chen and Giovannini argue that the use of OLS is problematic both conceptually and empirically. Conceptually, the band restriction is publicly available information, and therefore falls into agents' information set and rational agents can exploit the information to predict the future exchange rate. Ignoring them introduces a correlation between information and surprises which is not exploited by agents if they use simple OLS projections, and therefore implies a deviation from the rational expectations hypothesis. Emprically they show that since the error term is regulated by the band, its conditional distribution depends on the value of the independent variable at time t and it is thus neither identically distributed nor uncorrelated with the regressor. Estimation with the methodology they suggest could surely give interesting results to be compared with outcomes derived here. This promising augmentation is, however, left for future research.

Figure 2.3 (a) Expected future exchange rate and 95 % confidence interval (1 mo)



(b). Expected future exchange rate and 95 % confidence interval (3 mo)



Estimates of Expected Rate of Devaluation

In accordance with equation (2.33) the expected rates of devaluation can now be estimated by subtracting from each observed interest rate differential the corresponding estimate of the expected rate of depreciation within the band. That is, the expected rate of devaluation is given by

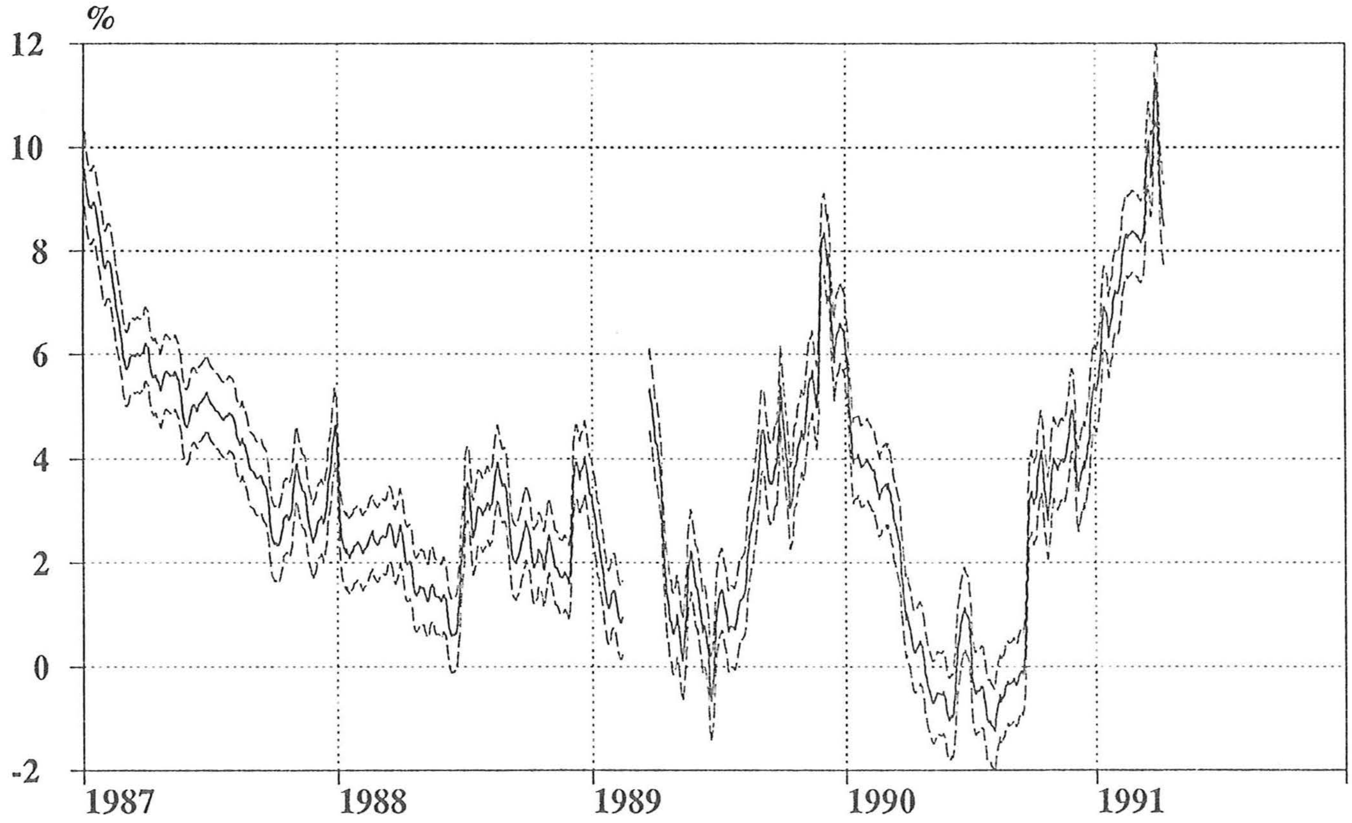
$$(2.37) \qquad \hat{g}(t) \equiv [\nu(t)z(t)] \equiv \delta(t) - [\hat{\beta}_0 + (\hat{\beta}_1 - 1)x(t)]/\Delta t.$$

The resulting point estimates and the 95 per cent confidence intervals of the expected rates of devaluation as a time-series (5 days moving averages) are shown in *figure 2.4*. The confidence intervals are computed under the assumption that the estimated coefficients in *table 2.4* are asymptotically normal. It is likely that the confidence intervals could be narrowed by explicitly using a truncated distribution when estimating the expected exchange rates within the band.

As expected, the estimated expected rates of devaluation are highly correlated with the interest rate differential, but they are not identical to the interest rate differentials. There are several situations where the expected rate of devaluation differs from that implied by the interest rate differentials. The interest rate differentials are always positive, but the expected rates of devaluation fluctuate much more, and occasionaly indicate zero or even negative expected rate of devaluation (that is, a positive expected rate of revaluation). As an example, during the summer 1990 the actual interest rate differential was as low as 1 percentage point and the expected rate of depreciation of the markka within the band was around 2 per cent. Thus the expected rate of revaluation was around 1 per cent.

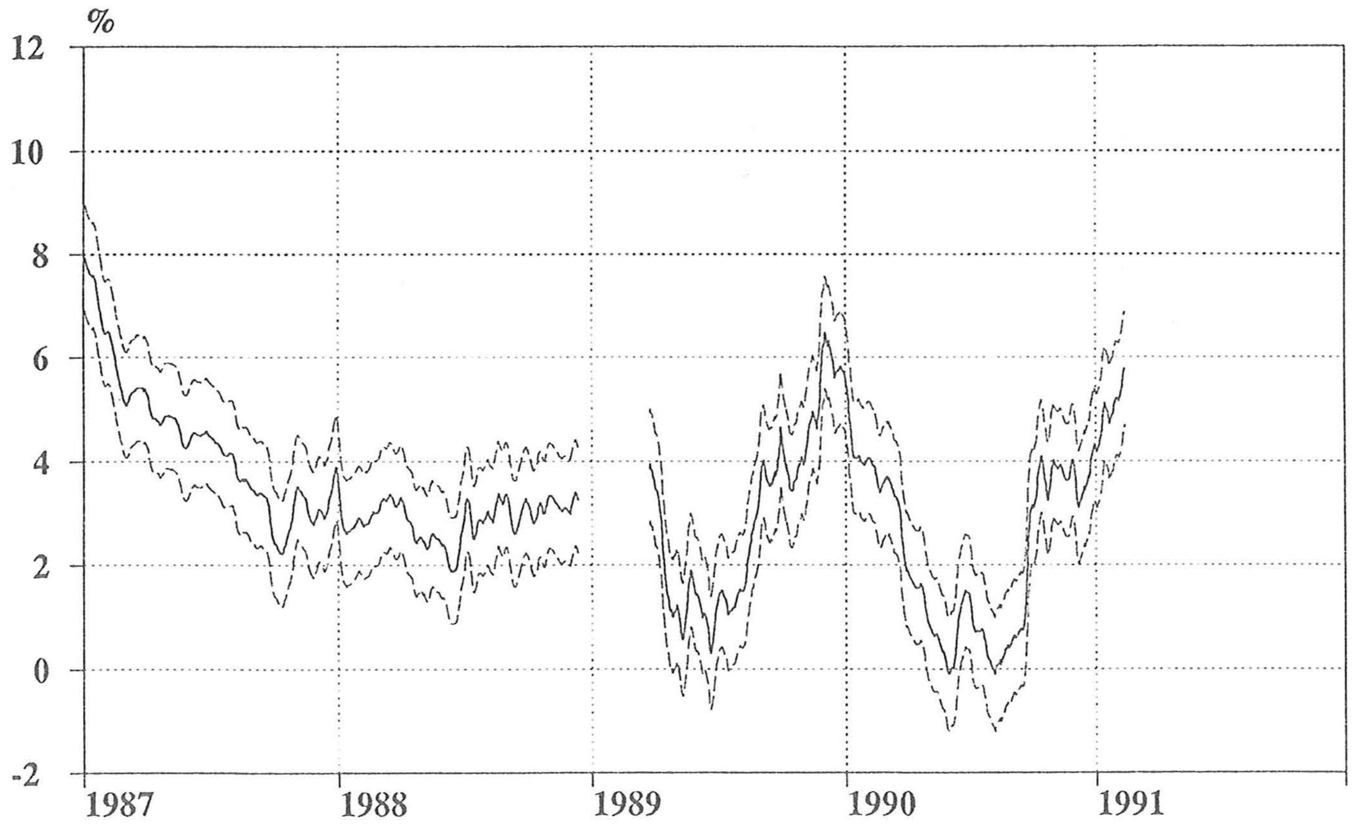
The peaks of the expected rate of devaluation correspond to those of the interest rate differentials except that they are around 2 percentage points higher in magnitude. The peaks in the second subperiod are identified with the uncertainty connected to announcements of the budget (*e.g.* in autumn 1989 and 1990) and also to the results of wage negotiations which take place usually in late autumn. Also the Parliamentary elections in spring 1991 caused high devaluation

Figure 2.4 (a) Devaluation risk, 1 mo, % per annum



2.1.1987-15.5.1991, 5 days moving average

(b). Devaluation risk, 3 mo, % per annum



2.1.1987-15.5.1991, 5 days moving average expectations. The average expected rates of devaluation are around 3.5 per cent for the first subperiod and slightly less than 3 per cent for the second subperiod. The typical 95 per cent confidence intervals for the rate of devaluation are ± 2 per cent.

It might be a bit surprising that the devaluation expectations are rather dominant during the whole period under investigation and especially already in autumn 1989 and early 1990 since the economy was still overheating causing no apparent pressure towards devaluation and since there was plenty of room also for the exchange rate depreciation within the band while the currency index was located at the lower part of the band. The presumable explanation for this phenomena is that the band, which private agents had in mind was the above-mentioned unofficial band with much narrower boundaries than the official one. So the devaluation expectations prevailing in the market were in fact related to this implicit band.

In order to interpret what an expected rate of devaluation of 3 per cent means, recall that the expected rate of devaluation by (2.31 and 2.32) is the product of the expected size of a devaluation and the probability intensity of a devaluation. If we suppose that the expected size of a devaluation is 5 per cent, the probability on an annualized basis is about 60 per cent in this case. If we assume that the size of the jump is 10 per cent, the corresponding probability is 30 per cent. In the extreme cases, where the expected rate of devaluation has been 10 per cent, with the expected size of the devaluation for instance 5 per cent, the probability on a per annum basis is 200 per cent. Thus the probability of a devaluation occuring within the next month is 200/12, that is about 17 per cent.

As can be seen from *Figure 2.4*, there is no increasing credibility of the exchange rate band for the markka during the period of January 1987 - May 1991. It is interesting to note that the opposite seems to be true in several other target zone experiments. There is plenty of evidence that the EMS has increased the credibility of economic policies in the participating countries, cf. Frankel and Phillips (1991), Rose and Svensson (1991), Svensson (1991a), and Weber (1991). On the other hand, in Sweden the exchange rate policy seems to have similar credibility problems as in Finland, cf. Lindberg *et al.* (1991).

We can compare these results with those obtained in section 2 (*Table 2.3 a-b*), where the devaluation risk was estimated directly from the relationship between interest rate differentials and the exchange rate. The results were around 2.5 per cent for one- and three-month interest rate differentials for the period before the revaluation whereas our average rate of expected devaluation for this period was around 3.5 per cent. For the second subperiod the differences are greater and reversed. From direct estimation we obtained 4.6 and 5.6 per cent average rates of devaluation expectations and after the adjusting the interest rate differentials we obtained 2.9 and 2.6 respectively for the one- and three-month horizons. So it seems that adjusting the interest rates differential for the expected rate of depreciation within the band has significant relevance. The reason such an adjustment is essential is that exchange rates within the band display mean reversion, causing the expected rate of depreciation within the band to be of about the same magnitude as the interest rate differentials.

2.4 Conclusions

In this chapter we have investigated the question of credibility in target zone models. It was shown that while a good 'fit' of a target zone model does not require perfect credibility, it does require that the degree of credibility has to be fairly stable over the sample period. In light of the evidence presented here, this has not been the case for Finland; the relationship between interest rate differentials and the exchange rate was systematically positive in both subperiods and maturities we examined, which is clearly contradictory to the prediction of the basic target zone model. Thus the interpretation of constant devaluation expectations was ruled out by the results.

A logical explanation of these findings can be found by allowing stochastic and time varying devaluation expectations into the model. It turns out, as shown by Bertola and Svensson, that almost any pattern of exchange rate and interest rate differential observation can result depending on the existence of devaluation risk.

Also shown by Bertola and Svensson, it is possible to infer this devaluation risk from data. Thus, the common measure of devaluation expectations, the interest rate differential, can be considerably improved upon by adjusting the interest rate differential for the expected rate of depreciation within the band.

It turns out that the adjustment is essential also for Finnish data. The reason such an adjustment is important is that the exchange rate of the markka within its band displays mean reversion causing expected rates of depreciation within the band to be about the same magnitude as the interest rate differential. The expected rates of depreciation within the band have been estimated by a simple method. The same method has been used to estimate the EMS exchange rate depreciation which consistently delivers the same type of results.

The clear difference between the EMS exchange rates and the exchange rate of the markka is that we can not notice any improvement in the credibility of the exchange rate band of the markka during the period 1987-1991.

On June 7, 1991 the markka was unilaterally pegged to the ecu. After this there were cumulative devaluation expectations while the market participants already expected a devaluation of the markka in conjunction with the ecu-peg. This did not happen in June, but the authorities were forced to do it in the autumn. The awaited devaluation was realized on November 15, 1991, when the markka was devalued by 12.3 per cent. Again, in April 1992 devaluation expectations rose as well in September. Since the economic preconditions for maintaing the stable exchange rate did not exist, the Board of Management of the Bank of Finland allowed the markka to float on September 8, 1992.

In light of the empirical results presented here and the experiences since the ecu-peg it seems that if we want to fix the value of the markka credibly and eliminate the further speculation on it, we have to restrict the possibility of a devaluation. As long as this option exists, it will be tested once in a while at the market. This is not only the problem of a unilateral pegging. The turbulence within the EMS currencies in September 1992 and pulling the pound sterling and the Italian lira out of the ERM showed, that membership in the EMS is not enough to remove speculative attacks as long as the realignment possibility still exists. A solution is, of course, the monetary union without national currencies, which would eliminate further speculative attacks.

The complementary measure could be to increase the independence of the central banks in advocating the price stability in the economy, which has been recommended in connection with discussion of the emerging European Central Bank (cf. Willms, 1990). But it should be recalled that achieving a credible exchange rate policy is not only a task for the central bank but rather it is a result of the fiscal policy followed as well as the income policy achieved, *e.g.* by government and labour unions. Alone the central bank, even if it is truely independent, is quite powerless in this sense.

It has been beyond the scope of this paper to explain the estimated expected rates of devaluation. Obviously, the next step is to analyse and compare these estimated expected rates of devaluation for the markka with other information about devaluation expectations like inflation differentials, unemployment, reserve levels, and real exchange rate. This is the theme in the next chapter.

3 Devaluation expectations and macroeconomic fundamenals

3.1 Introduction

In the previous chapter the market's devaluation expectations for the Finnish markka were estimated disregarding the cause of these devaluation expectations. The analysis was based on the assumption of uncovered interest rate parity, according to which the interest rate differencial between domestic and foreign rates reflects the total expected depreciation of the exchange rate. This total expected rate of depreciation was split into two components: the expected rate of depreciation within the band and the expected rate of a devaluation entailing a shift in the band within a certain period of time.

First the expected rates of depereciation within the band were estimated from the data and then, given these estimates, the expected rates of devaluation were constructed by subtracting the expected rate of depreciation within the band from the interest rate differentials. As a result, we obtained devaluation expectations which were correlated, but not identical to the "naive" estimate of devaluation expectations, *i.e.* interest rate differentials as such.

The estimated devaluation expectations as shown in *figure 2.4a - b* can be seen to have close links to the corresponding state in the prevailing business cycle. The years 1987-89 were characterized by strong growth in the Finnish economy. The pressure against the markka was not so apparent and the period was described by falling, but still positive devaluation expectations. However, already in the course of 1989 cumulative evidence of overheating symptoms were clearly observed by private agents and rising devaluation expectations subsequently dominated the market. Especially the time during autumn 1989 was already characterized with a high expected rate of devaluation. After the downturn of the economy in summer 1990 the devaluation expectations increased steadily, reaching an especially high level in March 1991, just before Parliamentary elections. The expectations of unilaterally changing the peg of the markka from a trade-weighted currency index to the ecu kept devaluation expectations at a high level until the summer of 1991, because market participants expected a devaluation of the markkka in connection with the ecu-peg.

The aim of this chapter is to link these estimated expected rates of devaluations to the observed macroeconomic fundamentals such as the money supply, competitiveness, real income, foreign exchange reserves, and other potential determinants of devaluations. Since the data of macroeconomic fundamentals is available only on a monthly basis, we use the monthly averages of estimated devaluation expectations during the 1987 January - May 1991.

The selection of explanatory variables is primarily based on theoretical considerations. In addition, the selection of variables has also been influenced by the experiences from the Finnish money and foreign exchange markets. A similar type of analysis has been performed by Lindberg, Svensson and Söderlind (1991) on Swedish data.

There is also other recent research where devaluation risk is linked with macroeconomic variables. Chen and Giovannini (1992b) have presented a methodology to explore the relation between expectations of parity changes and economic variables. Their model is derived under the framework of the escape clauses in economic policy and tested with some EMS currencies.

Edin and Vredin (1991) have examined the relationship between devaluation risk and related macroeconomic variables in four of the Scandinavian countries. Edin and Vredin build an econometric model to explain how the central parity of the exchange rate is determined. They treat the target exchange rate as a censored variable and with the help of a "shadow exchange rate", which is constructed in the spirit of a monetary approach, they estimate devaluations as a function of macroeconomic fundamentals.

Furthermore, there are some other devaluation models where the concept of the shadow equilibrium exhange rate is used to measure devaluation pressure. The most well-known is Blanco and Garber (1986), where the problem of recurrent devaluation and the timing of speculative attacks on the Mexicon peso is investigated. In addition, Flood and Garber (1984) use this concept when analysing the collapse time of a fixed exchange rate. The shadow exchange rate is solved also in these models using the monetary approach of exchange rate determination.

There are also some Finnish econometric studies where this type of research is achieved, albeit in a different framework and for different periods. Pikkarainen (1988) discusses the role of the Bank of Finland as an exchange rate authority. He uses a monetary model as a basic framework with certain modifications and estimates various reaction functions of the central bank explaining the average nominal value of the Finnish markka. OLS, logit, probit and tobit estimation methods are applied therein quarterly data for the 1961-1986 period. According to his results, it seems possible to construct successful indicators describing the pressure on the markka during the period investigated.

Starck (1989) presents estimation results where the interest rate differential between domestic and foreign currencies is explained by real income, inflation, the foreign exchange reserves and the current account. He finds that these variables are relevant factors behind the interest rate differentials in the short run. However, in his study the uncovered interest rate parity is not assumed and thus it is not possible to identify how the fundamentals affect the interest rate differential and the risk premium. His estimation period is 1981-87.

The rest of the chapter is organized as follows. Section 3.2 is devoted to the discussion of relevant macroeconomic variables behind the devaluation expectations. Section 3.3 presents the empirical collection of variables chosen and the model to be estimated. In next section the results are presented and section 3.5 concludes the chapter.

3.2 Determinants of devaluation expectations

In this section the task is to explore the determinants of devaluation expectations estimated in previous chapter. In our context we cannot directly use any theory of exchange rate determination since they mainly focus on the macroeconomic variables determining the equilibrium exchange rate as such. The issue here is how devaluation expectations depend on the state of the economy as described by a set of observed macroeconomic fundamentals. It seems warranted, however, to assume that the fundamentals which in general affect the exchange rate expectations are likewise affecting the devaluation expectations at least to a certain extent. Thus we start by using the monetary approach as an illustrative framework to discuss relevant macroeconomic fundamentals driving devaluation expectations.

Nevertheless, since a devaluation entails a tacit decision by a central bank or a government under the target zone regime, the principal question is what decision rule the private sector thinks the central bank or government is following when targeting the exchange rate. The theories that come closest to this type of question setting can be found under the framework of the so-called escape clauses in economic policy and the speculative attack literature. However, since there is not any systematic theory for a decision rule of the central bank, the ideas from these theories can be seen as only indicative when searching the linkage between devaluation expectations held by actors in financial markets and the relevant set of macrovariables determining these expectations.

3.2.1 Macroeconomic fundamentals in the monetary model of exchange rate determination

The common background in the most theoretical and empirical studies of the target zone models is some version of the monetary approach to exchange rate determination.[1] The monetary model has proved attractive because it yields

[1]For target zone models using the monetary approach, see footnote 2 in chapter 1.

explicit analytical solutions and allows direct application of results on regulated Brownian motion to the study of currency bands. i

In this framework the exchange rate is treated as an asset price which depends on expectations concerning exogenous real and monetary factors that will affect relative and absolute price levels in future periods. Changes in exchange rates reflect both expected changes in these exogenous factors and changes in expectations spurred by new information, *cf.* eq 2.1 in the previous chapter.[2]

Thus under the framework of the standard monetary model with flexible prices the exchange rate fundamentals are the money supply and the components of money demand. In this framework an increase in the domestic money supply will lead to a depreciation (devaluation) of equal proportion. An increase in the domestic real income leads to an appreciation (revaluation). Furthermore, an increase in the foreign interest rate calls for currency depreciation and an increase in the foreign price level leads to currency appreciation. Also an upward shift in the demand for money function (decrease in velocity) leads to currency appreciation.

