

*Roger Bjørnstad and Eilev S. Jansen*

**The NOK/euro exchange rate after  
inflation targeting:  
The interest rate rules**

**Abstract:**

Norway adopted a flexible inflation target in March 2001 following a long period with exchange rate targeting in various forms. The regime shift reverses the causal ordering between changes in the nominal exchange rate and changes in the interest rate. When the central bank targets the exchange rate, interest rates are rarely changed independently of foreign interest rates and only to counteract large movements in the exchange rate after interventions have failed to stabilise the exchange rate. With inflation targeting the interest rate is used to stabilise the domestic economy and has a strong impact on the exchange rate. The long run (steady state) relationship between the interest rate and the exchange rate is on the other hand not altered by the change in monetary policy regime. This means that the fundamental equilibrating mechanism - that is the PPP condition augmented with a risk premium - remains the same across regimes.

**Keywords:** monetary policy regime shift, NOK/euro exchange rate, role of interest rates, equilibrium real exchange rate, purchasing power parity, uncovered interest parity

**JEL classification:** C51, C52, C53, E42, F31

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**Address:** Roger Bjørnstad, Statistics Norway, Research Department. E-mail: roger.bjornstad@ssb.no

Eilev S. Jansen, Statistics Norway, Research Department. E-mail: eilev.jansen@ssb.no

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## 1 Introduction

This paper focuses on how a monetary policy regime shift - from exchange rate targeting to inflation targeting - affects the exchange rate determination in a small open economy. Norway adopted a flexible inflation target in March 2001. Before 2001 Norway followed various exchange rate targets, first targeting a tradeweighted basket of currencies (1978-1990) with several small realignments and a final big devaluation in May 1986, then pegging to theoretical ECU as of October 1990 until Norwegian Kroner (NOK) went into a "dirty" float in December 1992. In the period after the devaluation in May 1986 until March 2001 the exchange rate against ECU/euro was remarkably stable apart from episodes of international currency crises, especially the tripple crisis in Asia, Russia and South America in the fall 1998.

Despite an absence of international currency crises there has been greater variation in the nominal exchange rate after 2001q1 than before, see Figure 1. The standard deviation of the NOK/euro nominal exchange rate provides a simple measure: it was 18.5 % (around a mean of 8.15 NOK/euro) for the period 1987q1 - 2001q1 compared to 36 % (with mean 7.98 NOK/euro) for the period 2001q2 - 2006q3. This observation is in line with what you would expect if you compare a fixed exchange rate regime with an inflation targeting regime within a standard Mundell-Flemming model for the open economy, see Ch. 10.1 in Rødseth (2000). It is, however, at odds with international evidence as reported by Edwards (2006) who found no significant effect of the introduction of an inflation target on the exchange rate volatility for Australia, Canada, Israel, Mexico and Korea and even a significantly negative effect for Brazil and Chile.<sup>1</sup>

The role of the exchange rate in an inflation targeting framework is an unsettled matter. The inflation targeting literature pays relatively little attention to this issue. One reason may be that major contributors tend to focus on models for the closed economy. For example, Woodford (2003) has no entry for "exchange rates" or "devaluation" in the subject index. That said, writers like Ball (1999), Obstfeld and Rogoff (1995) and Svensson (2000) have argued that including the exchange rate in the interest rate reaction function of the inflation targeting central bank would result in more stable macroeconomic outcomes. However, practioners do not in general concur. The governor of the Bank of England has argued that even a 20 percent appreciation of Sterling early on in the inflation targeting period of the UK did not affect the effectiveness of inflation targeting to achieve stability, see King (2005). Allsopp et al. (2006) even claim that the appreciation of the exchange rate has had little bearing on domestic inflation and that the import price changes induced by the exchange rate pass-through are instead manifested in relative prices. The Norwegian central bank has so far been less clear on this issue, but the high volatility of the NOK/euro nominal exchange rate after 2001q1 quoted above suggests that the Norwegian central bank has not put much weight on the nominal exchange rate in the interest rate reaction function in the period of inflation targeting.

The starting point for our empirical work is a study by Bjørnland and Hungnes

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<sup>1</sup>Edwards (2006) first found a presence of conditional heteroscedasticity in simple linear regression models explaining the change of the nominal exchange rates for each country. In a second step he fitted and estimated a GARCH model in each case, including a dummy for the inflation targeting period. His conclusions were then based on the significance of the dummy.

(2006), who found a stable equilibrium correcting relationship for the NOK/euro exchange rate, estimated on a sample from 1983q1 to 2002q2. The long run or steady state part of that relationship can be interpreted as a Purchasing Power Parity (PPP) condition augmented with a risk premium<sup>2</sup>, whereas the changes in the exchange rate in the short term are driven by inflation rates and changes in interest rates in Norway and the eurozone, respectively. The empirical correlations suggest that an increase in the Norwegian interest rate relative to that of the eurozone weakens the Norwegian Krone in the short run. In an exchange rate targeting regime the interest rate is rarely used and only to counteract large movements in the exchange rate after interventions have failed to stabilise the exchange rate. A strict inflation targeting regime changes this. Interest rates are now to a larger extent used to regulate domestic demand in order to control inflation. The purpose of the present study is to investigate how the advent of inflation targeting has affected the empirical relationship between the exchange rate and its long run and short run explanatory variables.

There is recently an increasing number of empirical studies internationally that supports convergence towards PPP in the long run, see Sarno and Taylor (2002) and Sarno (2005), while on the other hand there is hardly any study that provides evidence in favour of the pure version of uncovered interest rate parity (UIP, to be defined below) as a model of exchange rate determination, see Froot and Thaler (1990) and the survey in Wadhvani (1999). Most empirical studies on Norwegian data reject the pure PPP hypothesis, but Akram (2006) has found support for PPP for the tradeweighted Norwegian exchange rate.

The paper is organised as follows. In Section 2 we give a brief outline of common theory for the determinants of the long run real exchange rate. In Section 3 we present the empirical evidence of Bjørnland and Hungnes (2006). We show how their empirical exchange rate relationship, which is well specified according to standard econometric criteria within sample, breaks down at the end of their sample - after four quarters of a new monetary policy regime. The breakdown leads us to reconstruct the empirical relationship - introducing interaction terms between changes in interest rates and a step dummy for the regime shift. The resulting model is presented in Section 4. The upshot of this is that the short run effects of interest rates change sign, whilst the long run equilibrium equation remains unchanged. Section 5 concludes.

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<sup>2</sup>Or it can be interpreted, as Bjørnland and Hungnes (2006) do, as a linear combination of a purchasing power parity condition and an uncovered interest parity condition, to be explained in Sections 2 and 3 below.

