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JEL classification: E58; F31; G15

Keywords: Target zone, STARTZ model, Intervention

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Exchange Rates in Target Zones –
Evidence from the Danish Krone

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Abstract

Although the ERM II rules allow the Danish krone to fluctuate against the euro within an official target zone of 4.5%, most of the time the exchange rate has remained in a narrow range around its unconditional mean. Estimating a Smooth Transition Autoregression Target Zone (STARTZ) model confirms that the exchange rate exhibits target zone dynamics consistent with a band of approximately 0.75 percent around its unconditional mean. We conclude that the Danmark Nationalbank intervention policy of intra-marginal operations successfully managed an informal target zone in the foreign exchange market.

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1. Introduction

Target zone models are an attempt to explain formally how the exchange rate behaves in a system with an upper and a lower exchange rate boundary. Krugman (1991) developed a basic target zone model in which the commitment of the monetary authorities to maintain the exchange rate within a certain band stabilizes the exchange rate because of the effects of this policy on market participants' expectations. Since the application of the Krugman model has provided mixed empirical results (Kempa and Nelles 1999), variants of this model consider the consequences of alternative types of target-zone intervention rules for the determination of the exchange rate (Svensson 1992, Klein and Lewis 1993). The introduction of the exchange rate mechanism (ERM) of the European Monetary System (EMS) provided researchers with the opportunity to test the target zone model empirically. Anthony and MacDonald (1998), Bessec (2003), Bekaert and Gray (1998), Chung and Tauchen (2001), Flood, Rose and Mathieson (1990), Tristani (1994) and Rose and Svensson (1995) investigated the period preceding the ERM crisis. All studies provided evidence in favor of exchange rate mean reversion, which supports the target zone model. Crespo-Cuaresma, Égert and MacDonald (2005) focused on the post-crisis period until 2004 and confirmed the presence of strong nonlinearities and asymmetries in the ERM. Interestingly, the nonlinear effect appears to differ across countries and is particularly strong in the case of Denmark. However, there exist many reasons why exchange rates tend to revert to the central parity in a target zone; Crespo-Cuaresma, Égert and MacDonald (2005), for example, put forward the idea that moral persuasion, stabilization of market expectations, increasing stability of the underlying fundamentals or central bank interventions can cause the mean-reverting effect. Hence, the empirical rationale of the mean reversion in target zones is still an open question, one which is addressed in this paper.

In this paper, we analyze the Danish krone (DKK)/euro (EUR) exchange rate between 1999 and 2011. Since 1999, Denmark has sought to prove to the financial markets that, regardless of the Danish unwillingness to adopt the euro formally, the official Danish policy of virtually fixing its exchange rate vis-à-vis the euro is credible. This is enforced by negotiating the tight ERM II band of +/- 2.25 percent around the central parity (instead of the standard +/- 15 percent band) and also by using monetary policy and relatively frequent intra-marginal interventions to keep the exchange rate within an even narrower range.[1] The Danish krone permanently fulfills the conditions for joining EMU since the exchange rate fluctuates

[1] For additional details regarding the ERM II and the Danish monetary and exchange rate policies see DNB (2003), ECB (2004), and Fatum and Pedersen (2009).

within the 1% band and was on average on the stronger side vis-à-vis the euro. The latter fact indicates that there is an informal target zone which is below the official target of DKK 7.46038 to the euro. Applying a smooth transition autoregression target zone (STARTZ) model we show that the exchange rate exhibits strong nonlinearities consistent with target zone dynamics. In addition, we augment the standard STARTZ model to analyse the effectiveness of the Danmarks Nationalbank (DN) intervention policy.

The remainder of the paper is organized as follows. In Section 2, as background to the analysis, we provide a brief introduction to the basic theoretical target zone model, while in Section 3 we present the empirical STARTZ model. Section 4 described the data used while in Section 5 we present estimation results of the STARTZ model applied to the Danish data. In section 6 we empirically analyze the effectiveness of DN intra-marginal intervention. Section 7 concludes.

