

## **Keskusteluaiheita - Discussion papers**

No. 398

Olavi Rantala

**AN ECONOMETRIC DIFFUSION MODEL  
OF EXCHANGE RATE MOVEMENTS  
WITHIN A BAND**

**IMPLICATIONS FOR INTEREST  
RATE DIFFERENTIAL AND CREDIBILITY  
OF EXCHANGE RATE POLICY**

This series consists of papers with limited circulation intended to stimulate discussion. The papers must not be referred to or quoted without the authors' permission.



**RANTALA, Olavi, AN ECONOMETRIC DIFFUSION MODEL OF EXCHANGE RATE MOVEMENTS WITHIN A BAND, IMPLICATIONS FOR INTEREST RATE DIFFERENTIAL AND CREDIBILITY OF EXCHANGE RATE POLICY.** Helsinki : ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 1992. 19 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; no. 398).

**ABSTRACT:** The paper presents a model of exchange rate movements within a specified exchange rate band enforced by central bank interventions. The model is based on the empirical observation that the exchange rate seems to lie usually strictly inside the band, at least in Finland. In this model the distribution of the exchange rate is truncated lognormal from the edges towards the center of the band and hence quite different from the bimodal distribution of the standard target zone model.

The model is estimated using the daily observations of the changes in the FIM exchange rate since 1987. The estimated model is used to compute the expected future values of the FIM/ECU rate in August 1991 - January 1992 and the corresponding interest rate differential between Finland and EMS countries. Subtracting this from the actual interest rate differential gives a measure of expected devaluation and devaluation risk premium. The premium was very large before the devaluation in November 1991 but afterwards it decreased considerably.

**KEY WORDS:** target zone exchange rate, reflecting barrier, devaluation risk



## 1. Introduction

Many European countries have adopted a target zone exchange rate mechanism where the exchange rate is allowed to float, but only within a specified band enforced by central bank interventions. Examples are countries participating in the European Monetary System and Nordic countries. The regulated floating of exchange rates has also been established under the Louvre accord in 1987 and the subsequent consultations among the major industrial countries, although these target zones have not been publicly announced.

Whether the exchange rate movements within a known band can be forecast is an important question for macroeconomic forecasters and for the private sector agents who operate in the foreign exchange and financial markets. The usual procedure in macroeconomic forecasting is to set the future exchange rate at the currently prevailing level. Implicitly this means that exchange rate changes are assumed to follow a pure random walk process so that the best forecast for the future exchange rate is the spot rate. However, taking the exchange rate band into account implies that the asymptotic distribution of the random walk exchange rate process is uniform and the long-run mean of the exchange rate is the midpoint of the band.

On the other hand, a model incorporating the simple random walk with bounds set by the band has some undesirable properties. It does not fit very well to the empirical observations of exchange rate behaviour near the edges of the exchange rate band. This can be seen below in figure 1 which depicts a simulation experiment where the FIM/ECU rate is assumed to follow a random walk process within the band. Obviously, if the random walk model were the correct model of exchange rate movements, there should sooner or later emerge situations where the exchange rate remains very close to the edges of the band for fairly long periods of time. But this does not seem to be consistent with the observations from the real world. For example, the FIM/ECU rate remained clearly below the upper bound of the exchange rate band in autumn 1991 although there were quite visible devaluation speculations.

Much of the recent literature on target zone exchange rate behaviour assumes that the fundamental which drives the exchange rate follows a random walk process. The customary approach in target zone modeling is to assume that central bank intervenes only at the edges of the band. When these two basic assumptions are combined, the exchange rate movements can be modeled by a stochastic process which implies that the asymptotic distribution of the exchange rate is bimodal, i.e. U-shaped. In other words, the conventional target zone model implies that the exchange rate should tend to lie at the edges of the band even more clearly than the random walk process described in figure 1 with the asymptotically uniform distribution implies.

Contrary to the standard approach in target zone literature this paper begins the modeling of the exchange rate behaviour from the empirical observation that the exchange rate seems to lie usually strictly inside the exchange rate band. This empirical fact has been taken into account in a stochastic diffusion model which is specified in section 3. In this model the distribution of the exchange rate is truncated lognormal from the edges towards the center of the band and hence quite different from the bimodal distribution of the target zone model.

By a certain transformation this model can be very easily estimated econometrically. The model is applied to the exchange rate behaviour in Finland and the estimation results are presented in section 4.

Finally, in section 5 the model is used to compute the expected future values of the FIM/ECU rate in August 1991 - January 1992. These are used in the estimation of the interest rate differential between Finland and EMS countries implied by a fixed exchange rate band. Subtracting this from the actual interest rate differential gives a measure of expected devaluation and devaluation risk premium. In autumn 1991 the interest rate differential was very large before the devaluation in November but afterwards the differential decreased considerably.

## 2. The target zone model of exchange rate movements

Recently considerable attention in international economics has been devoted to modeling the behaviour of exchange rate movements in the case where the free floating of the rate is confined within a predetermined range. By now there is a considerable body of literature of the target zone model. Some examples are Krugman (1991), Froot and Obstfeld (1991), Svensson (1991a,b,c). Kontulainen, Lehmussaari and Suvanto (1990) and Vajanne (1991) have applied the model in Finland.

In the standard formulation of the target zone model, pioneered by Krugman, the basic reason for exchange rate uncertainty is the stochastic fluctuation of the demand for money, especially the velocity of the money stock. Given the other factors of demand and the money supply, the velocity shocks would induce stochastic fluctuations in the exchange rate which would not remain in a finite band without offsetting central bank interventions.

The standard target zone model, however, assumes that the central bank intervenes only at the edges of the band. The assumption that the infinitesimal interventions at the edges are sufficient is mainly based on the properties of the regulated Brownian motion by which the changes in the exchange rate and the underlying fundamental are modeled. The basic assumption behind the regulated Brownian motion process is that the cost function associated with the optimal controlling of the random walk Brownian motion is linear with respect to the control and the state of the system. This means that the controller can instantaneously change the state (see Harrison (1985)).

These basic assumptions are not necessarily realistic if one tries to apply the regulated Brownian motion to exchange rate movements and central bank interventions in the foreign exchange market. It is more likely that the cost of intervention increases nonlinearly when the exchange rate moves towards the edges of the band and may even jump at the edge of the band if the exchange rate happened to move outside the band and the central bank were forced to devalue.