## 2 The long run real exchange rate

In the literature the long run real exchange rate are governed by two famous parity conditions: PPP and UIP. The Purchasing Power Parity (PPP) condition says that the log of nominal exchange rate ( $v_t$ ) - that is the domestic price for foreign currency in the home country - should be equal to the difference between the log of price levels at home and abroad,  $p_t$  and  $p_t^*$ <sup>3</sup>, *i.e.* :

$$(1) \quad v_t = p_t - p_t^*.$$

PPP is an equilibrium condition and does usually not hold, hence the real exchange rate is informative

$$(2) \quad rv_t = v_t - p_t + p_t^*.$$

$rv_t$  may thus be interpreted as a measure of the deviation from PPP and it must be stationary for the long run PPP to hold (see surveys by Froot and Rogoff (1995), Rogoff (1996), Sarno and Taylor (2002, 2003) and Taylor and Taylor (2004)).

The balance of payment constraint entails that, in the long run, any imbalances over the current account have to be financed over the capital account, and according to standard portfolio models this requires an interest rate differential. The cornerstone parity condition in capital markets is the Uncovered Interest Parity condition (UIP), which is defined by foreign exchange market efficiency

$$(3) \quad \Delta_k v_{t+k}^e = i_{t,k} - i_{t,k}^*,$$

where  $i_{t,k}$  and  $i_{t,k}^*$  are the nominal interest rates on similar domestic and foreign securities, respectively, with  $k$  periods to maturity;  $\Delta_k v_{t+k}^e = v_{t+k}^e - v_t$  and superscript  $e$  denotes market expectations based on information at time  $t$ . Oftentimes  $k$  is set equal to 1 for simplicity, as we do below. In its simplest form the efficient market hypothesis can be reduced to a joint hypothesis that foreign exchange market participants are - on aggregate - risk neutral and endowed with rational expectations, see Sarno (2005). Under those conditions  $i_t - i_t^*$  is an optimal predictor of the rate of depreciation (or appreciation) and the gain from investing in the home currency becomes

$$(4) \quad g_t^e = i_t - i_t^* + \Delta v_{t+1}^e.$$

The interest rate difference can, however, be seen as a risk premium,  $x_t$ , for the agents in the foreign exchange market

$$(5) \quad x_t = i_t - i_t^*$$

which we assume enters the long run equilibrium condition as an addendum to PPP in steady state

$$(6) \quad v_t = p_t - p_t^* - \delta(i_t - i_t^*).$$

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<sup>3</sup>In the sequel we use price indices and hence (1) expresses relative PPP, see p. 261 in Rødseth (2000).

In the sequel we label this condition "PPP with a risk premium". The interpretation is that the exchange rate for foreign currency in Norway is determined by supply and demand, see Ch. 3 in Rødseth (2000). Demand is defined by the size of the central bank's foreign reserves, whereas agents, mainly abroad, supply foreign currency. The assertion is that these agents charge a risk premium for holding Norwegian kroner which is proportional to the interest rate difference in the long run.

Bjørnland and Hungnes (2006) follow Juselius and MacDonald (2006) and derive a long run condition like (6) from a different perspective: In the long run it is assumed that the current account,  $ca_t$ , depends on deviations from PPP and the capital account,  $ka_t$ , depends on deviations from UIP such that

$$(7) \quad ca_t + ka_t = \gamma(v_t - p_t + p_t^*) + \lambda(i_t - i_t^* + \Delta v_t^e).$$

A hypothetical situation with balance of payments requires the expression in (7) to be equal to zero. Moreover, in equilibrium the expectational change in the nominal exchange rate is zero,  $\Delta v_{t+1}^e = 0$ , and equation (7) becomes

$$(8) \quad v_t = p_t - p_t^* - \lambda/\gamma(i_t - i_t^*).$$

Equation (8) combines the two central parity conditions and it is dubbed "PPP & UIP" in Section 3 below. No matter which interpretation we rely on, another way of seeing the equilibrium condition, expressed in (6) or (8), is that any non-stationarity in  $rv_t$  can be removed by non-stationarity in  $i_t - i_t^*$ .

### 3 The exchange rate targeting regime (1983q1 - 2001q1)

#### 3.1 The Bjørnland and Hungnes study - Cointegration results and dynamic modelling

Bjørnland and Hungnes (2006) explore the above hypotheses about the long run real exchange rates within the framework of standard multivariate cointegration analysis, see Johansen (1988). The variables used in their econometric analysis are the log of the nominal NOK/euro exchange rate<sup>4</sup> ( $v$ ), log of Norwegian ( $p$ ) and eurozone (trade weighted) consumer prices ( $p^*$ ), and Norwegian ( $i$ ) and eurozone (trade weighted) 3-months money market interest rates ( $i^*$ ). The data are quarterly and cover the period 1983q1 – 2002q2. The start date is set to exclude the turbulence in the international capital markets in the early 1980s. They report unit root tests suggesting that all variables are intergrated of first order,  $I(1)$ , while rejecting the hypothesis of integration of second order,  $I(2)$ .<sup>5</sup>

They proceed to estimate a fourth order VAR, and based on this model, the cointegration tests indicate one cointegration vector ( $\beta$ ) at the 1 percentage significance level. Table 1 shows the results of testing restrictions on the  $\beta$ -vector: using the likelihood ratio test statistics they reject the hypotheses ( $H_1$ ) of pure PPP and ( $H_2$ ) the interest rate differential being the only explanatory variables (or pure UIP as it were). Moreover, they find that neither of these hypotheses can be rejected when the rest of the cointegration vector is left unrestricted ( $H_3$  and  $H_4$ ), suggesting that the two hypothesis should be combined. The final hypothesis ( $H_5$ ) of PPP and UIP combined is not rejected and the restricted cointegration vector has a coefficient with an expected sign: if the Norwegian interest rate is high relative to the eurozone interest rate the equilibrium real exchange rate must be low, which is consistent with a strong (or appreciated) Norwegian krone.

Table 1: Test results for restrictions on the long run cointegration vector in Bjørnland and Hungnes (2006)

Hypothesis		$\beta_0 v + \beta_1 p + \beta_2 p^* + \beta_3 i + \beta_4 i^*$	Restrictions	Test statistics [ $p$ -value]
$H_1$	Pure PPP	$\beta_0 = 1, \beta_1 = -1, \beta_2 = 1, \beta_3 = 0, \beta_4 = 0$		$\chi^2(4) = 35.72$ [0.00**]
$H_2$	Pure UIP	$\beta_0 = 0, \beta_1 = 0, \beta_2 = 0, \beta_3 = 1, \beta_4 = -1$		$\chi^2(4) = 18.57$ [0.00**]
$H_3$	Augm. PPP	$\beta_0 = 1, \beta_1 = -1, \beta_2 = 1$		$\chi^2(2) = 2.67$ [0.26]
$H_4$	Augm. UIP	$\beta_3 = 1, \beta_4 = -1$		$\chi^2(1) = 0.87$ [0.34]
$H_5$	PPP & UIP	$\beta_0 = 1, \beta_1 = -1, \beta_2 = 1, \beta_3 = -\beta_4$		$\chi^2(3) = 6.07$ [0.11]
Sample period: 1983q1 – 2002q2				$T = 78$
For the $p$ -values ** and * mean "significant at 5% and 1% levels", respectively				

Bjørnland and Hungnes (2006) go on to estimate a single equation model as a parsimonious representation for the exchange rate that includes the last equilibrium

<sup>4</sup>NOK/theoretical ecu before the introduction of the euro 1. January 1999.