2. The basic target zone model of exchange rates

The basic Krugman (1991) model is expressed in continuous time and starts from the general asset market approach, where the spot rate *s* is related to a set of current fundamentals *f* and the instantaneous expected change of the spot rate

$$s = f + \lambda E\left[ds\right]/ dt \ . \tag{1}$$

In the target zone literature the vector of fundamentals often includes relative money supply and relative income, as in the a simple forward-looking flexible-price monetary model of the exchange rate. To calculate agents' spot rate expectations, fundamentals consisting of private sector fundamentals as well as policy variables are assumed to change over time according to the equation of motion:

$$df = \mu dt + \sigma \, dv \ , \tag{2}$$

i.e., a constant drift term and *dv* the increment of a standard Wiener process, scaled by its own standard deviation σ. Under a free float, the authorities do not react to changes in the exchange rate, neither by directly intervening in the foreign exchange market, nor by altering policy instruments such as the supply of money. In the simplest case when the drift μ is zero, the expected rate of depreciation is also zero, implying that the level of the exchange rate is determined by the current level of fundamentals. According to this one-to-one relationship, both the fundamentals as well as the exchange rate emerge as unit root processes.

In the target zone model, the authorities stand ready to intervene and alter f at the edges of the band to keep the spot rate between its upper and lower limits, s^{max} and s^{min} respectively. If the target zone is credible and the market believes that intervention will be successful at the edges of the band, the central bank's commitment exhibits a stabilizing impact on the exchange rate by influencing agents' exchange rate expectations. A general solution can be derived applying Ito's Lemma:[2]

$$s = f + A_1 e^{\xi_1 f} + A_2 e^{\xi_2 f} \qquad (3)$$

where ξ_1 and ξ_2 are the roots of the quadratic equation

$$\xi^2 \lambda \frac{\sigma^2}{2} + \xi \lambda \mu - 1 = 0 \,, \qquad (4)$$

and A_1 and A_2 are constants determined by the so-called "smooth pasting" conditions. The two main results of the Krugman (1991) model arise from the typical S-shaped relationship between the exchange rate and the fundamental (Garber and Svensson, 1995). Firstly, the slope of the exchange rate curve is less than one at all times. This is due to the fact that although the fundamental evolves as a unit root process, the exchange rate is constrained to stay within the band, resulting in exchange rate expectations that are skewed towards the center of the band the more the exchange rate approaches one of its limits s^{max} or s^{min}. The nonzero exchange rate expectation stabilizes the exchange rate without central banks actually intervening in the market. Clearly, the closer the exchange rate comes to the boundary, the greater the stabilizing effect of exchange rate expectations is. In the limit, when the exchange rate reaches the edges of the band, the expected change of the exchange rate completely offsets the impact of a given shock on the market. The important policy implication is that the exchange rate's volatility is less than the volatility of its fundamental, which is sometimes called the 'honeymoon' effect. Secondly, the smooth pasting property of the model generally

[2] See Sarno and Taylor (2003), pp. 179 -181, for details.

suggests a nonlinear relationship between the exchange rate and the fundamental, which clearly serves as a starting point for the subsequent empirical analysis.

3. A STARTZ model of the Danish krone exchange rate

Starting with the basic target zone model, a growing literature about theoretical and empirical issues emerged from the early 1990s onwards.[3] Building on the empirical contribution de Jong (1994), for example, Iannizzotto and Taylor (1999) and Taylor and Iannizzotto (2001) made use of the simulated method of moments to estimate and test a target zone model, using data for several ERM currencies during the 1980s and 1990s. Although they cannot reject the target zone model, their results show that the non-linear effect is much smaller than the theoretical model of Krugman (1991) would imply. To test empirically whether and where such boundaries in the DKK/EUR exchange rate are, we apply Lundberg and Teräsvirta's (2006) STARTZ model, which was developed to investigate the validity of the basic target zone assumptions as well as to adequately characterize the dynamic behavior of an exchange rate fluctuating within a target zone. In particular, we take advantage of the model's capability of analyzing possible *informal* target zones, i.e. exchange rate bands that are neither announced to the public nor necessarily properly defined by official authorities.