The simple monetary model has been severely critized for its reliance on price flexibility and on purchasing power parity as the essential elements of exchange rate determination (*cf. eg.* Dornbusch, 1988). For resource-dependent economies, such as Finland, it is nearly impossible to proceed without giving attention to

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[2]The reduced form in (2.1) can be derived for a small open economy with free capital movements from the model with the following structure:

(3.1)' $m(t) - p(t) = \beta y(t) - \alpha i(t) + v(t), \ \beta,\alpha > 0,$

(3.2)' $e(t) = p(t) - p^*(t),$

(3.3)' $E_t[de(t)]/dt = i(t) - i^*(t),$

(3.4)' $dv(t) = \eta dt + \sigma dz.$

Equation (3.1)' describes the equilibrium condition for the domestic money market, where m is the log of the domestic money supply, p is the log of domestic price level, y is the log of the exogenous GNP, i is the nominal interest rate, and v is a random money demand shock, which is assumed, in (3.4)' to follow a white noise process with a drift coefficient η and variance σ^2 per unit of time. The variables of the foreign economy are denoted by the asterisks. Equation (3.2)' states that purchasing parity always hold. According to the uncovered interest rate parity condition (3.3)' the expected rate of depreciation of the exchange rate is set equal to the interest rate differential. Substituting (3.2)' into (3.1)' together with (3.3)' gives then the exchange rate as set out in equation (2.1).

such fundamentals as the terms of trade or the real exchange rate when discussing the relationship between macroeconomic fundamentals and devaluation expectations.

By assuming prices adjust sluggishly to shocks in the economy, we obtain a role also for the real exchange rate.[3] Incorporating the real exchange rate into the model implies that a higher real exchange rate indicates an expected devaluation. The reason for this relation is that a real exchange rate will be associated with a low domestic price level and thus with a high level of the real money stock. The return to equilibrium is achieved through a corresponding increase in the price level which introduces an expected depreciation of the exchange rate . However, if a high real exchange rate is interpreted as a sign of strong competitiveness, one would perhaps expect the reverse relation, *ie.* falling devaluation expectations with a rising real exchange rate.[4] For example, in Pikkarainen (1988) a lagged deviation from PPP has a negative coefficient, and it is statistically significant. Also in Lindberg, Svensson and Söderlind (1991) the competitiveness argument is supported by the data when they investigate devaluation expectations of the Swedish krona during the period 1982-91, but in Edin and Vredin (1991) the monetary argument is supported by their data for the Nordic countries during the period 1978-89.

3.2.2 Role of credibility and recurring speculative attacks

Escape clauses in economic policy

The fact that the stable exchange rate had for years been included in government programmes in Finland and that the Bank of Finland had strongly committed itself to a policy of strengthening the credibility of the fixed exchange rate had

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[3]For instance Miller and Weller (1989, 1991) have introduced a model where a stochastic version of Dornbusch's overshooting model (1976) is used as the basis for analyzing exchange rate behaviour under a target zone.

[4]This approach is supported *eg.* by Frenkel and Mussa (1981), where PPP is taken as the long-run constraint for policy makers.

not impressed economic agents which is clearly seen in the time series of devaluation expectations we are trying to explain. The lack of credibility with respect to economic policy is a typical dilemma in all countries with a history of periodic devaluations and relatively high inflation.

These types of credibility problems have been focused upon in recent research on international finance (see *e.g.* Lohmann, 1992 and Chen and Giovannini, 1992b and the references given there). In this literature, it has been widely recognized that if the option to use exchange rate policy exists, it will have effects even if it is not used. Without central bank credibility, private agents will continue to expect a high inflation rate, and this will increase the cost of any attempt to stabilize domestic prices. Establishing credibility means convincing the public that the central bank will not deviate from its exchange rate target in order to attain any short-term benefits associated with surprise inflation. This requires that the public must be convinced that the authorities have some incentive to refrain from introducing monetary surprises.

In general, the lack of confidence in macroeconomic policy can be shown to result from a variety of sources (see Agenor and Taylor, 1992). First, the government's disinflation effort may be perceived as being inconsistent with other policies being pursued simultaneously, and be recognized by the public. For instance, a disinflationary program which does not include measures to limit the public sector budget deficit will lack credibility, because the public understands its inconsistent nature.

Secondly, the lack of credibility may result from the time-inconsistency dilemma for the government: its optimal *ex post* strategy may differ from its *ex ante* strategy. For instance, once nominal wages are set by the private sector, the authorities may find it tempting to disinflate by less than they had promised, in order to generate output gains. The policymaker wants everyone to expect low inflation, so that they will face a favorable trade-off between inflation and unemployment. But merely announcing of a policy of low inflation is not credible. Once expectations are formed, the authority has an incentive to renege on its announcement in order to reduce unemployment. The policymaker's incentive to inflate need not be motivated only by employment considerations; it can also arise due to the presence of short-term rigidities in the tax-system or because the government wants to reduce the real value of its nominal debt. Private economic agents understand the incentive to renege and therefore in circumstances in which a policymaker has an *ex post* incentive to renege its promises, rational agents will discount announcements of future policy actions or assurances regarding the continuation of present policies.

A third source of credibility problems is incomplete or asymmetric information: private agents may not be able to assess how serious the government really is about stabilizing the economy. Imperfect information of this sort is particulary relevant in countries where policymakers tend to change rapidly.

Finally, a fourth source of credibility problems results from the uncertainty regarding the predictability of policy reforms or measures. In a stochastic world, even if a program is coherently formulated and time-consistent, in the sense that policymakers have no incentive to depart from the announced policy measures, exogenous shocks may occur which may be large enough to throw the programme "off track". Such shocks may be external in nature (such as, for instance, the behaviour of oil prices or interest rates) but may also result from the policy environment itself, in particular when the authorities have imperfect control over policy instruments. For instance, the announcement of a fiscal target will not be fully credible if the government does not adequately control the level of government expenditure. Another example relates to a situation in which the rate of inflation depends on the rate of expansion of domestic credit, which in turn depends on both deterministic and stochastic factors. Private agents will in general be aware of this and will accordingly form a probability that the target will not be met. The lower the degree of precision over policy instruments the more likely it is that agents will anticipate the possibility of a future collapse of the stabilization effort. The lack of policy predictability may create, therefore, doubts about the sustainability of the reform process, and will affect the degree of credibility of an otherwise consistent and viable programme.

There are, however, several factors which might mitigate the credibility problem. First, if the authorities' credibility depends on their past behaviour, then "cheating" will incur a future penalty. Knowing this, the private sector will be more likely to expect adherence to announced intentions. Second, when the authorities' true intentions are uncertain, today's exchange rate policy may help "signal" these intentions to the private sector, creating favorable future price expectations, and thus also supplying an incentive for adherence to an exchnage rate target. Third, credibility problems may be mitigated by "tying one's hands" by joining a monetary union (provided partner countries themselves maintain a low-inflation policy stance) or by giving up some discretionary power over exchange-rate adjustment to some supra-national authority.

Speculative attacks

In the literature of speculative attack[5] the research focuses on the issue of balance of payments crisis resulting from the central bank's attempt to peg the exchange rate in the presence of unsustainable domestic policies. When agents perceive that the authorities' commitment and ability to maintain a fixed exchange rate is weak, speculative attacks may occur. If successful, a speculative attack will be self-fulfilling in the sense that it will lead to a devaluation or a realignment of the currency outside a target zone. Such an attack may occur when, for instance, the competitiveness of a high-inflation country has been eroded by maintaining nominal exchange rate parity. This will, therefore, generate speculation that a currency will be devalued which may lead to an eventual exhaustion of the authorities' foreign exchange reserves and their external borrowing capacity, forcing them to devalue. Such a situation may be exacerbated if price setters incorporate the possibility of a devaluation in their pricing behaviour, thereby adding further inflationary pressure.

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[5] In general, a speculative attack is a situation in which speculators suddenly acquire a large portion of the government's stock of a resource whose price the government is committed to stabilize. The early literature on speculative attacks (Salant and Henderson, 1978) discussed rational speculative attacks in the context of commodity markets, in particular, the gold market.

Since the original contribution of Krugman (1979)[6], it has been recognized that these crises need not to be the result of unpredictable speculative behaviour. Rather, they are consistent with the result of the optimizing behaviour of rational investors who readjust their portfolios in anticipation of a breakdown of a fixed exchange rate parity, once they realize that *e.g.* the domestic credit policy of a country is inconsistent with the exchange rate level maintained by the central bank. Especially the work of Flood and Garber (1984) established a clear and convincing linkage between the collapse of a fixed exchange rate and expectations held by actors in financial markets.

3.2.3 Summary

Summarizing the above discussion, forming devaluation expectations private agents will presumably look at a wide variety of economic indicators. Firstly, if we assume that the private sector has some kind of "monetary model" behind their thinking of the rule the central bank is following, changes in the money supply or in components of money demand will influence their expectations. The real exchange rate as a measure of competitiviness might have an impact as well.

The ideas that arise from the above discussion on escape clauses in economic policy might be such as that the central bank or government can be forced to devalue, for instance, if the government's disinflation efforts are perceived as being inconsistent with other policies being pursued simultaneously, or if unemployment becomes too high, or if the government's borrowing requirement reaches an unsustainable level. Thus the domestic inflation rate, the unemployment rate, the nearness of a general election, and targets for the public sector borrowing are indicators that might be followed when devaluation expectations are formed .

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[6]Flood and Garber (1984), Obstfeld (1984), Grilli (1986) and Buiter (1987), among others have extended Krugman's model in several important respects.

The speculative attack literature emphasises in turn on the role of foreign reserves reaching a critical level and the balance of payments crisis as reasons forcing authorities to devalue. The role of reserves is stressed in the case where the central bank in question has no commitment with other countries' central banks to defend the currency band.

Collecting the above terms we thus end up with the following set of macro fundamentals which might influence devaluation expecations:

$$g(t,\tau) = f(\underset{+}{m(t)}, \underset{-}{y(t)}, \underset{?}{q(t)}, \underset{+}{p(t)}, \underset{+}{UNE(t)}, \underset{+}{GOV(t)}\ \underset{-}{RES(t)}, \underset{-}{CUA(t)}) \tag{3.1}$$

where m(t) is the domestic money supply, $y(t)$ is domestic GDP, $q(t)$ is the real exchange rate defined as a difference between foreign prices in domestic currency and home prices, $p(t)$ is the domestic inflation rate, $UNE(t)$ is the unemployment rate, $GOV(t)$ is the government net borrowing requirement, $RES(t)$ refers to the foreign reserves of the central bank, and $CUA(t)$ is the balance on the current account.

It is important to observe that including the money supply, foreign exchange reserves and the current account in the same model may lead to potential multicollinearity problems.[7] Similar types of problems might appear if the unemployment rate is included in the model, which can be seen as a proxy for the money supply as well. The problems connected with multicollinearity are considered later when the estimation results are presented.

[7] In an open economy, the money supply is the sum of foreign exchange reserves and central bank credit for the private sector (CBC) in the balance sheet of the central bank:
(a) $M^s = RES + CBC$ and hence $\Delta M^s = \Delta RES + \Delta CBC$, moreover
(b) $\Delta RES = CUA + CA$, where CA is the capital account balance, and
(c) $\Delta M^s = CUA + CA + \Delta CBC$

3.3 Description of the data

The money supply m we use is the (log level) of *M2* (FIM billion), which is available with a time lag of three months[8] and published by the Bank of Finland. Alternatively, the annual growth rate of the money supply ($m\%$) is applied.

The monthly unemployment rate *UNE* (%) used is the number of registered unemployed as a per centage of the work force as published by the Ministery of Labour and available with a one-month lag.

The government net borrowing requirement *GOV* (FIM mill) or alternatively the debt stock of the government *GD* (FIM bill.) is applied. These statistics are published by the Ministery of Finance with a one-month lag.

The domestic inflation rate p (%) is included as well with a one-month lag.

Domestic output, y (%) used in the analysis is the yearly percentage growth rate of the monthly GDP-indicator published by the Statistical Central Office. It is available with a two-month lag. As an alternative for total output, the annual growth rate in the volume of industrial production I (%) with a two-month lag has been applied.

The real exchange rate q, expressed as a difference of the log of the OECD countries' weighted consumer price index[9] in markka and the log of the domestic consumer price index, can be calculated when consumer price statistics

[8]In the regression equation the explanatory variables reflect only the most recent information available during month t. The idea is to include the most important variables in the current information set that agents might use in forming devaluation expectations. The explanatory variables are consequently appropriately lagged or in the cases where a particular statistic is revealed sometime during the month, constructed as averages of lagged values (cf. Lindberg *et al.*, 1991).

[9]Turkey is excluded from the OECD average.

become available *ie.* with a one-month lag. Also longer lags and as well as the yearly percentage changes of real exchange rate (*q%*) are used.

The foreign exchange reserves of the Bank of Finland *RES* (FIM billion) are announced weekly by the Bank of Finland. The variable enters the equation as an average of the monthly figures for month t and month t-1.

The current account balance *CUA* (FIM billion per month) is published by the Bank of Finland with a two-month lag.

The most interesting explanatory variables are shown in Appendix 3.1, *figures 3.1a - 3.1f.*

3.4 Estimation results

The estimation method used is OLS with Newey-West (1987) standard errors employing lags of 12 months. This allows for heteroskedastic and serially correlated error terms. The estimation period is January 1987 - May 1991.

The basic regression equation to be estimated is:

$$g(t,\tau) = a_0 + a_1 m(t\text{-}3) + a_2 UNE(t\text{-}1) + a_3 GOV(t\text{-}1) + a_4 p(t\text{-}1) + a_5 y(t\text{-}2) + a_6 q(t\text{-}1) + a_7 RES(t,t\text{-}1) + a_8 CUA(t\text{-}2) \quad (3.2)$$

where $g(t,\tau)$ is the expected rate of devaluation for one-month and three-month horizons, $a_1,a_2,a_3,a_4 > 0$, $a_5,a_7,a_8 < 0$ and the sign of a_6 being ambiguous.

It turned out that the money supply, both the log level and the growth rate, did not get a statistically significant coefficient. In addition, *m%* had a systematically negative sign. The government net borrowing requirement and whole debt were practically insignificant. The domestic inflation rate got a positive coefficient as expected, but it was insignificant as well.

The real exchange rate was applied in several ways. The coefficient of the log level of the real exchange rate with a one-month lag turned out to be positive, as implied by the monetary approach, but it was statistically insignificant. Taking longer lags (two and three months) did not improve the results. The coefficient of the rate of real exchange rate depreciation, *q%* was in turn systematically negative, but again the coefficient was not statistically significant.

As an example results from the basic regression type (3.2) are reported in Appendix 3.2.

The next step was thus to estimate the equation excluding all the clearly insignificant variables. The results are reported in *table 3.1*.

The excluded variables had limited explanatory power as the exclusion only showed up in a minor drop of the R-square values. Moreover, the potential multicollinearity seems not to disturb the results, while the coefficients of *UNE, RES* and *CUA* remain quite stable when the money supply is left out.

The equation has relatively high explanatory power (R^2), and all the coefficients have the expected signs. The coefficients of the unemployment rate have a positive effect on the expected rate of devaluation, at a 1 per cent significance level. A one per cent increase in the unemployment rate induces an almost one-to-one correspondence to the expected rate of devaluation within a one-month horizon. The coefficient for the three-month horizon is smaller in size. Foreign exchange reserves and the growth rate of GDP are negative and significant at a 1 per cent level except for the GDP coefficient for the 3-month maturity, which is significant at a 5 per cent level. The current account balance is statistically the weakest variable. It has a negative effect, which is significant only at a 10 per cent level for the 1-month maturity, and for the 3-month maturity it is not significally different from zero. *Figures 3.1a* and *3.1b* show the predicted values of the estimated models together with the actual values.

Table 3.1. OLS-regressions of estimated expected rate of devaluation on selected macroeconomic variables (1 month and 3 months maturity)

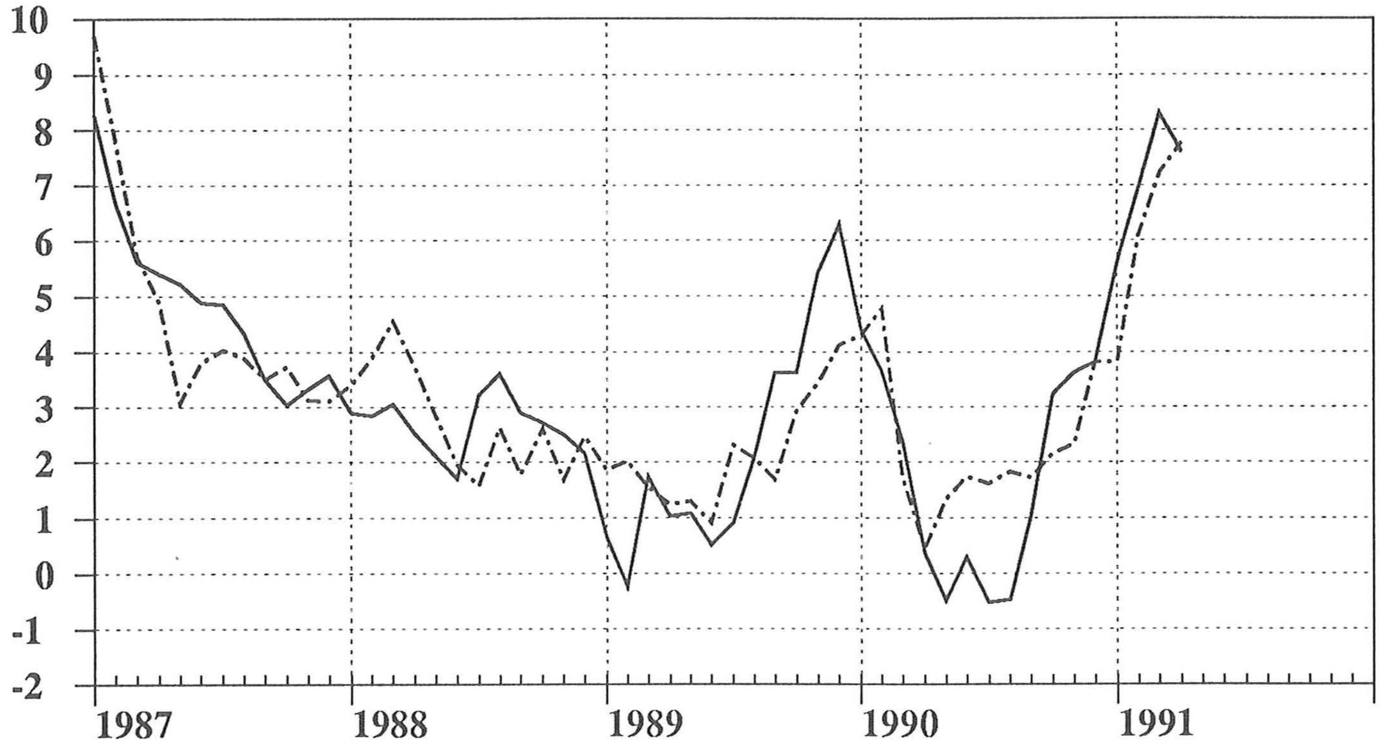
Constant	6.41**	6.82***
	(2.64)	(1.99)
Rate of unemployment	.87***	.48***
(per cent)	(.23)	(.19)
Growth rate of GDP	-.55***	-.39**
(per cent)	(.15)	(.13)
Foreign exchange reserves	-.27***	-.21***
(FIM billion)	(.05)	(.04)
Current account	-.52*	-.23
(FIM billion per month)	(.30)	(.18)
Diagnostics		
N	52	50
R^2	0.70	0.65
σ	1.22	0.90
DW	0.87	0.79

Newey-West standard errors within parentheses (12 lags). N is the number of observations, σ is the standard deviation of the residuals. The sample period is January 1987-May 1991. A * denotes significance on a 10 per cent level, ** on a 5 per cent level and *** on a 1 per cent level.