<sup>5</sup>More details are given in Bjørnland and Hungnes (2003).

relationship. In doing so, they adopt a general-to-specific methodology to an equilibrium correction model for the change in the NOK/euro exchange rate. That is, the general model includes the equilibrium correction term lagged one period and it has three lags of the difference of each of the variables : exchange rate, Norwegian and eurozone prices, and domestic and eurozone interest rates.

The model is simplified using PcGets 1.02 (see Hendry and Krolzig (2001)), which requires the general as well as the simplified models to satisfy a battery of misspecification tests to ensure that each model is data congruent. Also the procedure allows for impulse dummies which are chosen by the model based on an outlier detection procedure, rather than being imposed a priori. The reduction process yields the following final EqCM equation (standard errors in parentheses):

$$\begin{aligned}
 \Delta v_t = & \text{const} + \underset{(0.26)}{1.25} \Delta p_t + \underset{(0.25)}{0.65} \Delta p_{t-2} - \underset{(0.41)}{1.56} \Delta p_t^* - \underset{(0.41)}{1.31} \Delta p_{t-3}^* \\
 (9) \quad & + \underset{(0.73)}{2.72} \Delta i_t - \underset{(1.09)}{2.47} \Delta i_{t-2}^* - \underset{(0.05)}{0.27} (v - p + p^*)_{t-1} - \underset{(0.35)}{1.86} (i - i^*)_{t-1} \\
 & + \text{dummies} + \hat{\varepsilon}_t, \text{ where } \text{dummies} = D93q1, D97q1, D02q2 \\
 & \hat{\sigma} = 1.05\% \qquad T = 1983q1 - 2002q2 = 78
 \end{aligned}$$

The model appears to be well specified, according to the misspecification tests, reported below in Table 2, with recursively stable and significant coefficients within the sample period. We note however that the last observation (2002q2) is dummied out. The PPP and interest differential parts of the long run equation are split into separate terms, and significance of both terms corroborates the results from the cointegration analysis.

Efficient single equation estimation requires the explanatory variables to be weakly exogeneous with respect to the long run parameters (see Engle et al. (1983)). When the restricted cointegration vector (resulting from  $H_5$ ) is combined with weak exogeneity restrictions (see Johansen (1992)) on eurozone prices, and domestic and foreign interest rates, that specification is not rejected.<sup>6</sup> However, an additional restriction of weak exogeneity of domestic prices with respect to the long run parameters is rejected, as you would expect, suggesting that there may be a possible simultaneity problem.

Bjørnland and Hungnes (2006) investigate further the forecasting properties of equation (9) by means of rolling regressions within sample using the methodology of Meese and Rogoff (1983). They start with an estimation period 1983q1 - 1997q4 adding one new quarter and deleting the first observations in each regression, and they find that the model outperforms a Random walk model as well as a model which has PPP as the equilibrium correcting term on forecast horizons = 1, 2, 3, and 4 quarters ahead.

Our focus here is on what happens to this exchange rate equation after 2002q2, noting that the Bjørnland and Hungnes (2006) equation remains invariant to the first 4 quarters of observations after the introduction of a new monetary policy regime 29. March 2001.

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<sup>6</sup>The test statistics is  $\chi^2(6) = 6.01$ , which gives a  $p$ -value of 0.09.

### 3.2 Breakdown

When we extended the data set to include observations up to and including 2006q3 and reestimate the empirical equilibrium correction model in (9), a massive rejection of the specification occurred. Table 2 shows that the model is no longer a congruent representation of the data, and the rejection is particularly clear over a sample covering 1983q1 - 2004q2, extending the data set with 8 new quarters compared to Bjørnland and Hungnes (2006).

Table 2: Diagnostic tests for the model in Bjørnland and Hungnes (2006), i.e. equation (9), with three different sample periods. [p-values in square brackets]

Test	period: 1983q1-2002q2	period: 1983q1-2004q2	period: 1983q1-2006q3
<i>AR 1-5</i>	$F(5, 60)$ 1.06[0.39]	$F(5, 68)$ 1.99[0.09]	$F(5, 77)$ 0.98[0.43]
<i>ARCH 1-4</i>	$F(4, 57)$ 1.05[0.28]	$F(4, 65)$ 5.01[0.001]**	$F(4, 74)$ 3.90[0.006]**
<i>Normality</i>	$\chi^2(2)$ 2.89[0.24]	$\chi^2(2)$ 11.59[0.003]**	$\chi^2(2)$ 6.85[0.03]*
<i>Hetero</i>	$F(20, 44)$ 0.74[0.77]	$F(20, 52)$ 0.37[0.54]	$F(20, 61)$ 0.85[0.36]

Figure 2 shows recursively estimated coefficients of equation (9) on the extended sample period 1983q-2006q3. Along with the 1-up Chow-test of parameter stability (or the breakpoint Chow statistics in the terminology of Hendry and Doornik (2001)) these graphs clearly suggest a breakdown of the relationship from 2002q2 onwards. The out-of-sample one-step-ahead forecasts for the period 2002q3 - 2006q3 in Figure 3 show a very significant forecast failure, in particular between 2002q3 and 2004q2.

## 4 The inflation targeting regime (2001q1-2006q3)

### 4.1 What happened after 2002q1?

From Bjørnland and Hungnes (2006) we would expect (the changes in) the interest rate difference and the inflation difference to be the major explanatory variables behind the changes in the nominal NOK/euro exchange rate.

As is shown in the Data appendix, Norway entered the new inflation targeting regime in 2001q2 with a positive interest rate difference to the eurozone of 2.5 percentage points. In the next 6 quarters the interest rate difference increased to nearly 4 percentage points, see the upper part of Figure 4. This was mainly due to a reduction of interest rates in the eurozone, but also the fact that the Norwegian central bank took interest rates to a hike in 2002q2 and 2002q3 in response to what was considered to be a too generous wage settlement in May 2002, see Figure 5. This coincided with a sharp appreciation of the NOK/euro exchange rate. It was followed by an equally rapid depreciation in the next 6 quarters when the economy entered a recession and Norwegian interest rates decreased at higher speed than the eurozone interest rates until the interest rate difference was eliminated by 2004q1. The comovements of the interest rate changes and the exchange rate changes in this period are at odds with the short run effects in equation (9). After this point of time there was almost zero interest rate difference.

The difference in inflation rates, however, shows shifting correlations with the exchange rate movements. As is seen from the middle part of Figure 4 there is a positive correlation between the inflation difference and the exchange rate from 2000q1 to 2002q4, while there is a negative correlation between the two variables from 2003q1 to 2006q3. The reduced difference in inflation between Norway and the eurozone can hardly explain that the krone appreciated against euro after 2004q1. A possible driving force for this appreciation may however be found in the bottom part of Figure 4: The oil price (Brent blend) was more than doubled in that period.