The STARTZ approach models the transition dynamics of both the conditional mean and the conditional variance between the central parity and the boundaries of the band. It is assumed that the transition depends nonlinearly on the distance between the current exchange rate and the central parity of the target zone. In particular, the conditional mean is expected to behave like a random walk process in the neighborhood of the central parity, whereas close to the boundary the exchange rate tends to follow a white noise process due to the stabilizing influence of exchange rate expectations. Our application of the STARTZ model parameterizes the first and second moments of the deviation of the exchange rate from its unconditional mean, $z_t = s_t - \bar{s}$, as:[4]

$$z_t = \sum_{i=1}^{k} \alpha_i z_{t-i} + \left(z^L - \sum_{i=1}^{k} \alpha_i z_{t-i} \right) G^L + \left(z^U - \sum_{i=1}^{k} \alpha_i z_{t-i} \right) G^U + \phi \Delta ID_t + \varepsilon_t \qquad (5)$$

[3] Sarno and Taylor (2003) and Taylor (1995) survey the target zone literature.

[4] Since the Danish krone was on average on the stronger side vis-à-vis the euro, we use the unconditional mean of the exchange rate (DKK 7.4431 per euro) instead of the official parity (DKK 7.46038 per euro). This is in line with the findings of Crespo-Cuaresmo, Egert and MacDonald (2005).

$$G^{L}\left(z_{t-1},\psi,\theta,z^{L}\right)=\left(1+\exp\left(-\psi\left(z^{L}-z_{t-1}\right)\right)\right)^{-\theta},\tag{6}$$

$$G^{U}\left(z_{t-1},\psi,\theta,z^{U}\right)=\left(1+\exp\left(-\psi\left(z_{t-1}-z^{U}\right)\right)\right)^{-\theta},\tag{7}$$

$$\varepsilon_t=\upsilon_t^{iid}\sqrt{h_t}\ ,\tag{8}$$

where υ_t^{iid} ~N(0,1). Moreover, z^L and z^U denote the lower and upper edges of the band, respectively. Functions (6) and (7) are generalized logistic functions with θ denoting an asymmetry parameter and ψ a slope parameter. The interpretation of the mean dynamics defined in equations (5) to (8) is that in the neighborhood of the central parity, the behavior of the exchange rate is mostly driven by a linear combination of its own lagged values, as both transition functions G^U and G^L remain small. Close to the boundaries of the target zone, however, the exchange rate depends nonlinearly on the lagged value of the deviation. For instance, when the exchange rate approaches the upper bound, G^U becomes larger, imposing a smooth transition from the autoregressive behavior towards white noise-like dynamics around z^U. As is well known from the literature, we might expect the exchange rate volatility to shrink substantially at the edges of the band if the target zone works properly. In order to control for this hump-shaped distribution of the conditional variance, Lundberg and Teräsvirta (2006) parameterize the volatility process similarly to the mean dynamics:

$$h_t=\beta_0+\beta_1\varepsilon_{t-1}^2+\beta_2h_{t-1}+\left(\xi-\left(\beta_0+\beta_1\varepsilon_{t-1}^2+\beta_2h_{t-1}\right)\right)G^L+\left(\xi-\left(\beta_0+\beta_1\varepsilon_{t-1}^2+\beta_2h_{t-1}\right)\right)G^U\tag{9}$$

where $\xi>0$ ensures positivity of the conditional variance.[5] The process defined in equation (9) allows for a smooth transition from GARCH-like behavior around the fundamental value and a close-to-constant conditional variance at the edges of the band.

4. Data

We use daily spot Danish krone exchange rates against the euro (the price of one euro expressed in Danish krone) to calculate the percentage deviation of the exchange rate from its unconditional mean, $z_t=100\cdot(s_t-\bar{s})$. In terms of the preceding discussion, therefore,

[5] Of course, the respective parameters in the transition function will be allowed to differ from those in the mean equation.