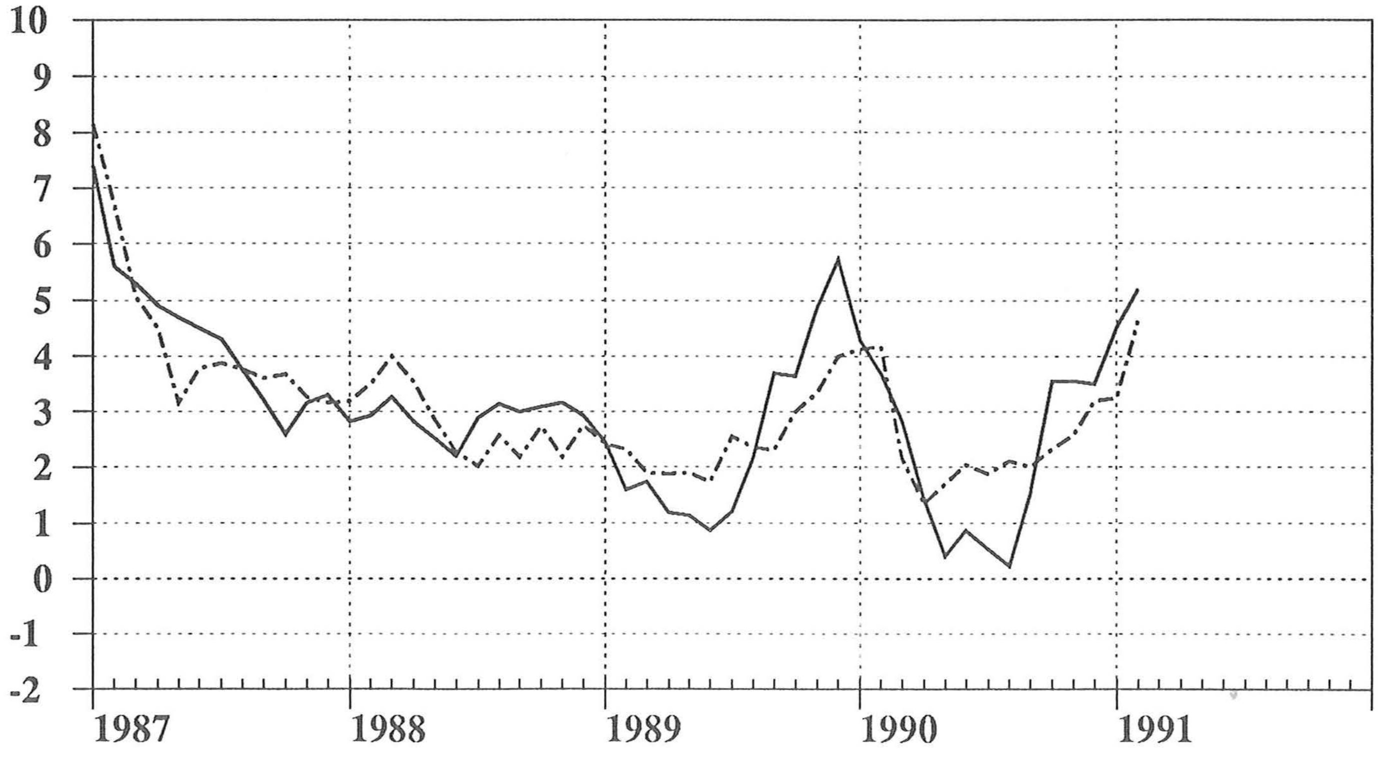
In the corresponding study on the devaluation expectations of the Swedish krona, Lindberg *et al.* also use a dummy variable for parliamentary elections, which appears to have a significant effect on devaluation expectations. However, in our sample it seems impossible to identify the effects of elections with a simple dummy variable. In addition, Lindberg *et al.* also report results of rolling regressions with a window of 36 months to check the stability of the estimated coefficients. The idea is to check the experience from the foreign exchange market, which suggest that the market participants follow fads in the sense that

Figure 3.1. Actual and fitted values from the devaluation expectations, (——— actual values, -·-·- fitted values)

(a) Devaluation expectations (1-month horizon), %



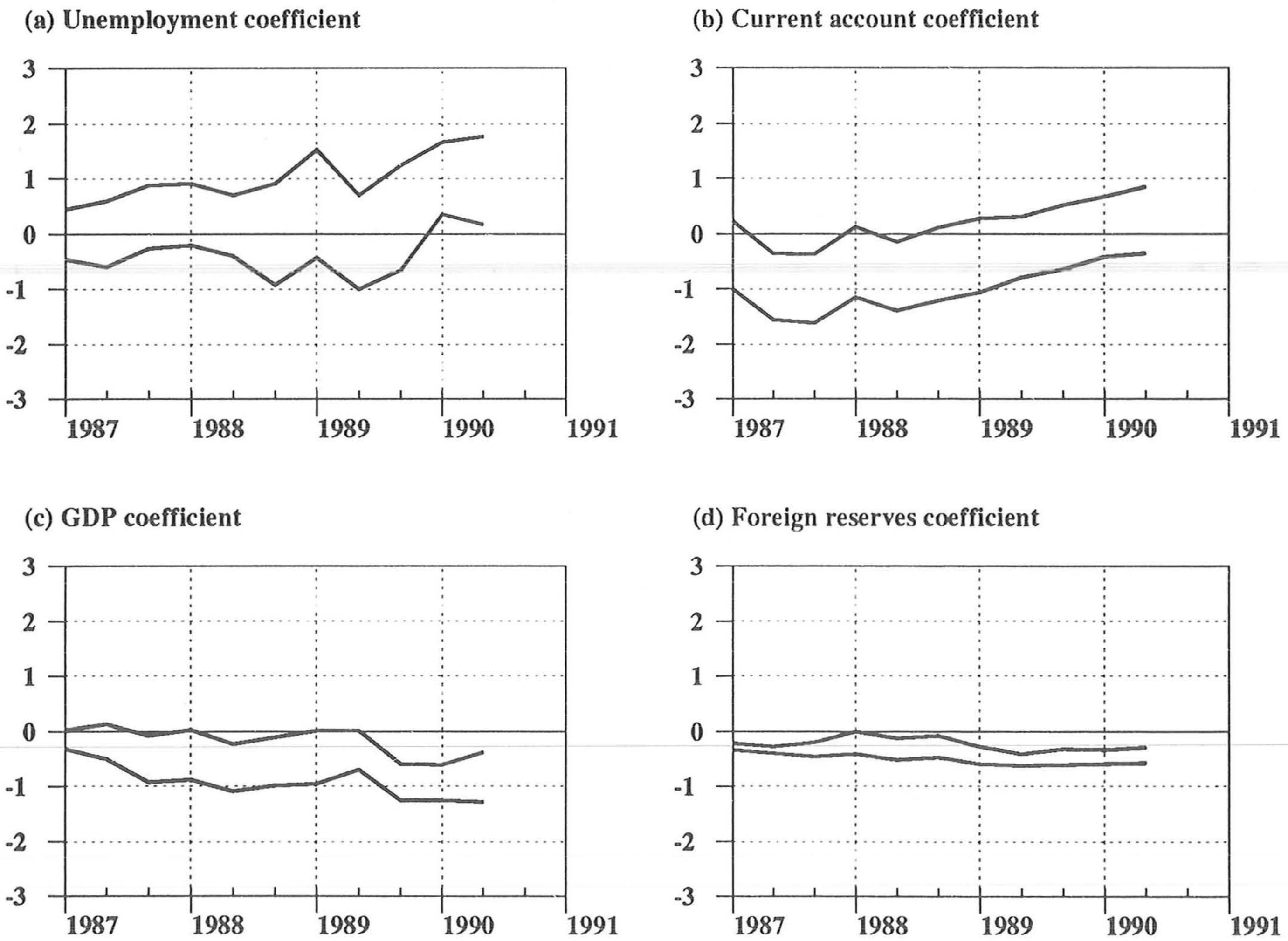
(b) Devaluation expectations (3-month horizon), %



they focus for a while on a particular variable in forming expectations, then switch to focus on another variable for a while etc. Unfortunately, the Finnish data does not yet allow for as thorough a study as theirs because we have only 50 months within the sample. However, we have used the idea of rolling regressions with a window of 24 months. The first window covers the period January 1987-December 1989 and the last covers the period July 1989-May 1991. Because of the lack of degrees of freedom (19 per estimation) these results must be considered as only tentative.

The results are reported for the one-month maturity in *figures 3.2a* to *3.2d*. These diagrams show the development at a 95 per cent confidence interval for the coefficients of the unemployment rate, GDP growth rate, foreign exchange reserves and the current account.

Figure 3.2. 95 % confidence intervals for the estimated coefficients (1 mo)



The coefficients of the foreign exchange reserves and GDP are the most stable ones. Both almost always have significant negative signs. The coefficients of the unemployment rate and current account show a different pattern. In the beginning the coefficient of the unemployment rate is not significantly different from zero. Then, when unemployment starts rising in the middle of 1990, it gets a significantly positive sign. The coefficient of the current account deficit is at the beginning significantly negative, but at the end of the period it changes towards zero and even becomes slightly positive. This might reflect the fact that when the current account deficit ceased worsening in the course of 1990, the market's focus shifted to other factors.

All together, the results from the rolling regressions confirm to some extent the expected behavior of the participants in foreign exchange markets. In different periods they focus on different macroeconomic variables.

3.5 Conclusions

The chapter has examined how devaluation expectations can be explained by regressing estimated expected rates of devaluation on selected macroeconomic variables. The results indicate that the unemployment rate has a significant positive effect on devaluation expectations, and the annual growth rate of GDP, foreign exchange reserves and the current account have significant negative effects.

The money supply and real exchange rate, calculated as the difference between domestic and foreign consumer prices, did not have any statistically significant bearing on devaluation expectations. The reason for these failures might be partly explained by qualitatively scant proxies of these variables. Especially, the real exchange rate as an indicator of the competitiviness should perhaps be measured with relative unit labor costs or with wage differences. This type of data is not, however, available on a monthly basis. Furthermore, in connection with the real exchange rate, a cumulative indicator could be more feasible than the current one.

Although the results were somewhat encouraging, one should interpret the results with caution. The coefficients might be unstable over time, consistent with the idea that market agents in forming devaluation expectations focus on a particular macroeconmic variable for a while, and then shift to another. It is also possible, that some variables are followed more carefully after they pass some "threshold".

APPENDIX 3.1: Some macroeconomic variables

Figure A3.1a. Money supply, FIM.bill.

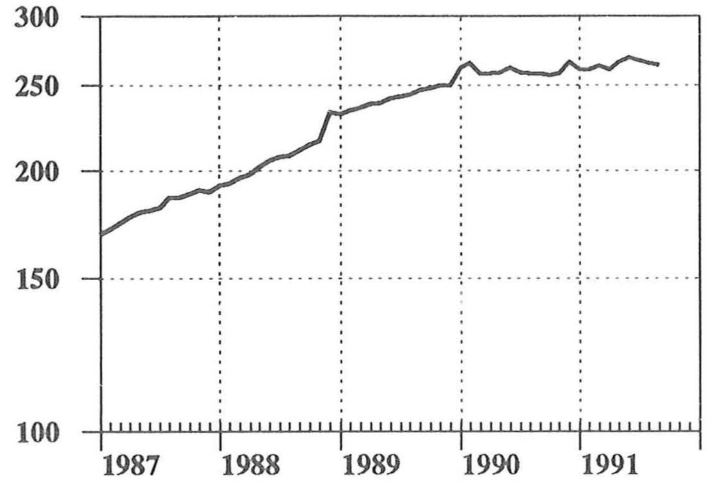


Figure A3.1b. Foreign exchange reserves, FIM bill.

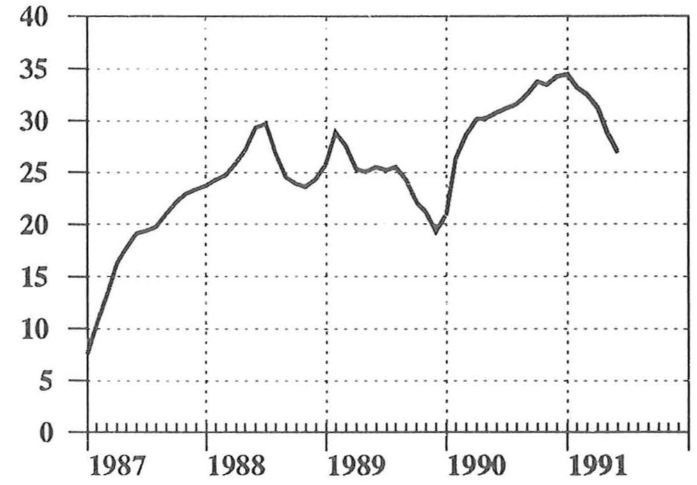


Figure A3.1c. Current account, FIM bill.

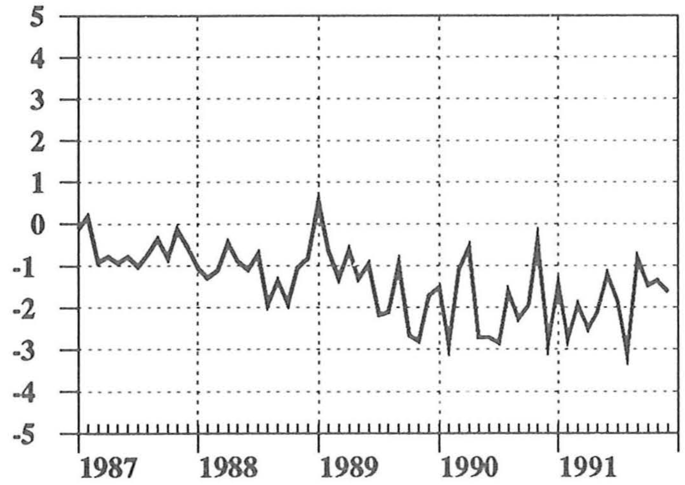


Figure A3.1d. Growth rate of GDP, % per year

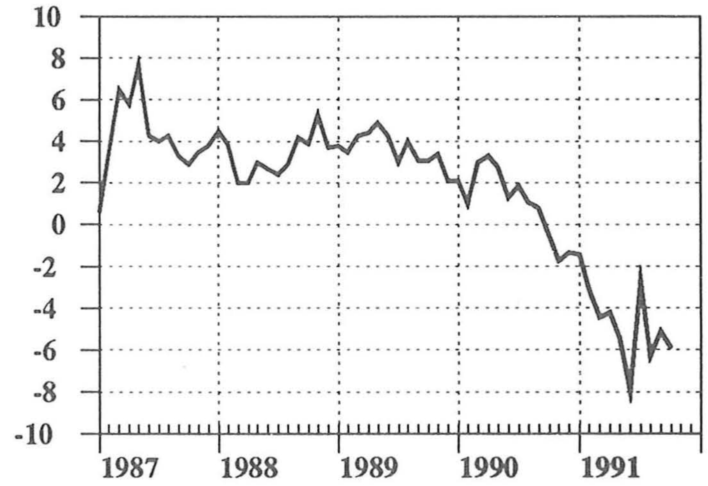


Figure A3.1e. Unemployment rate, %

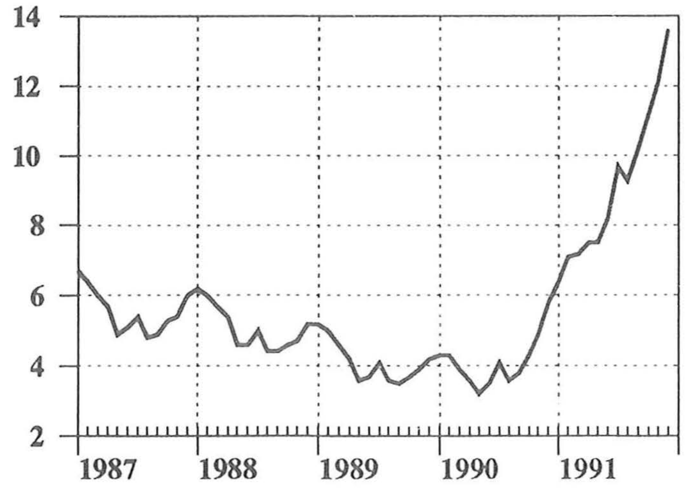
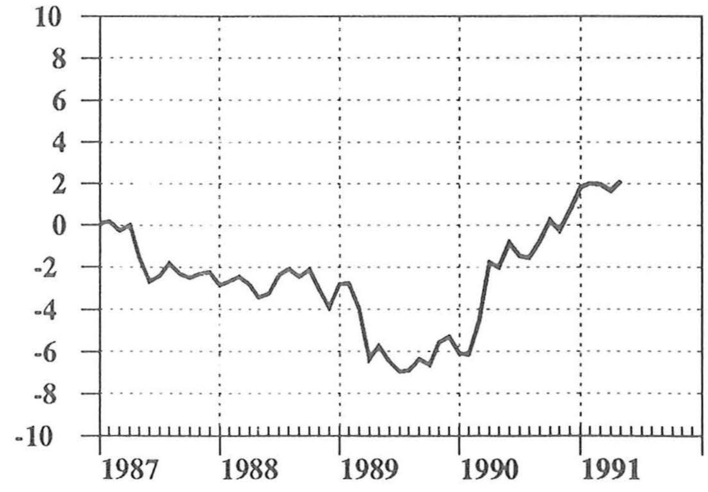


Figure A3.1f. Change of the real exchange rate ,%



Appendix 3.2: OLS-regressions of estimated expected rate of devaluation on selected macroeconomic variables (1-month and 3-month maturities)

Constant	5.91** (2.89)	6.31*** (2.21)
Rate of money growth (per cent per year)	-0.08 (.06)	-0.11** (0.05)
Rate of unemployment (per cent)	1.00*** (.29)	.64*** (.24)
Government borrowing requirement (FIM bill. per month)	-0.05 (.15)	-0.06 (.10)
Domestic inflation rate (per cent per year)	0.19 (.33)	0.26 (.24)
Growth rate of GDP (per cent)	-.51*** (.11)	-.33** (.08)
Rate of real exchange rate depreciation, per cent per year	-0.07 (.16)	-0.08 (.11)
Foreign exchange reserves (FIM billion)	-.28*** (.04)	-.23*** (.03)
Current account (FIM billion per month)	-.46 (.26)	-.17 (.18)
Diagnostics		
N	52	50
R-squared	0.74	0.73
σ	1.55	0.76
DW	0.91	0.88

Newey-West standard errors with 12 lags are in parentheses.The sample period is Janauary 1987-May 1991. N is the number of observations, and σ is the standard deviation of the residuals. A * denotes significance on a 10 per cent level, ** on a 5 per cent level and *** on a 1 per cent level.

4 Deviations from uncovered interest rate parity: a foreign exchange rate risk premium or bias in expectations

4.1 Introduction

During 1987-91, the observed *ex post* returns on financial assets denominated in Finnish markka were persistently much higher than those on similar assets included in the Bank of Finland currency basket. This persistence of excess returns is puzzling from the viewpoint of the theory of efficient financial markets because it suggests that some portfolio (one that would hold Finnish markka-denominated securities and go short in securities denominated in foreign currencies) could earn extraordinary profits. This phenomenon had indeed an enormous effect on the behaviour of Finnish firms. It led enterprices to borrow substantial amounts in foreign currencies.

There are two main lines of reasoning of justification for these observations. The first is to assume that the *ex post* excess returns serve as unbiased estimates of the expected returns, an assumption that leads to the conclusion that there has been a considerable foreign exchange risk premium associated with Finnish markka assets. The second is to consider that there is a sustained divergence between the expected and the realized values of returns, a fact that would likely arise when the probability distribution of the exchange rate is asymmetric entailing that there might be *e.g.* a large probability of a small appreciation and a small probability of a large depreciation.

The risk premium, which can be defined as the differential between the expected rate of return on similar bonds or deposits denominated in home and foreign currencies, has been much discussed in the international finance literature. The discussion about risk premia has mostly, however, concerned floating exchange rate regimes. For a credible, completely fixed, exchange rate regime with free capital mobility, the foreign exchange risk premium should be zero. That is, bonds denominated in home and foreign currency of the same maturity should, absent of default risk, be perfect substitutes since there is no exchange rate risk, and domestic and foreign interest rates should be equal.

Target zones, nevertheless, imply some remaining exchange rate uncertainty because of potential movements inside the band and because of a realignment risk. Thus they are characterized by non-zero and fluctuating interest rate differentials. This is not surprising, since the expected rate of depreciation of a currency varies both with the exchange rate's position in the band and with the probability and size of a realignment. For instance, with a credible band a currency which is at the strong edge of its band can only depreciate, which contributes to a positive interest rate differential.

The issue arises, however, whether the exchange rate uncertainty due to movements within the band and realignments is sufficient to create a significant foreign exchange risk premium. The rigorous derivation of an endogenous risk premium in a target zone is nevertheless a difficult task, since the underlying exchange rate is a complicated nonlinear and heteroskedastic stochastic process.

The existence of a risk premium is especially important in the connection of the target zone literature since the models rely on uncovered interest rate arbitrage and thus disregard the risk premium. Observed interest rate differentials must accordingly be interpreted as arising wholly from expected currency depreciation, *i.e.* from exchange rate movements inside the band and from devaluations.

The competing approach to explain the apparent failure of uncovered interest parity is that there has been a systematic difference between the observed return differentials and their expected values. This situation would arise when the probability distribution is asymmetric and includes a small probability of a very large change in the exchange rate. The phenomenom is called the "peso problem".[1]

The peso problem arises thus, when a potential change in the current currency regime has a significant influence over the expected value of the exchange rate, but when this change does not take place over some relevant length of time. The problem is particulary relevant for exchange rates within the exchange rate bands displaying a significant realignment risk. The sample distribution may not be representative of the underlying distribution of the error term, unless the sample includes a large number of realignments.

As it was shown in chapter 2, the period under investigation in this study is characterized with highly time-varying devaluation expectations of the Finnish markka. While there were no devaluations under the period examined, it fulfils the characteristics of the typical peso problem.

The aim of this chapter is to search for an answer to the question of how much of excess returns observed in the Finnish forward exchange rate market can be attributed to a potential risk premium and how much is due to an ex post forecast bias caused by unrealized devaluation expectations during the sample period. The rest of the chapter is organized as follows. In section 4.2, after a short introduction to the results of theoretical and empirical findings of a risk premium, the existence of the risk premium in a target zone is examined. An expression for the risk premium using the model by Svensson (1992a) is derived. Svensson's model, in contrast to the previous literature, takes the exchange rate's heteroscedasticity within the band as well as a separate devaluation risk into account. In terms of this model the upper bound on the risk premium for the Finnish markka is approximated. Section 4.3 introduces in turn the role of the peso problem as a possible explanation of the substantial *ex post* forward rate

[1]The peso problem in connection with the exchange rate market was investigated *e.g.* by Krasker (1980) and Lizondo (1983). The phenomenon has been called the "peso problem" because it was initially associated with the persistent expectation of a devaluation in the Mexican peso market. Similar foreign exchange crises happened in the EMS countries in the 1980's. For instance, the French franc and Italian lira have experienced several crises, which fulfil characteristics of a peso problem. Neither is it completely unknown in connection with floating exchange rates, *e.g.* with the US dollar (see Borensztein, 1987).

forecast errors. The relevance of the peso approach is tested empirically using the estimated devaluation expectations on the Finnish data. Section 4.4 concludes the paper.

4.2 Role of the foreign exchange risk premium

4.2.1 The risk premium in foreign exchange markets: some theoretical and empirical findings

It is well known that uncovered interest parity has been rejected in a large number of empirical tests (see *e.g.* Hodrick, 1987, Froot and Thaler, 1990, and Kaminsky and Peruga, 1990). The exchange rate risk premium has been the favorite way of explaining the apparent failure of uncovered interest parity.

Following convention, the exchange rate risk premium or excess return can be defined as

$$(4.1) \qquad P(t) = (F(t,N) - E[S(t+N)\,|\,I(t)]) \;/\; S(t),$$

where $S(t+N)$ is the period $t+N$ spot rate, $F(t,N)$ is the period t forward rate for delivery in period $t+N$, and $E(\cdot\ |I(t)$ denotes expectation conditional on time t information.

There are numerous empirical tests that have been performed to study the existence of the foreign exchange rate risk premium. An early line of research on risk premium relied on tests whether the forward exchange rate is an unbiased and efficient predictor of the future spot exchange rate.[2] The method to determine the presence of the forward bias has been to regress the log of the actual change in the spot exchange rate $\Delta S(t+N)$ on the log of the forward premium $F(t)\text{-}S(t)$, that is:

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[2]This joint hypothesis testing is usually called the UBFR hypothesis *i.e.* unbiased forward rate hypothesis.

$$(4.2) \qquad log[S(t+N)/S(t)] = \alpha + \beta log[F(t)/S(t)] + u(t+N),$$

and if agents are risk neutral and rational and there are no restrictions for international capital movements, then we would expect $\alpha = 0$, $\beta = 1$. Such tests are usually conducted on bilateral exchange rates and the null hypothesis of no risk premium is in most cases rejected[3].