The starting point in the target zone model and any other model of regulated floating is the definition of the limits of exchange rate movements

$$(1) \quad L \leq S(t) \leq U$$

Accordingly, it is assumed that the spot price of foreign exchange,  $S(t)$ , is confined within a range defined by constant limits  $L$  and  $U$ .

Krugman assumes that the stochastic process of the log of the velocity,  $v(t)$ , which drives the float of the exchange rate is a random walk Ito process

$$(2) \quad dv(t) = \sigma dZ(t)$$

The Wiener process  $dZ(t) = \epsilon(t)\sqrt{dt}$  is the limit of the difference  $Z(t+h)-Z(t) = \epsilon(t)\sqrt{h}$ , when  $h \rightarrow 0$ . Variable  $\epsilon(t)$  is a standard normal deviate and parameter  $\sigma$  is the constant standard deviation of the random shocks.

In the simplest case Krugman's model states that the log of the spot exchange rate at time  $t$ ,  $s(t) = \ln S(t)$ , in the target zone equilibrium is the following function of the logs of the money supply,  $m(t)$ , and velocity

$$(3) \quad s(t) = m(t) + v(t) + A(e^{\phi v(t)} - e^{-\phi v(t)})$$

where  $\phi = \sqrt{(2/\beta\sigma^2)}$  and  $\beta$  denotes the semi-elasticity of money demand to interest rate. Constant  $A < 0$  is determined from the tangency of the exchange rate function (3) and the edges of the exchange rate band (see Krugman (1991)).

Changes in the money supply,  $m(t)$ , are used to prevent the exchange rate from moving outside of the bounds of the predetermined band. The target zone model implies that the distribution of the exchange rate is bimodal so that most of the mass of the density function is concentrated near the edges of the band (see Svensson (1991b)). This means that simply by looking at the actual exchange rate behaviour one should be able to observe time periods when the exchange rate remains continuously close to the edges of the band.



One way to evaluate Krugman's model would be to use the traditional econometric estimation and testing procedures. However, the model is nonlinear and very difficult to estimate even though the underlying specification of the money market and foreign exchange market behaviour is very simple. The estimation problems can be seen clearly if stochastic differentiation is used to derive the exchange rate movements implied by equations (2) and (3). Therefore in the following only a simple reference case will be illustrated. In this experiment it is assumed that  $\beta = \infty$  so that the exchange rate follows a random walk process within the bounds of the exchange rate band

$$(4) \quad dS(t) = \sigma S(t) dZ(t)$$

Figure 1 demonstrates a simulation where equations (1) and (4) have been used to generate a random walk target zone FIM/ECU rate starting from 4.94 FIM in the beginning of last year and ending with the devaluation November 14, 1991. The standard normal deviate  $\epsilon(t)$  was produced by a computer. Analogously to the target zone model, those shocks that would take the exchange rate outside the band have been cut off. The standard deviation parameter  $\sigma = 0.002$  was estimated from the actual daily changes in the exchange rate.

In this experiment the simulated exchange rate goes very close to the upper edge of the band and at times it hits the upper bound in the latter part of 1991. However, in reality the exchange rate remained clearly below the upper limit of the band even in August - November when there was a considerable devaluation pressure on the FIM. At that time there were visible devaluation expectations which can be seen below in figure 7 which shows that the forward exchange rate rose above the upper edge of the band already in August 1991 and remained there until the devaluation.

Thus in contrast to the basic assumption of the standard target zone model the central bank was forced to intervene perhaps exceptionally strongly when the exchange rate still was inside the band. Accordingly, the random walk model and the standard target zone model do not describe adequately the exchange rate movements, at least in Finland.

### 3. An alternative model

Contrary to the assumption of the standard target zone model it seems reasonable to assume that the central bank tries to keep the exchange rate inside the band by intervening within the whole fluctuation range and not just at the edges. Therefore the exchange rate usually lies strictly inside the band. This empirical fact must be taken into account if one wants to make a realistic model of exchange rate movements within the band.

Of course this is just one elementary aspect of the behaviour of the FIM exchange rate. There may be many models which satisfy this necessary condition. When analyzing the alternative approaches, one might start from theories of exchange rate determination and various central bank policy alternatives. However, there are so many potential behavioral modes that this is not very practical starting point for an econometric study. Instead, we may take a time series analytic point of view and look directly for such stochastic processes which satisfy the basic properties of the empirically observable exchange rate behaviour.

If the exchange rate is allowed to move freely to the edges of the band, the exchange rate behaviour can be modeled by the regulated Brownian motion. In this sense the bounds of the exchange rate band in Krugman's model are reflecting barriers of the exchange rate process. This means that the exchange rate may occasionally hit the edges of the band but then it is reflected back towards the center of the band. In principle there may be a large family of such processes.

Assume that the changes in the spot exchange rate can be described by the following Ito diffusion process

$$(5) \quad dS(t) = \theta(S)dt + \sigma(S)dZ(t)$$

Let  $L$  denote the constant lower edge and  $U$  the constant upper edge of the band as before. Denote the conditional probability density function of the exchange rate by  $f(S, t; S_0, t_0)$ .

Then limits L and U are reflecting barriers of process (5) if

$$(6) \quad \delta(\sigma^2(S)f(S,t))/\delta S - 2\theta(S)f(S,t) = 0$$

when  $S(t) = L$  or  $S(t) = U$ . Specifically, the edges of the band may be called natural reflecting barriers of the exchange rate process if  $\sigma(L) = 0$  and  $\theta(L) > 0$  and, on the other hand  $\sigma(U) = 0$  and  $\theta(U) < 0$  (c.f. Ingersoll (1987)). Then at the lower edge the drift pulls the exchange rate upwards and at the upper bound downwards. Bertola and Caballero (1990) have analyzed the reflecting barrier properties of the target zone model. Contrary to the assumption of the standard target zone model we, however, assume that the exchange rate lies strictly inside the band and therefore  $f(L,t)=f(U,t)=0$ .

Modeling the behaviour of the exchange rate movements becomes easier if we assume that the distribution of the stochastic shocks is symmetric around the center of the exchange rate band. A priori there does not seem to be any reason to assume otherwise. Therefore in the following the symmetry of the distribution is assumed and we may start to build the model by denoting the absolute deviations of the exchange rate from the center of the band, C

$$(7a) \quad X(t) = |S(t) - C|$$

$$(7b) \quad 0 \leq X(t) \leq V$$

The width of the band is  $2V$  so that  $0 < V = U-C = C-L < C$ .