### 4.2 Cointegration results and dynamic modelling

When we estimate the model of Bjørnland and Hungnes, that is a fourth order VAR in  $v$ ,  $p$ ,  $p^*$ ,  $i$ , and  $i^*$  on the extended data set (1983q1-2006q3), cointegration tests give strong support for two cointegration vectors. We can write these  $\beta$ -vectors as

$$\begin{aligned} &\beta_{01}v + \beta_{11}p + \beta_{21}p^* + \beta_{31}i + \beta_{41}i^* \\ &\beta_{02}v + \beta_{12}p + \beta_{22}p^* + \beta_{32}i + \beta_{42}i^* \end{aligned}$$

with loadings  $\alpha_{01}$  and  $\alpha_{02}$ , respectively, in the exchange rate equation of the VAR. With rank equal to 2 there are several ways to test the hypotheses relating to PPP and stationarity of the interest rate differential (or risk premium) by various sets of restrictions on the  $\beta$ -vectors. Restricting the first vector to represent PPP, *i.e.* (1,-1,1,0,0), and the second vector to capture stationarity of the risk premium, *i.e.* (0,0,0,1,-1), are jointly rejected with a test statistic  $\chi^2(6) = 44.28$  [0.00\*\*]. Likewise, we reject with  $\chi^2(3) = 27.15$  [0.00\*\*] the case where the first vector is restricted to

capture the hypothesis of "PPP with a risk premium"  $(1,-1,1, \beta_{31},-\beta_{31})$ , whilst the second vector is only restricted not to enter the exchange rate equation, *i.e.* the loading  $\alpha_{02}$  is set to zero in that equation. Finally, the same result - rejection with  $\chi^2(2) = 14.55 [0.00^{**}]$ , obtains when we allow the two vectors to enter the exchange rate equation with restrictions for a combination of them to yield "PPP with a risk premium", *i.e.* a joint test of:

$$\begin{aligned}\beta_{01} + (\alpha_{01}/\alpha_{02})\beta_{02} &= 1 \\ \beta_{11} + (\alpha_{01}/\alpha_{02})\beta_{12} &= -1 \\ \beta_{21} + (\alpha_{01}/\alpha_{02})\beta_{22} &= 1\end{aligned}\quad (\text{for PPP})$$

and

$$\beta_{31} + (\alpha_{01}/\alpha_{02})\beta_{32} = -(\beta_{41} + (\alpha_1/\alpha_2)\beta_{42})$$

for the additional risk premium term.

However, if we impose price homogeneity *a priori* and estimate a fourth order VAR in  $v$ ,  $p-p^*$ ,  $i$ , and  $i^*$ , and in addition condition on the price of oil,  $p^{oil}$ , and a deterministic trend as regressors, cointegration tests indicate the existence of only one cointegration vector (using the test procedure suggested by Harbo et al. (1998)).<sup>7</sup> As is seen from Table 3 below, we are able to establish the same results as for the shorter sample, when we condition the model as described above. We note that the pure PPP and the stationarity of the risk premium, which in this case is equivalent to testing pure UIP, are clearly rejected when tested separately, whereas the hypothesis of "PPP with a risk premium" is accepted by an even higher  $p$ -value than in case of the equivalent hypothesis  $H_5$  (PPP&UIP) in Table 1. Again, when the restricted cointegration vector (resulting from  $H_5$ ) is combined with weak exogeneity restrictions (see Johansen (1992)) on domestic and foreign interest rates, that specification is not rejected.<sup>8</sup> However, an additional restriction of weak exogeneity of relative prices with respect to the long run parameters is rejected, as you would expect, so the simultaneity problem we noted above is still present.

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<sup>7</sup>The support for one cointegration vector is marginal: with one exogenous variable ( $p^{oil}$ ) and a trend, Table 2 in Harbo et al. (1998) applies, which gives formal support to one cointegration vector only at the 10 percent level. The economic identification of the long run relationship can continue without the deterministic trend, since a test of its significance (based on rank equal to 1) shows that it can be dropped from the cointegration space:  $\chi^2(1) = 1.36 [0.24]$ .

<sup>8</sup>The test statistics is  $\chi^2(4) = 0.46$ , which gives a  $p$ -value of 0.98.

Table 3: Test results for restrictions on the long run cointegration vector when we condition price homogeneity and the price of oil as an exogeneous variable

Hypothesis	Restrictions	Test statistics [p-value]
$H_1$	Pure PPP $\beta_0 = 1, \beta_1 = -1, \beta_2 = 0, \beta_3 = 0, \beta_4 = 0$	$\chi^2(4) = 15.81$ [0.00**]
$H_2$	Pure UIP $\beta_0 = 0, \beta_1 = 0, \beta_2 = 1, \beta_3 = -1, \beta_4 = 0$	$\chi^2(4) = 11.55$ [0.02*]
$H_3$	Augm. PPP $\beta_0 = 1, \beta_1 = -1$	$\chi^2(1) = 0.01$ [0.90]
$H_4$	Augm. UIP $\beta_2 = 1, \beta_3 = -1$	$\chi^2(1) = 0.24$ [0.63]
$H_5$	PPP w/risk pr. $\beta_0 = 1, \beta_1 = -1, \beta_2 = -\beta_3$	$\chi^2(2) = 1.71$ [0.84]

Sample period: 1983q1 – 2006q3 T = 94

For the p-values \*\* and \* mean "significant at 5% and 1% levels", respectively

Equipped with this long run relationship we go on to remodel the changes in the NOK/euro exchange rate general to specific. This time, however, we include some extra variables in order to capture possible effects of the change in the monetary policy regime. Our reduction procedure gives us the following specification (standard errors in parentheses):

$$\begin{aligned}
 \Delta v_t = & \text{const} + \underset{(0.16)}{0.89}(\Delta p_t - \Delta p_t^*) - \underset{(0.16)}{0.47}(\Delta p_{t-1} - \Delta p_{t-1}^*) \\
 & - \underset{(0.05)}{0.24}\Delta_2 v_{t-1} - \underset{(0.004)}{0.024}\Delta_4 p_t^{oil} - \underset{(0.28)}{1.70}\Delta\Delta p_t^{j^{ae}} STEP_{2001q2} \\
 (10) \quad & - \underset{(0.99)}{9.68}\Delta_3 i_t STEP_{2001q2} + \underset{(1.93)}{16.33}\Delta_3 i_{t-1}^* STEP_{2001q2} \\
 & - \underset{(0.03)}{0.10}(v - p + p^*)_{t-1} - \underset{(0.22)}{0.79}[(i - \Delta p) - (i^* - \Delta p^*)]_{t-1} - \underset{(0.0026)}{0.006}p_{t-1}^{oil} \\
 & + \text{dummies} + \hat{\varepsilon}_t
 \end{aligned}$$

