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Monetary Policy and Exchange Rate Interactions in a Small Open Economy

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Abstract

The transmission mechanisms of monetary policy in a small open economy like Norway are analysed through structural VARs, with special emphasis on the interdependence between monetary policy and exchange rate movements. By imposing a long-run neutrality restriction on the real exchange rate, thereby allowing the interest rate and the exchange rate to react simultaneously to news, I find considerable interdependence between monetary policy and the exchange rate. In particular, following a contractionary monetary policy shock, the real exchange rate immediately appreciates, after which it gradually depreciates back to the baseline. The results are found to be consistent with findings from an "event study".

Keywords: VAR; monetary policy; open economy; identification; event study

JEL classification: *C*32; *E*52; *F*31; *F*41

I. Introduction

An understanding of the transmission mechanism of monetary policy is imperative in order to implement an efficient monetary policy strategy in the many countries that have recently adopted inflation targeting. For a small open economy, the exchange rate plays a central role in relation to monetary policy. It is highly significant in the *formulation* of monetary policy (as an important influence on the overall price level) and, in itself, is also *influenced* by monetary policy. Hence, monetary policy and exchange rate interactions may be substantial in the sense that each variable reacts to news in the other. Furthermore, by adopting inflation targeting, many countries have had to abandon a (long-lasting) regime of fixed exchange rates and switch to one where the exchange rate now floats, thereby effectively losing an anchor for the exchange rate. This may have rendered

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the exchange rate more volatile in response to shocks than previously experienced. Hence, exact knowledge of the exchange rate reaction to monetary policy has become crucial for efficient policy implementation in the inflation-targeting period.

In this paper, I analyse the transmission mechanism of monetary policy in Norway, which is one of the last countries in Europe (so far) to adopt inflation targeting. While research on the monetary transmission mechanism in the euro area has been substantial; very few empirical studies have tried to analyse the effects of monetary policy in the small open economies outside the euro area, with Norway as a compelling example.

Quantitative studies of the monetary transmission mechanism have to a large extent been based on vector autoregressive (VAR) models, initiated by Sims (1980). However, although successful in providing a consensus with regard to the effects of monetary policy in the closed economy, VAR studies of the open economy have posed many puzzles, in particular concerning the effects on the exchange rate. Whereas Dornbusch's (1976) exchange rate overshooting hypothesis predicts an instant exchange rate appreciation in response to a contractionary monetary policy shock, VAR studies have instead found that if the real exchange rate appreciates, it does so for a prolonged period of up to three years, thereby yielding hump-shaped behaviour that violates the uncovered interest parity (UIP) condition.[1]

A major challenge in the VAR literature is how to properly address the problem of simultaneity between monetary policy and the exchange rate. Most of the VAR studies of open economies deal with the simultaneity issue by placing recursive, contemporaneous restrictions on the interaction between monetary policy and exchange rates, thereby restricting monetary policy to react with a lag to news in the exchange rate or vice versa; see e.g. Eichenbaum and Evans (1995), Lindé (2003), Mojon and Peersman (2003), Peersman and Smets (2003) and Favero and Marcellino (2004) among others. However, by not allowing for potential simultaneity effects in the identification of monetary policy shocks, they may have produced a numerically important bias in the estimate of the degree of interdependence. This has been emphasised by Faust and Rogers (2003), who show that the effects on the exchange rate will be very sensitive to the zero short-run restriction imposed on the contemporaneous interaction between monetary policy and the exchange rate.

To allow for simultaneity, I use an alternative identification that restricts the long-run multipliers of the shocks, but leaves the contemporaneous relationship between the interest rate and the exchange rate intact. Identification

[1] This phenomenon has also been referred to as delayed overshooting; see Cushman and Zha (1997).

is achieved by assuming that monetary policy shocks can have no long-run effect on the level of the real exchange rate. In the short run, however, monetary policy is free to influence the exchange rate. Eventually, though, the effect dies out and the real exchange rate returns to its initial level. This is a standard neutrality assumption that holds for a large class of models in the monetary policy literature; see Obstfeld (1985) and Clarida and Galí (1994). Such a restriction has recently been found to be highly successful in alleviating the exchange rate puzzle in several other open economies; see Bjørnland (2006).

After having allowed for a contemporaneous relationship between the interest rate and the exchange rate, the remaining VAR can be identified using standard recursive zero restrictions on the impact matrix of shocks that are commonly used in the closed economy literature, i.e., assuming a lagged response in domestic variables, such as output and inflation, to monetary policy shocks. These restrictions are less controversial. Studies which identify monetary policy without these restrictions have found qualitatively similar results; see e.g. Faust, Swanson and Wright (2004).

To my knowledge, there are no comparable studies of monetary policy in Norway.[2] However, it is only recently that Norway abandoned a regime of targeting the exchange rate and instead adopted inflation targeting. This paper therefore contributes to the literature on how monetary policy can be identified and analysed in a small open economy and establishes some stylised facts on the effects of monetary policy in Norway.

The focus of interest is on the inflation-targeting period. However, uncertainty about the transmission mechanism for a country like Norway, that has just adopted inflation targeting, implies that the experience prior to inflation targeting has to be addressed. Furthermore, the VAR analysis is complemented with results using an "event study", where immediate responses in the exchange rate (as well as in other asset prices such as stock prices) associated with particular policy actions are analysed. I argue that this link between surprise monetary policy actions and initial exchange rate responses should be a feature that properly identified VAR models, at least on impact, should be able to replicate.

I find that a contractionary monetary policy shock has the usual effects identified in other international studies: temporarily increasing the interest rate, while lowering output and consumer-price inflation gradually, thereby also ruling out any price puzzle that has often been found in the literature. On the other hand, contrary to recent findings, I find a substantial effect on the exchange rate which appreciates on impact. The maximal impact occurs almost immediately, after which the real exchange rate gradually

[2] Some studies, however, have tried to estimate interest rate rules for Norway; see e.g. Olsen, Qvigstad and Røisland (2002) and Bernhardsen and Bårdsen (2004).

depreciates back to the baseline, consistent with the Dornbusch overshooting hypothesis and to a large extent with UIP. Furthermore, by complementing the VAR analysis with an event study, I find further support for the hypothesis that asset prices react immediately to news, with exchange rates (as well as stock prices) responding instantaneously to monetary policy shocks.