Denmark is taken as the home economy and the euro area as the foreign economy. In order to keep its currency inside the deviation band, the ERM II member state adjusts its short-term interest rates and/or intervenes in the foreign exchange market. To control for the impact of domestic monetary policy we introduce the first difference of the interest differential between Danish and euro area money markets $\Delta\left(i_t^{EUR} - i_t^{DKK}\right)$, where i_t^{DKK} is the overnight DKK eurodeposit interest rate, and i_t^{EUR} denotes the EUR overnight eurodeposit interest rate. The sample period is January 4 1999 to 31 August 2011. Daily exchange rates are represented in the upper panel of Figure 1. The time series of the exchange rate reveals only little fluctuation, even during times of the recent financial crisis.

[Figure 1about here!]

Should the currency reach either the upper or the lower limit of the band, both the European Central Bank (ECB) and the national central bank intervene to maintain the exchange rate inside the interior of the band. The ECB is only obligated to intervene when a currency reaches one of the band limits. The official central rate is DKK 7.46038 to the euro and the official deviation band is set to +/- 2.25 percent. However, marginal interventions are generally avoided in favor of intra-marginal interventions. The Danish krone has at no point been near the edges of the band, and so our analysis pertains only to intra-marginal interventions carried out unilaterally by DN. As can be seen in the lower panels of Figure 1, interventions of the DN were sporadic and clustered over the sample period. The percentage of trading days in which intervention occurred is 0.12. The average DN intervention was EUR 9.5 million, indicating the accumulation of reserves of EUR 31.239 million. Conditional on the occurrence of intervention, the mean absolute value of purchases or sales is EUR 269 million. In addition, 43.5 percent of intervention occurred on trading days when the Danish krone exchange rate of the Euro is above average, which, overall, happened in 51% of the cases. Considering the nonstandard operations in the aftermath of the crisis this points to an overall symmetric intervention policy. Intervention operations of the DN are presented in the lower panel of Figure 1. The time series reveals a fairly balanced trading record of the DN until the financial crisis also unfolded in the foreign exchange market (Melvin and Taylor, 2009). The failure of Lehman Brothers triggered large-scale deleveraging also of Danish investors with the result of capital repatriation from Euro Area financial markets. The DN started to buy euro against Danish krone to prevent the currency from appreciation and accumulated the observed reserves. These intervention operations can be viewed as a means of neutralising nonstandard foreign exchange order flow, which did not undermine the credibility of the target zone.

5. The STARTZ model: estimation results

The modeling procedure for building STR models was carried out as suggested by Granger and Teräsvirta (1993), Teräsvirta (1994), Teräsvirta and Anderson (1992), and Lundberg and Teräsvirta (2006). First, linear autoregressive models were estimated in order to choose the lag order of the autoregressive term on the basis of the Akaike Information Criterion. We found that second-order autocorrelation seemed to be appropriate for the (stationary) dynamics of the exchange rate deviation from the unconditional mean. Second, we tested linearity against the STR model rejected the null hypothesis of linearity at the one percent marginal significance level (Granger and Teräsvirta, 1993). The parameter estimates of the STARTZ model represented in Table 1 are obtained by recursively maximizing the (quasi) log-likelihood by means of the BFGS (Broyden, Fletcher, Goldfarb, and Shanno) algorithm.[6]

- Insert Table 1 about here -

The estimated model passes a number of diagnostic checks for remaining serial correlation and conditional heteroskedasticity in the standardized residuals. We also tested the model against remaining nonlinearities in both conditional mean and variance. Based on the proposed estimation strategy in Lundberg and Teräsvirta (2006), we accept the model as adequately specified. The point estimates of the coefficients are appropriately signed and exhibit low standard deviations, except for the interest differential coefficient. The missing influence of interest rate shocks to the level of the exchange rate might reflect the willingness of Danish authorities to accommodate exchange rate policy by domestic monetary policy. This is also revealed in *Danmarks Nationalbank Report and Accounts (2010)* where it is stated that, 'In 2010, Danmarks Nationalbank adjusted its monetary-policy interest rates seven

[6] Note that we derived robust standard errors for the estimated coefficients. This is important because conditional normality cannot be maintained. Under fairly weak regularity conditions, however, the resulting robust estimates are consistent even when the conditional distribution of the residuals is non-normal (Bollerslev and Wooldridge, 1992).