The excess returns in favor of the Finnish markka assets, *i.e.* the *ex post* realized deviations from uncovered interest rate parity, are shown in *table 4.1*. In the first part of the table we show the average of *ex post* excess returns on one-month and three-month markka deposits over the sum of interest rates on the currencies included in the Bank of Finland's currency basket and the rate of depreciation of the markka with respect to the basket during the period of January 1987 to May 1991. We observe that excess returns averaged nearly 4 per cent per annum. The same information is given in *figure 4.1 a - b*, where daily observations are shown. The excess returns have been highly variable, *e.g.* from -19 to +40 per cent calculated over one-month deposits and positive differencies have been dominating.

Further evidence on the low predictive ability of the forward rate is given in the bottom part of *table 4.1*, where the regressions linking the one-month and three-month precentage change in the spot FIM price of the basket to the corresponding one-month and three-month forward premium from the previous month are shown.

The results are similar to those estimated in other studies. The forward exchange rate has a negative coefficient, which means that on average it mispredicts not only the magnitude but also the direction in which the spot exchange rate moved during a subsequent period. Forward premiums have therefore been severely biased predictions of subsequent exchange rate movements. The poor results are not surprising in a target zone like the Finnish band during a period when the

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[3]See *e.g.* Boothe and Longworth (1986), Cumby and Obstfeld (1984) and Fama (1984). Abraham (1985), Gregory and McCurdy (1986), Margarita (1987) have tested the unbiased hypothesis within the EMS. Oxelheim (1985) and Hörngren and Vredin (1989) have analyzed the Swedish krona, and Haaparanta and Kähkönen (1985) the Finnish markka.

Table 4.1.(a) Average ex post excess returns on one-month and three-month Finnish markka assets (% per annum)

	average	min	max
one-month	3.834	-18.99	40.83
three-month	3.917	-2.99	17.15

Note: Sample: January 2,1987 to May 31,1991, daily observations.

(b) One-month and three-month forward premium and subsequent FIM depreciation:

$\log [S_{t+i} / S_t] = \alpha + \beta \log(F_{t,i} / S_t)$; H_0: $\alpha=0$ and $\beta=1$

	α	β	R^2	σ	D.W.
one-month	0.004 (0.0005)	-0.092 (0.01)	0.10	0.000018	0.17
three-month	0.010 (0.0007)	-.243 (0.02)	0.23	0.000036	0.11

Note: Method of estimation OLS. Standard errors are given in parentheses. σ is the standard error of the residuals. Low values for the Durbin-Watson statistics is an indication of the overlapping problem, while the sampling horizon is shorter than forecasting horizon. Sample: April 17, 1989 to May 31, 1991, daily observations.

spot rate was kept within the band, but the forward exchange rates reflected a possible regime shift of the exchange rate band.

The other line of early empirical research on a risk premium in the foreign exchange market relied on tests for serial correlation in the predicting error. Significant autocorrelation is a violation of market efficiency since it says that past information can be used to improve upon the forecasts made by forward rates. Studies such as Cumby and Obstfeld (1981), Frankel (1980) and Hansen and Hodrick (1983) showed that for several currencies the exchange rate forecast errors were serially correlated. These results were interpreted as evidence against

Figure 4.1a Excess return on Finnish markka assets (1 mo), % per annum

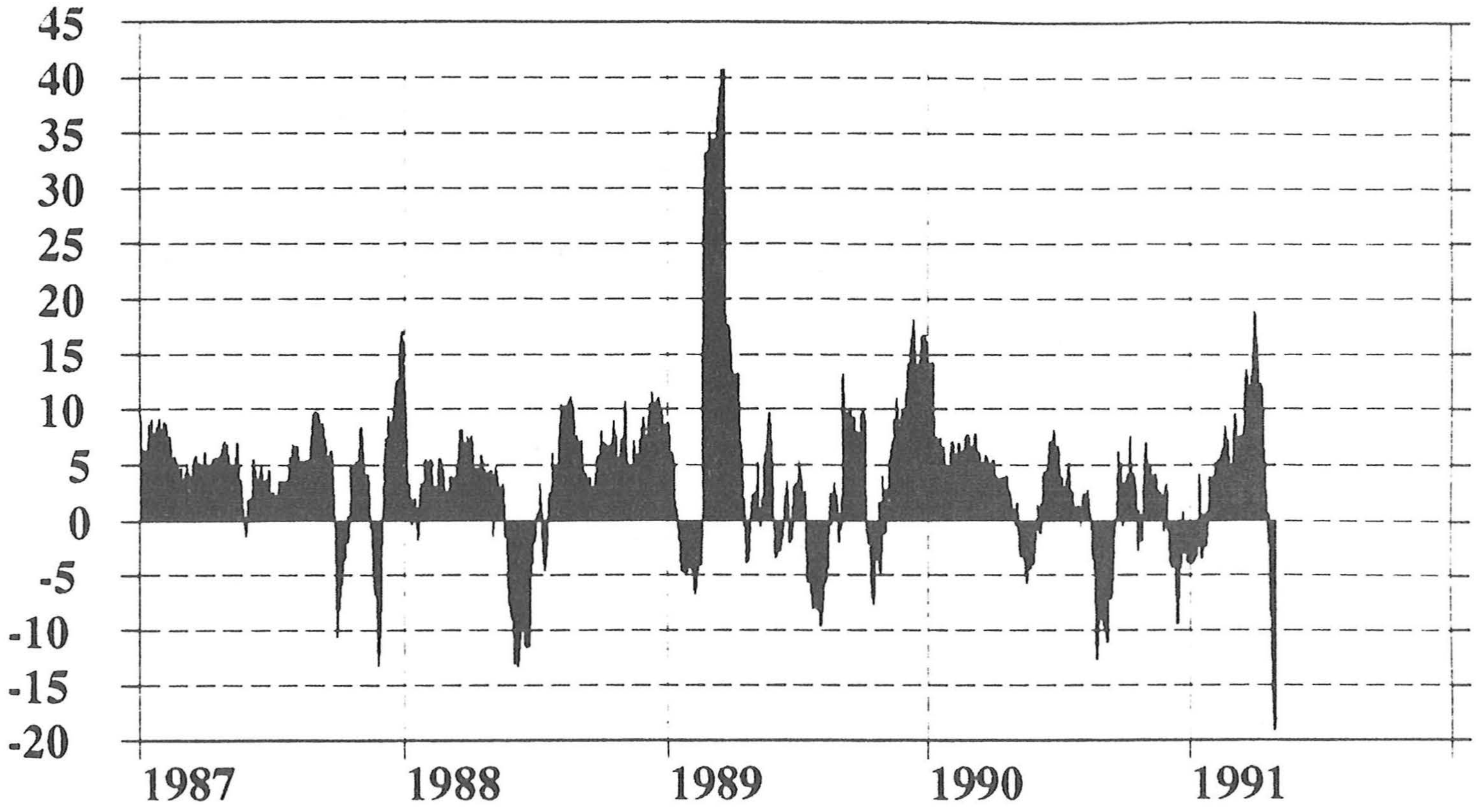
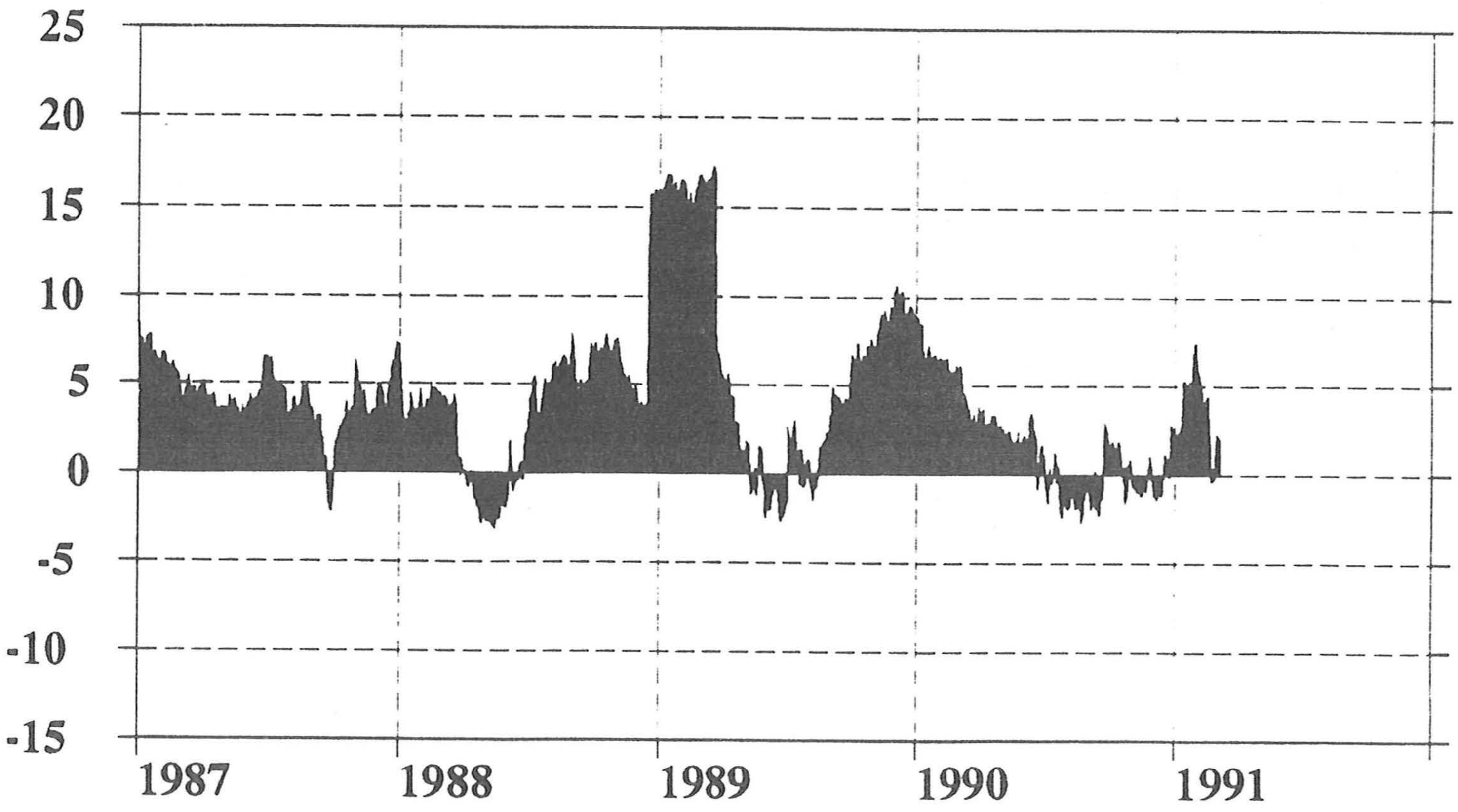


Figure 4.1b Excess return on Finnish markka assets (3 mo), % per annum



perfect substitutability between foreign and domestic assets and evidence for a risk premium.[4]

The third and most direct set of evidence as to the existence of non-zero forward bias requires the direct modeling of the risk premium as an independent variable. The approach relies on models of international asset pricing. In this framework the existence of a risk premium is completely consistent with market efficiency and rational expectations, since the forward rate incorporates all available information but differs from the expected spot rate.[5]

A useful dichotomy of the asset market approach to exchange rate determination is to separate models with a macroeconomic foundation from those rooted in modern finance theory. The portfolio balance approach, which includes flexible and sticky price monetary exchange rate models as special cases, is an important member of the former group. While the portfolio balance models were not originally couched in terms of explicit utility-maximizing behaviour, they can be rationalized on this ground under plausible assumptions.[6] If investors maximize single-period utility that is a function of mean and variance of end of period wealth, asset demands can be written as linear functions of expected relative rates of return. However, the slope coefficients exhibit nonlinear dependence on the coefficient of relative risk aversion and the covariance matrix of relative rates of return.

Probably the most direct test of this type an asset pricing model is made by Frankel (1982,1986). Frankel's results imply risk premia of about 1 per cent per year for six major currencies with relative risk aversion in the range estimated by earlier studies *e.g.* equal to 2. Thus his results showed that empirically risk

[4]In contrast, problems caused by overlapping observations, heteroskedasticity and cross-correlation of error terms do not indicate a violation of speculative efficiency nor do they bias the coefficients estimated by OLS. Rather, they produce inefficient estimates - the standard errors of the coefficients are incorrect.

[5]The following discussion makes use of the surveys by Hodrick (1987) and Meese (1989).

[6] See Frankel (1982). The results are also familiar from Kouri (1977) and Dornbusch (1982).

premiums would be too small to account for the rejection of the joint hypothesis of efficiency and no risk premium.

Finance-oriented models of exchange rate determination generally treat the rate of return and price variables as exogenous, and focus on optimal asset demands. While the postulated asset demand equations of the portfolio balance approach are replaced by asset demands derived from microeconomic foundations, the general equilibrium solution for rates of return and prices is lost. Optimal asset demands are derived contingent on particular stochastic specifications for prices and interest rates.

In this type of individual utility maximization model the equilibrium price of an asset is found by equating the foregone marginal utility from purchasing an asset to the conditional expectation of the present discounted value of the marginal utility of return from holding the asset.[7] To price a nominal forward exchange contract, money is introduced into the real asset pricing model by the restriction that agents purchase a country's money. Arbitrage ensures that the N-period forward price of foreign exchange be equal to the expected present value of a known return $R(t,N)$ at time t of investing in a nominally risk-free discount bill with payoff in period $t+N$, multiplied by the spot rate that will prevail at $t+N$. The asset pricing model provides the interpretation of the discount factor as the intertemporal marginal rate of substitution between period t and $t+N$ money, Q(t+N,N). Thus the forward rate can be written as

$$(4.3)\qquad F(t,N) = E[Q(t+N,N)*S(t+N)*R(t,N)\,|\,I(t)].$$

Using the definition of conditional covariance (4.3) may be rewritten as

$$(4.4)\qquad F(t,N) = E[S(t+N)\,|\,I(t)] + Cov[Q(t+N,N)*R(t,N),S(t+N)\,|\,I(t)],$$

[7]Solnik (1974) pioneered this class of international asset pricing models. Contributors to the literature also include Grauer, Litzenberger and Stehle (1976), Kouri (1977), Fama and Faber (1979), Stulz (1981), Lucas (1982), Hodrick and Srivastava (1984), and Svensson (1985), among others.

where $Cov[\cdot,\cdot|I(t)]$ denotes covariance conditional on the information set $I(t)$, and the derivation of (4.4) makes use of the first-order condition for utility maximazation $E[Q(t+N,N)*R(t,N)|I(t)] = 1$. Now the second term on the right-hand side of (4.4) has the interpretation of a risk premium (*cf.* eq. 4.1).

It can be seen that the existence of a risk premium is completely consistent with market efficiency and rational expectations, since the forward rate incorporates all available information but differs from the expected future spot rate. The forward rate will be an unbiased predictor of the future spot rate only when the second term on the right-hand side of (4.4) is zero. This can arise when agents face uncertain returns from holding forward contracts that are uncorrelated with the uncertain returns of all other assets or with agent's consumption opportunities. Risk neutrality is not sufficient to produce the unbiased forward rate hypothesis in this class of intertemporal asset pricing model since it ensures only that the marginal rate of substitution of money is not a function of consumption. However, risk neutrality guarantees that the expected real profit is zero, but there will still be a nominal expected profit on a forward foreign exchange position.

Perhaps the most careful estimations of the determinants of the risk premium in line of the model presented above are studies by Cumby (1988), Engel and Rodrigues (1987), and Kaminsky and Peruga (1990). Cumby examined whether returns to forward speculation for five different currencies are consistent with a consumption beta-model of the risk premium. This model requires that the relative return to two different assets move proportionately to the relative conditional covariances of the return to each asset and the rate of change of consumption. Cumby models the time-varying conditional covariance between the rate of change of consumption and the real return to forward speculation by projecting the observed covariances on a set of variables that include U.S. industrial production growth and the U.S. terms of trade. He finds that while the comovements of the estimated *ex ante* returns to forward speculation and the estimated conditional covariances are broadly consistent with the predictions of the consumption-beta model, on the whole his model does not provide an adequate description of returns to forward speculation.

Engel and Rodrigues (1987) introduced maximum likelihood estimation of a model of international asset pricing based on CAPM. The international CAPM implies that excess returns to forward speculation are proportional to the conditional variance of these returns and to the share of the corresponding assets in the market portfolio. The authors allow for a time-varying variance-covariance matrix that is modeled alternatively as a function of real and monetary shocks, and also using the ARCH model. As in Cumby's study, Engel and Rodriques rejected the hypothesis that the systematic prediction errors in the forward discount can be explained by mean-variance optimization models (cf. also Frankel, 1988).

Kaminsky and Peruga (1990) investigated the existence of a time-varying risk premium in the foreign exchange market using the intertemporal asset pricing model. In their model the risk premium is due to consumption risk, which is measured by the covariance between returns and the marginal utility of money. The conditional covariance is modeled using a GARCH-in-Mean model. Although a time-varying risk premium is an important determinant of the expected returns, tests of ICAPM restrictions show that a more flexible specification of the model is needed.

Summing up, the results of empirical estimations of the risk premia are still controversial. The empirical literature generally rejects uncovered interest arbitrage - that is, it rejects the hypothesis of a zero risk premia. On the other hand, the empirical findings seem to indicate rather small risk premia. Different specific models of the determination of risk premia are generally rejected.

4.2.2 The risk premium in a target zone

In a target zone exchange rate regime both the exchange rate uncertainty within the band and the second source of uncertainty, devaluation expectations, must be taken into account when the role of the risk premium is examined. A model considering these features is derived by Svensson (1992a), which builds on Merton's (1971) model of continuous-time portfolio choice with state variables affecting an asset's rates of return and rates being mixed Brownian and Poisson processes. In the following we briefly describe the key elements of the Svensson model in order to see what the determinants of the risk premium are in a target zone regime where the band is not fully credible.[8]

The setup of the model

The setup of Svensson's model is the following. The investor consumes home and foreign goods and has access to bonds denominated in home and foreign currency. Nominal goods prices, interest rates and exchange rates are exogenous stochastic processes that are functions of one single state variable, the exchange rate. Nominal bonds, exchange rates and two consumption goods are introduced as in Kouri's (1976) model of the determinants of the forward exchange premium.

A small open economy with free capital mobility is considered. The home currency price of the home good and the foreign currency price of the foreign good are sticky, and for simplicity set constant and equal to unity.[9] Foreign exchange interventions keep the exchange rate in a band of $\pm 100b$ per cent around the central parity. The central parity is now and then shifted $100g$ per cent by devaluations or revaluations. These devaluations occur according to a Poisson process $N(t)$ with intensity $\nu > 0$.

Inside the band the exchange rate is a stochastic process which follows the stochastic differential equation

$$(4.5) \qquad dS/S = \mu_S(S,N)dt + \sigma_S(S,N)dz + gdN,$$

where the drift $\mu_S(S,N)$ is the home currency's expected rate of depreciation within the band, dz is the increment of a Wiener process (that is, $E(dz) = 0$ and $Var(dz) = dt$), and $\sigma_S(S,N)$ is the instantaneous standard deviation of the rate of

[8]See Svensson (1992a) for a full theoretical treatment and technical details of the model.

[9]Svensson shows that the results with flexible and stochastic prices are the same as with sticky prices in this setup.

exchange rate depreciation within the band. The last term is the jump of *100g* per cent when a devaluation occurs.

The exchange rate's drift and instantaneous standard deviation depend only on where in the band the exchange rate is, that is, on $s = S/a(N)$, where a is the central parity at time 0. The expression s is called the normalized exchange rate. The normalized exchange rate will obey $ds/s = dS/S - gdN$, hence

(4.6) $$ds/s = \mu_S(s)dt + \sigma_S(s)dz.$$

There is a representative investor with preferences given by the expected discounted utility which is dependent of real consumption

(4.7) $$E_t \int_{t=\tau}^{\infty} u(c(\tau))exp[-\delta(\tau-t)]\tau, \quad \delta > 0,$$

where $u(c)$ is a standard instantaneous utility function and c is real consumption. The real consumption is in turn given by the consumption of foreign and home goods. The consumption share of foreign goods is β and the share of home goods $(1-\beta)$. Using the Cobb-Douglas utility function results in the exact price index which will be used to deflate nominal returns. The price index follows a stochastic differential equation, where the relative change in the price index when a devaluation occurs is given by a Poisson component. Also the real rates of return on two assets, the domestic and foreign currency short-term bonds are given by stochastic differential equations where a devaluation affects the rate of returns.

The portfolio problem of the investor is then to choose the portfolio share of foreign bonds (w_f) and consumption c so as to maximize the expected utility subject to the real wealth (W) taking into account the dependence of the expected rate of return on home, $\mu_h(s)$, and foreign bonds, $\mu_f(s)$, and the instantaneous standard deviation, $\sigma_S(s)$, on the normalized exchange rate. Thus the normalized exchange rate s will be a state variable that affects the expectation and the instantaneous standard deviation of the assets' real rates of return. The resulting value function will then be a function of both wealth and the state variable

$$(4.8) \qquad I(W,s) = \max_{W,s} E_t \int_{t=\tau}^{\infty} u(c(\tau))exp[-\delta(\tau-t)]\tau, \quad \delta > 0,$$

Svensson shows that from the Bellman equation for this problem follows a first order condition for the share of foreign bonds. This first-order condition can be written at the following equation for the equilibrium share of foreign bonds:

$$(4.9) \quad w f = \beta + \frac{\mu_f - \mu_h}{\gamma(W,s)\sigma^2_S} + \frac{I_{Ws}(W,s)s}{I_W(W,s)\gamma(W,s)} + \frac{I_W[W(1+w_f g)/(1+g)^\beta, s]}{I_W(W,s)} \frac{vg/(1+g)^\beta}{\gamma(W,s)\sigma^2_S},$$

where $\gamma\ (W,s) = -I_{WW}(W,s)W/I_W(W,s)$ is the relative aversion to wealth risk.

The equilibrium share of foreign bonds consists of the sum of four terms which can be written as $w_f = w^G_f + w^T_f + w^H_f + w^D_f$.

Accordingly, the equilibrium portfolio of foreign and home bonds can be separated into four different portfolios. The first term on the right-hand side of (4.9), $w^G_f = \beta$ corresponds to the share of foreign bonds in a global minimum-variance portfolio, the share of domestic bonds is $w^G_h = 1- \beta$. This is the portfolio an infinitely risk averse investor would choose (when γ approaches infinity). With the portfolio shares of foreign and home bonds equal to the consumption shares of foreign and home goods, the variance of real wealth is minimized and equal to zero.