The paper is organised as follows. The VAR methodology is explained in Section II. Section III reports the empirical results for the baseline model. Section IV focuses on the robustness of the results with respect to the recent inflation-targeting period, using both VAR and event analysis. Section V concludes.

II. The Identified VAR Model

The choice of variables in the VAR reflects the theoretical set-up of a new-Keynesian small open economy model, as in Svensson (2000) and Clarida, Galí and Gertler (2001). In particular, the VAR model comprises the annual changes in the log of the domestic consumer price index (π_t)—referred to hereafter as inflation, the log of real GDP (y_t), the three-month domestic interest rate (i_t), the (trade-weighted) foreign interest rate (i_t^*) and the log of the real exchange rate against a basket of trading partners (e_t); see the Appendix. The nominal interest rate is chosen to capture monetary policy shocks, consistent with the fact that the Central Bank of Norway (Norges Bank) uses interest rate instruments in its monetary policy setting; see Olsen *et al.* (2002). This is in line with Rotemberg and Woodford (1997), who find central bank behaviour to be well modelled by a policy rule that sets the interest rate as a function of variables such as output and inflation.

In this paper I build on the traditional closed economy VAR literature, as in Sims (1980) and Christiano, Eichenbaum and Evans (1999, 2005), among many others, in that a standard recursive structure is identified between macroeconomic variables and monetary policy. This implies that macroeconomic variables such as output and inflation do not react contemporaneously to monetary shocks, whereas the monetary policymaker might respond immediately to macroeconomic news. That monetary policy affects domestic variables with a lag is consistent with the transmission mechanism of monetary policy emphasised in the theoretical set-up in Svensson (1997). Further, Bagliano and Favero (1998) show that when monetary policy shocks are identified in this recursive way on a *single* monetary policy regime, the responses of the shocks suggest a pattern for the monetary transmission mechanism that is consistent with what would be found using financial market information (from outside the VAR), thereby limiting the Rudebusch (1998) critique of structural VARs.[3]

When turning to the open economy, the traditional approach has been to expand the recursive Cholesky decomposition to also include the exchange rate. The exchange rate is usually placed last in the ordering, assuming a lagged response in monetary policy to exchange rate shocks; see Eichenbaum and Evans (1995). However, VARs identified in this way have often produced a significant delayed exchange rate response to monetary policy shocks. To overcome this problem, Kim and Roubini (2000) have suggested that one should allow for contemporaneous interaction between monetary policy and the exchange rate, assuming instead that the monetary policymaker cannot respond contemporaneously to the foreign interest rate. As a result, they observe fewer puzzles in the exchange rates than other studies, although for some countries, a pronounced delay-overshooting puzzle remains.

As motivation, I begin by analysing the effects of a monetary policy shock using a VAR with the five variables introduced above which is identified with (i) Cholesky ordering, assuming first that the exchange rate is ordered after the interest rate, and then that they swap places (reverse order), and (ii) Kim and Roubini identification, that restricts monetary policy from responding contemporaneously to foreign interest rates. Figure 1 displays (left frame) the effect of a contractionary monetary policy shock on the interest rate, the latter normalised to increase by 1 percentage point initially and (right frame) the corresponding effect on the

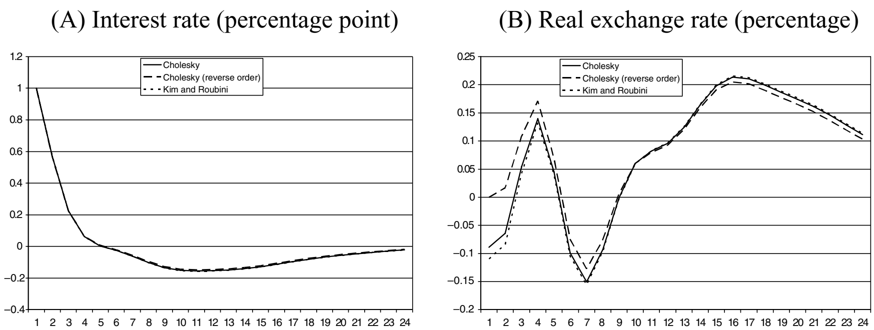

Fig. 1. Response to a monetary policy shock, using the Cholesky and the Kim and Roubini identifying restrictions, quarterly data

[3] Rudebusch (1998) questioned the validity of using structural VARs for monetary policy analysis. He showed that the structural shocks stemming from a recursively identified VAR may not be identical to monetary policy shocks identified outside the VAR.

level of the real exchange rate. Clearly, neither of the identification schemes suggests an exchange rate response in line with Dornbusch overshooting, as the exchange rate shows puzzling cyclical behaviour. Note also that the effect on the exchange rate is negligible, an appreciation of no more than 0.1 percent initially. Hence, by restricting monetary policy from responding immediately to all shocks, I am unable to generate exchange rate responses consistent with conventional beliefs.

Structural Identification

This approach differs from traditional methods, in that I allow monetary policy to react contemporaneously to *all* shocks. Instead I assume that monetary policy shocks are restricted from having long-run effects on the real exchange rate. As already emphasised, this is a standard neutrality assumption that holds for a large class of models in the monetary policy literature. In particular, Clarida and Galí (1994) show that this kind of restriction on the real exchange rate is consistent with a stochastic version of the two-country, rational-expectations open-macro model developed by Obstfeld (1985). The model exhibits the standard Mundell–Fleming–Dornbusch results in the short run when prices react sluggishly, but in the long run, prices adjust fully to monetary policy shocks. Note, however, that although monetary policy shocks are neutral with respect to the exchange rate in the long run, the real exchange rate may still be permanently affected by other demand and supply shocks, thereby allowing for long-run deviations from purchasing power parity (PPP). A feature of persistent deviation from PPP is consistent with the findings of many recent studies of exchange rate determination; see e.g. Rogoff (1996) for a survey and Bjørnland and Hungnes (2006) for an application to Norway.