where  $\text{dummies} = D93Q1, D97Q1, DUM98, D01Q2, D03Q2,$

and  $DUM98 = D98Q3 + D98Q4 - D99Q1 - D98Q2$

$$\hat{\sigma} = 0.85\% \quad T = 1983q1 - 2006q3 = 95$$

The model given by (10) contains several new features.  $p_t^{oil}$  is the log of the price of Brent oil (USD/barrel), and  $p_t^{j^{ae}}$  is (log of) consumer price index (net of energy prices and excises), the differenced series  $\Delta p_t^{j^{ae}}$  is commonly used as a measure of core inflation. In order to capture possible effects of the change of the monetary policy regime we have introduced a step dummy, which enters the equation as an interaction term with other variables:  $STEP_{2001q2} = 0$  up to and including 2001q1 (*i.e.* the exchange rate targeting regime) and  $STEP_{2001q2} = 1$  after 2001q1 (*i.e.* the inflation targeting regime). The variables interacting with the step dummy are  $\Delta_3 i_t$  and  $\Delta_3 i_{t-1}^*$ , which capture the short term dynamics of home and foreign interest rate changes, and the change in core inflation,  $\Delta\Delta p_t^{j^{ae}}$ , which can be interpreted as an expectational variable. The Norwegian central bank targets this inflation measure and changes in the core inflation can be interpreted by agents to signal future interest rate moves.

We note that the short term effects of the interest rates are highly significant under inflation targeting and of opposite signs compared to those we found for the

exchange rate targeting period. The introduction of the interaction terms renders the change in interest rates insignificant on its own.

There is also a significant negative autoregressive effect in the short run ( $\Delta_2 v_{t-1}$ ) and an equally significant strengthening effect of oil price increases ( $\Delta_4 p_t^{oil}$ ) on the exchange rate.

In the long run relationship we have substituted the level of nominal interest rates with the level of real interest rates, *i.e.*  $(i - \Delta p)_t$  and  $(i^* - \Delta p^*)_t$ , respectively. This is a mere reparametrisation as it does not impose any additional restrictions on the model. The coefficients of the interest rates in the levels part of the equation are unaffected by this. If we look at the long run impact of the interest rate difference on the level of the real exchange it is now  $-7.9$  compared to  $-6.9$  in equation (9). The short term effects of home and foreign inflation are somewhat reduced compared to the specification in equation (9).

The model shows no sign of misspecification as is seen from Table 4. This is further reinforced by the recursive breakpoint Chow statistics in Figure 6. Also the recursively estimated coefficients are fairly stable, the exceptions are some signs of instability in the long run coefficient of the real exchange rate in 2002, and in the long run coefficient of the oil price towards the end of the full sample when that coefficient becomes only barely significantly different from zero.

Table 4: Diagnostic tests for the model (10) estimated on the full sample (1983q1 - 2006q3)

<i>AR 1-5</i>	$F(5, 74)$	1.02[0.41]
<i>ARCH 1-4</i>	$F(4, 71)$	0.33[0.85]
<i>Normality</i>	$\chi^2(2)$	4.33[0.11]
<i>Hetero</i>	$F(26, 52)$	0.71[0.83]

Based on data from 1972q2 - 1997q4 Akram (2004) reported a short term effect of the changes in the price of oil in a model explaining the changes in the tradeweighted exchange rate of Norwegian kroner. He also found that this effect was stronger if the oil price fell below 15 USD per barrel. These findings have been corroborated by later studies, see for example Bårdsen et al. (2005). Bjørnland and Hungnes (2006), on the other hand, found no oil price influence on the long run real exchange rate.

The number of observations available after the regime shift does not invite extensive testing of the forecasting properties of the model. Figure 7 shows one-step-ahead forecasts for the period 2005q3-2006q3, when the model in equation (10) is estimated with data up to and including 2005q2. The model is rejected on standard forecast tests as it fails to forecast the almost unchanged exchange rate in 2006q1.

### 4.3 The impact of changes in interest rates, price levels and the price of oil

In Figure 8 we illustrate the responses of the nominal exchange rate to permanent changes in price levels and interest rates in Norway and the eurozone and in the

price of oil. A common feature of these impulse responses is overshooting, *i.e.* that the short term effects are stronger than the long term effects.

According to our model, a simultaneous increase in consumer prices in Norway and the eurozone will not affect the nominal exchange rate in the long run and even the short term effects are small, except for the first quarter provided the shock also increase the core inflation  $\Delta p_t^{j_{ae}}$  by the same amount. If  $\Delta \Delta p_t^{j_{ae}} > 0$ , agents will expect future interest rate increases and this strengthens the exchange rate immediately. By quarter 2 after the shock, however, the effect is reversed and the increased price level has weakened the currency. From this quarter onwards a 1 per cent increase in eurozone prices and a 1 per cent increase in domestic prices leave the NOK/euro exchange rate unchanged.

A reduction in the interest rate difference with 1 percentage point leads to a depreciation of Norwegian kroner of 1.9 percentage points in the long run. Figure 8 shows that an interest rate change in the eurozone has a larger impact on the exchange rate than an interest rate increase of equal size in Norway in all quarters until the equilibrium state is attained. Figure 8 shows the development in the exchange rate following an increase in the eurozone interest rate of 0.25 percentage point. The maximum impact is 2 per cent depreciation of the kroner after 4 quarters. A drop in the Norwegian interest rate of 0.25 percentage point leads to a maximum of 1.3 per cent depreciation, which occurs after 3 quarters.

A 10 percent permanent reduction in the price of oil weakens the NOK/euro exchange rate by 0.7 percent after 4 quarters and 0.5 percent in the long run.

## 5 Conclusions

The main finding of this paper is that the regime shift matters. The introduction of an inflation target changes the way the NOK/euro exchange rate is determined. We find after the regime shift that the short term effect of the interest rates interacting with a step dummy render the interest rates variables themselves insignificant, which is consistent with the loss of significance of those variables when equation (9) in Bjørnland and Hungnes (2006) is estimated on the extended sample, see Figure 2.

Also, and more importantly, we find that the signs of the short term interest rate effects change. We interpret this to mean that the regime shift reverses the causal ordering between changes in the nominal exchange rate and changes in the interest rate. When the central bank targets the exchange rate, interest rates are rarely used and only to counteract large movements in the exchange rate when interventions have failed. With inflation targeting the interest rate is used to stabilise the domestic economy and the exchange rate responds strongly to interest rate changes with the expected sign.

The long run (steady state) relationship is not altered by the change in monetary policy regime. The strengthening effect on the exchange rate from a high oil price is small, only marginally significant, and unrelated to the regime shift. This means that the fundamental equilibrating mechanism - that is the PPP condition augmented with a risk premium - remains the same across regimes.

Two important caveats are worth mentioning. First, the number of observations available after the regime shift is still small and does not allow post sample evaluation. Second, and closely related, it is possible that we have not fully cap-

tured the role of expectations in the determination of the exchange rate. In equation (10) the change in core inflation ( $\Delta\Delta p_t^{j^{ae}}$ ) may be conceived of as a signal of future interest rate changes by the agents in foreign exchange markets: an increase in core inflation is likely to be met by a subsequent increase in interest rates by the central bank. More important, the effect of an interest rate change on the exchange rate may be different and stronger if it comes as a surprise to the agents compared to the case where it is anticipated. The forward rates in the euro market for Norwegian kroner strongly suggest that neither the Norwegian interest rate hike in 2002q2 and 2002q3 nor the fall in interest rates in the subsequent period were expected by agents. This is a topic for further research as more data accrue.