The other three terms correspond to "speculative" portfolios of zero value. The second term is the foreign bonds' share of wealth w^T_f in a standard tangency portfolio. The third term is the foreign bonds' share of wealth w^H_f in a hedge portfolio against movements in the state variable s. The fourth term is the foreign bond's share in wealth w^D_f in a portfolio resulting from the devaluation risk.

It can be seen, that if for instance the utility function is logarithmic, the hedge portfolio is zero. Also, if the relative aversion to wealth risk is unity, the portfolio has a very simple form.

The real risk premium ρ can now be derived as the expected real rate of return differential between home and foreign currency bonds. It has the following form

$$(4.10) \qquad \rho = \mu_h - \mu_f - vg/(1+g)^\beta .$$

The first two terms give the expected real rate of return differential between home and foreign currency bonds due to exchange rate movements inside the band in the absence of devaluations. The third term is the expected real rate of return differential between home and foreign currency bonds due to devaluations.

It follows from (4.10) and (4.9) that the real risk premium can be written as the sum of two terms,

$$(4.11a) \qquad \rho = \rho_b + \rho_d,$$

where the two terms are given by

$$(4.11b) \qquad \rho_b = [\beta + w^H_f(W,s) - w_f]\ \gamma(W,s)\ \sigma^2_S(s) \qquad \text{and}$$

$$(4.11c) \qquad \rho_d = \frac{I_W[W(1+w_f g)/(1+g)^\beta, s] - I_W(W,s)}{I_W(W,s)} vg/(1+g)^\beta ,$$

where again $w^H_f\ (W,s)$ is the foreign bonds' share in the state-variable hedge portfolio.

The real risk premium is the sum of two separate risk premia, ρ_b and ρ_d. The risk premium ρ_b is due to exchange rate uncertainty within the band. It is product of three factors. The first factor is the sum of the consumption share of foreign goods and the share of foreign bonds in the hedge portfolio, less the total portfolio share of foreign bonds. The second factor is the relative aversion to wealth risk, and the third is the instantaneous variability of exchange rate depreciation within the band.

The risk premium ρ_d is due to the exchange rate uncertainty caused by devaluations. It is the product of two factors. The first factor is the relative jump in the marginal utility of real wealth if a devaluation occurs. The second factor is the expected real rate of return differential between home and foreign currency bonds due to devaluations.

The nominal foreign exchange risk premium $\tilde{\rho}$ can be defined as the expected nominal rate of return differential between home and foreign currency bonds. That is the nominal risk premium equals the interest rate differential less the expected rate of depreciation of the home currency,

$$\tilde{\rho} = i(s) - i^* - \mu_S(s) - vg, \tag{4.12}$$

where $i(s)$ and i^* are the nominal rates of return of home and foreign bonds respectively. The foreign currency interest rate i^* is taken to be constant. The expression $\mu_S(s)$ is the expected rate of depreciation of the home currency within the band and vg is the expected rate of depreciation due to devaluations.

It follows that we can write the nominal risk premium also as the sum of two terms,

$$\tilde{\rho} = \tilde{\rho}_b + \tilde{\rho}_d, \tag{4.13a}$$

where the two terms are given by

$$\tilde{\rho}_b = \rho_b - \beta\sigma^2_S(s) \text{ and} \tag{4.13b}$$

(4.13c) $$\tilde{\rho}_d = \rho_d + vg[1-1/(1+g)]$$

$$= \frac{I_W[W(1+w_f g)/(1+g)^{\beta},s]/(1+g)^{\beta} - I_W(W,s)}{I_W(W,s)} \quad vg.$$

The nominal risk premium also consists of two separate risk premia, one due to exchange rate movements inside the band, and the other due to devaluations. The nominal risk premium $\tilde{\rho}_b$ is in general the corresponding real risk premium less the covariance between the rate of depreciation and the rate of inflation. The latter term, the "convexity term" due to Jensen's inequality, has the simple form since nominal home goods prices are assumed to be constant in the price index.

The nominal risk premium is not invariant to the currency denomination because of Siegel's paradox and the convexity term. This is so because owing to Jensen's inequality the expected rate of depreciation of the foreign currency is not equal to the inverse of the expected rate of depreciation of the home currency: $1/E(S) \neq E(1/S)$. The real risk premium on the other hand is invariant to the currency denomination. See, for instance, Sibert (1989) and also the next chapter for further discussion on this point.

4.2.3 Approximation of the size of the risk premium for the Finnish exchange rate target zone[10]

The size of the risk premium due to exchange rate uncertainty within the band

The real risk premium is proportional to the rate of variance of exchange rate depreciation within the band. It is possible to estimate this variance for the Finnish markka both theoretically and empirically. To get a theoretical estimate

[10]The procedure applied here to find a risk premium for the Finnish markka is analogous to that of Svensson (1992a), where a narrow band like the Swedish target zone is investigated.

it is possible to use Krugman's (1991) target zone model, where the log of the exchange rate is given by the folllowing function (*cf.* chapter 2)

(4.14) $$\ln s(f) = f + A_1 exp(\lambda f) + A_2 exp(-\lambda f)$$

where $\lambda = (2/\alpha\sigma^2)^{1/2}$, f is a regulated Brownian motion with zero drift, rate of variance σ^2 and lower and upper bounds $\underline{f}$ and $\overline{f}$, and $\alpha > 0$ can be interpreted as the semi-elasticity of money demand with respect to the nominal interest rate, and

$$A_1 = (\alpha\sigma^2/2\Delta)[exp(\lambda_2\underline{f}) - exp(\lambda_2\overline{f})]\lambda_2 < 0$$
$$A_2 = (\alpha\sigma^2/2\Delta)[exp(\lambda_1\overline{f}) - exp(\lambda_1\underline{f})]\lambda_1 > 0$$
$$\Delta = exp(\lambda_1\overline{f} + \lambda_2\underline{f}) - exp(\lambda_1\underline{f} + \lambda_2\overline{f}) > 0.$$

Inserting $sinh(\lambda f) = [exp(\lambda f) - exp(-\lambda f)]/2$ and $cosh = [exp(\lambda f) + exp(-\lambda f)]/2$, we can write expression (4.14) in a simpler form:

(4.14') $$\ln s(f) = f - sinh(\lambda f)/[\lambda cosh(\lambda\overline{f})],$$

and the instantaneous standard deviation of the rate of exchange rate depreciation is then by Ito's lemma given as

(4.15) $$\sigma_S(f) = \sigma\, d\ln s \,/\, df = \sigma[1 - cosh\,(\lambda f)/cosh(\lambda\overline{f})].$$

The instantaneous standard deviation obtains its maximum for the middle of the band and it is given as $\sigma_S(0) = \sigma[1 - 1/cosh(\lambda\overline{f})]$.

To get a numerical estimate of the theoretical standard deviation, the fundamental band for the Finnish exchange rate band is needed. Using the same parameter values as Svensson for the Swedish band, namely $\sigma = 0.1$ per $\sqrt{year}$, which corresponds to a standard deviation of the exchange rate of *10* per cent per $\sqrt{year}$ under a free float; $\alpha = 3$ *years*, which corresponds to a money demand interest rate elasticity of *0.3* with a *10* per cent per year nominal interest rate. A fundamental band of $\pm$ *12.5* per cent results in an exchange rate band of

$\pm$ *3* per cent.[11] Compared to Swedish figures, the Finnish exchange rate band is twice as wide and thus the fundamental band is markedly wider as well.

The corresponding theoretical standard deviation $\sigma_S(0)$ for the Finnish exchange rate is *0.036*, that is, *3.6* per cent per year. Hence the variance is *0.00131*, which corresponds to *13.1* basis points (*0.131* per cent) per year. Thus, even with a relatively high risk aversion $\gamma(W,s) = 8$ and with a relatively large expression $(\beta + w^H_f(W,s) - w_f) = 0.5$ (remembering that β is the share of foreign goods, $w^H_f(W,s)$ is the share of foreign bonds in a hedge portfolio and w_f is the total share of foreign bonds), the real risk premium would be bounded by *52* basis points per year (*i.e.* about *0.5* per cent).

To get the nominal risk premium $\tilde{\rho}_b$ due to exchange rate uncertainty inside the band, the term $\beta\sigma^2_S(s)$ should be subtracted from the real risk premium. It is thus obvious that the nominal risk premium is smaller than the real risk premium. For instance, with β less than *0.5*, this second term is less than *6.5* basis points. As Svensson notes, the nominal risk premium due to exchange rate uncertainty within the band can be very close to zero while the second term in expression (4.13b) might be on the same order of magnitude as a small real risk premium. Another interesting point is that many models used as theoretical frameworks for empirical studies of the foreign exchange risk premium include the assumption that absent devaluation risks imply that the real risk premium is zero. This makes the nominal premium simply identical to the negative of the covariance between the rate of depreciation and the rate of inflation and completely unrelated to any risk aversion.

The empirical variance for the Finnish exchange rate index is actually smaller than the theoretical variance of 0.131 per cent per year. The variance computed from the daily exchange rate changes for the period January 1987 - May 1991

[11]We can solve the corresponding upper and lower fundamental bounds knowing the exchange rate bounds from the following equation,

$$e(\bar{f}) = \bar{f} - [(exp(\lambda\bar{f}) - exp(-\lambda\bar{f}))/2]/[\lambda(exp(\lambda\bar{f}) + exp(-\lambda\bar{f}))/2].$$

is equal to 0.036 per cent *i.e.* 3.6 basis points.[12] From monthly data it is even smaller, 2.8 basis points. The real risk premium with correspondig parameter values as before would thus be about 14 basis points.

Thus, it seems that we can safely disregard both the real and the nominal risk premium due to exchange rate movements inside the band also for the Finnish target zone (± 3 per cent).

The size of the risk premium due to devaluation risk

To get an empirical estimate of the risk premium ρ_d due to devaluation risk some simplifying assumptions have to be made. The elasticity of the marginal utility of wealth, the relative aversion to risk, is assumed to be stable and it can be approximated by a constant $\gamma > 0$, that is $\gamma(W,s) = \gamma$. Then $I_W(W,s)$ can be approximated by $A(s)W^{-\gamma}$. The expression in (4.11c) can be then approximated by

$$(4.16) \qquad \rho_d = \left[\frac{(1+g)^{\beta\gamma}}{(1+w_f g)^{\gamma}} - 1 \right] vg/(1+g)^{\beta},$$

and the nominal risk premium has the expression

$$(4.17) \qquad \tilde{\rho}_d = \left[\frac{(1+g)^{\beta(\gamma-1)}}{(1+w_f g)^{\gamma}} - 1 \right] vg.$$

The nominal risk premium is less in magnitude than the corresponding real risk premium. Now it is possible to approximate the size of a risk premium using estimated values for the expected rate of devaluation (*i.e.* vg) from the actual Finnish data.[13] The rates of devaluation expectations have varied between -4 and 14 per cent per year calculated from one-month and three-month interest rate differentials. By assuming an expected size of a devaluation (g) we can calculate

[12] The jump caused by the revaluation (17.3.1989) is excluded from the sample, because we are interested in the variance inside the band.

[13] These estimations are reported in *chapter 2*.

the corresponding probability of a devaluation within the year. For instance, if the estimated rate of devaluation expectation is 10 per cent, it corresponds to an expected devaluation of 0.10 with the probability of 100 per cent within a year (about 8.2 per cent within a month). The size of the real risk premium is also dependent on the assumed relative risk aversion (γ) and also on the share of foreign bonds (w_f). In *tables 4.2* and *4.3* it is shown the corresponding real and nominal risk premiums for different devaluation expectations, for different risk aversion coefficients and for two different shares of foreign bonds.

As can be seen from expressions (4.16) and (4.17), the risk premium is increasing in β for a positive g and γ larger than unity and it is decreasing in the share of foreign bonds for a positive g. In *table 4.2a*, the share of foreign bonds is assumed to be 0.25, which corresponds to the average share of the foreign debt of the total debt in Finnish economy. The coefficient β is assumed to be 0.3, which describes quite a high share of foreign goods in the total consumption bundle (actually this share is less in Finland, about 0.2). In the next table, the share of foreign bonds is assumed to be only 0.10, which underestimates the actual share, but gives a higher risk premium. Exaggregated values are used to get an approximation of the upper limit for the risk premium. Also values $\gamma = 8$ and a devaluation risk 20 per cent per year can be considered as already extreme while from the data the highest estimated rate of devaluation with 5 per cent confidence interval was around 14 per cent per year. The most common risk aversion coefficients used in the literature are usually in range from 2 to 4.

Summing up the results from *tables 4.2* and *4.3*, when reasonable values of the share of foreign goods ($\beta < 0.3$), the share of foreign bonds ($w_f > 0$), relative risk aversion ($\gamma < 8$) and expected size of a devaluation less than 0.20 per cent with probability of 100 per cent per year are used, the risk premia due to devaluation risk, both real and nominal, remain at the highest at 1.6 per cent. Actually, in the most probable cases the values are less than one per cent.

Table 4.2a. Real risk premium (%) due to devaluation risk (w_f = 0.25)

Expected size of a devaluation 100*(g)	risk aversion 2	4	8
5	0.02	0.04	0.09
10	0.08	0.15	0.31
15	0.15	0.30	0.60
20	0.23	0.45	0.92

Note: β = 0.30 and the probability of a devaluation is 100 % per year.

Table 4.2b. Real risk premium (%) due to devaluation risk (w_f = 0.10)

Expected size of a devaluation 100*(g)	risk aversion 2	4	8
5	0.10	0.19	0.40
10	0.37	0.75	1.56
15	0.80	1.64	3.74
20	1.37	2.84	6.10

Note: β = 0.30 and the probability of a devaluation is 100 % per year.

Table 4.3a. Nominal risk premium (%) due to devaluation risk ($w_f = 0.25$)

Expected size of a devaluation 100*(g)	risk aversion 2	4	8
5	-0.05	-0.03	0.02
10	-0.21	-0.13	0.03
15	-0.47	-0.32	-0.02
20	-0.84	-0.61	-0.15

Note: $\beta = 0.30$ and the probability of a devaluation is 100 % per year.

Table 4.3b. Nominal risk premium (%) due to devaluation risk ($w_f = 0.10$)

Expected size of a devaluation 100*(g)	risk aversion 2	4	8
5	0.02	0.12	0.32
10	0.09	0.47	1.28
15	0.18	1.03	2.85
20	0.30	1.77	5.03

Note: $\beta = 0.30$ and the probability of a devaluation is 100 % per year.

Consequently, while the risk premia due to exchange rate uncertainty within the band were insignificant, risk premia arising from devaluation risks were considerably larger, but they are still relatively small compared to the expected rate of devaluation. Therefore, it seems warranted to rely on uncovered interest rate parity also for a target zone with a width of ± 3 like the Finnish exchange rate band.

4.3 Explaining interest rate differentials by expected currency depreciation

In the previous section the size of the risk premium was approximated to be quite moderate using the framework of continuous-time portfolio choice model. According to these results, it seems that it might not be the risk premium which explains the observed substantial interest rate differentials between assets denominated in Finnish markka and in foreign currencies. The logical explanation for these remarkable differentials could thus be the other possibility discussed at the beginning of this chapter, *i.e.* the observed excess returns are due to errors in expectations.

The issue in this section is thus to illustrate the relation between the returns on financial assets and a potential change in the policy stance that would bring about a substantial shift of the exchange rate band in addition to expected movements of the currency within the band. If the change were to occur, the currency would depreciate, and the excess return would be eliminated, but as long as the change does not occur, the excess return is persistently positive.

Nevertheless, the estimation of the model constructed in this section can not be interpreted as a test of uncovered interest rate parity marked by a negligible risk premium as such. If there exists a risk premium after all, it cannot be identified by this type of estimation, since it appears on both sides of the equation. Even so, the results are interesting because it is a demanding task to get even illustrative evidence of different factors determining the observed interest rate differentials between the Finnish markka and foreign currency denominated assets. In addition, this experiment has the advantage over traditional peso-models, because we can use an estimated time-series to describe the private sector's devaluation expectations, which are usually unobservable.

4.3.1 Empirical methodology

The starting point is again the uncovered interest rate parity condition:

$$(4.18) \qquad i(t,\Delta t) - i^*(t,\Delta t) = E_t[\Delta s(t)]/\Delta t + E_t[\Delta c(t)]/\Delta t.$$

In expression (4.18), the interest rate differential is defined as the sum of the rate of total expected change of the exchange rate, which in turn is divided into two components: the expected rate of depreciation of the exchange rate within the band, $E_t[\Delta s(t)]/\Delta t = \mu_S(s)$ and the expected rate of devaluation, $E_t[\Delta c(t)] = vg$.

(i) Expected rate of depreciation within the band

The expected rate of exchange rate change within the band, $E_t[\Delta s(t)]/\Delta t$, is estimated with the similar approach as in chapter 2, but now from the monthly data (while the latter part of the expression (4.18) is available only on a monthly basis). Accordingly, the expected exchange rate change within the band is explained only with the current exchange rate[14]. The expected rates of change of the exchange rate were estimated for one-month and three-month horizons, and transformed to annualized changes. The estimated regressions are reported in *appendix 4.1*. The predicted values of the regressions are denoted by $(\hat{Y}_{1,\tau})$, where $\tau=1$ and $\tau=3$ indicate one-month and three-month estimations respectively.

[14]The regression equations were in following form

$$s(t+\Delta t) = \beta_0 + \beta_1 s(t) + \xi(t+\Delta t).$$

(ii) **The devaluation expectations**

The devaluation expectations to be used in the model are in turn the predicted values of equation (3.13) reported in chapter 3, where the devaluation expectations were estimated as a function of unemployment, GDP growth rate, foreign exchange reserves and the current account. Compared to the models of the peso problem used in the literature[15], we have now the advantage that we can describe the peso problem component with a time-series, which is estimated from the data. The predicted value is denoted by $(\hat{Y}_{2,\tau})$ in the following.

The model to be estimated can now be written in the following form:

$$(4.19) \qquad \delta(t,\tau) = \alpha_0 + \alpha_1 \hat{Y}_{1,\tau} + \alpha_2 \hat{Y}_{2,\tau} + \xi(t,\tau).$$

where $\delta(t,\tau)$ are the interest rate differentials. The *a priori* hypothesis for the coefficients are rather complicated in this type of equation. Only if the risk premium really is negligible, *i.e.* the hypothesis that α_0 is zero and the coefficients of α_1 and α_2 are equal to one, which is the test for the uncovered interest rate parity, are warranted. But supposing that the risk premium is not negligible, the estimated expected rate of devaluation (the predicted values of equation 3.13) is really an estimate of the sum of the foreign exchange risk premium and the 'true' expected rate of devaluation. Also in that case the equation (4.19) may have a small α_0, while α_1 and α_2 are equal to one, even if the risk premium is large. That is the reason why this is actually not a test of uncovered interest rate parity.

Another concrete problem in estimation is the possible autocorrelation and hetroskedasticity of the error terms. The autocorrelation of the error terms results from the overlapping phenomenon in estimation of three-month interest rate differentials by monthly data and in both maturities it might follow from the original estimations where the error terms were autocorrelated as well. We can produce consistent estimators using OLS estimation but we have to correct the

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[15]See *e.g.* Bachman (1992), Kaminsky and Peruga (1991), and Lewis (1988, 1989) for a recent modelling of a peso problem in connection with exchange rate markets.

standard errors by the method proposed by Hansen (1982) and White (1980) as in previous estimations. This allows for heteroskedastic and serially correlated errors. In addition we again use the method suggested by Newey and West (1987) to guarantee that the heteroskedasticity and autocorrelation consistent covariance matrix is positive definitive.

4.3.2 Estimation results

The estimation results are shown in *table 4.4* and in *figures 4.2 a -b*. The results are in many respects as anticipated. First, the estimated constants in both equations remained rather small. In fact, they are rather close in size to the risk premia which were approximated in the previous section. Nevertheless, it should be remembered that it remains undetermined in this connection whether a small intercept really indicates a minor role for the risk premium in determining the interest rate differentials.