times. The ECB kept the interest rate on its main refinancing operations at 1 percent in 2010. Danmarks Nationalbank's unilateral interest rate changes took place against the background of a widening spread between short-term Danish and European money-market interest rates.'[7]

The identifying restrictions of the STARTZ model, $\psi_i > 0$ and $\theta > 0$, are satisfied, which supports the view that the Danish krone exhibits time series properties consistent with the theoretical target zone model. Regarding the coefficients of the volatility process, the estimation results do not reveal any smooth transition patterns. Since the absolute values of the ψs are quite large, both G^U and G^L remain very small irrespective of the current misalignment. Thus, a standard GARCH process seems sufficient to describe the second moment dynamics. More importantly, the estimates of z^L and z^U reveal boundaries of the Danish krone of approximately 0.74 percent around the unconditional mean. The conclusion we draw from the estimated STARTZ model is that Danish monetary authorities succeeded in introducing an *informal* exchange rate band around an unconditional mean on the strong side of the official ERM II parity.

6. A stylized model of Danish foreign exchange intervention

Since the informal target zone has not been announced to the public, it is far from obvious what mechanism sufficiently restricted the exchange rate to this narrow range. In this section, we argue that a policy of systematic intra-marginal intervention may account for this observation. To identify a stabilizing influence of central bank intervention in the Danish krone-euro foreign exchange market, we first provide some theoretical intuition along the lines of Garber and Svensson (1995). In a second step, the standard STARTZ model is augmented to incorporate DNB intervention operations.

6.1 Exchange rate target zones and intra-marginal intervention

The modifications of the basic target zone model in order to account for intra-marginal intervention are expected to alter the time series process of the composite fundamental.[8] If the central bank aims at stabilizing the exchange rate, persistent shocks to the 'private sector'

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[7] See http://www.nationalbanken.dk/DNUK/Publications.nsf/side/FCEA1B58CF642359C1257855002D466F/$file/Report_Acc_2010_UK_web.pdf

[8] See Sarno and Taylor (2003), pp. 192 – 194.

fundamental has to be offset by official intervention, a situation often referred to as 'leaning – against-the-wind' operations.

To develop further insights into the working of intra-marginal intervention, we first refrain from incorporating any target zone commitment giving rise to a model of managed floating. Recalling that $z_t = s_t - \bar{s}$, we can write the exchange rate equation (1) as

$$s = f + \lambda E[dz]/dt + \lambda E[d\bar{s}]/dt \ . \tag{10}$$

Subtracting the central parity from both sides gives:

$$z = h + \lambda E[dz]/dt \ , \tag{11}$$

where $h = f - \bar{s} + \lambda E[d\bar{s}]/dt$ is the drift of the misalignment. A successful policy of leaning against the wind may be observed in a mean reversion of the drift term

$$\frac{E[dh]}{dt} = -\rho h, \quad \rho > 0 \, , \tag{12}$$

where ρ denotes the rate of error correction. The solution to the model

$$z = \frac{h}{1 + \lambda\rho} \, , \tag{13}$$

reveals a stabilizing influence on the exchange rate, because $1/(1 + \lambda\rho) < 1$. Thus, even in the absence of a target zone, a managed float provides exchange rate smoothing to the extent the central bank is willing to offset changes in private sector fundamentals. If we additionally allow for marginal intervention, we may also observe a honeymoon effect, albeit smaller than in the basic target zone model. This is due to the fact that the probability of the exchange rate actually triggering marginal intervention is small if the policy of intra-marginal intervention is successful (Garber and Svensson, 1995).