I first define Z_t as the (5×1) vector of the macroeconomic variables discussed above, $Z_t = [i_t^*, y_t, \pi_t, i_t, \Delta e_t]'$, where all variables but the real exchange rate are specified in levels. Assuming Z_t to be invertible, it can be written in terms of its moving average (ignoring any deterministic terms):

$$Z_t = B(L)v_t, \tag{1}$$

where v_t is a (5×1) vector of reduced-form residuals assumed to be identically and independently distributed, $v_t \sim iid(0, \Omega)$, with positive definite covariance matrix Ω. $B(L)$ is the (5×5) convergent matrix polynomial in the lag operator L, $B(L) = \sum_{j=0}^{\infty} B_j L^j$. Following the literature, the underlying orthogonal structural disturbances (ε_t) are assumed to be written as linear combinations of the innovations (v_t), i.e., $v_t = S\varepsilon_t$. The VAR can then be written in terms of the structural shocks as

$$Z_t = C(L)\varepsilon_t, \tag{2}$$

where $B(L)S = C(L)$. If S is identified, I can derive the MA representation in (2), as $B(L)$ is calculated from a reduced-form estimation. To identify S, the ε_t's are normalised so they all have unit variance. The normalisation of cov(ε_t) implies that $SS' = \Omega$. Under a five-variables system, this imposes 15 restrictions on the elements in S. However, as the S-matrix contains 25 elements, to orthogonalise the different innovations, 10 additional restrictions are needed. With a five-variables VAR, one can identify five structural shocks. The two shocks that are of primary interest are the monetary policy shocks (ε_t^{MP}) and real exchange rate shocks (ε_t^{ER}). I follow standard practice in the VAR literature and only loosely identify the last three shocks as inflation (or cost-push) shocks (moving prices before output) (ε_t^{π}), output shocks (ε_t^{Y}) and foreign interest rate shocks ($\varepsilon_t^{i^*}$). After ordering the vector of structural shocks as $\varepsilon_t = [\varepsilon_t^{i^*}, \varepsilon_t^{Y}, \varepsilon_t^{\pi}, \varepsilon_t^{MP}, \varepsilon_t^{ER}]'$ and following the standard closed economy literature in identifying monetary policy shocks, the recursive order between monetary policy shocks and the (domestic) macroeconomic variables implies the following restriction on the first three rows in the S-matrix:

$$\begin{bmatrix} i^* \\ y \\ \pi \\ i \\ \Delta e \end{bmatrix}_t = B(L) \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} \varepsilon^{i^*} \\ \varepsilon^{Y} \\ \varepsilon^{\pi} \\ \varepsilon^{MP} \\ \varepsilon^{ER} \end{bmatrix}_t . \tag{3}$$

The foreign interest rate is placed at the top of the ordering, while assuming that it will only be affected by exogenous foreign monetary policy contemporaneously, a plausible small country assumption. Furthermore, the standard restrictions in the closed economy (that macroeconomic variables do not simultaneously react to policy variables, while the simultaneous reaction of the macroeconomic environment to policy variables is allowed for) is taken care of by placing output and inflation above the interest rate in the ordering, and by assuming zero restrictions on the relevant coefficients in the S-matrix as described in (3). This provides us with nine contemporaneous restrictions directly on the S-matrix. Note, however, that although the suggested restrictions follow standard assumptions, the responses to the monetary (or exchange rate) shock will be invariant to the ordering of the first three variables (foreign interest rate, output and inflation). This follows from a generalisation of the well-known findings in Christiano *et al.* (1999, Proposition 4.1), stating that when the monetary policy variable (the interest rate) is ordered last in a Cholesky ordering, the responses to the monetary policy shock will be invariant to the ordering of the variables above the interest rate. Instead, the ordering of the variables becomes a computational convenience with no bite. The real bite here is the assumption that the first three variables in the VAR do not respond contemporaneously to a monetary policy shock (or the exchange rate shock).

The matrix is still one restriction short of identification. Since I do not want to restrict monetary policy and the exchange rate from responding contemporaneously to each other (i.e., $S_{54}, S_{45} \neq 0$), I suggest imposing the restriction that a monetary policy shock can have no long-run effects on the real exchange rate which, as discussed above, is a plausible neutrality assumption. This can be found by setting the values of the infinite number of relevant lag coefficients in (2), $\sum_{j=0}^{\infty} C_{54,j}$, equal to zero; see Blanchard and Quah (1989). There are now enough restrictions to identify and orthogonalise all shocks. Writing the long-run expression of $B(L)S = C(L)$ as $B(1)S = C(1)$, where $B(1) = \sum_{j=0}^{\infty} B_j$ and $C(1) = \sum_{j=0}^{\infty} C_j$ indicate the (5×5) long-run matrix of $B(L)$ and $C(L)$, respectively, the long-run restriction $C_{54}(1) = 0$ implies

$$B_{51}(1)S_{14} + B_{52}(1)S_{24} + B_{53}(1)S_{34} + B_{54}(1)S_{44} + B_{55}(1)S_{54} = 0. \quad (4)$$

The system is now just identifiable and the parameters can be identified in two steps. First, using the recursive Cholesky restriction identifies the non-zero parameters above the interest rate equation. Second, the remaining parameters can be uniquely identified using the long-run restriction (4), where $B(1)$ is calculated from the reduced-form estimation prior to (1). Note that (4) reduces to $B_{54}(1)S_{44} + B_{55}(1)S_{54} = 0$, given the zero contemporaneous restrictions.[4]

To sum up, the restrictions allow for contemporaneous interaction between monetary policy and exchange rate dynamics, without having to resort to methods that deviate extensively from the established view of how monetary policy shocks are identified in the closed economy literature.[5]

III. Empirical Results

The model was first estimated using quarterly data from 1993Q1 to 2004Q3. Using an earlier starting period would have made it hard to identify a stable

[4] Alternatively, the interest rate and the exchange rate can swap places. The zero long-run restriction on the real exchange rate will then be $C_{45}(1) = 0$, which together with the contemporaneous restrictions imply $B_{44}(1)S_{54} + B_{54}(1)S_{55} = 0$. This will provide exactly the same results.

[5] To my knowledge, Galí (1992) was the first to combine short- and long-run restrictions to identify money supply shocks. Other papers that combine short- and long-run restrictions to separate nominal and real demand shocks include, among others, Bjørnland (2000) and Alexius and Post (2005). However, none of these papers identifies monetary policy shocks explicitly, as is done here.

monetary policy regime, as the Norwegian krone has been fixed to a series of different currencies: 1978–1990, *vis-à-vis* a trade-weighted currency basket, and 1990–1992, *vis-à-vis* the ECU exchange rate. In some periods, Norges Bank then increased/decreased the interest rate when there was depreciating/appreciating pressure. An increase in the interest rate differential has therefore often coincided with a weaker exchange rate, while an interest rate increase may have prevented the exchange rate from falling even further; see Norges Bank (2000, p. 16).