This confines the exchange rate within the bounds of the band but how would we expect variable  $X(t)$  to behave? There are, of course, many alternatives but a simple specification which takes into account the special feature of the reflecting barrier process defined above is

$$(8) \quad dX(t) = a(V - X(t))dt + \sigma(V - X(t))dZ(t)$$

where parameters  $a \leq 0$  and  $\sigma \geq 0$  are constants.

Then at the edges of the band,  $X(t) = V$ , the standard deviation  $\sigma(V-X(t))$  goes to zero and as a continuous function of time Ito process (8) cannot pass the limits set by the band despite the random shocks. Moreover, if  $a < 0$ , the drift term tends to push the exchange rate back towards the center of the band. In this sense the bounds of the band are reflecting barriers although strictly speaking  $X(t) < V$  so that the edges are asymptotes of exchange rate process (8). In the limiting case where  $a = 0$  the expected change is zero and the exchange rate follows a random walk process.

One important reason for the rather simple specification (8) is the econometric and mathematical tractability of the model. For other specifications the econometric estimation and mathematical analysis of the model would soon become much more difficult. But even model (8) is not easy to estimate because of the heteroscedastic error term. However, we get an estimating model of exchange rate movements by performing the following logarithmic transformation

$$(9a) \quad Y(t) = \ln(V - X(t))$$

$$(9b) \quad \equiv \ln(V - |S(t) - C|)$$

Then we can use Ito's lemma to see that (8) and (9a) yield

$$(10a) \quad dY(t) = -(a + \sigma^2/2)dt - \sigma dZ(t)$$

$$(10b) \quad \equiv \mu dt - \sigma dZ(t)$$

Accordingly, the transformed exchange rate  $Y(t)$  is normally distributed and therefore the exchange rate  $S(t)$  itself follows a truncated lognormal distribution defined from the edges towards the center of the band. The maximum likelihood estimators of the parameters of random walk process (10b) are (c.f. Lo (1986))

$$(11) \quad \mu = \Sigma(Y_t - Y_{t-1})/n$$

$$(12) \quad \sigma^2 = \Sigma(Y_t - Y_{t-1} - \mu)^2/n$$

where  $n$  is the number of observations. The parameter estimates are simply the mean and variance of the differences of the transformed data  $\ln(V - |S(t) - C|)$ . The precision of estimators (11) and (12) increases with the number of observations (see Ingersoll (1987)). Therefore estimation with daily observations is preferable to less frequently sampled data.

#### 4. Estimation results

Table 1 presents estimation results obtained from daily observations of the changes in the FIM exchange rate during different band regimes since 1987. Model (10b) implies that the residual random shock,  $\epsilon_t$ , should be a standard normal deviate if the model is correct. Therefore the sum of the squared standardised residuals is tested by a chi-square test. The critical value at the five percent level is  $\chi^2_{.95} \approx (N(1.96) + \sqrt{(2n-3)})^2/2$ , where  $N(\cdot)$  denotes the standard normal distribution function.

One problem in the estimation is the relatively small number of observations and trendwise changes in the exchange rate in some subperiods. Moreover, in some periods the exchange rate has fluctuated in a way which is not fully explained by model (10b). There are some serially correlated changes in the transformed data which can be explained by an autoregressive model

$$(13) \quad Y_t - Y_{t-1} = \mu(1 - \sum \alpha_i) + \sum \alpha_i(Y_{t-i} - Y_{t-i-1}) + \sigma \epsilon_t$$

In some estimation periods coefficients  $\alpha_i$  are negative and statistically significant with a maximum lag of three days,  $i=3$ . The estimated coefficients with the standard errors in parentheses are presented in table 1. The statistically significant autocorrelation is not very high as compared to the total variance of the differences of  $Y_t$ , as can be seen in figure 4 below.

Fortunately, the observed high frequency autocorrelation does not complicate the computation of expected future exchange rates for longer future horizons, say for a few months or longer periods ahead. During such longer periods the expected changes in  $Y_t$  converge to the long-run mean  $\mu$ , as can be seen from equation (13).

Table 1. Estimation results with daily observations 1987-1992

Estimation period	3.1.1987- 29.11.1988	30.11.1988- 16.3.1989	17.3.1989- 6.6.1991	7.6.1991- 14.11.1991	16.11.1991- 31.1.1992
a	-0.005	-0.024	-0.010	-0.015	-0.013
$\mu$	-0.003	0.003	0.002	-0.021	0.009
$\sigma^2$	0.016	0.042	0.016	0.072	0.009
$\chi^2$	485	73	558	101	47
$\chi^2_{.95}$	516	86	592	122	58
n	487	75	560	110	49
$\alpha_1$	-0.17 (0.04)		-0.18 (0.04)	-0.22 (0.10)	
$\alpha_2$			-0.09 (0.04)	-0.18 (0.10)	-0.52 (0.08)
$\alpha_3$				-0.23 (0.10)	
L	101.3	100.5	96.5	4.72953	5.39166
U	106.0	106.8	102.5	5.02207	5.72516
C	103.65	103.65	99.5	4.87580	5.55841
V	2.35	3.15	3.0	0.14627	0.16675

Generally, the results seem to support the model. Estimates of parameter a are generally negative although slightly different in different estimation periods. The autocorrelation tested by equation (13) has increased since the beginning of the ECU linkage on June 7th, 1991.

The time period from the ECU linkage until the devaluation on November 15th, 1991 is divided in two quite different subperiods, as can be seen in figure 2. The variance of the daily changes in the FIM/ECU rate increased considerably as speculation regarding a devaluation intensified starting on August 9th, 1991. The changes in the transformed exchange rate data in the subperiods are shown below in figures 3 and 4. The estimation results for the FIM/ECU rate are presented in table 2.

Table 2. Estimation results for the FIM/ECU exchange rate

Estimation period	2.1.1991-8.8.1991	7.6.1991-8.8.1991	9.8.1991-14.11.1991	2.1.1991-14.11.1991	16.11.1991-31.1.1992
a	-0.003	0.015	-0.038	-0.012	-0.013
$\mu$	-0.001	-0.017	-0.016	-0.008	0.009
$\sigma^2$	0.008	0.004	0.109	0.041	0.009
$\chi^2$	147	38	66	215	47
$\chi^2_{.95}$	167	50	78	238	58
n	151	42	68	219	49
$\alpha_1$			-0.25 (0.12)	-0.17 (0.07)	
$\alpha_2$			-0.22 (0.13)	-0.15 (0.07)	-0.52 (0.08)
$\alpha_3$			-0.27 (0.13)	-0.18 (0.07)	

Summarising the estimation results we may conclude that the model is supported by the data, at least in the sense that parameter a is usually negative. There are some estimation problems associated with the exact size of the parameter and its stability when measured from a high frequency sample.