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## 6 Data appendix

### Variable definitions

The original data set (as in Bjørnland and Hungnes (2006))

$v_t$  = log of the nominal exchange rate between NOK/euro. Before the introduction of euro (1. January 1999), theoretical ecu is used.

$p_t$  = log of the domestic price (CPI, Norway).

$p_t^*$  = log of the foreign price (euro area CPIs).

$i_t$  = domestic interest rate (3 month money market rates, Norway).

$i_t^*$  = foreign interest rate (3 month money market rates, euro area).

Additional variables:

$p_t^{oil}$  - (log of) price of Brent crude oil (USD/barrel).

$p_t^{jae}$  - (log of) consumer price index, net of energy prices and excises (Norway).

$\Delta$  - difference operator, *i.e.*  $\Delta x_t = x_t - x_{t-1}$ .

$(i - \Delta p)_t$  - real interest rates, Norway.

$(i^* - \Delta p^*)_t$  - real interest rates, euro area.

In equation (10) we define:

$STEP_{2001q2} = 0$  up to and including 2001q1 (*i.e.* exchange rate targeting regime)

$STEP_{2001q2} = 1$  after 2001q1 (*i.e.* inflation targeting regime)

$Dxxqy = 1$  in 19xx or 20xx, quarter  $y$  and 0 otherwise

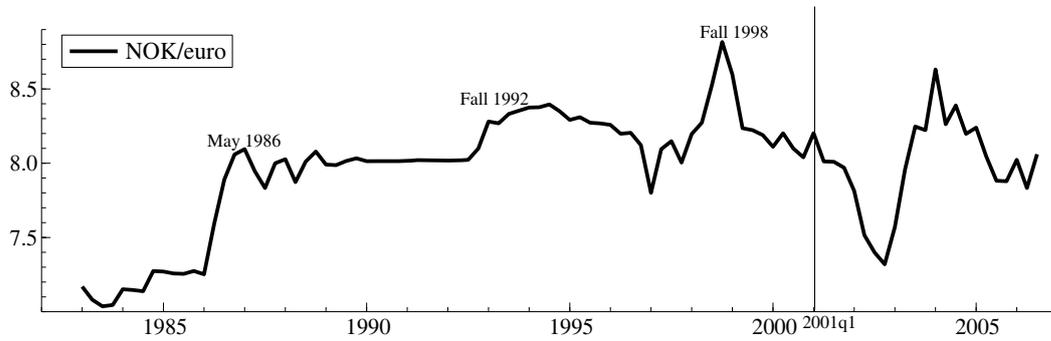


Figure 1: Norwegian kroner per euro, 1983q1 -2006q3

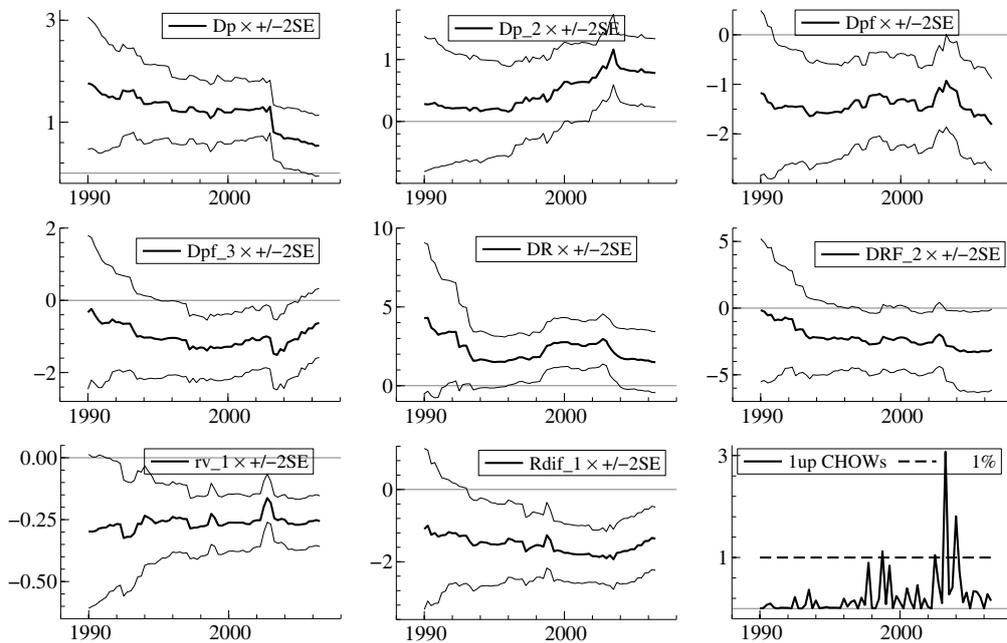


Figure 2: Recursive estimates of the coefficients in the exchange rate model of Bjørnland and Hungnes (2006), 1983q1 -2006q3

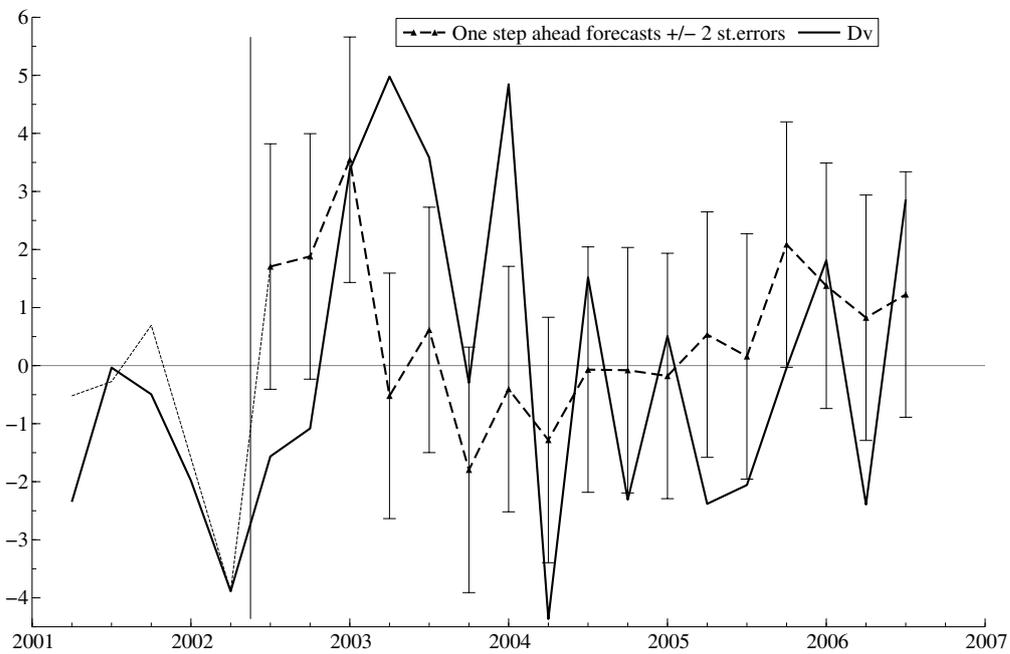


Figure 3: One step ahead forecasts with  $\pm 2$  standard errors for the exchange rate model of Bjørnland and Hungnes (2006), 1983q1 -2006q3