At the end of 1992, however, the Norwegian krone was floated. Since then, the krone has been under a managed float with monetary policy specified at maintaining a stable krone exchange rate against the ECU exchange rate (and, from 1999, the euro exchange rate), albeit without any fluctuation margins or any obligations for the central bank to intervene in the foreign exchange market. Eventually, in 2001, Norges Bank was given the mandate of targeting inflation. Although adopted relatively late, Norges Bank had for some years already oriented monetary policy instruments to bring price inflation down towards European levels. Olsen *et al*. (2002) argue that with the exception of the brief period 1996/97 to 1998, monetary policy can be described as following close to some kind of Taylor rule from 1993. Hence, I begin by reporting estimates of the baseline model for the period 1993–2004 and then, in Section IV, focus explicitly on the inflation-targeting period.

Consistent with most other related studies, the variables, with the exception of the real exchange rate, are specified in levels. This implies that any potential cointegrating relationship between the variables will be implicitly determined in the model; see Hamilton (1994). Sims, Stock and Watson (1990) also argue in favour of using VAR in levels as a modelling strategy, as one avoids the danger of inconsistency in the parameters caused by imposing incorrect cointegrating restrictions, though at the cost of reducing efficiency.[6] Giordani (2004) argues that when following the theoretical model set up in Svensson (1997) as a data-generating process, rather than including output in levels, one should either include the output gap in the VAR, or the output gap along with the trend level of output. However, as pointed out by Lindé (2003), a practical issue that Giordani does not address is how to compute trend output (thereby also the output gap). I therefore follow Lindé (2003) and include a linear trend in the VAR

[6] In the case of identifiable cointegration relationships, I could have estimated a structural vector error-correction model and provided the asymptotic distribution of the impulse response functions using the methods of Vlaar (2004). However, tests for long-run relationships using the Johansen cointegration tests suggest that the variables are not cointegrated; the trace test for one cointegration vector (the largest eigenvalue) with associated p-value was 66.14 [0.093] (all variables in levels) or 66.26 [0.092] (all variables but the real exchange rate in levels). After having adjusted for degrees of freedom, there is even less evidence of cointegration.

along with output in levels. In that way I try to address this problem by modelling the trend implicit in the VAR. The real exchange rate is clearly non-stationary ($t_{ADF} = -3.089$), and is differenced to obtain stationarity. By applying long-run restrictions to the first-differenced real exchange rate, the effects of monetary policy shocks on the *level* of the exchange rate will eventually sum to zero; see Blanchard and Quah (1989).

In order to account for extreme outliers, three impulse dummies (that take the value 1 in one quarter and 0 otherwise) are included for the following periods: 1997Q1, 1997Q2 and 2002Q2. The dummies represent respectively, a severe appreciation pressure against the Norwegian krone in the first quarter of 1997, subsequent depreciation in the second quarter, and a severe appreciation of the Norwegian krone in 2002 in excess of its fundamentals; see Bjørnland and Hungnes (2006). In addition, I also include a dummy that takes the value 1 in the period 1996Q4–1998Q1, and 0 otherwise. The dummy accounts for the fact that although monetary policy can be described as following a Taylor rule from 1993, from late 1996 to early 1998, deviations from this rule were observed as the exchange rate was also targeted; see Olsen *et al.* (2002). The dummy turns out to be significantly negative in the interest rate equation, implying that the interest rate should have been lower had the rule been followed over the whole period. However, although all the dummies turn out to be significant, removing them from the analysis does not change the main results.

The lag order of the VAR model was determined using the Schwarz and Hannan–Quinn information criteria and the F-forms of likelihood-ratio tests for model reductions. A lag reduction to two lags could be accepted at the 1 percent level by all tests. Using two lags in the VAR, there is no evidence of autocorrelation, heteroscedasticity or non-normality in the model residuals.[7] Chow break tests also suggested stable equations.

Structural Identification Scheme

Figure 2 graphs the impulse responses using the structural model. Frames A–D display the responses in the interest rate, the real exchange rate, GDP and inflation to a monetary policy shock (normalised to increase the interest rate by 1 percentage point in the first quarter). The results are shown with probability bands represented as 0.16 and 0.84 fractiles.[8] The

[7] Vector AR 1–4 test: $F(100, 38) = 2.05$ [0.01]; vector normality test: $\chi^2(10) = 6.35$ [0.78], vector heterogeneity test: $\chi^2(300) = 320.80$ [0.1956]. Additional diagnostic tests can be obtained from the author on request.

[8] This is the Bayesian simulated distribution obtained by Monte Carlo integration with 2,500 replications, using the approach for just-identified systems. The draws were made directly from the posterior distribution of the VAR coefficients, as suggested in Doan (2004).

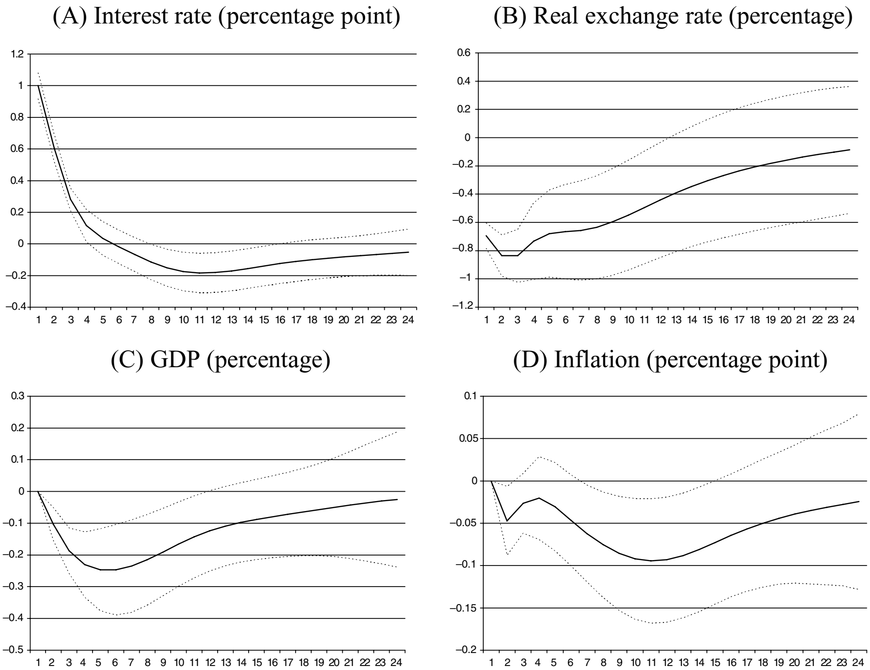

Fig. 2. Response to a monetary policy shock, using the structural VAR, quarterly data
Note: The dotted lines are probability bands.

monetary policy shock increases interest rates temporarily. There is a degree of interest rate inertia in the model, as a monetary policy shock is only offset by a gradual lowering of the interest rate. The nominal interest rate returns to its steady-state value after a year and then goes below steady state. Both the interest rate inertia and the "reversal" of the interest rate stance are consistent with what has come to be regarded as good monetary policy conduct. As Woodford (2003) shows, interest rate inertia is known to let the policymaker smooth the effects of policy over time by affecting private sector expectations.