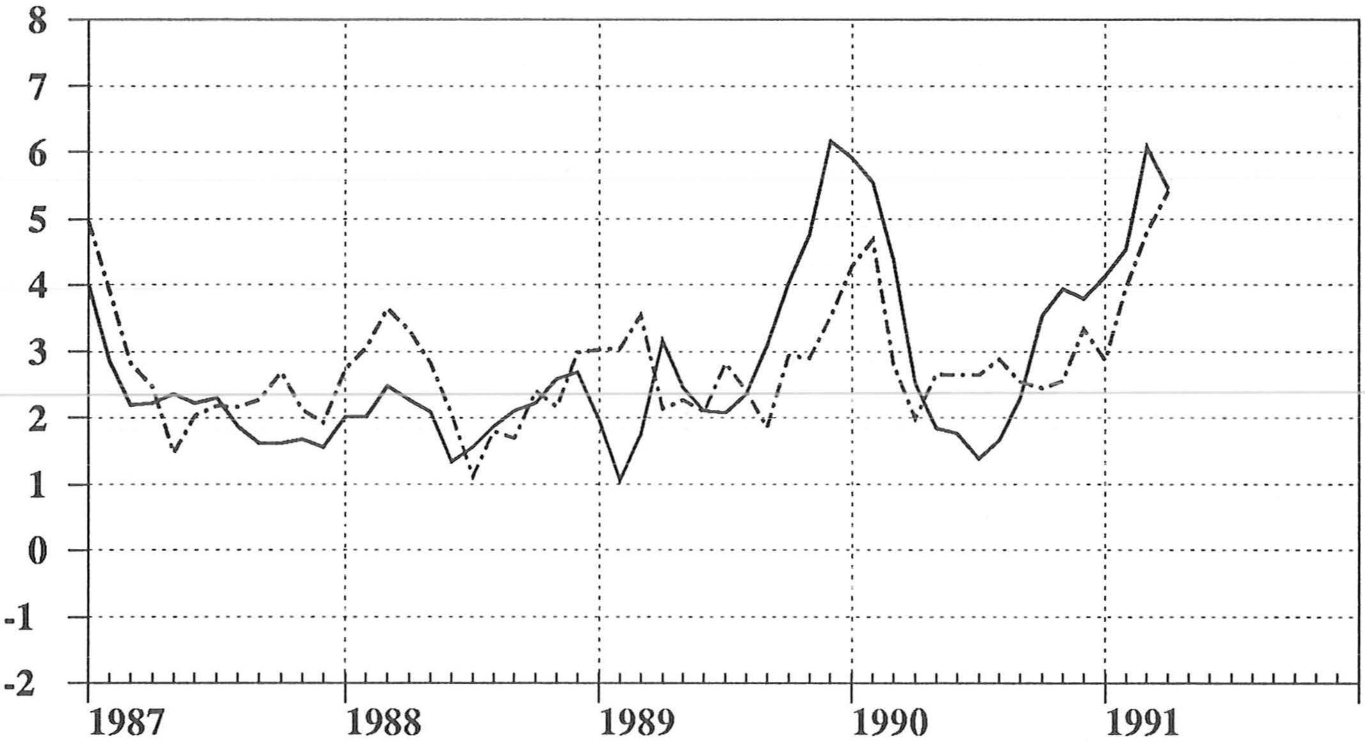
Table 4.4 OLS regressions of interest rate differentials on expected depereciation of the exchange rate

Dependent variable	Constant	Coefficients		R^2	σ	LM
	α_0	α_1	α_2			
δ (t,1)	0.938*	0.577*	0.643*	0.42	1.016	11.74*
	(0.23)	(0.19)	(0.12)			
δ (t,3)	0.511	0.641*	0.777*	0.35	0.882	11.97*
	(0.45)	(0.22)	(0.21)			

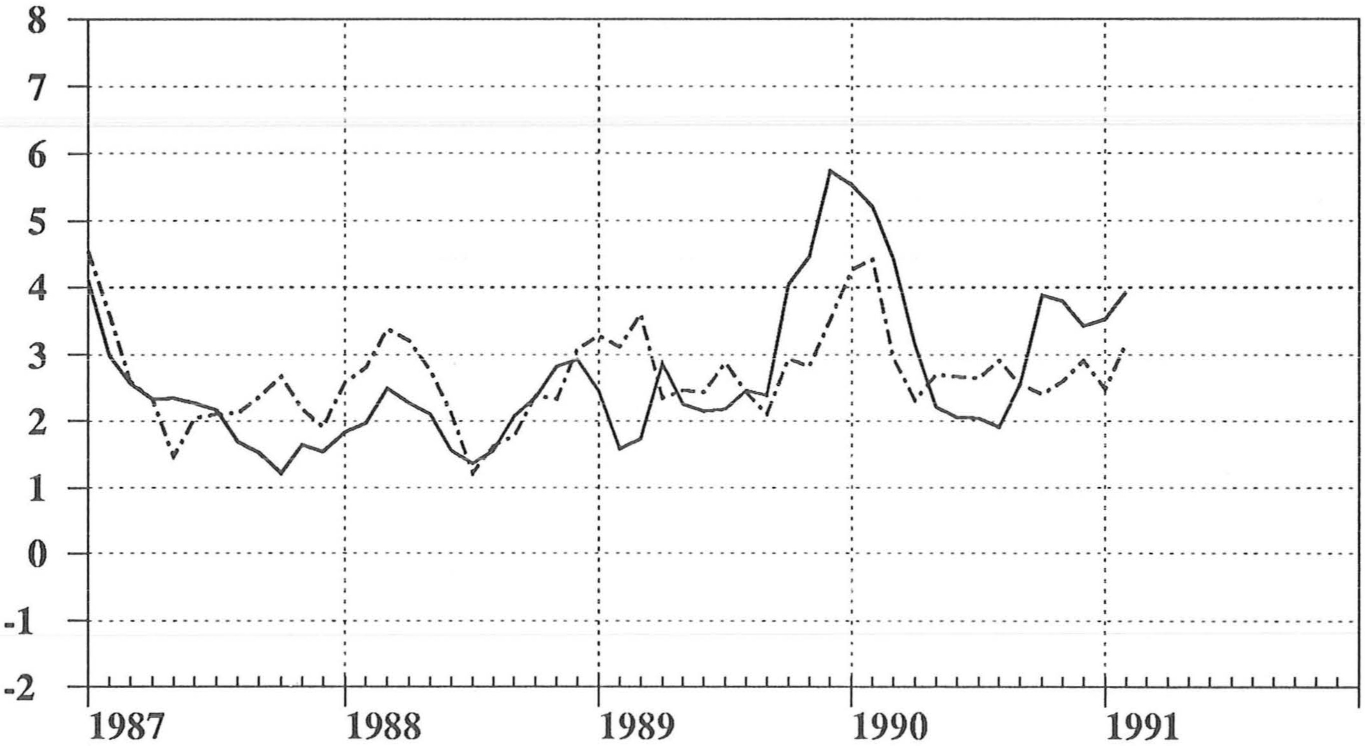
Notes: OLS on (4.19) with Newey-West standard errors within parentheses. σ is the standard deviation of the residuals. LM-statistics is the Lagrange Multiplier test for 4th order residual autocorrelation. It is F-distributed and in both equations H_0: no autocorrelation is rejected. The number of nonzero autocorrelation of the errors has been then set to 4 to compute the standard errors. (The standard errors were not very sensitive to this number). A * denotes significance on a 1 per cent level. Sample: January 1987 to May 1991. Number of observations for δ(t,1): 52 and for δ(t,3): 50.

Figure 4.2 Interest rate differentials and the predicted values
(——— actual values, -·-·-·- predicted values)

(a) 1-month interest rate differentials, %



(b) 3-month interest rate differentials, %



Second, the coefficients of α_1 and α_2 are of reasonable size, and they are significant at a one per cent level as well as obtaining the correct sign. The explanatory power is also at an acceptable level recognising that we are explaining the interest rate differentials.

The results clearly indicate that the role of devaluation expectations cannot be ignored when interest rate differentials are explained. Potential movements of the exchange rate within the band can not alone explain the observed interest rate differentials since these also reflect the expectations of a regime shift. So without including devaluation expectations we get outcomes that underpredict the interest rate differentials. Accordingly ignoring the risk of changing regimes leads to difficulties with the concept of a risk premium in simple testing of forward exchange rate bias. When the devaluation risk is ignored, there is a possibility to misinterprete the results as showing a remarkable risk premium, which in fact is the expected but unrealized regime shift.

4.4 Conclusions

This chapter has discussed two possible explanations of ex post observed deviations from the uncovered interest rate parity condition. First, the role of the foreign exchange rate risk premium was considered. For a target zone such as the Finnish exchange rate band, the risk premium was found to be small especially in relation to devaluation expectations.

Of course there could be risk premia for other reasons than those modeled here. As Svensson (1992a) points out *e.g.* market imperfections, regulations, institutional practises and transactions costs are possible candidates. In the current situation concerning the Finnish economy, a default risk as a possible source of risk premium is not so unrealistic either. If these features are allowed for, a different type of framework is required. Second, in contrast to previous research on the forward exchange bias, which has ignored the risk of changing regimes, it was argued that this risk should be seriously considered as a determinant of the interest rate differentials and accordingly of forward exchange rate bias. A simple peso-problem model was used to demonstrate how this is possible to take into account. The empirical results supported the hypothesis that devaluation expectations are an important component in explaining the interest rate differentials. Consequently, empirical models of the forward bias should explicitly incorporate devaluation expectations as a potential explanatory variable.

Appendix 4.1 OLS-regressions of the expected exchange rate within the band on the current exchange rate [$s(t+\tau)= \beta_0 + \beta_1(s(t) + u(t+\tau)$].

Dependent variable	β_0	β_1	R^2	σ	DW
s(t+1)	-0.220	0.869	0.84	0.121	2.057
	(0.09)	(0.05)			
s(t+3)	-0.615	0.642	0.57	0.283	0.663
	(0.14)	(0.08)			

Notes: Standard errors are in parentheses. σ is the standard error of residuals. Sample period: January 1987 - May 1991, monthly observations.

5 Pricing options on a constrained currency index: some simulation results[1]

5.1 Introduction

The specification of a statistical distribution, which models the price changes of the underlying security, plays a fundamental role for classical arbitrage pricing of options. The basic currency option valuation formulas, such as Garman and Kohlhagen (1983), and Grabbe (1983) assume that the exchange rate, like the stock price in the Black and Scholes (1973) article, follows an Ito process. The stochastic part of the exchange rate is assumed to follow a geometric Brownian motion, which implies a lognormal distribution of exchange rate changes.

However, the assumption that price changes are lognormally distributed may be less valid in the foreign exchange market than in the stock market. The reason is found in active exchange rate management policies, such as market interventions and shifts in monetary or fiscal policy, that do not have any counterparts in the stock market.[2]

In the case of exchange rates for which there exists a currency agreement such as the exchange rate mechanism of the EMS or the currency index system used in Nordic countries, the assumption that underlying exchange rate movements follow a geometric Brownian motion is even less justified than in the case of floating exchange rates. In these cases the constraints imposed by a target zone

[1]This chapter is based on the joint paper with Tom Berglund and Staffan Ringbom.

[2]Distributions that violate the log-normality assumption, however, do not necessarily indicate that the Black and Scholes type of model should be discarded. If a model predicts reasonably well, violations of some of the assumptions are relatively unimportant. Unfortunately, empirical tests of the Black and Scholes model applied to currency options show systematic, significant mispricing, see *e.g.* studies by Bodurtha and Courtadon (1987), Goodman, Ross and Schmidt (1985), Shastri and Tandon (1986), and Tucker, Peterson and Scott (1988). However, the observed mispricing has not been large enough to create profit opportunities, when transactions costs including the bid-ask spread are taken into account.

and possibility of realignments must be included in a model of the exchange rate process.

In general, option pricing models that allow jumps in the price of the underlying instrument have been studied by Cox and Ross (1976), Cox, Ross and Rubinstein (1979), and Merton (1976). A generalized valuation formula for the case where the security price is a combination of an Ito process and a random point process is presented by Aase (1988).

In Merton's (1976) jump-diffusion model it is assumed that the stock price dynamics can be written as a combination of two types of changes: (i) 'normal' vibrations in price, *e.g.* due to a temporary imbalance between supply and demand, gradual changes in the economic outlook, or other marginally significant new information. This component has a continuous sample path, and can be modeled by a standard geometric Brownian motion with a constant variance per unit of time. (ii) 'Abnormal' price changes which are due to the arrival of important new information about the stock. Typically, such information will be specific to the firm or possibly its industry although occassionally general economic information could be the source. This component is modeled by a "jump" process with an inherently noncontinuous sample path reflecting the non-marginal impact of the information. The prototype Merton uses for the jump component is a "Poisson-driven" process, which implies that the jumps are independently distributed over time.

When analyzing the jump-diffusion model in the pricing of stock options Ball and Torous (1985) found that significant discrepancies between Black-Scholes and Merton call prices may occur if the underlying common stock return process is dominated by the presence of large jumps which occur infrequently. However, their empirical evidence suggested that no such jumps were present in the case of stocks. However, they suggested that the return on other financial securities, such as foreign exchange may still be more accurately modeled as a compound Poisson jump-diffusion process characterized by infrequent large jumps.

Empirical evidence of the existence of discontinuities in the sample path of exchange rates and of the impact to currency option pricing can be found in Borensztein and Dooley (1987), and in Jorion (1988).[3]

All the mentioned references of mixed jump-diffusion models have used the assumption that the jump and the diffusion process are mutually independent. There are two reasons for this. Firstly, the model will become much more complicated, if dependency is assumed. Secondly, the exact form of the dependency is a difficult empirical question.

In this chapter we are interested in the effects of allowing the exchange rate movements and the probability of a jump to be mutually dependent as compared to the assumption of the independence of these two stochastic processes. It is shown that this dependence has significant effects on the valuation of a currency option.

What we have in mind is an option on a currency with a fixed but adjustable exchange rate band. From a practical point of view the formal currency arrangement supporting the band designed by given index boundaries represents an important simplification compared to the general approach for mixed jump-diffusion processes, because exact identification of the jumps is possible.

The approach we will take in this chapter is to compute prices of currency options using simulated currency data. Simulation of the underlying exchange rate movements allows us to study in detail how certain properties of the currency basket system will affect the pricing of currency options.

The simulation approach is also justified by the fact that the jump component is difficult to estimate from historical data. Neither the intensity nor the expected level of the jump may necessarily be iterable from the history of previous jumps,

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[3]Jorion (1988) estimates the parameters of interest and finds that exchange rates display significant jump components, which are more manifest than in the stock market. These discontinuities seem to arise even after explicit allowance is made for possible heteroskedasticity in the usual diffusion process. He shows also, that ignoring the jump component in exchange rates can lead to serious mispricing errors for currency options.

rather the jump is a result of complex economic and political considerations that may vary over time.

The outline of this chapter is as follows. In the next section the principle of risk-neutral valuation on pricing of options in the present context is briefly discussed. The following sections describe the process used to generate the currency data under the alternative assumptions and the specification of the parameter values used in the simulations. In section 5.5, the simulation results for the prices of options on a currency index are presented. Conclusions are given in section 5.6.

5.2 Principle of risk-neutral valuation in the present context

At the heart of the derivation of the Black-Scholes type of currency option pricing formula is the arbitrage technique by which investors can follow a dynamic portfolio strategy using the underlying currency and riskless borrowing to exactly reproduce the return structure of an option. By following this strategy in combination with a short position in an option, the investor can eliminate all risk from the total position, and hence to avoid arbitrage opportunities, the option must be priced such that the return on the total position must equal the risk-free rate of interest.

However, for the Black-Scholes arbitrage technique to be carried out, investors must be able to revise their portfolios continuously and the underlying instrument's price must follow a stochastic process that generates a continuous sample path. In effect, this requirement implies that over a short interval of time, the price of the underlying instrument cannot change by much.[4]

In the presence of jumps the hedging argument breaks down. Proper pricing requires that the market's aversion to jump risk has to be taken into account.

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[4]See Merton (1976).

However, there are plausible reasons why the premium attached to jump risk may be negligible in the case of exchange rates. The most important one is that the jump, be it re- or devaluation, is likely to be uncorrelated with the changes in aggregate wealth in the world economy. This should be the case especially if the world market beta for the domestic aggregate wealth against global wealth is close to one, that is if the systematic risk of the domestic economy equals the global average. In the following we will assume that no risk-premium is required by the market for the jump risk in exchange rates.

The assumption that the domestic and the foreign economy are expected to react alike to exogenous stochastic shocks allows us to derive the domestic risk-free interest rate from the foreign rate by assuming that the instantaneous expected return is the same for default-free holdings irrespective of the currency it is denoted in. The risk premium is zero, and interest rates are linked by the uncovered interest rate parity condition, which relates the interest differential to expected changes in exchange rates.[5]

[5]See the discussion in chapter 4. As noted there, even in a case of risk neutrality, the uncovered interest rate parity may seen to be violated due to Jensen's inequality. Its effects on the computation of the domestic interest rate will be discussed in section 5.5 of this chapter.

5.3 Experimental design

5.3.1 Exchange rate movements within the index band when jumps are excluded

We start by assuming that the movements of the currency index[6] within the index band can be described as a discrete time Markov process on a compact state space.[7]

The essential defining property of a Markov process is that the conditional distribution of its future values given all current information is the same as the conditional distribution of its future values given only its current value. This is a common assumption when considering, for example, exchange rates and stock prices, where the absence of expected speculative profits imply that all the relevant information is included in the current price.

In the absence of jumps, the process of the log of the currency index is characterized by the expression[8]:

$$(5.1) \qquad J^*_t = max\left\{0,\ min\ \{2c,(c+b(J^*_{t-1}-c) + \sigma\phi^{-1}(X_t^{(1)})\}\right\},$$

where $2c$ is the width of the band, b is the strength of the assumed mean reverting tendency within the index band, and $X_t^{(1)}$ is a standarized uniformly distributed random variable, which through the inverse of the cumulative

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[6]For convience we will talk about movements of the index although movements of the specific currency (markka) with respect to the index would be more natural.

[7]A continuous-time model is not a possible choice in this framework, because we are solving the model numerically.

[8] In the background we have a stochastic base $(\Omega,\mathcal{F},(\mathcal{F}_t)_{t\in N},P)$ on which every process is measurable and adapted.

$\Omega = \mathop{X}\limits_{i=0}^{\infty} \mathbb{R}^3$, $\mathcal{F} = \bigotimes\limits_{i=0}^{\infty} \Re^3$, $\mathcal{F}_t = \bigotimes\limits_{i=0}^{t} \Re^3$, is sufficiently large for our purposes.

standard normal density function ϕ^{-1} produces a normally distributed random shock. The dispersion of the shock is scaled by σ. The boundaries of the index are imposed through the min and max functions, which will keep the index value within the band.

It should be noted that this simplifying assumption about the exchange rate being a truncated normal distribution in (5.1) is inconsistent with the Krugman (1991) target zone model used previously. In the extended Krugman target zone model with intramarginal interventions that follow an Ornstein-Uhlenbeck process the fundamental is truncated normal. With the exchange rate being a nonlinear function of the fundamental, the distribution of the exchange rate is not truncated normal either. However, if the exchange rate function is approximately linear, a the result shown by Lindberg and Söderlind (1992), the exchange is approximately truncated normal.[9]

The mean reverting property means that when the system is in a state far removed from the midpoint, it is more likely to move towards the midpoint than in the opposite direction. If $b=1$, the corresponding unbounded process, the second argument in the min function in (5.1), is a random walk. If $|b| < 1$, the corresponding process is a stationary autoregressive process of order one.

The values for the coefficient b and for the standard deviation σ can be estimated from historical data.

5.3.2 The jump characteristics

A jump means that the whole index band is moved up or down. Furthermore, the index number jumps to a new location within the new band.

Since the range of the band is given, it is sufficient to model the process for the lower bound $(J_t^{(1)})$. The change of the lower bound of the index, *i.e.* a

[9] I am grateful to Lars Svensson for drawing my attention to this point.

revaluation *(A)* or a devaluation *(D)*, is defined by the following expression:

$$(5.2) \qquad \Delta J_t^{(1)} = -\mathit{1}_{At}(X_t^{(2)})a_1(X_t^{(3)}) + \mathit{1}_{Dt}(X_t^{(2)})d_1(X_t^{(3)}).$$

Normally $\Delta J_t^{(1)}$ is zero. If the indicator function $\mathit{1}_A$ takes the value one, a revaluation occurs and the size of the jump is given by $a_1 X_t^{(3)}$ and if the indicator function $\mathit{1}_D$ takes the value one, a devaluation occurs and the size of the jump is given by $d_1 X_t^{(3)}$. The term $X_t^{(3)}$ is a standard uniformly distributed independent stochastic variable which is independent of $X_t^{(1)}$. The terms a_1 and d_1 denote inverse functions of lognormal cumulative distribution functions. Thus the size of the re- or devaluation is lognormally distributed.

By choosing the lognormal distribution we eliminate jumps in the wrong direction, which could occur if negative values were possible. Furthermore, very small jumps are unlikely, while large jumps are possible.

$X_t^{(2)}$ is a standard uniformly distributed independent stochastic variable[10] which will determine whether a revaluation or devaluation will occur. This is determined according to *Figure 5.1.*

Figure 5.1. The determination of re- and devaluations using a uniformly [0,1] distributed random variable $X^{(2)}$.

If $\quad A$: $X^{(2)} \leq q(j)$, a revaluation occurs, while if
$\quad D$: $X^{(2)} > 1\text{-}p(j)$, a devaluation occurs.

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[10] Also independent of $X^{(1)}$ and $X^{(3)}$.

The probability for a revaluation $q(j)$ and $p(j)$ for a devaluation are assumed to be Bernoulli-type probabilities as follows:

$$(5.3) \qquad q(j) = k_a \left(1 - j/2c\right)^n \text{ and } p(j) = k_d \left(j/2c\right)^n$$

with the natural restriction,

$$\forall j \in [0, 2c]: q(j), p(j) \geq 0 \ \& \ q(j) + p(j) \leq 1.$$

If $n=0$, the probability will not depend on the position within the band. Thus, the probability is evenly distributed over the whole fluctuation area.

The total unconditional probability of a revaluation or devaluation is given as an integral of the probabilities over the whole fluctuation area

$$(5.4) \qquad p = \int_{[l.b,u.b]} p(j)\, d\bar{P}(j), \qquad q = \int_{[l.b,u.b]} q(j)\, d\bar{P}(j)\,,$$

where $\bar{P}$ is a stationary probability measure for the position within the band, $j \in [\, l.b.,u.b.]$.

5.3.3 Exchange rate movements including jumps

The process determining the position of the currency index value within the index band ($J_t^{(2)}$), including the possibility of a jump, is defined as follows:

$$(5.5) \qquad J_t^{(2)} = \mathbf{1}_{A_t^c \cap D_t^c}(X_t^{(2)}) J^*_t(X_t^{(1)}) + \mathbf{1}_{A_t}(X_t^{(1)}) a_2(X_t^{(2)}) + \mathbf{1}_{D_t}(X_t^{(1)}) d_2(X_t^{(2)}),$$

where $\quad A_t = [0, q(J^{(1)}_{t-1})]$ and $D_t = [(1-p\,(J^{(1)}_{t-1})),1]$

when $t > 0$, $A_0 = D_0 = \varnothing$

Since the location of the index number within the band after a jump is unknown, we assume the location is Beta-distributed within the new index band. Beta-distibution is chosen because it guarantees that the new position is centred in the middle of the band and the probability of landing outside the range is zero. Thus, a_2 and d_2 are inverse functions of the cumulative Beta-distribution function, where the parameters α and β are determined to correspond to *a priori* expectations.

The process of the log of the currency index is now easily defined as

(5.6) $$I = (I_t)_{t \in \mathrm{N}}, \text{ where } \forall t \in \mathrm{N} : I_t = J_t^{(1)} + J_t^{(2)}.$$

The log of the index is the sum of the lowerbound and the position in the band. Thus the currency index process can be written as

(5.7) $$S = (S_t)_{t \in \mathrm{N}}, \text{ where } S_t = exp(J_t^{(1)} + J_t^{(2)}).$$

5.4 Specification of the parameter values used in the simulation experiments

Parameters and starting values which are used in the simualtions of the exchange rate movements are defined in Table 5.1.

The width of the index band is set to 6 %, which corresponds to the currency band used in Finland. In our experiments 11 evenly distributed initial states that start at the lower and end at the upper boundary are explored.

Table 5.1. Parameter settings used in the simulation experiments

Symbols	Description	Value
Starting value:		
x	The relative index position within the band	$x \in [0,1]$
I_{lb}	The lower bound of the index.	97
I_{ub}	The upper bound of the index.	103
I_t	The initial position within the band	97-103
Parameters:		
b	The strength of the mean reversion property.	0.9985
σ	The standard deviation of the error term in the unconstrained autoregressive process.	0.00145
Θ	The expected log size of the jump	0.05
δ	The standard deviation of log of the jump.	0.01
$\max_j \{p(j)+q(j)\}$	The probability of the jump: (j) is the relative position within the (log) band.	0.005
$E(x \mid j)$	The expected relative position of the index value within the new (log) index band after the jump.	0.5
$Var(x \mid j)$	The variance of the relative position of the index within the new (log) band.	0.001

The strength of the mean reverting property is fixed to the estimated value from the daily observations of the Finnish currency index in the period 1987-1989.[11] The standard deviation, which is used in the simulations is estimated from the same data.