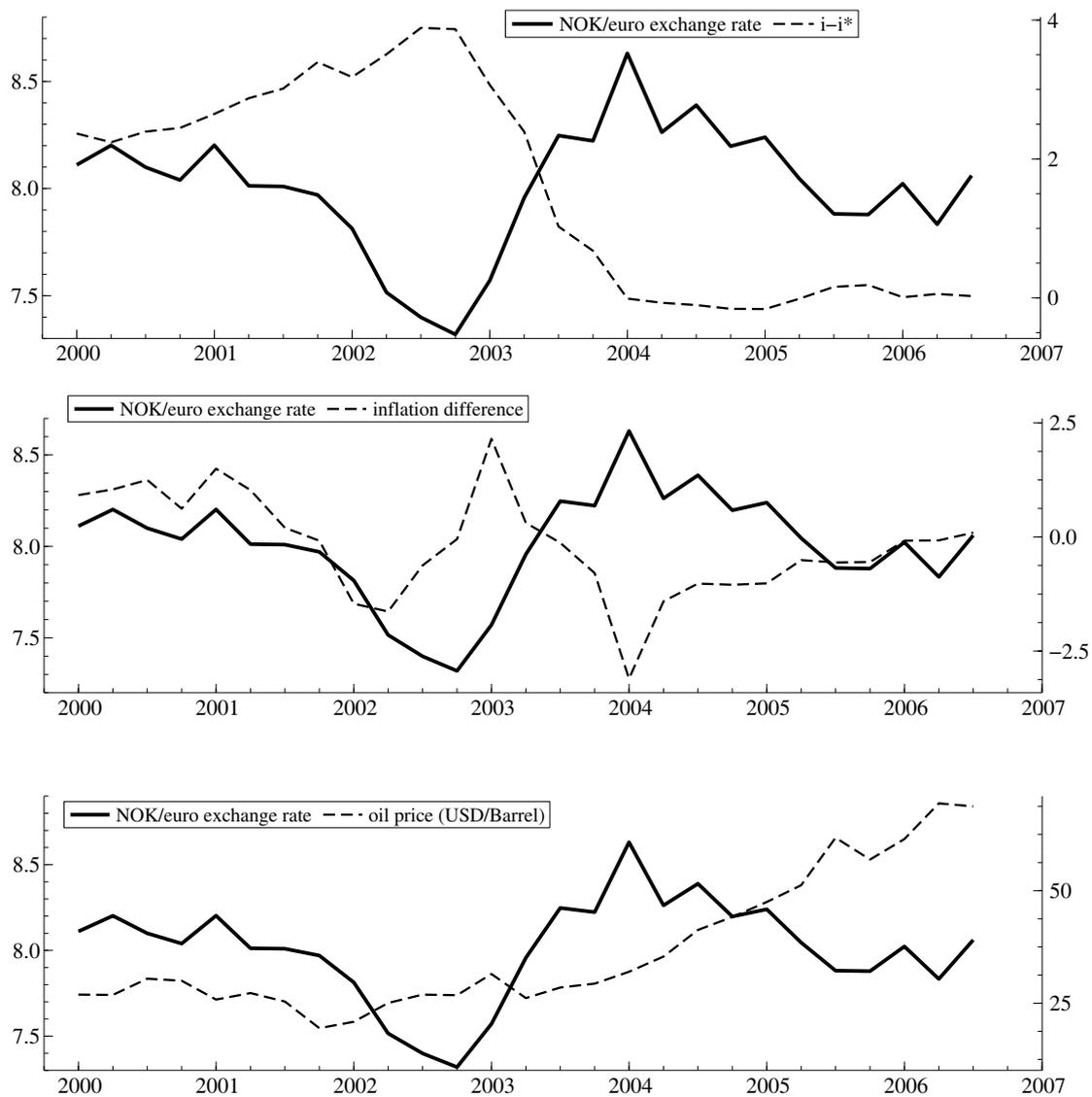


Figure 4: In the upper diagram the NOK/euro exchange rate is plotted against the difference in inflation between Norway and the eurozone, in the middle diagram it is plotted against interest rate, where as the bottom diagram shows the exchange rate vs the price of oil (USD per barrel). All graphs refer to the period 2000q1 -2006q3

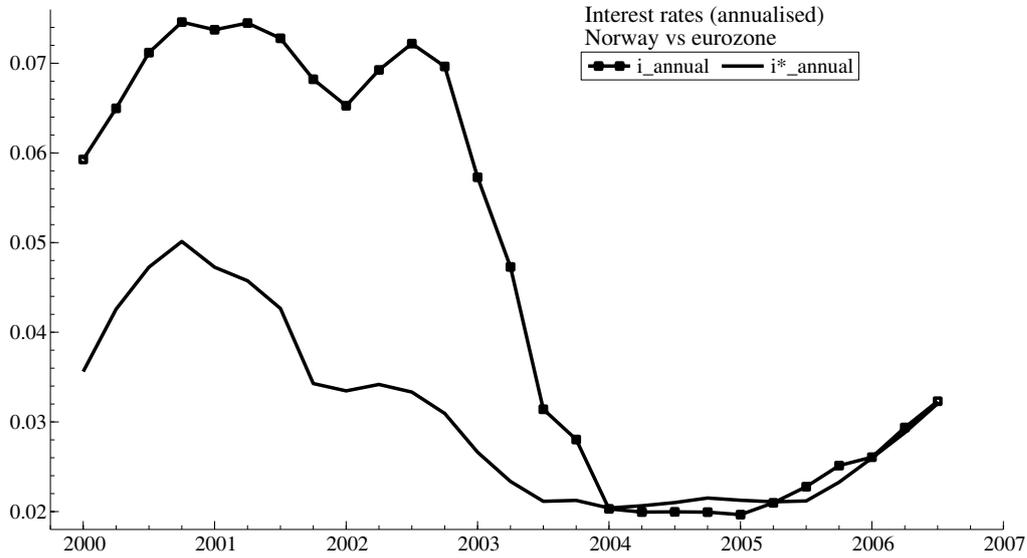


Figure 5: Annualised 3-months interest rates in Norway and in the eurozone, 2000q1 -2006q3