Turning to the effect on the real exchange rate, there is no evidence of any exchange rate puzzle. Instead, the monetary policy shock has a strong and immediate impact on the real exchange rate, which appreciates (falls) by around 0.8 percent following a 1 percentage point increase in the interest rate. The exchange rate remains appreciated for two quarters, before it gradually depreciates back to the baseline. However, the initial response is large compared to the subsequent appreciation, thereby essentially confirming Dornbusch overshooting.

Consistent with the appreciated exchange rate, output starts to fall gradually and reaches a minimum after a year. Thereafter the effect quickly dies out. Inflation falls slightly at first, but then gradually declines and reaches a minimum after approximately two years. Interestingly, there is no evidence of any price puzzle (where prices actually increase initially) which has commonly been found in the literature; see Eichenbaum (1992).

The effects of the other shocks are as expected (available from the author on request). In particular, an exchange rate shock that depreciates the exchange rate by 10 percent leads to a temporary increase in the interest rate of 10–15 basis points. Note, however, that although the central bank responds to the exchange rate, this is not direct evidence of stabilisation of the exchange rate independent of the less controversial objectives such as inflation and output. More likely, it is the result of the monetary policymaker's reaction to exchange rates due to the monetary policy lag in influencing objectives such as output and inflation, as was evident from Figure 2.

How do these results compare to other studies of monetary policy in Norway? To my knowledge, there are no comparable studies, although some attempts have been made to estimate interest rate reaction functions. Olsen *et al*. (2002) and Bernhardsen and Bårdsen (2004) investigate the relationship between policy rates and macroeconomic variables, using simple interest rate rules such as the Taylor rule. Both find that the interest rate responds significantly to output gap and inflation, although alternative variables like unemployment and wages may do equally well in augmented Taylor rules. Bernhardsen and Bårdsen also examine the role of the exchange rate in a standard Taylor rule. When incorporated into a single-equation framework, the exchange rate turns out to be significant, but with the wrong sign. However, when the Taylor rule is estimated simultaneously with a reaction function for the exchange rate, the coefficients have the right signs. Hence, the simultaneity issue is also important for consistent estimation of parameters in Taylor rules.

Variance decompositions (not reported here but available on request) show that monetary policy shocks (which explain 70 percent of the interest rate variation initially) explain relatively little of the overall variability in each of the model and account for no more than 5 percent of the variation in the real exchange rate, output or inflation. The exchange rate shock (which explains almost 90 percent of the exchange rate variation initially) also explains a modest share of the variance in the other variables. The fact that the real exchange rate is dominated by its own shocks and only weakly affects other macroeconomic variables is commonly found in the literature and referred to as the exchange rate disconnect; see Obstfeld and Rogoff (1995). Several contributions in the new open economy macroeconomics literature have extended the Obstfeld and Rogoff sticky-price general equilibrium model to account for this stylised fact. However, as will be seen below, I find that the interaction between the exchange rate and other macroeconomic variables increases when the focus is on the inflation-target period (see Section IV).

Uncovered Interest Parity (UIP)

After having asserted that exchange rate behaviour is consistent with Dornbusch overshooting in qualitative terms, I now examine whether the subsequent response in the exchange rate is consistent with UIP. If UIP holds following a contractionary monetary policy shock, the fall in the interest rate differential $(i_t^* - i_t)$ will be offset by an expected depreciation of the exchange rate between time t and $t+1$. To explore this issue in more detail, I follow Eichenbaum and Evans (1995) and define ψ_t as the *ex post* difference in return between holding one-period foreign or domestic bonds. Measured in domestic currency, excess return is then given by:

$$\psi_t = i_t^* - i_t + 4(s_{t+1} - s_t), \tag{5}$$

where s_t is the nominal exchange rate and s_{t+1} is the forecasted three-month-ahead exchange rate response.[9] One implication of UIP is that the conditional expectations of the excess return should be zero:

$$E_t \psi_{t+j} = 0 \tag{6}$$

for all $j \geq 0$, where E_t denotes conditional expectations. Figure 3 reports the point estimates (and both one and two standard errors) of the dynamic response function in (6) on the basis of the estimated VARs. Note that since it is the real exchange rate that is included in the VAR, I have to adjust for the effect of monetary policy shocks on prices to obtain the effect on the nominal exchange rate: $s_t = e_t - p_t^* + p_t$.[10]

According to Figure 3, with the exception of the first quarter, the response essentially fluctuates around zero, as is consistent with UIP. The initial deviation from zero follows from the delayed reaction in the exchange rate of one quarter (see Figure 2). Hence, although overall consistent with UIP, the results point in the direction of an initial deviation. This is important information that the policymaker may want to consider when setting the interest rate.

[9] The exchange rate is multiplied by four in order to be annualised, as the interest rate is measured in annual terms.

[10] To be precise, I could only correct for domestic inflation impulses, as foreign prices are not among the endogenous variables in the VAR. This restriction is equivalent to assuming that domestic monetary policy has a negligible effect on foreign prices, which is a common small open economy assumption; see e.g. Dornbusch (1976). Therefore, the excess return calculated will only be correct up to the point that this assumption is warranted.