The log of the expected size of the devaluation or revaluation is set to 0.05. The standard deviation around the expected size is assumed to be 0.01. These figures correspond to our view that very small currency realignments are unnecessary, while the realignment usually will be made before the required magnitude will grow too large, due to actual or potential speculative pressure. The case in which the probability of a jump is dependent on the position within the band is parametrized as follows: The probability of a jump at its highest is 0.005 at the boundaries of the band. For a revaluation the maximum is at the lower bound and for a devaluation at the upper bound. For the rest of the band the probability is determined as a quadratically decreasing function which reaches zero at the other boundary.

In the benchmark experiment the overall probability stays the same, the difference being that the probability for devaluations as well revaluations will be constant throughout the band.

When dependence is assumed, the expected relative value of the index after the jump is in the middle of the new band. The variance of the expected value is set to 0.001. In the benchmark case the expected relative value of the index after the jump is the same as before the jump.

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[11]The estimated regression was: $S_t = a + bS_{t-1} + e_t$, where S_t is the log of the currency index.

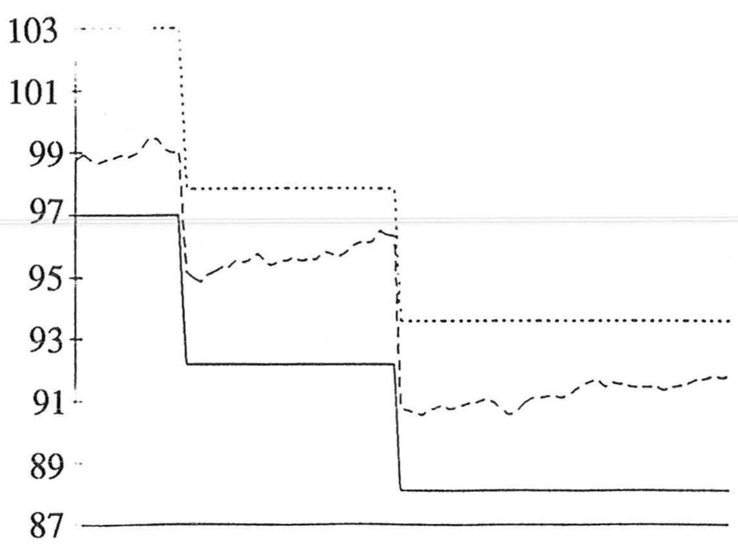
5.5 Simulation experiments

5.5.1 General considerations

To evaluate options on our index we start by using the above model to generate a data set. A set of 30 000 exchange rates at the expiration date of the option are produced for each 11 initial state. The initial time to expiration in our simulations is 10, 20, 30, 60, and 90 days. Once the data is given the values of the currency options are computed.

An example of the time path of the exchange rate procuded by our simulation model is given in *Figure 5.2.* The exchange rate in the figure appreciates from 99 to 91.8 and two revaluations occur during 90 days.

Figure 5.2. Time path of the exchange rate (90 days)



The strike prices of the options are determined next. For our 11 starting values we define three corresponding strike prices. Thus at time 0 the options are either at-the money, in-the-money or out-of-the-money. The in-the-money and out-of-the-money options at time 0 are defined to have a strike price, which is one standard deviation below or above the current rate.

The foreign interest rate is defined as the weighted average of interest rates of the currencies in the basket. We used the average of daily observations of the three-month currency basket eurorate for the year 1989, which was 9.9 %.

The domestic interest rate when determined by the model guarantees the elimination of expected speculative profits between the synthetic forward and domestic default-free money market instruments.[12]

However, even in the case of risk neutrality, the uncovered interest rate parity may be violated due to Jensen's inequality. The convexity problem of nominal interest rates arising from the Jensen's inequality is solved in our model using logharitmic values of the future exchange rates.[13]

5.5.2 The results

In the following the results for two maturities are reported. These are 90 days, which represents a long time to expiration and 10 days, which represents a short time. The results for these two maturities will be reported in parallel to highlight the effects of the time to expiration.

To make interpretation easier the main results of this study are reported in graphical form. Since the results will depend on the starting location of the exchange rate within the band the graphs will report the outcome with the starting state on the category axis, the first state being the lower border and the

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[12]See section 5.2 for a discussion of how the domestic interest rates are determined.

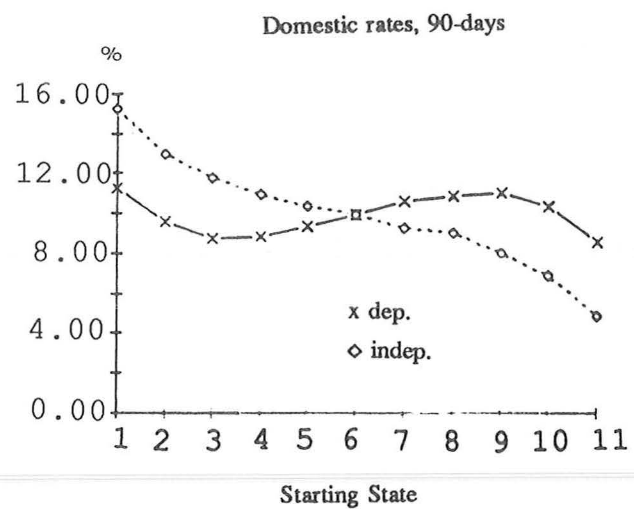
[13] This problem is known as Siegel's (1972) paradox which states that, even in the absence of risk aversion, the efficiency condition in the forward foreign exchange market cannot be that expected nominal profits are zero. This is because nominal profits can be expressed in terms of either currency. It cannot be the case that the forward home-currency price of foreign currency equals the expected future spot rate of foreign currency $F = E(S)$, and the forward foreign price of home currency equals expected future spot price of home currency $1/F = E(1/S)$. Because of Jensen's inequality, expected nominal profits must exit - at least in terms of one of the two currencies. This convexity term is sometimes erroneously interpreted as a component of the risk premium. For a detailed discussion of the effects of Siegel's paradox, see Roper (1975), McCulloch (1975), Stockman (1978) and Frankel (1979).

eleventh or last state the upper border of the initial band.

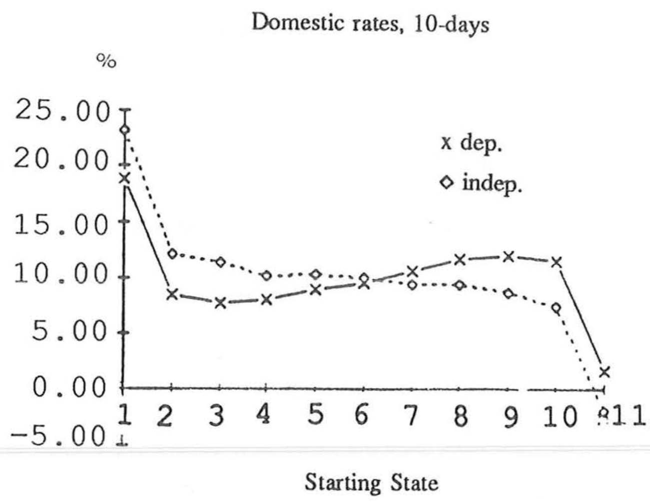
The first results that are of crucial interest with respect to how the options are priced are the domestic interest rates and the volatilities produced by the model. The fact that the exchange rate is not allowed to cross the border of the band unless there is a jump is clearly reflected in the domestic interest rates as seen in *Figure 5.3a* for the 90-day option, and in *Figure 5.3b* for the 10-day option.

***Figure 5.3.* Domestic interest rates as a function of the starting state within the band**

(a)



(b)



In general, the border will push the exchange rate in the other direction. At the lower border this will produce an expected depreciation and high interest rates, and at the upper border an expected appreciation and consequently low domestic rates. This is most transparent in the case in which the jump probability is independent of the exchange rate position. In the 10-day case the presence of the border is clearly felt exclusively in the most extreme starting states.

An interesting picture emerges if the level of the interest rate in the 90-day case is compared to the level of the interest rate in the 10-day case.

It is seen that a relatively steeply sloping yield curve is required to eliminate expected speculation profits close to the borders of the band. The fact that the domestic rate turns negative at the upper border for the independent case indicates that there are states in which independence between the jump and the position in the band can no longer be reconciled with the absence of speculative
profits.

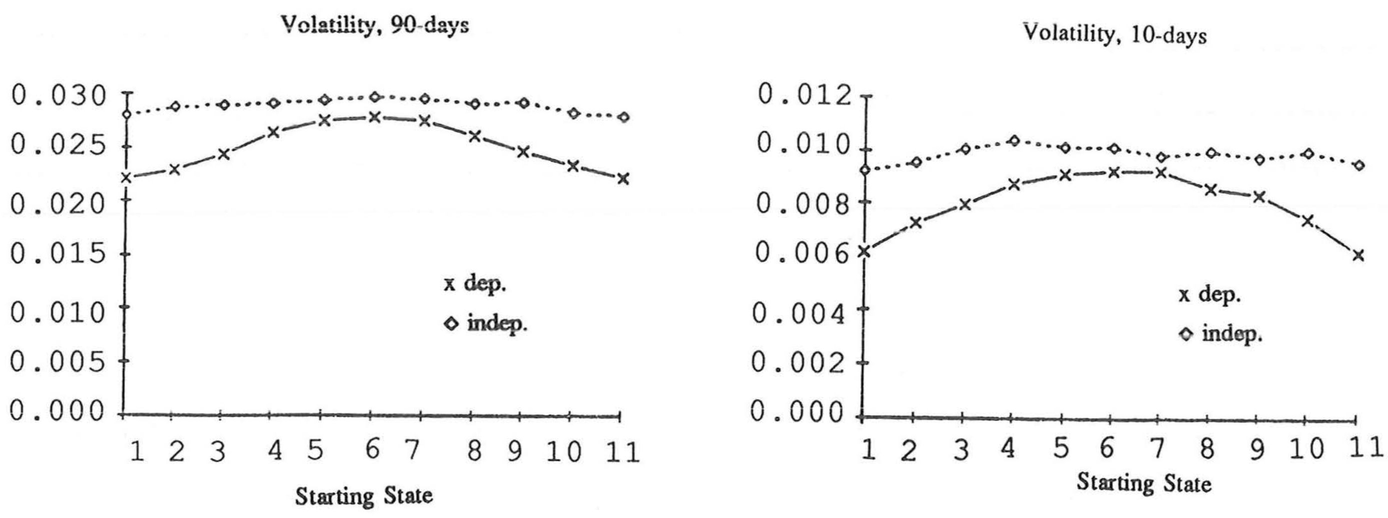
The main difference between our main case in which the probability of a jump depends on the state within the band, and the bench-mark, the independent case, is that the effect of the closeness to the border of the band will be counteracted by an increasing jump probability in the dependent case. The outcome is an S-shaped pattern for the domestic rate, which is almost horizontal.

Figure 5.4 reports the observed average volatilities. The observed volatilities to a large extent reflect jumps in the band. In the benchmark case these jumps are equally likely and of the same magnitude independently of the exact starting state within the band; this translates into a volatility which is largely independent of the starting state.

For the dependent case, however, the size of the jump will depend on the state in which it occurs. As such the jump size of the band, conditional to the fact that it occurs, is independent of the state, but the expected position of the exchange rate within the removed band will be in its middle. Thus, the realized jump is expected to be smaller when it takes off from a state close to the border of the band than when it occurs in a state more distant from the border. This explains the fact the volatility tends to drop as we move from the middle of the band towards the borders.

Figure 5.4. The standard deviation of the exchange rate as a function of the starting state within the band

(a) (b)



Close to the borders the volatility is affected by two counteracting tendencies:

(i) *The jump probability is higher in the dependent case than in the independent case, which implies a higher volatility for the dependent case.*

(ii) *The expected size of the jump is smaller in the dependent case* [14], *which implies a lower volatility for the dependent case.*

It turns out that (ii) will dominate (i) and the volatility will be markedly lower in the dependent case.

Figure 5.5 reports the call option prices based on our simulation data. These prices are obtained using the formula:

[14]The expected size of the jump in the exchange rate at the border is in the independent case jump in border, whereas in the dependent case the term denoting the width of the band c should be subtracted.

$$(5.8) \qquad C_t(s) = \frac{e^{-r\tau} \sum_{i=1}^{30000} max\,(S_{t+\tau}(\omega^i) - X,0)}{30000} \;/\; S_t = s,$$

where τ is time to expiration, $r\tau$ is the domestic interest rate until the time to expiration, ω is a realization path on the underlying probability space and i indexes the simulation run, S is the exchange rate, and X the exercise price. This formula gives slightly downward biased option values, due to the fact that the implicit interest rates are path dependent and should be treated as stochastic interest rates. However the same error is made when currency options are valued using the Garman-Kohlhagen model (1983), instead of the model presented by Grabbe (1983).

Three sets of expiration prices where used: out-of-the-money, at-the-money, and in-the-money. The at-the-money options have an exercise price equal to the present exchange rate, the out-of-the-money an exercise price one standard deviation (computed ex post) above the present rate, and the in-the-money an exercise price one standard deviation below the present rate.

The results exhibited in *Figure 5.5* clearly mimic the results for the interest rates reported in *Figure 5.3*. As expected this is most apparent when the relative impact of volatility is smallest i.e. in the prices for the in-the-money options in *5e* and *5f*.

The relatively large difference for the out-of-the-money options close to the lower border of the band is due to the fact that the independent case makes the probability of an upward jump in the band (i.e. essentially in the "wrong" direction) much more probable than the dependent case does.

Figure 5.5. Call option prices as a function of the starting position within the band when the probability of a realignment is dependent *vs.* independent of the exchange rate position within the band.

Figure a

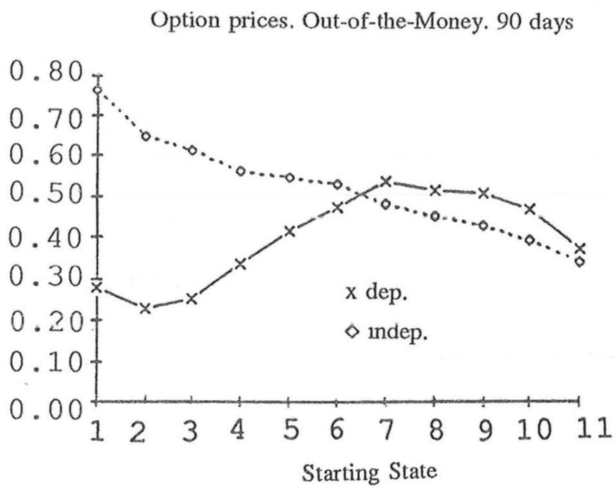


Figure b

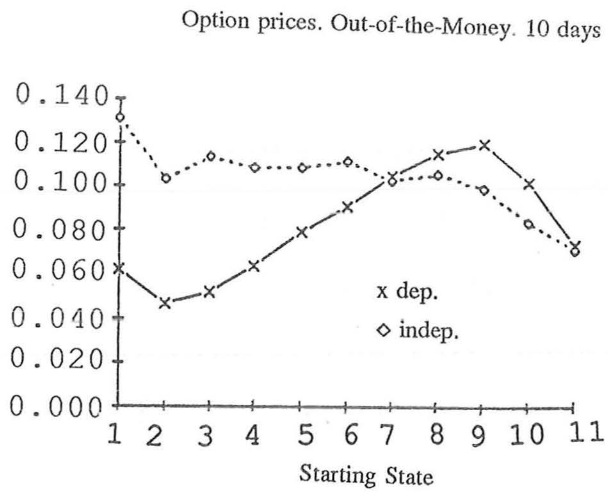


Figure c

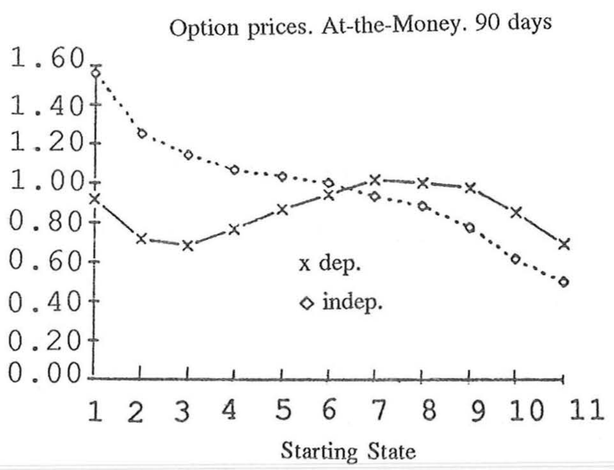


Figure d

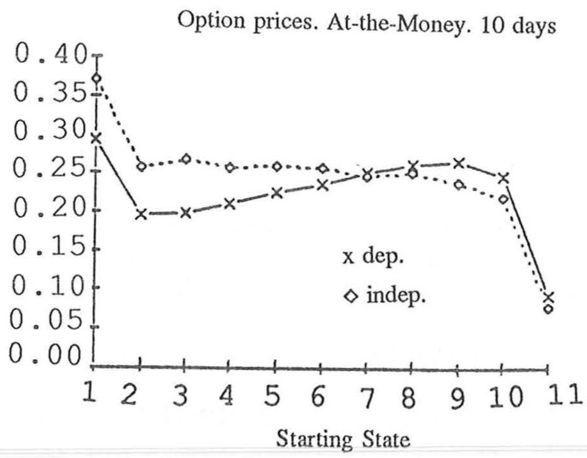


Figure e

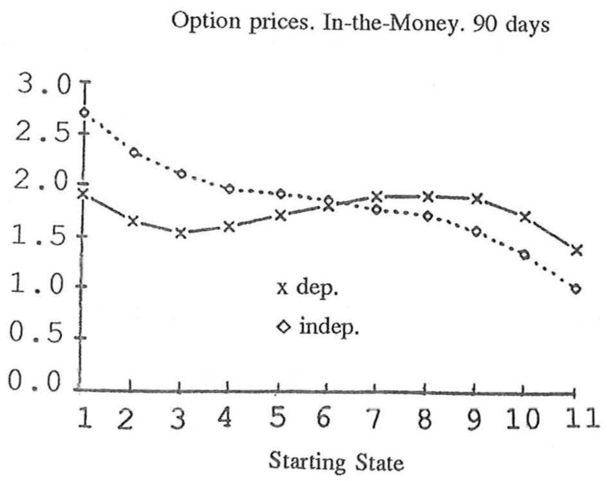
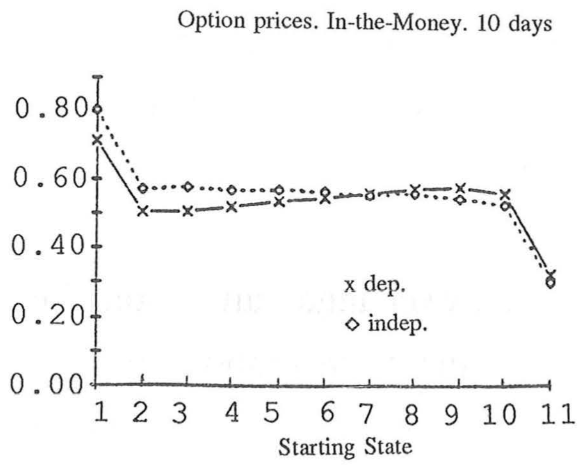


Figure f



In the dependent case the probability of a jump in the wrong direction approaches zero as the exchange rate approaches the border, whereas for the independent case this probability stays on the same level as for all other states within the band.

As a consistency check the value of call options with exercise prices given by the lower border and the upper border were also computed. The results are reported in *Figure 5.6.*

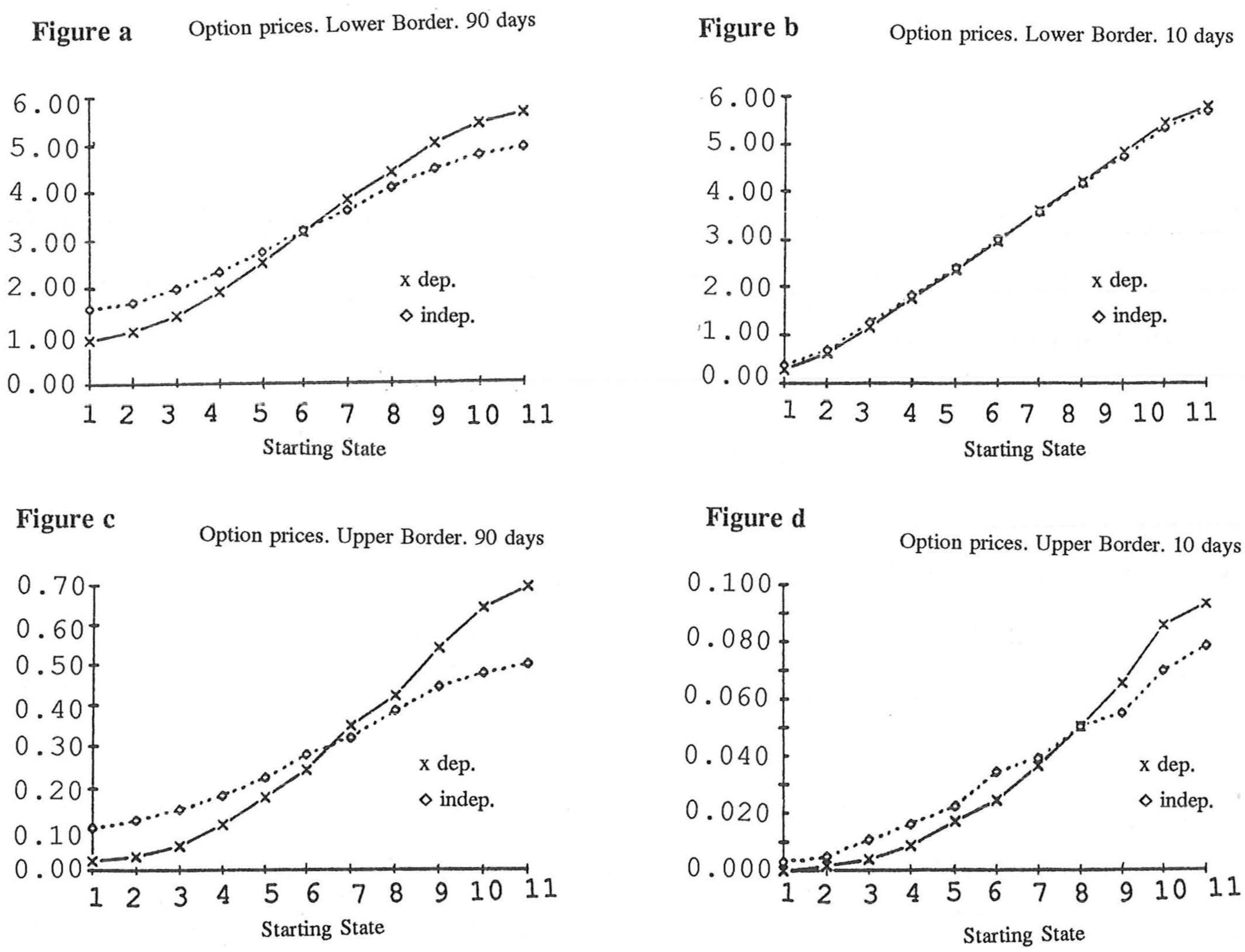
The prices for the independent and the dependent case follow each other quite closely which shows that the degree of out-of or in-the-moniness is a more important explanatory factor for the observed option prices than is the difference between our main case and the benchmark. The observed main case versus benchmark difference is mainly due to the lower probability for jumps in the "wrong" direction and a higher probability for jumps in the "right" direction when the jumps depend on the location of the exchange rate within the band as compared to the independent case. This difference is less pronounced for the 90-day than for the 10-day option because of the tendency in the dependent case for a jump to switch the process to the middle of the band.