Both the mean,  $\mu$ , and the variance,  $\sigma^2$ , seem to have varied in different estimation periods. However, to some extent these changes have been opposite so that the effect on parameter a =  $-\mu - \sigma^2/2$  is smaller than it otherwise might be.

It seems as if the variance of the exchange rate fluctuations increases when the exchange rate is near the edges of the band for a long time because of revaluation or devaluation pressure. An example of the former case is the period of November 30, 1988 - March 16, 1989 and of the latter case period August 8 - November 14, 1991. This seems to be in contrast with the standard target zone model, which implies that the variance goes to zero at the edges of the band. However, the exchange rate has not been at the edges like the target zone model implies so that actually we have no empirical observations of the variance at the edges.

## 5. The expected future exchange rate and the interest rate differential

The target zone model can be applied to assess the credibility of a target zone exchange rate policy. The model gives the future path of the expected exchange rate, which can be used to compute the corresponding interest rate differential with respect to foreign countries. Comparing this to the actual interest rate differential at different maturities gives an idea of the financial market agents' expectations concerning the timing and size of a shift of the exchange rate band.

Usually this analysis has been based on the uncovered interest rate parity (see Svensson (1991b,c)). However, the uncovered interest rate parity should not be applied unconditionally because there may be other reasons for the interest rate differential than just an expected change in the exchange rate. An interest rate differential may also reflect the risk premium associated with unexpected exchange rate movements. Moreover, even in the case of completely fixed exchange rates and totally free capital movements there may be interest rate differentials between countries because of the credit risk premium resulting from foreign indebtedness (see Rantala (1990)).

The risk premium associated with exchange rate changes must be taken into account when the exchange rate movements have an impact on the economic activity, in other words when the changes in the exchange rate correlate with changes in output, consumption etc. This is certainly true in the case of an exchange rate policy which changes the position of the exchange rate band, i.e. in the case of an active devaluation or revaluation. Indeed, the purpose of such an exchange rate policy is to influence the real economic activity, at least in the short run.

But in the case of a relatively narrow band the exchange rate movements within the band may be assumed to be generally independent of the real economic activity, at least of the fundamental cyclical changes in the economy. The exchange rate fluctuations within a fixed band result mainly from the shocks in domestic and international financial markets and the central bank interventions in the foreign exchange and financial markets. In fact we can decompose the changes in the exchange rate into two components so that one component is the change within the band and another component is the shift of the band. This was already implicitly done in the empirical analysis by estimating the parameters for different band periods.



Completing model (5) in this way means that it can be rewritten in the form

$$(14) \quad dS(t) = \theta(S)dt + \sigma(S)dZ(t) + \pi(F)dQ(t)$$

The last term in equation (14) takes into account the shifts of the band associated with devaluations or revaluations which depend on a vector of fundamentals  $F(t)$ . The changes in the exchange rate band typically take place discretely in time so that variable  $dQ(t)$  may be assumed to be a Poisson process. Variable  $\pi(F)$  measures the size of the shift, which may also be assumed to be a stochastic variable.

The following analysis concerns the interest rate differential implied by expected exchange rate changes within the band. These are assumed to be independent of the changes in real economic activity so that we can apply the uncovered interest rate parity. In fact we assume that such exchange rate changes are comparable to stochastic price level movements in a closed economy general equilibrium model where monetary policy and the price level have no impact on the real economic activity (c.f. Cox, Ingersoll and Ross (1985)). In complete analogy with such a model we may assume that the interest rate differential associated with expected exchange rate movements within the band does not include any risk premium term because the stochastic exchange rate changes do not correlate with those fundamentals which determine agents' utility.

Denote the short-term foreign interest rate by  $r(t)$ . Then the equilibrium price of a domestic zero-coupon financial instrument maturing at time  $T \geq t$ ,  $P(S, r, t, T)$ , is determined by the price of a foreign zero-coupon instrument,  $P'(r, t, T)$ , and the conditional expectation of the exchange rate,  $E_t(S(T))$ , so that

$$(15a) \quad P'(r, t, T) = P(S, r, t, T)E_t(S(T))/S(t)$$

$$(15b) \quad P'(r, T, T) = P(S, r, T, T) = 1$$

Accordingly, we assume that the uncovered interest rate parity holds in this case. It does not hold in general if the changes in the exchange rate correlate with the fundamentals of real economic activity and portfolio choice.

Because the relationship between the interest rate  $R(\cdot)$  and the price  $P(\cdot)$  of a zero-coupon instrument with a term to maturity of  $T - t$  is by definition  $P(\cdot) = \exp(-R(\cdot)(T-t))$  the interest rate differential is

$$(16) \quad R(S, r, t, T) - R'(r, t, T) = (\ln E_t(S(T)) - \ln S(t)) / (T-t)$$

In the case of the exchange rate model developed earlier in this study the exchange rate changes in the lower and upper part of the band are mirror images of each other. Solving equations (8) and (9) for a predetermined spot exchange rate,  $S(t)$ , gives the future value of the exchange rate,  $S(T)$ , at time  $T \geq t$

$$(17a) \quad S(T) = \min( C, L + (S(t) - L)e^{\mu(T-t) - \sigma Z(T)} \mid L < S(s) \leq C, s \geq t )$$

$$(17b) \quad S(T) = \max( C, U + (S(t) - U)e^{\mu(T-t) - \sigma Z(T)} \mid C \leq S(s) < U, s \geq t )$$

The conditional expected value is

$$(18a) \quad E_t(S(T)) = \min( C, L + (S(t) - L)e^{-a(T-t)} \mid L < S(s) \leq C, s \geq t )$$

$$(18b) \quad E_t(S(T)) = \max( C, U + (S(t) - U)e^{-a(T-t)} \mid C \leq S(s) < U, s \geq t )$$

Using equations (16) and (18a-b) we can compute the interest rate differential implied by the expected movement of the exchange rate within the band. Figure 6 below depicts the expected changes in the FIM/ECU exchange rate for a three-month forecasting horizon in August 1991 - January 1992. These are obtained from equations (18a-b) using parameter value  $a = -0.012$ , which is the estimate for period January 2 - November 14, 1991 given in table 2.