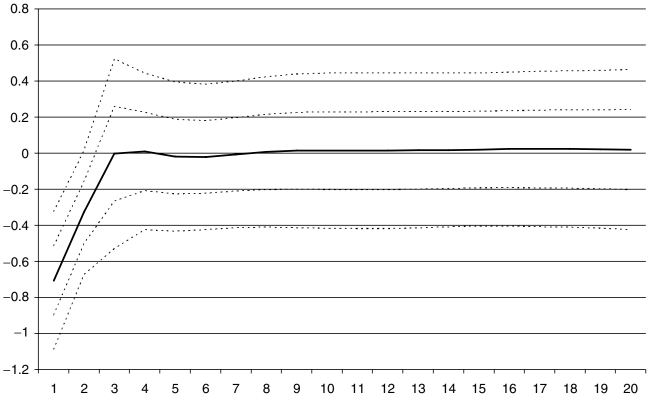

Fig. 3. Excess returns

Robustness: Additional Variables

Leeper, Sims and Zha (1996) and Faust (1998) have criticised the VAR approach for lack of robustness when additional variables are incorporated in the model. Before turning to the recent inflationary period in more detail, I examine the robustness of the above results with respect to omitted variables. In particular, I augmented the baseline structural VAR (sequentially) with the nominal wage, the oil price, money and some foreign variables. I chose the nominal wage because it is an important variable indicating inflation pressure that the central bank may want to respond to when setting the interest rate; see e.g. Olsen *et al.* (2002). Hence, omitting it may lead to biased results. When included in the VAR, the nominal wage is placed after inflation in the ordering, thereby reflecting the fact that nominal wages may be a mark-up on inflation.

Inclusion of the oil price serves multiple purposes. First, it is an asset price that the central bank may want to respond to, as a higher oil price will feed into higher prices via the cost channel. Second, and probably more importantly, Norway is a net oil exporter, where higher oil prices have historically tended to coincide with a higher level of activity in the domestic economy as well as an appreciated exchange rate; see Haldane (1997). Although petroleum income has been regulated since 2001 to be phased into the economy on par with development in expected return on the Government Petroleum Fund, the oil price is still an important asset price that affects the economy in a cyclical way. In the VAR model, the oil price is placed first in the ordering, so as to reflect a plausible small-country assumption as in Bjørnland (2000), while allowing domestic and foreign monetary policy to respond to oil-price shocks.

The introduction of money in to the VAR is motivated by Leeper and Roush (2003), who criticise VAR studies that exclude money on the grounds that it plays no role in the transmission of monetary policy. Instead, they find that the estimated impact of monetary policy on economic activity increases monotonically with the response of money. Here, I follow Eichenbaum and Evans (1995), and place money (M2) right before the interest rate in the VAR ordering, thereby allowing the central bank to also respond to money contemporaneously. For consistency with how I measure inflation, I use annual changes in M2. However, using M2 in levels, a narrower measure of money (M0) or an indicator of credit (K1) yields similar results.

The VAR is finally augmented with foreign variables to investigate any omitted variable bias from excluding foreign (demand and supply) shocks. I include (trade-weighted) foreign GDP and inflation in the VAR. These variables are treated as exogenous because Norway is a small country compared to its trading partners.

Figure 4 graphs the response of the exchange rate to a monetary policy shock using the four augmented VARs. In all frames, the baseline (five variables) structural VAR with a one standard error band is included for comparison. Overall, the response in the exchange rate remains robust to these alterations; it shows an initial appreciation that gradually depreciates back to equilibrium. The main difference emerges when I add money or other foreign variables. In the case of money, the response in the exchange rate is amplified in the first quarters, but then follows the same path of adjustment as the baseline. When adding foreign variables, the initial response is also amplified somewhat, but then the speed of adjustment back to equilibrium is somewhat quicker.

Interestingly, the responses in the other variables (GDP and inflation) remain virtually unchanged to all of these alterations (results available on request). In particular, adding money to the VAR does not magnify the responses in GDP or prices significantly, as was the case in Leeper and Roush (2003). The main reason may be that in contrast to Leeper and Roush, I have already included a forward-looking variable like the exchange rate in the baseline VAR, which plays an important role in the monetary transmission in an open economy. Moreover, I find no evidence of the so-called *liquidity puzzle* commonly found in the literature (where money supply increases following a contractionary monetary policy), as here the money supply falls (temporarily) with the higher interest rate.[11]

[11] Responses to the other shocks are also very much as expected. In particular, an oil-price shock appreciates the real exchange rate and increases output (temporarily) and inflation (gradually). Consistent with the higher level of activity in the oil-producing economy, the interest rate is raised by 10 basis points (after a year) for an initial 10 percent increase in the oil price.

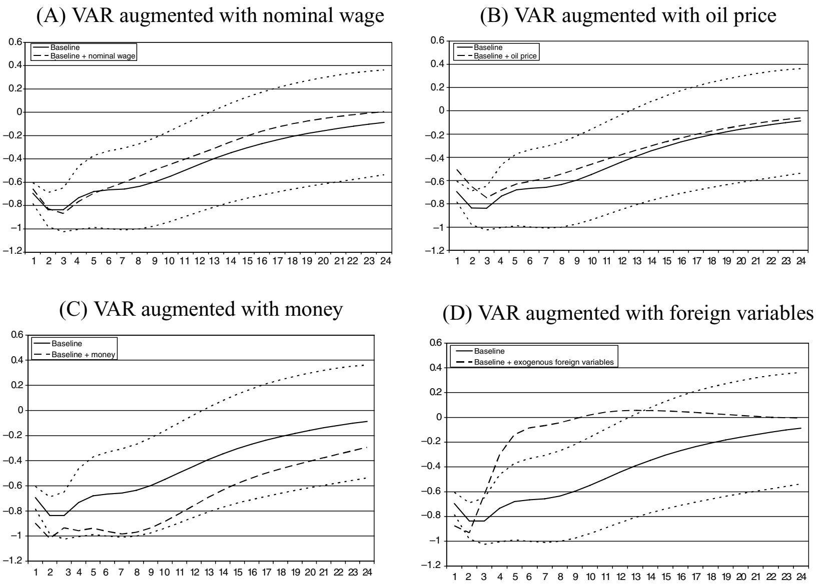

Fig. 4. Robustness: response in the real exchange rate (in percentage) to a monetary policy shock using augmented structural VARs, quarterly data
Note: The dotted lines are probability bands based on the baseline structural VAR (from Figure 2).