6.2 Empirical evidence from Danmarks Nationalbank intervention operations

The specific form of the stabilizing influence of intervention on exchange rates, as discussed above, is driven by the assumption that the central bank permanently operates in the market. This is in contrast to the real-world intervention policies of central banks, where we in fact find intervention operations to be sporadic and clustered (Sarno and Taylor, 2001). Based on this observation a stabilizing influence of intervention according to equations (12) and (13) will only be identified in periods when intervention operations actually took place. As a result we test for the influence of intervention by augmenting the transition functions with observed (lagged) FX operations

$$G^L\left(z_{t-1},\psi,\theta,z^L\right)=\left(1+\exp\left(-\left(\psi_1+\psi_2 DNI_{t-1}\right)\left(z^L-z_{t-1}\right)\right)\right)^{-\theta}, \tag{6'}$$

$$G^U\left(z_{t-1},\psi,\theta,z^U\right)=\left(1+\exp\left(-\left(\psi_1+\psi_2 DNI_{t-1}\right)\left(z_{t-1}-z^U\right)\right)\right)^{-\theta}, \tag{7'}$$

where the variable $DNI_t = D_t \cdot INT_t$ denotes the product of an indicator variable $D_t \in \{-1,1\}$ and the observed intervention INT_t. The inclusion of the indicator variable controls for the fact that the intended effect of the operation can only occur if the central bank buys foreign currency in the case of a negative deviation ($D_t = 1,\ if\ z_t < 0$) and sells foreign currency in the case of a positive deviation ($D_t = -1,\ if\ z_t > 0$). Regarding the volatility equation, we consider the results of our basic STARTZ model, where we found little indication for nonlinearities in second moments; we therefore opt for a more parsimonious specification using a simple GARCH(1,1) process. The results of the intervention augmented STARTZ model are presented in Table 2.

- Insert Table 2 about here -

The estimated specification passes the usual diagnostic tests for remaining serial correlation and conditional heteroskedasticity in the standardized residuals as well as tests against remaining nonlinearities. The autoregressive coefficients as well as the estimated edges of the band are similar to those of the standard regression. More interestingly, the statistically significant value of the intervention coefficient reveals a stabilizing influence in the sense that exogenous shocks become less persistent in periods when market participants observed target zone-consistent FX operations of Danish authorities. Due to the structure of eq. (6') and (7') this influence is more pronounced the more the exchange rate deviates from the unconditional mean. Note, however, that the time series of DNI_t also contains a number of negative values indicating some 'counterproductive' operations leading to an increased persistence of shocks.

In line with the general experience of target zones DN intervention typically occur only when the exchange rate deviates from the unconditional mean by more than a certain tolerance level. Thus, the influence of intervention operations might also be identified by a tighter (informal) exchange rate band rather than an intervention-related decreasing slope of the S-curve. In order to test for an intervention-related time-varying exchange rate band we estimate the STARTZ model of equation (5) to (8), whereby the upper and lower edges of the band are functions of central bank operations:

$$z^{U} = z^{U\max} - \kappa \cdot DNI_{t} \tag{14}$$

$$z^{L} = -z^{U}\,. \tag{15}$$

Of course, equations (14) and (15) suggest a symmetric influence of intra-marginal intervention on the target zone. The estimation results of the augmented STARTZ model are presented in Table 3.

- Insert Table 3 about here -

The estimated model again passes a battery of diagnostic checks for remaining serial correlation and conditional heteroskedasticity in the standardized residuals as well as tests against remaining nonlinearities. The estimated half-width of the band in periods of central bank's absence from the market is clearly larger than before. However, it should be mentioned that the estimator's standard error is quite large. The point estimate of the intervention coefficient is appropriately signed and statistically significant. An absolute value of the coefficient κ indicates that a one billion euro intervention on average narrows the target zone by 0.23 percentage points, which also gives rise to an economically significant influence of intervention on the width of the target zone.

7. Conclusion

In this paper, we have analyzed Danish exchange rate policy between January 1999 and August 2011. In particular, our estimation results for a Smooth Transition Autoregression Target Zone (STARTZ) model reveals that Danmarks Nationalbank (DN) successfully managed to keep the exchange rate within a narrow band around its unconditional mean. This informal target zone is identified by the fact that exchange rate shocks became less permanent as deviations grew implying a regime transition from autoregressive to white-noise behavior of the exchange rate. We also estimated an intervention-augmented STARTZ model, to show that the DN intra-marginal interventions exerted a stabilizing effect on exchange rates, which may also interpreted as an informally narrowed band width of the official target zone.