The expected exchange rate has been used to compute the interest rate differential according to equation (16). This has been subtracted from the actual differential between three-month Helibor and ECU rates to obtain the "devaluation risk premium", which is shown in figure 5. In fact this variable measures primarily the annualized expected devaluation. It may also contain a credit risk premium induced by the foreign indebtedness but the dominant part has probably been the interest rate differential associated with the expected devaluation.

The premiums for three months and other short maturities were very large in autumn 1991 before the devaluation. At the same time the forward FIM/ECU rates rose above the upper bound of the exchange rate band. This can be seen in figure 7 which depicts the three-month forward rate computed from the covered interest rate parity.

The interest rate differential decreased considerably after the devaluation and the forward rates returned into the exchange rate band in late November 1991. Thus the credibility of the exchange rate policy improved markedly.

## 6. Conclusion

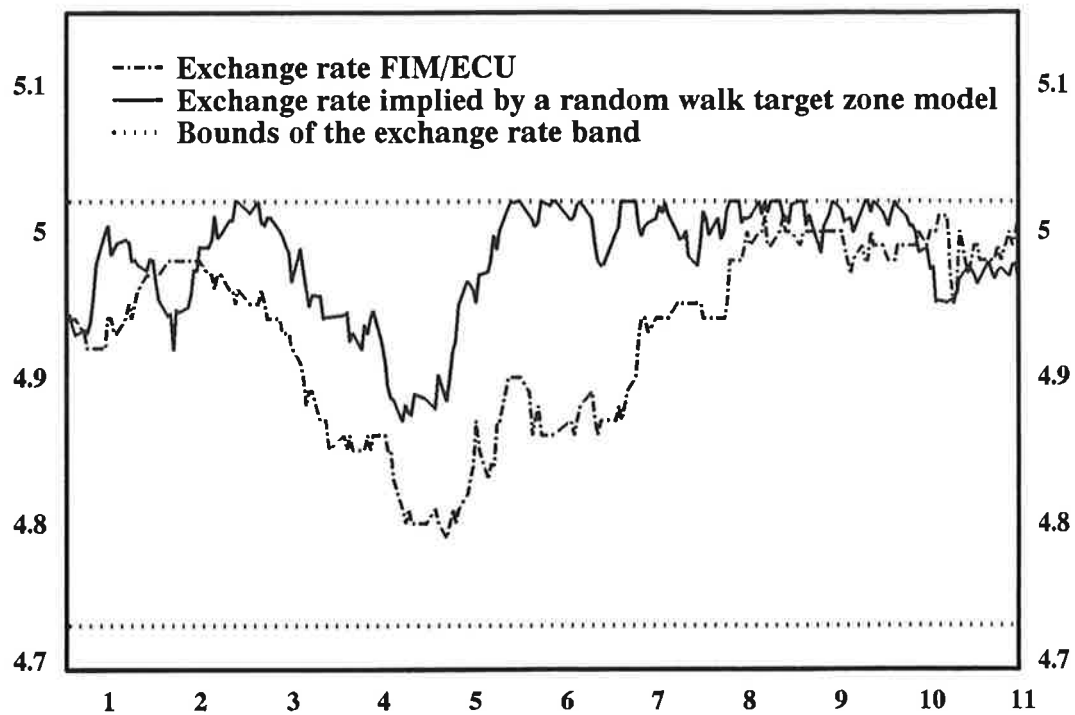
The model of exchange rate movements within a fixed band developed above is an alternative approach to the standard target zone model. It is, of course, only a step towards more realistic econometric treatment of exchange rate behaviour in a monetary policy regime where the float of the exchange rate has been confined within predetermined limits. Specifying a special kind of reflecting barrier model which is consistent with some empirical observations of exchange rate behaviour has not yet given a model which would explain the exchange rate movements perfectly by statistical standards.

However, the results give some support to the model. The distribution of the exchange rate has more mass near the center of the band than implied by the pure random walk model with an asymptotically uniform distribution and much more than in Krugman's target zone model with a bimodal distribution.