IV. The Inflation-targeting Period, 1999–2004

The analysis has so far been conducted for the period 1993–2004, using quarterly data. As of March 2001, however, Norges Bank was given a new mandate of targeting inflation. The operational target of monetary policy was set to be an annual consumer-price inflation of close to 2.5 percent over time. Although officially adopted in 2001, the Central Bank of Norway had already announced in 1999 that the best way to achieve exchange rate stability against the euro was to orient monetary policy instruments towards reducing price inflation in line with the corresponding inflation objective of the European Central Bank; see Gjedrem (1999) and Norges Bank (1999). Hence, for all practical purposes, inflation targeting was introduced in 1999. In the VAR analysis reported below, I therefore examined the monetary transmission mechanism during the recent inflation-targeting period, defined broadly as 1999–2004. Due to the relatively short sample, monthly data were used. This exercise therefore also tests robustness with respect to observational frequency, albeit with a shorter sample.[12] The VAR analysis

[12] Using monthly data for the period 1993–2004 confirms the baseline results, although the magnitude of the response is slightly larger initially. This is not surprising given the noisier characteristics of monthly data.

is also complemented with results using an "event study", where immediate responses in the exchange rate (as well as in other asset prices) associated with particular policy actions are analysed on a daily basis.

Monthly Data in the VAR

The focus now is to examine the transmission mechanism of monetary policy during the recent inflation-targeting period. In particular, I examine whether the results reported above appear to be robust to the institutional change of monetary target, or whether the transmission mechanism has changed in any important way. Note, however, that as GDP is not available at a monthly frequency, the unemployment rate is included instead.

Figure 5A displays the responses to the monetary policy shocks for the unemployment rate and inflation, whereas Figure 5B graphs the results for the real exchange rate.[13] These results confirm in several important ways the transmission mechanism reported above. Following a contractionary monetary policy shock (that increases the interest rate by 1 percentage point in the first month), unemployment increases gradually, until it reaches a maximum after about a year. Throughout this period inflation responds very little, but falls considerably after 13 months. The minimum is reached after 19–23 months.

Consistent with the results reported earlier, the real exchange rate appreciates immediately. However, the initial effect is much larger than in the baseline model, with an immediate adjustment of slightly less than 4 percent. This is not surprising, given that the exchange rate is now floating. However, the exact magnitude of the response may to some extent

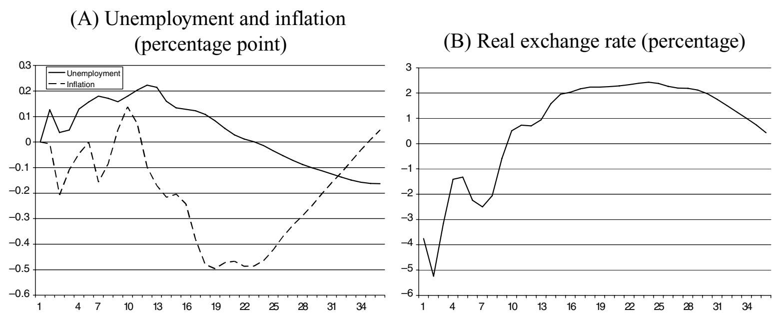

Fig. 5. Response to a monetary policy shock using the structural VAR, monthly data

[13] Consistent with the quarterly baseline model, the VAR was estimated using six lags, a constant, trend and a dummy that takes the value 1 in 2002M5–6. Using six lags, there is no evidence of any residual misspecifications.

reflect the fact that I used monthly data which display relatively more volatility.[14] After 1–2 months, the exchange rate depreciates back to equilibrium as in the baseline scenario. There is, however, some evidence that the exchange rate depreciates by more than the initial appreciation, before the effect eventually dies out. I believe that this pattern stems from the fact that the VAR was estimated over a relatively small sample, characterised by a substantial exchange rate variation.

Overall then, the transmission mechanism to monetary policy shocks in the inflation-targeting period is in line with what I found in the baseline model, i.e., an immediate effect in the exchange rate, followed by a hump-shaped response in the domestic variables. However, the speed of adjustment to shocks is slightly quicker and the impact effect is amplified somewhat.

What is the contribution of monetary policy shocks to overall variability? Variance decompositions for the first four years (see Table 1) emphasise that monetary policy shocks now explain more than 15 percent of the exchange rate variation in the first two months. The effect then quickly dies out. The effect on unemployment is also quite substantial; 20 percent of the unemployment variation is explained by monetary policy shocks after two years. Despite this, the contribution to inflation variability is still quite modest. Hence, the exchange rate volatility with respect to monetary policy has clearly increased in the present inflation-targeting period, but with the overall variance in the variables still explained by shocks other than monetary policy shocks. Meanwhile, the contribution of monetary policy shocks to interest rate variation has declined and explains less than 60 percent of the initial variation, after which it declines quickly. Hence, after the inflation-targeting period was introduced, monetary policy became more systematic, with the interest rate responding more to economic variables and less to unsystematic monetary policy shocks. This is important news for policymakers, as well as for market participants.

Table 1. *Variance decomposition: the contribution of monetary policy shocks*

Months	Interest rate	Real exchange rate	Unemployment	Inflation
1	61	14	0	0
4	22	15	3	1
12	9	6	19	1
24	17	5	21	8
48	15	4	21	9

[14] Results using shorter lag length essentially confirm the above results, although the magnitude of the response is reduced somewhat.

Event Analysis

An alternative (non-VAR) approach to studying the *impact* of monetary policy shocks on the exchange rate is through event studies. These measure the immediate response of the exchange rate to shocks associated with particular policy actions in real time, thereby avoiding the issue of identification altogether. In sharp contrast to the majority of conventional VAR studies, event studies find that a surprise monetary policy shock has a substantial effect on the exchange rate. For instance, Zettelmeyer (2004) and Kearns and Manners (2006) find that a surprise monetary policy shock which increases the interest rate has a significant appreciating effect on the exchange rate. This link between surprise monetary policy actions and initial exchange rate responses is therefore a feature that properly identified VAR models should be able to replicate.

As an alternative to the VAR analysis, I therefore specify an event analysis for the official inflation-targeting period (2001–2004). Following Zettelmeyer (2004). I study the immediate (i.e., same-day) response of the exchange rate to specific monetary policy actions. Since it is the unanticipated content of these policy actions that is of interest, I measured the reaction of the three-month interest rate. The choice of the three-month interest rate as the policy measure reflects the fact that it is sufficiently "short" to reflect the policy targets, but still "long" enough to react only to the extent that changes in the policy rate were unanticipated. Hence, the following regression was specified:

$$\Delta s_t = \alpha + \beta \Delta i_{3m,t} + \varepsilon_t, \tag{7}$$

where $\Delta i_{3m,t}$ is the change in the three-month interest rate on the day of the policy announcement and Δs_t is the change in the nominal exchange rate the same day.[15] I chose the nominal rather than the real exchange rate in this analysis, as prices rarely change on a daily basis. However, if relative prices change over the sample, there may be some differences when using nominal than real exchange rates. To account for this, I also included a constant to capture any trend depreciation, although it generally turned out to be insignificant.