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Table 1:

The Estimated STARTZ model

(in percent) 1999.01.04 – 2011.08.31

α_1	0.70 (22.88)***
α_2	– 0.10 (3.38)***
ϕ	0.54 (1.54)
z^U	0.74 (4.25)***
z^L	– 0.74 (4.24)***
ψ_m	23.48 (4.52)***
θ_m	0.09 (1.78)*
ξ	0.001 (8.39)***
ψ_{v1}	83.51 (9.65)**
ψ_{v2}	30.96 (4.96)***
θ_v	0.93 (41.04)***
β_0	0.000006 (3.31)***
β_1	0.10 (4.85)***
β_2	0.88 (37.17)***
LLh	12566.39
AR(5)	0.87
ARCH(5)	0.73
NRNL	0.17

Notes: The sample contains daily observations of the euro spot exchange rate against the Danish krone from January 1999 to August 2011. α_i, z^i, θ_m, ψ_i indicate the estimated parameters of the mean equation, ξ, θ_v, φ_i, β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters, LLh is the log likelihood value. AR(p) denotes the p-value for the Ljung-Box statistic for serial correlation of the residuals up to p lags. ARCH(q) denotes the p-value for the Ljung-Box statistic for serial correlation of the standardized squared residuals up to q lags. NRNL is the lowest p-value for no remaining nonlinearity up to ten lags. t-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. *(**,***) denotes significance at the 10% (5%, 1%) level.

Table 2:

The Estimated Intervention-Augmented STARTZ Model

(in percent) 1999.01.04 – 2011.08.31

α_1	0.71 (11.44)***
α_2	– 0.09 (4.19)***
ϕ	0.50 (1.44)
z^U	0.73 (7.86)***
z^L	– 0.73 (7.90)***
ψ_1	7.39 (5.17)***
ψ_2	1.61 (2.28)**
θ_m	0.36 (1.96)**
β_0	0.000006 (3.31)***
β_1	0.10 (4.78)***
β_2	0.88 (35.76)***
LLh	12568.96
AR(5)	0.86
ARCH(5)	0.69
NRNL	0.20

Notes: The sample contains daily observations of the euro spot exchange rate against the Danish krone from January 1999 to August 2011. α_i, z^U, z^L, θ, ψ_i indicate the estimated parameters of the mean equation, β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters, LLh is the log likelihood value. AR(p) denotes the p-value for the Ljung-Box statistic for serial correlation of the residuals up to p lags. ARCH(q) denotes the p-value for the Ljung-Box statistic for serial correlation of the standardized squared residuals up to q lags. NRNL is the lowest p-value for no remaining nonlinearity up to ten lags. *t*-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. *(**,***) denotes significance at the 10% (5%, 1%) level.

Table 3:

The Estimated Intervention-Augmented STARTZ Model

(in percent) 1999.01.04 – 2011.08.31

α_1	0.71 (13.50)***
α_2	– 0.12 (3.00)***
ϕ	0.50 (1.74)*
z^{Umax}	1.21 (1.56)
κ	0.23 (1.91)*
ψ	-14.47 (16.79)***
θ_m	0.08 (1.38)
β_0	0.000006 (5.97)***
β_1	0.10 (10.38)***
β_2	0.88 (81.72)***
LLh	12568.62
AR(5)	0.86
ARCH(5)	0.77
NRNL	0.21

Notes: The sample contains daily observations of the euro spot exchange rate against the Danish krone from January 1999 to August 2011. α_i, z^{Umax}, κ, θ, ψ indicate the estimated parameters of the mean equation, β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters, LLh is the log likelihood value. AR(p) denotes the p-value for the Ljung-Box statistic for serial correlation of the residuals up to p lags. ARCH(q) denotes the p-value for the Ljung-Box statistic for serial correlation of the standardized squared residuals up to q lags. NRNL is the lowest p-value for no remaining nonlinearity up to ten lags. *t*-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. *(**, ***) denotes significance at the 10% (5%, 1%) level.

Figure 1: Daily exchange rates, the target zone bands and DN intervention