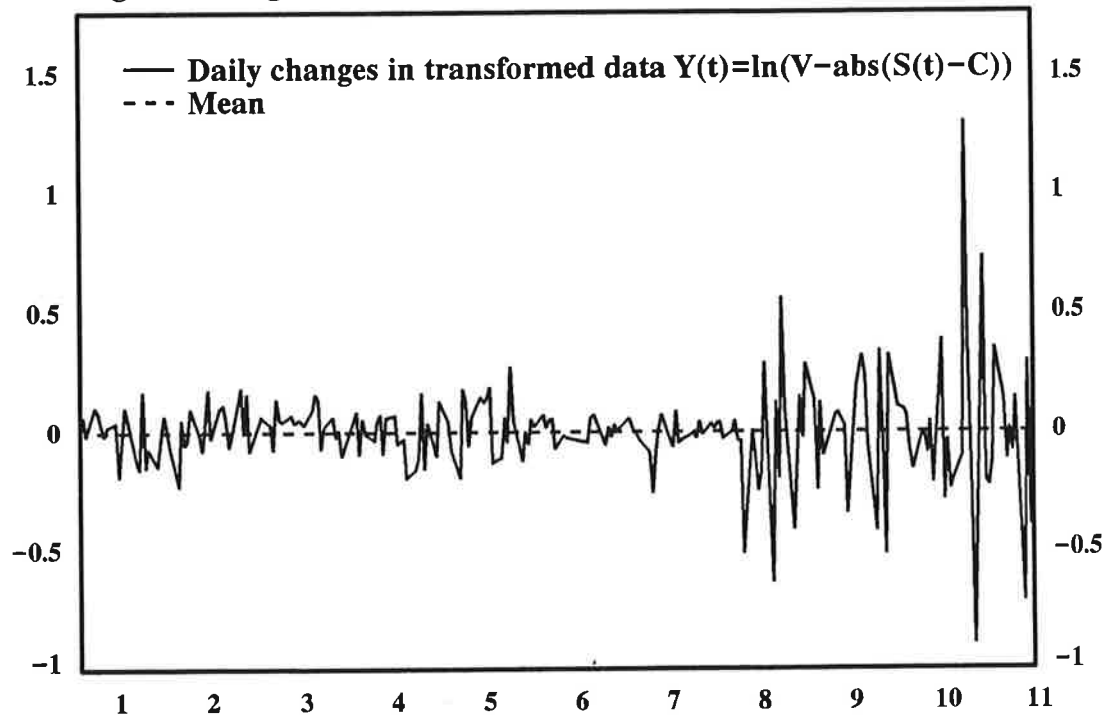
## References

- Bertola G. and Caballero R.J. (1990): Target zones and realignments, Centre for Economic Policy Research discussion paper no. 398, March 1990.
- Cox J.C., Ingersoll J.E. and Ross S.A. (1985): A theory of the term structure of interest rates, *Econometrica*, March, 385-407.
- Froot K.A. and Obstfeld M. (1991): Exchange-rate dynamics under stochastic regime shifts, A unified approach, *Journal of international economics* 31, 203-229.
- Harrison J.M. (1985): *Brownian motion and stochastic flow systems*, Wiley, New York.
- Ingersoll J.E. (1987): *Theory of financial decision making*, Rowman & Littlefield.
- Kontulainen J., Lehmussaari O-P. and Suvanto A. (1990): The Finnish experience of maintaining a currency band in the 1980s, Bank of Finland discussion papers, 26/90.
- Krugman P.R. (1991): Target zones and exchange rate dynamics, *The quarterly journal of economics*, Vol.CVI, August 1991, Issue 3, 669-682.
- Lo A.W. (1986): Maximum likelihood estimation of generalized Ito processes with discretely sampled data, NBER technical working paper No. 59.
- Rantala O. (1990): Foreign borrowing and international creditworthiness - an option pricing approach (in Finnish), Pellervo economic research institute working papers 14/1990.
- Svensson L.E.O. (1991a): The term structure of interest rate differentials in a target zone: theory and Swedish data, *Journal of monetary economics*, 28, 87-116.
- Svensson L.E.O. (1991b): Target zones and interest rate variability, *Journal of international economics*, 31, 27-54.
- Svensson L.E.O. (1991c): The simplest test of target zone credibility, IMF staff papers, 38, 655-665.
- Vajanne L. (1991): Testing target zone models on Finnish data, November 1991, ETLA.

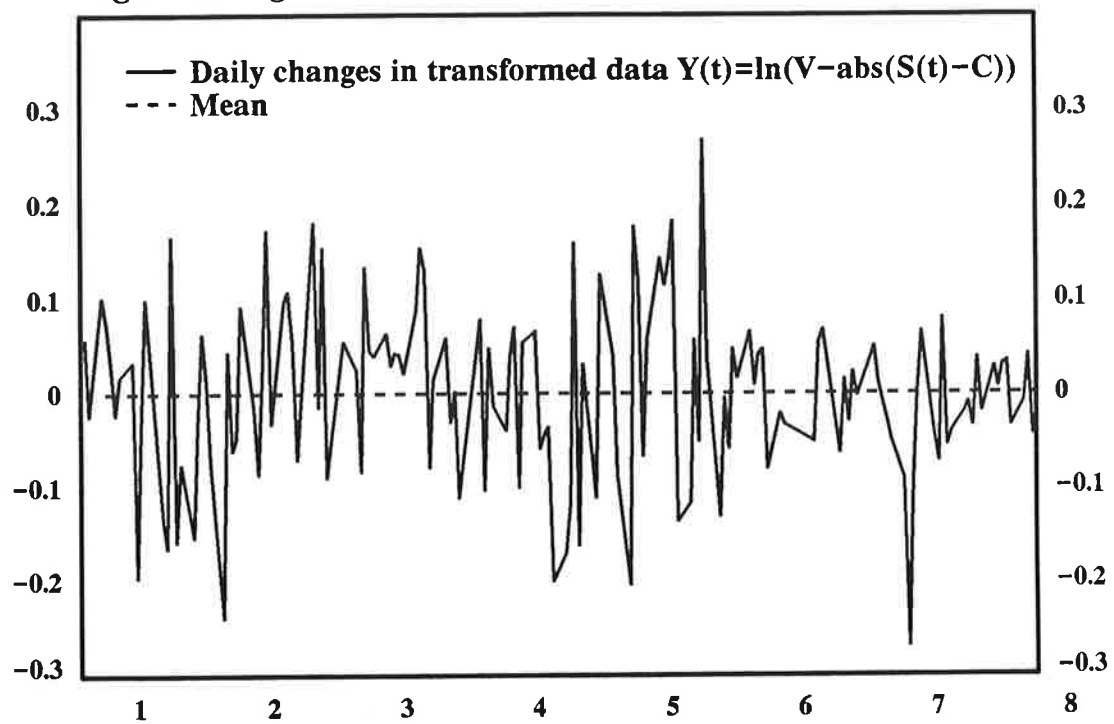
**Fig.1: Exchange rate January 2 – November 14, 1991**



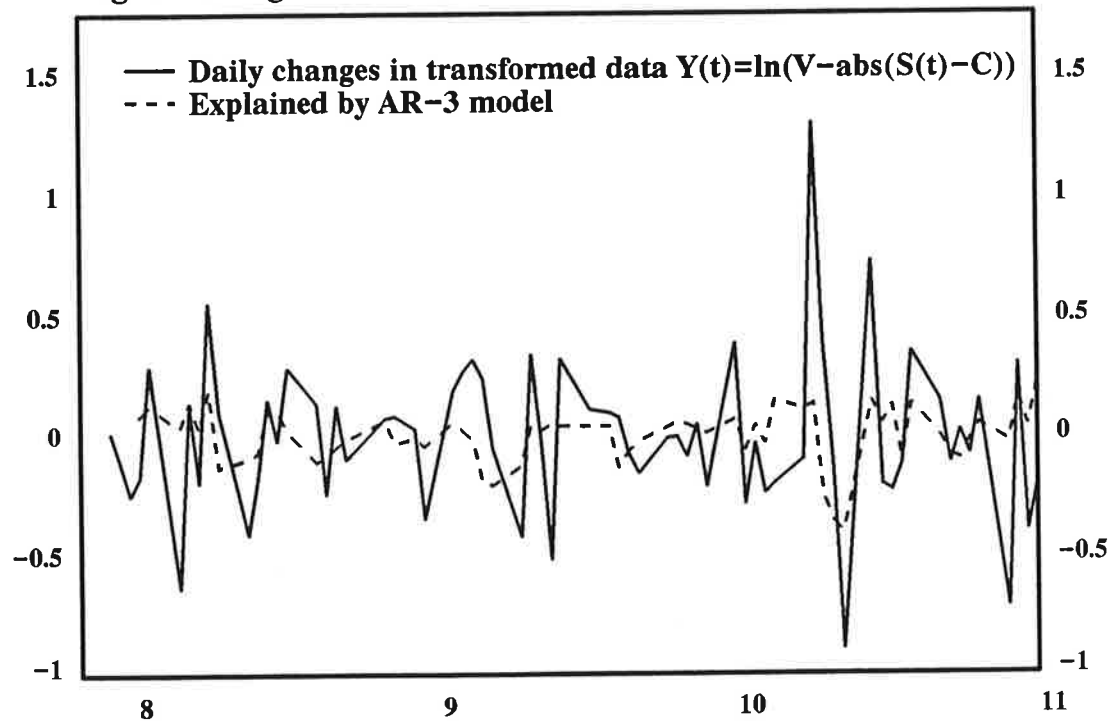
**Fig.2: Changes in FIM/ECU January 2–November 14, 1991**