To be able to focus more directly on the impact of the differences in second and higher moments of the exchange rate distribution on the expiration date, we computed a new set of option prices with different striking prices. The striking prices in this new case were determined on the basis of the average log value of the exchange rate at the expiration date. This implies that the expiration prices will differ considerably between our main case and the bench mark case. However, this will remove the deviation produced by the differences in the expected exchange rate [15] on the expiration date. The results based on the adjusted strike are reported in *Figure 5.7.*

Figure 5.7 reveals that adjusting the strike price to account for the expected change in the exchange rate will make the differences between the option prices

[15] The stochastic component in the average as compared to the actual mean, or the simulation error is disregarded.

Figure 5.6. Option prices at the boundaries



correspond quite closely to the differences in volatilities as displayed in *Figure 5.4* for the at-the-money as well as for the in-the-money case.

However, this is not the case for the out-of-the-money option. For that option the differences are most notable, as they were in *Figure 5.5*, for the states close to the lower border reflecting the higher probability for an upward jump in the independent case.

When moving from the first starting state towards the eleventh in the 90-day case the option value computed for the dependent process will approach the value for the independent process up to the state 7, and then fall off again, whereas for the 10-day case, the value for the dependent process will intersect the value for the bench mark, and stay above it up to and including the upper border. This difference is explained by the higher probability in the dependent case of an upward jump when the exchange rate is close to the upper border. This effect will have a smaller impact for the 90-day than for the 10-day option. For the 90-day option the fact that the exchange rate is expected to land after a jump in the middle of the band, where the probability of further jumps is at its minimum, will make the overall effect of jumps smaller than for the 10-day option.

As a summary of the comparison of the option values produced under our specification of the dependence between the location within the band and the jumps produced by re- or devaluations and the option values produced under the assumption of independence, we conclude that the most notable difference will arise because of differences in the expected exchange rate change.

The independence assumption will produce the result that the exchange rate must be expected to depreciate when it is close to the lower border and to appreciate when close to the upper border. A constant jump probability, furthermore, requires a steeply sloping yield curve for domestic interest rates close to the borders of the band, not to give rise to expected speculative profits. In general our results indicate that the shape of the yield curve is quite sensitive to the specific assumptions made about the exact exchange rate dynamics.

Figure 5.7. **Call option prices when the strike prices are adjusted to correspond to the expected change in the exchange rate.**

Figure a

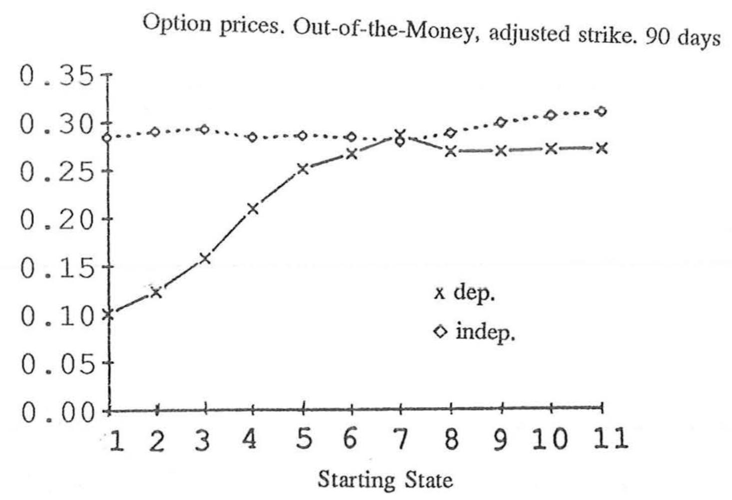


Figure b

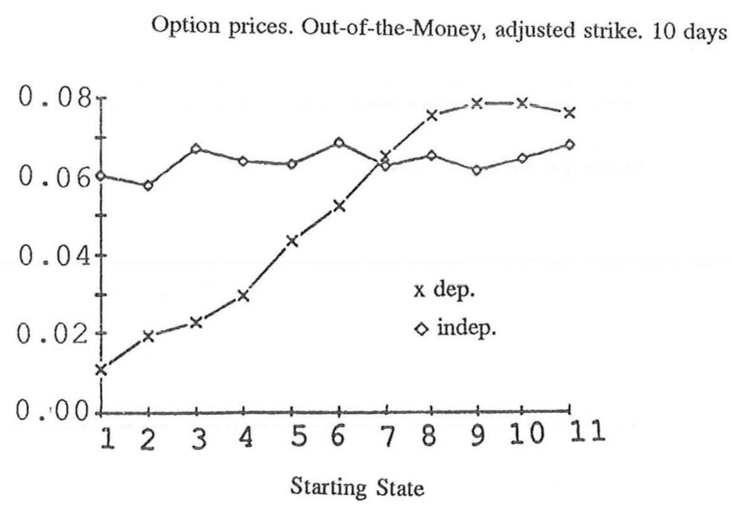


Figure c

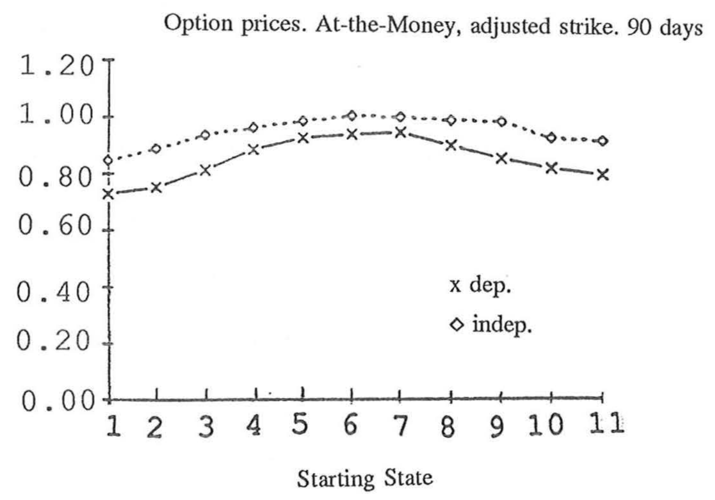


Figure d

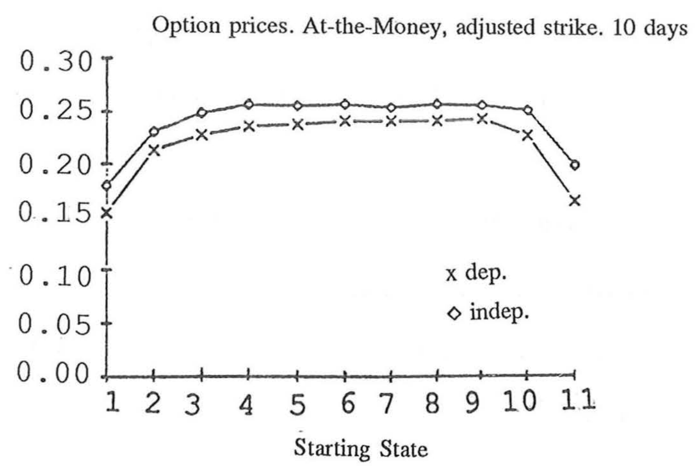


Figure e

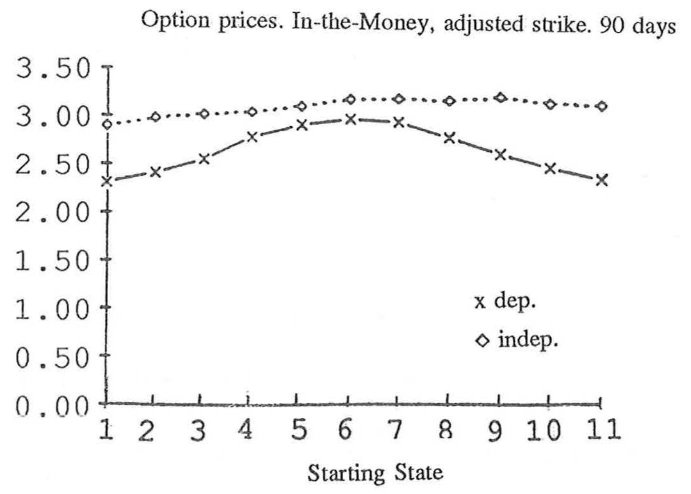
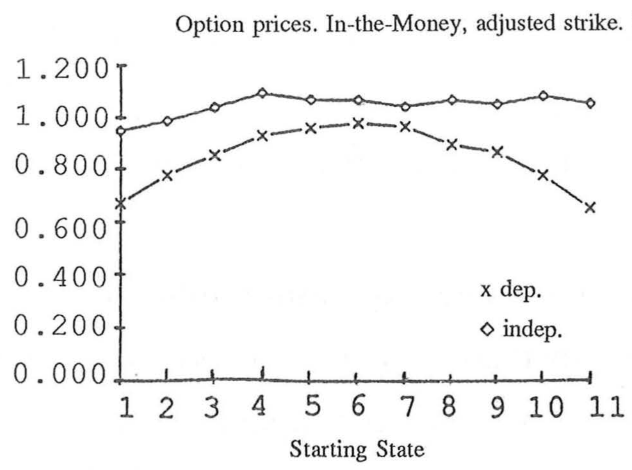


Figure f



The largest differencies in option prices produced by the two models will arise for out-of-the-money options close to the lower border. The way the dependence between the location within the band and the jumps is modelled the probability of a revaluation will be highest at the lower border, which will make the call option on the foreign currency far less valuable than in the case where the probability of a revaluation at the lower border is the same as for a devaluation.

5.5.3 Comparisons to the Garman-Kohlhagen model

Since the most widely used model for pricing exchange rate options is the Garman and Kohlhagen (1983) version of the Black and Scholes (1973) model, it is natural to ask how the prices produced by the present model will differ from those produced by Garman and Kohlhagen model. The Garman and Kohlhagen gives the following expression for the value of a call option:

(5.9) $$C = Se^{-rf\tau}\,\Phi(d_1) - Xe^{rd\tau}\,\Phi(d_2),$$

where $$d_1 = \frac{\ln(S/X) + rd - rf + \sigma^2/2)\,\tau}{\sigma\sqrt{\tau}}$$

and $$d_2 = d_1 - \sigma\sqrt{\tau}$$

When applying the above formula to the valuation of the options produced by our simulation experiment, proper values for the input variables have to be selected. Since all other input variables than the volatility normally will be observed we will focus on the choice of the volatility measure. The foreign interest rate is taken to be the 9.9 % used in our simulations, and the domestic rate is the one produced as a result of our simulations. An analogous choice would be the volatility produced by our 30 000 simulation runs as input in the model.

The other two candidates used in the present paper are: the correct volatility in the case of no restrictions for the assumed diffusion process, which is called the unconstrained standard deviation, abbreviated as unc.std., and a simulated proxy for the standard deviation conditional on no jumps, which will be called in the band standard deviation.[16] The Garman-Kohlhagen option prices produced by these standard deviations are given along with our simulated option values in *Figure 5.8*.

Figure 5.8 reveals that our simulated option values in most cases will remain below the Garman and Kohlhagen option value based on our simulated standard deviation, whereas it will lie above the option values produced by the other candidates. The reason for the tendency of the simulated volatility to overestimate the true value of the option lies in the fact that the standard deviation is more sensitive to extreme values than the option price is itself.

Figure 5.8 also shows that jumps may contribute significantly to the value of the option. This is especially true in the out-of-the-money case, where the use of a standard deviation estimated on observations that do not include a jump would produce grossly misleading results.

[16] With no constrains the index will follow an AR (1) process. It is easily shown using the formula for the sum of geometric series that the variance of the index k-periods from now will be: $\sigma^2 \frac{1-b^{2k}}{1-b^2}$,
where σ^2 is the variance of the error term, k is the number of periods ahead, and b is the autoregressive coefficient in the model $|b| < 1$.

Figure 5.8. Simulated option prices compared to Garman-Kohlhagen prices under different estimates for the volatility parameter used as input variable in the Garman-Kohlhagen model

Figure a

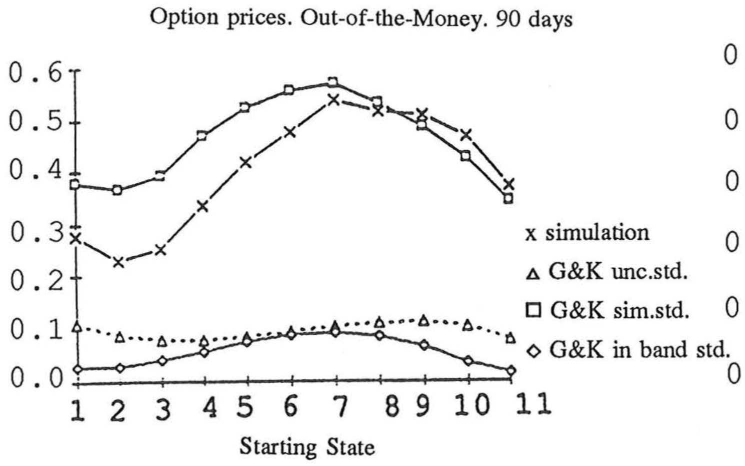


Figure b

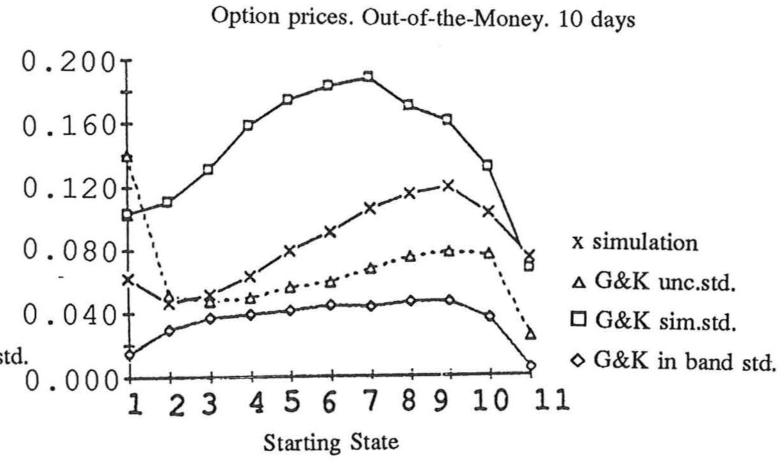


Figure c

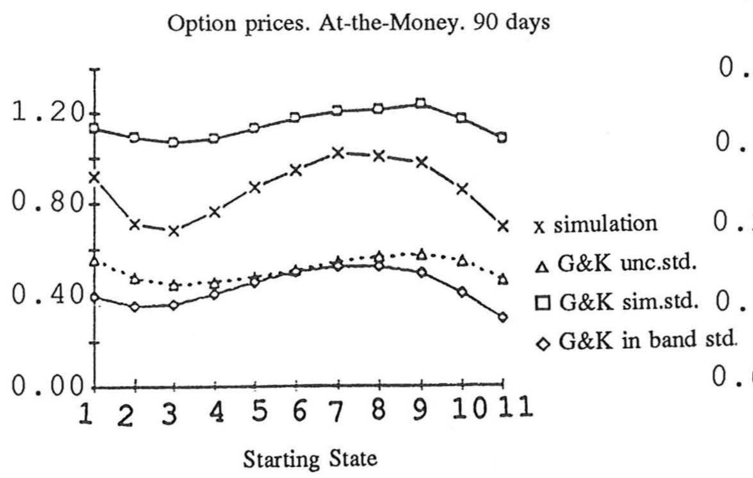


Figure d

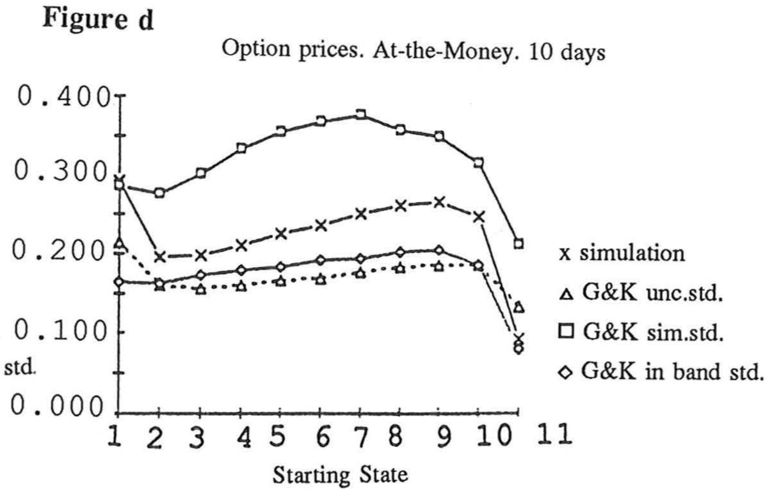


Figure e

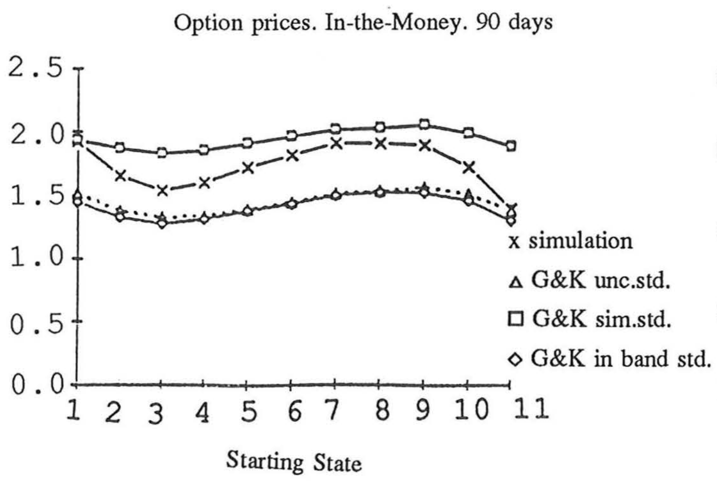
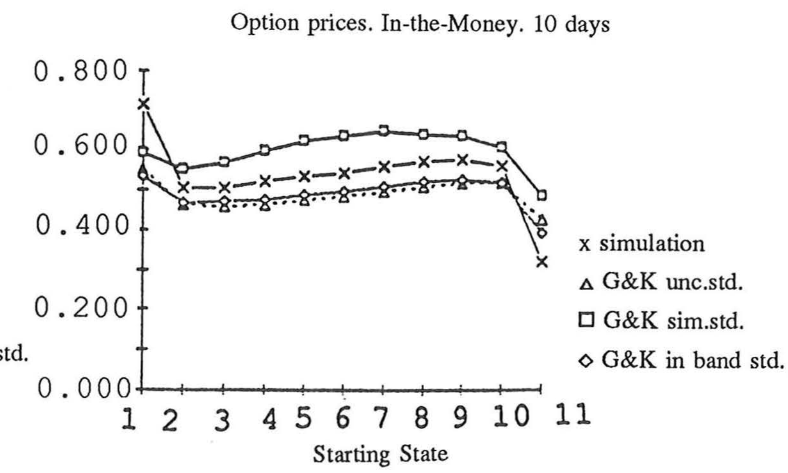


Figure f



5.6 Conclusions

This chapter uses a simulation model to analyze the consequences of removing the assumption of independence between the jump produced by re- or devaluations and the exchange rate position within the band. A simple form of dependency is introduced which makes the probability of a devaluation grow from zero quadratically towards the upper border, while the probability of a revaluation grows quadratically from zero towards the lower border.

Our results indicate that the expected change in the exchange rate produced by the independence case will produce unrealistic outcomes. To preclude profitable speculation the exchange rate must be expected to depreciate when it is close to the lower border, while it must be expected to appreciate when close to the upper border. These types of outcomes are unrealistic in this context, while the results indicate a credible band, which is not assumed in our model. It turns out that these phenomena are avoided if the occurrence of re- or devaluations will depend on the location within the band, given a realistic set of parameter values.

The largest difference in the call option values produced by the two models will be for out-of-the-money options close to the lower border. The constant probability of an upward jump in the independent case will drive up the option price as opposed to our dependent case in which it will be driven down by a relatively high probability of a downward jump. Even for in-the-money options a difference of 25 % at its maximum was observed for the 90-day option. Thus, whether independence between the jump and the location within the band is assumed or not seems to be of considerable importance for the pricing of an option on the index.

Finally, when the option values based on our simulation experiments were compared with the option prices calculated with the widely used Garman and Kohlhagen model it turned out that the Garman and Kohlhagen model gave rise to over- as well underestimation. When the simulated standard deviation was used in the Garman and Kohlhagen model the prices generally were above the simulated values, but when all jumps were disregarded when computing the standard deviation the reverse turned out to be true. Once again the out-of-the-money options exhibited the most notable differences.

The present simulation model is still subject to several apparently unrealistic features. Perhaps the most striking is the fact that de- and revaluations are made dependent on the exchange rate position within the band in a rather simplistic fashion. A more realistic model would derive probability estimates for re- and devaluations from simulated interest rate differentials. That would guarantee realistic interest rate dynamics, which is not the case in the present model.

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