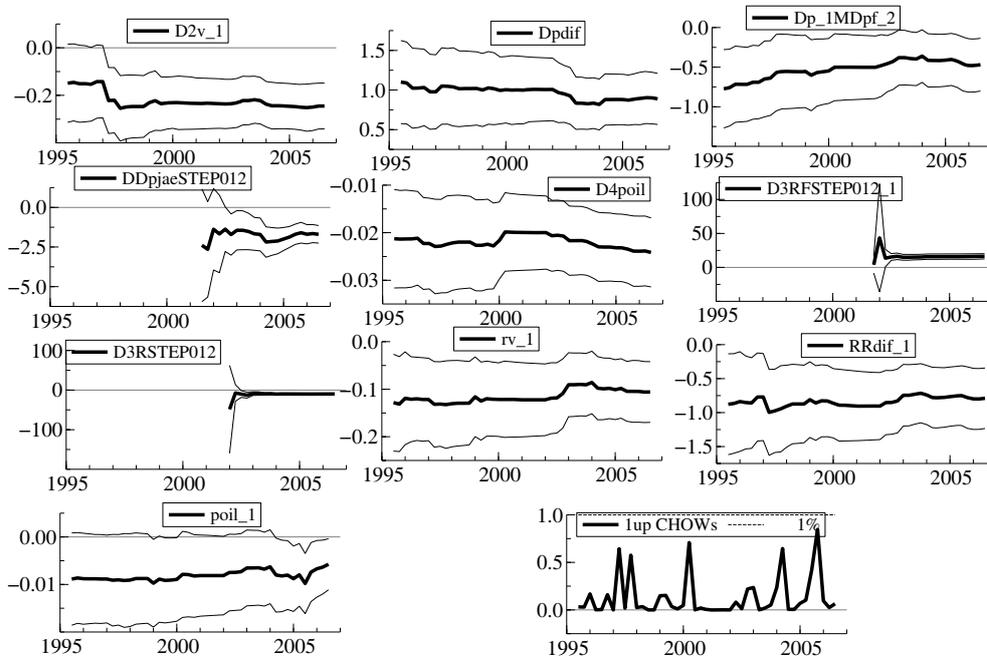


Figure 6: Recursive estimates of the coefficients (plus/minus 2 standard errors) in the preferred exchange rate model for the extended sample 1983q1 -2006q3

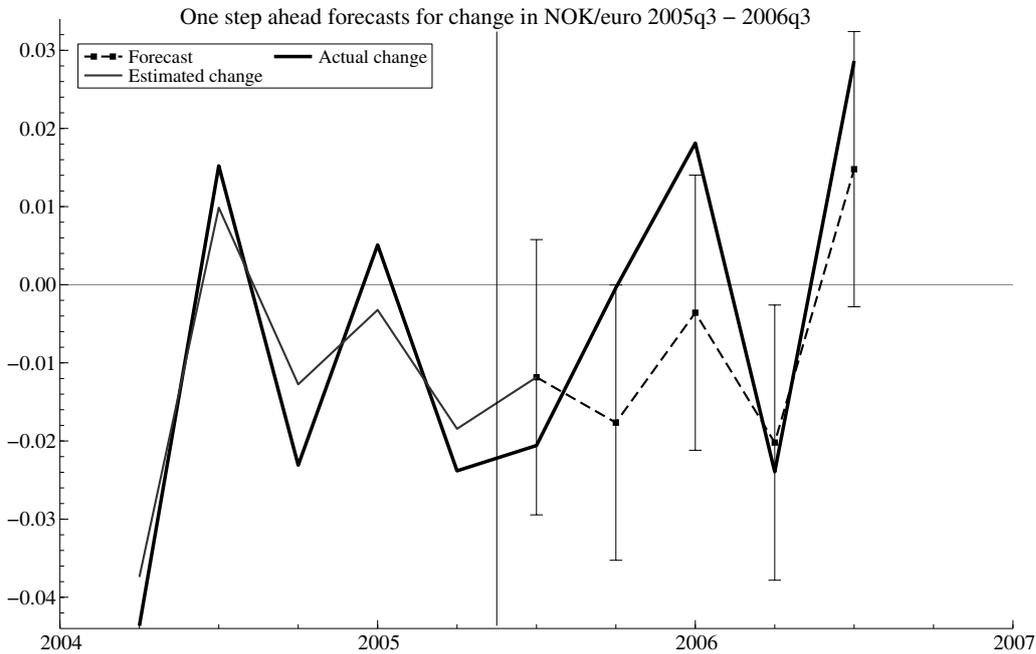


Figure 7: In sample one-step-ahead forecasts for the relative change in the NOK/euro exchange rate 2005q3-2006q3 (the model is estimated on 1983q1-2005q2)

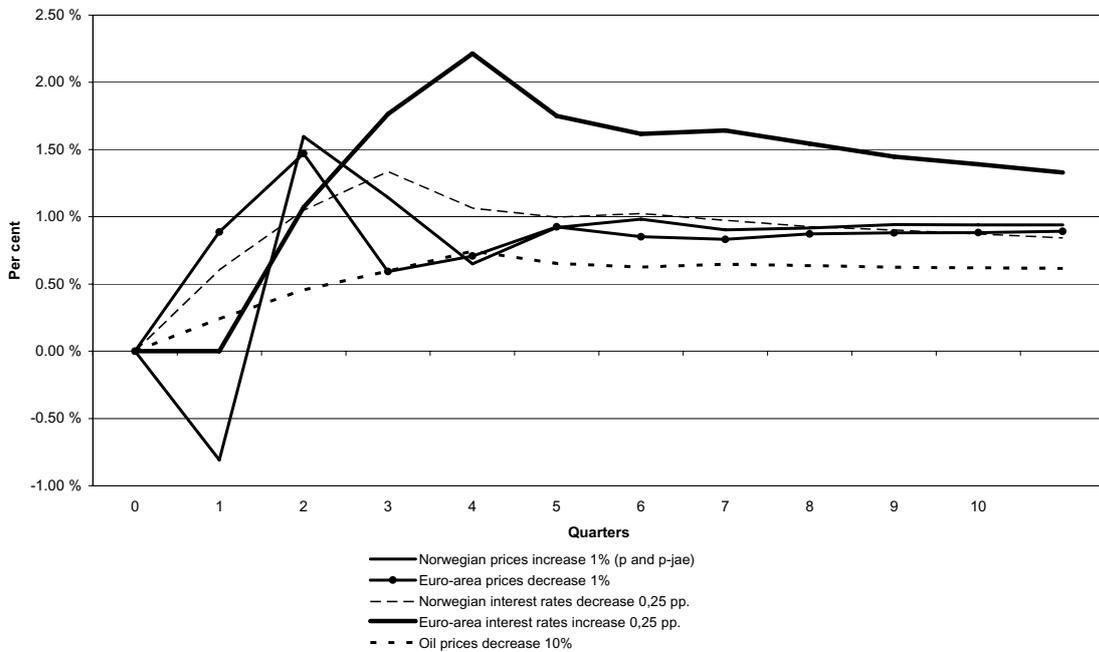


Figure 8: Impulse responses of the nominal exchange rate to permanent changes in price levels and interest rates in Norway and the eurozone and in the price of oil