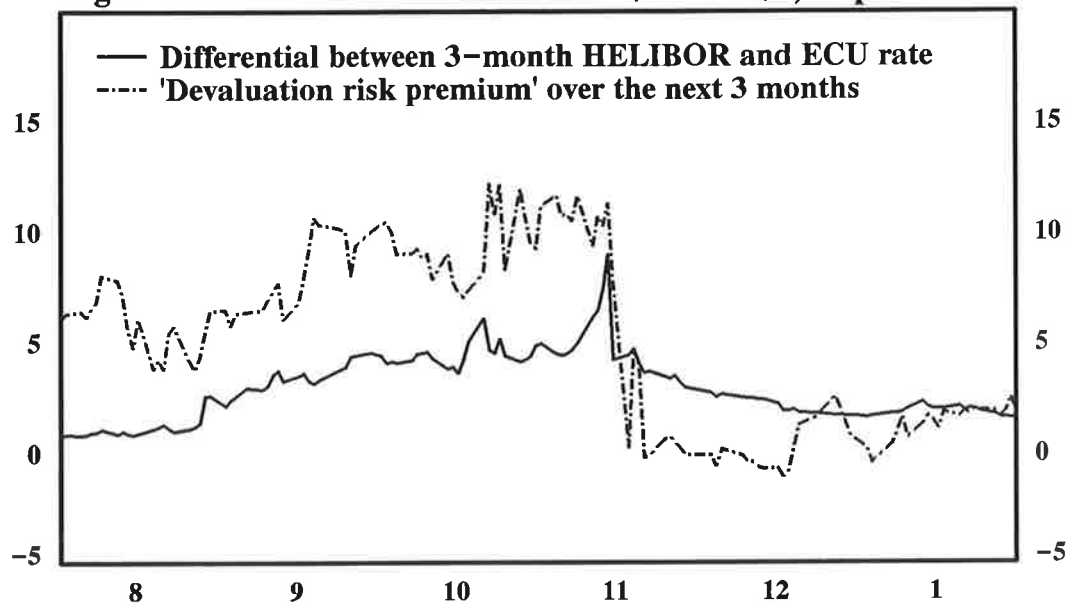
**Fig.3: Changes in FIM/ECU January 2–August 8, 1991**



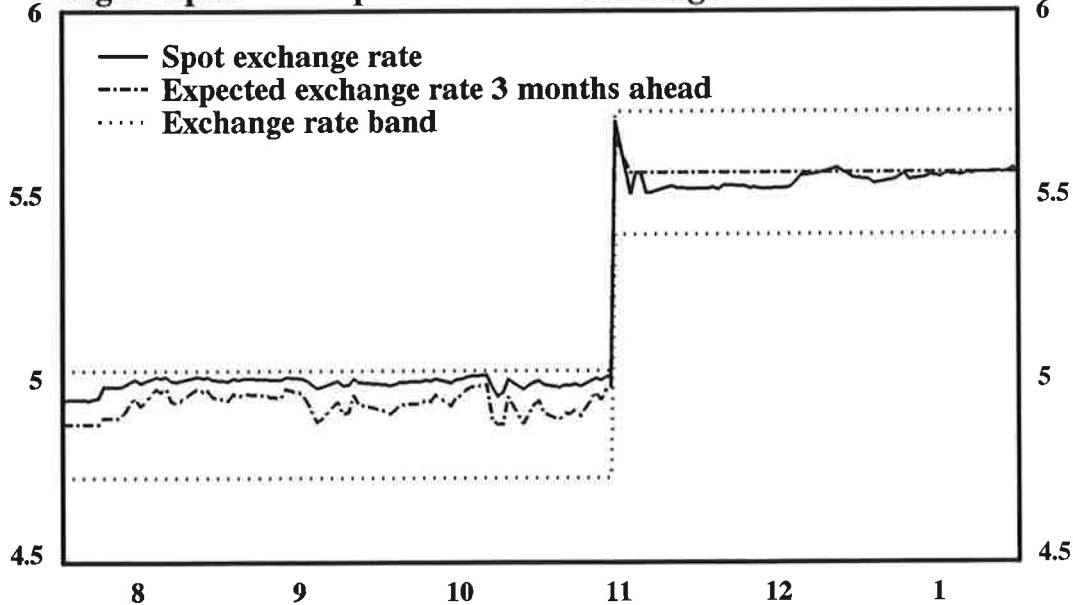
**Fig.4: Changes in FIM/ECU August 9–November 14, 1991**



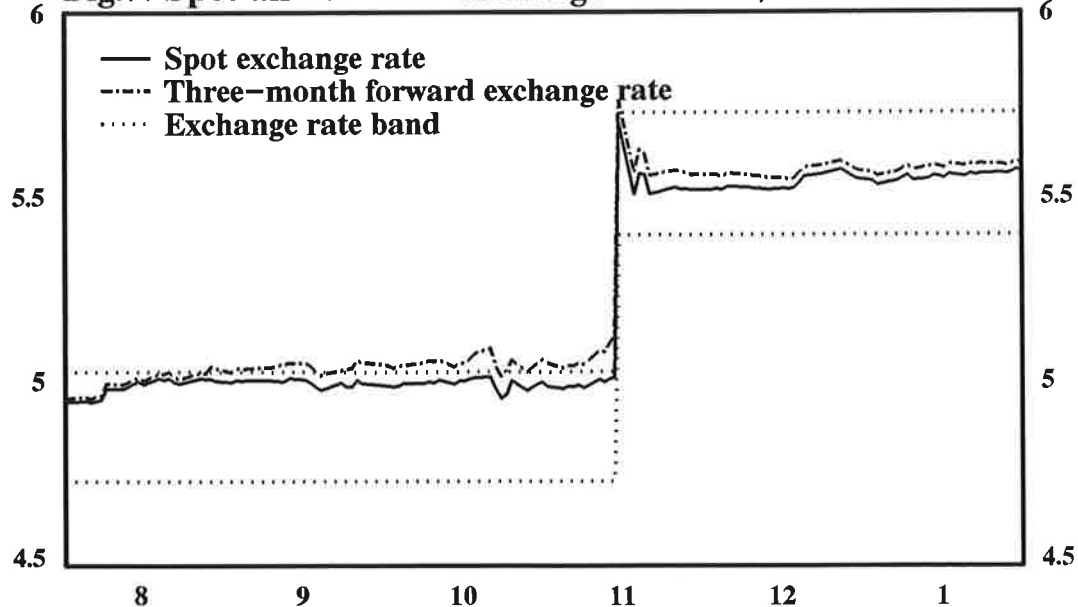
**Fig.5: Interest rate differential 1991/8–1992/1, % p.a.**



**Fig.6: Spot and expected future exchange rate FIM/ECU**



**Fig.7: Spot and forward exchange rate FIM/ECU**







ELINKEINOELÄMÄN TUTKIMUSLAITOS (ETLA)  
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY  
LÖNNROTINKATU 4 B, SF-00120 HELSINKI

---

Puh./Tel. (90) 609 900  
Int. 358-0-609 900

Telefax (90) 601 753  
Int. 358-0-601 753

KESKUSTELUAIHEITA - DISCUSSION PAPERS ISSN 0781-6847

- No 370 VESA KANNIAINEN - JAN SÖDERSTEN, Undervaluation of Corporate Shares Revisited: A Note. 27.06.1991. 9 p.
- No 371 MARKKU RAHIALA - TIMO TERÄSVIRTA, Forecasting the Output of Finnish Forest Industries Using Business Survey Data. 29.07.1991. 13 p.
- No 372 MARKKU KOTILAINEN, Exchange Rate Unions: A Comparison to Currency Basket and Floating Rate Regimes - A Three-Country Model with Endogenous Prices. 29.07.1991. 47 p.
- No 373 EIKE HINDOV, On Population Development in Estonia and Finland. 20.08.1991. 47 p.
- No 374 JUHA KETTUNEN, A Search Theoretical Analysis of the Finnish Unemployment Insurance System. 28.08.1991. 25 p.
- No 375 JUHA KETTUNEN, Regional Mobility of Unemployed Workers. 28.08.1991. 19 p.
- No 376 JUHA KETTUNEN, Työttömyysturvajärjestelmän vaikutukset työnetsintään: Tutkimusaineistokuvaus. 28.08.1991. 13 s.
- No 377 WIDGRÉN MIKA, Voting Power in the EC Decision Making and the Consequences of two Different Enlargements. 04.09.1991. 24 p.
- No 378 JUKKA LASSILA, Income Tax Indexation in an Open Economy. 11.09.1991. 17 p.
- No 379 KARI ALHO - KATARIINA LEIKAS, Arvio kotitalouksien varallisuudesta 1960-1990. 14.10.1991. 28 s.
- No 380 TIMO TIAINEN, Viennin markkinaosuudet ja kilpailukyky Suomen teollisuuden eri toimialoilla 1970-1985. 21.10.1991. 148 s.
- No 381 JUSSI RAUMOLIN, Prospects for Logistics in Europe in the 1990s. 21.10.1991. 24 p.
- No 382 SYNNÖVE VUORI, Teknologiapanosten vaikutukset ja teknologian diffuusio: Kirjallisuuskatsaus. 21.10.1991. 29 s.
- No 383 PEKKA VALKONEN - RAIMO LOVIO: Suomalaiset patenttoijat Yhdysvalloissa 1980-luvulla: Menestyksen suhteellisuus. 21.10.1991. 19 s.

- No 384 ROBERT HAGFORS, Kulutusmenojen arviointia kotitaloustyypeittäin Suomessa vuosille 1960-1985. 04.11.1991. 30 s.
- No 385 GEORGE F. RAY, Innovations Diffused - A Random Walk in History. 15.11.1991. 46 p
- No 386 HARRI LUUKKANEN, Diffusion of Numerically Controlled Machine Tools in Finnish Engineering Industry. 18.11.1991 37 p.
- No 387 JUHA KETTUNEN, A Programme for Estimating Nonlinear Maximum Likelihood Models with an Application to Duration Models of Unemployment. 27.11.1991. 25 p.
- No 388 JUKKA LASSILA, Tax Threats and Wage Formation. 10.12.1991. 23 p.
- No 389 WILLIAM C. BRAINARD - JAMES TOBIN, On the Internationalization of Portfolios. 10.12.1991. 39 p.
- No 390 RISTO MURTO, Duration, Immunization and Models of the Term Structure of Interest Rates. 27.12.1991. 31 p.
- No 391 VESA KANNIAINEN, Diffusion, R&D and Public Policy: Is it Better to be a First Mover or Fast Second? 14.01.1992. 25 p.
- No 392 RISTO MURTO, Testing Continuous Time Models of the Term Structure of Interest Rates in the Finnish Money Market. 22.01.1992. 42 p.
- No 393 RAIMO LOVIO, The Influence of Foreign Companies on the Birth and Development of the Finnish Electronics Industry. 29.01.1992. 9 p.
- No 394 JUHA KETTUNEN, Time-Dependent in Semi-Parametric Models of Unemployment Duration. 05.02.1992. 27 p.
- No 395 OLAVI LEHTORANTA, Estimating Stocks of Fixed Capital: Methods used in Different Countries. 13.02.1992. 73 p.
- No 396 HANNU JAAKKOLA, The Diffusion of Information Technology in Finnish Industry: State-of-the-art & Analysis. 14.02.1991. 33 p.
- No 397 Elinkeinoelämän Tutkimuslaitoksen toiminta vuonna 1991. 25.02.1992.
- No 398 OLAVI RANTALA, An Econometric Diffusion Model of Exchange Rate Movements within a Band - Implications for Interest Rate Differential and Credibility of Exchange Rate Policy. 06.03.1992. 19 p.

Elinkeinoelämän Tutkimuslaitoksen julkaisemat "Keskusteluaiheet" ovat raportteja alustavista tutkimustuloksista ja väliraportteja tekeillä olevista tutkimuksista. Tässä sarjassa julkaistuja monisteita on rajoitettusti saatavissa ETLAn kirjastosta tai ao. tutkijalta. Papers in this series are reports on preliminary research results and on studies in progress; they can be obtained, on request, by the author's permission.