[15] Ideally, one would measure the same-day responses. However, decisions on interest rate changes are announced in the afternoon at 2pm, whereas the daily observations of the three-month interest rate (NIBOR) and the exchange rates are reported at 12am and 2:15pm, respectively. Hence, all the adjustment in the interest rate and almost all the adjustment in the exchange rate would be observed to take place on the day following the interest rate decisions. Hence, for both variables, I had to study changes in the interest rate on the day succeeding the monetary policy announcement. However, for the exchange rate, I also had to include the adjustment for the policy day, since some of the adjustment would be observed to take place from 2pm to 2:15pm on that day.

Table 2. *Coefficient estimates on the response in the euro/NOK exchange rate from event study, t-value in parentheses*

	Announcement followed by a change in target rate		All announcements
	OLS	IV	OLS
β	−1.77	−3.41	−1.37
t-Statistic	(−1.02)	(−0.99)	(−2.42)

Note that the regression of (7) would only result in unbiased estimates of the impact effect of monetary policy shocks if there were no other shocks that affect market interest rates on the same day.[16] To deal with the problem that interest rates may also reflect other shocks that happened to coincide with monetary policy actions, i.e., news about interest rates abroad, I could control for such shocks directly. This would be possible only to the extent that these shocks are observable and measurable. Instead, I therefore followed a more straightforward approach proposed by Zettelmeyer (2004) and used the underlying change in the monetary policy target as an instrument in regression (7). This instrument is correlated with the change in the three-month interest rate on the day of the policy announcement. If the policy action is not endogenous to same-day economic news, then it will also be uncorrelated with any noise that might affect the interest rate on the day of the announcement.

Table 2 reports the coefficient on β using equation (7) for the daily change in the euro/NOK exchange rate following a change in the three-month interest rate on the day of a policy decision for the period 2001–2004. There were 34 interest rate meetings during this period. However, only 12 of them resulted in an announcement of a change in the interest rate. Since this is a fairly short sample, I investigated the response to announcements of interest rate changes as well as to all announcements, as the latter may be a surprise to the market, either due to a lack of response from the central bank when one was expected or because the announcement gave strong indications of future policy changes.

Table 2 emphasises that, in all cases, a surprise monetary policy shock will lead to an immediate appreciation of the exchange rate. The exchange rate response lies in the interval of 1.5 to 3 percent for each percentage point

[16] Unbiased estimates also require that monetary policy actions not be endogenous to exchange rate movements or other news that also affected exchange rates on the day of the policy announcement. However, the short sample used here makes it easy to establish that these conditions are satisfied. In particular, there are no indications that the policy may have reacted to contemporaneous exchange rate movements by, for instance, intervening in the foreign exchange market on the day of the policy announcement.

Table 3. *Coefficient estimates on response in the OSEBX from event study, t-value in parentheses*

	Announcement followed by a change in target rate	
	OLS	IV
β	−5.45	−6.64
t-Statistic	(−5.57)	(−3.34)

change in the interest rate, which is in line with the results reported above. However, unless the whole sample is used, the effect is not significant. Given the few observations available, this is not very surprising.

Finally, if the monetary policy announcement is a true surprise to the market, then one should expect all asset prices to react to the news immediately. This has been demonstrated by, among others, Bernanke and Kuttner (2004) and Rigobon and Sack (2004) using event-type studies, and Bjørnland and Leitemo (2008) using VARs; stock prices in the U.S. were found to fall significantly following a surprise increase in the target rate. For comparison, I therefore also examined the responses in stock prices (sp_t) on the Oslo Stock Exchange (OSEBX) to the surprise interest rate decisions. Table 3 reports the coefficient on β using equation (7) for the daily change in the OSEBX, with sp_t replacing s_t in equation (7). The stock price reacted significantly and as expected to the monetary policy announcements; it fell by 5–6 percent for each percentage point increase in the interest rate. This then confirms a simultaneous asset price reaction to monetary policy shocks.

V. Concluding Remarks

In this paper, the effects of monetary policy in an open economy are analysed through structural VARs, with particular emphasis on a possible interdependence between the monetary policy stance and exchange rate movements. I explicitly account for the interdependence between monetary policy and exchange rates by imposing a combination of short-run and long-run restrictions. In particular, I build on the traditional VAR literature in that I identify recursively a standard structure comprised of macroeconomic variables and monetary policy, so that monetary policy can react to all shocks, but the macroeconomic variables react with a lag to monetary policy shocks. However, this approach differs from the traditional method in that I also allow monetary policy to respond contemporaneously to the exchange rate, which in itself is allowed to react simultaneously to all shocks. In order to identify and orthogonalise all shocks, I assume instead that monetary policy shocks can have no long-run effects on real exchange rates, which is a standard neutrality assumption.

After having allowed for full simultaneity between monetary policy and the exchange rate, I find that a monetary policy shock now implies a strong and immediate appreciation of the exchange rate. Thereafter, the exchange rate gradually depreciates back to the baseline, as is consistent with the Dornbusch overshooting hypothesis and broadly consistent with UIP.

With regard to the other variables, the monetary policy shock temporarily lowers output (while increasing unemployment) and has a sluggish but negative effect on consumer price inflation. However, there is no evidence of the so-called price puzzle, which is commonly found in the literature. When compared to previous periods, the exchange rate volatility with respect to monetary policy shocks increased in the current inflation-targeting period, while the contribution of monetary policy shocks to interest rate variation declined. The increase in exchange rate volatility is not surprising given that Norway no longer has a (long-run) anchor for the exchange rate. On the other hand, by making monetary policy more transparent, more of the interest rate variance can now be explained by fundamental variables, and less by unsystematic monetary policy. This is important news to policymakers, as well as to market participants.

Finally, by complementing the VAR analysis with an event study for the inflation-target period, I find further support for the fact that exchange rates, as well as other asset prices (especially stock prices), react immediately to news. In particular, exchange rates and stock prices fall by approximately 2 and 5 percent, respectively, for each 1 percentage point increase in the interest rate. It is reassuring that the results found using the VAR analysis are consistent with the findings from event studies.

Appendix Data

Unless indicated otherwise, the source is Norges Bank, Oslo.

- (i^*) The three months' foreign effective interest rate calculated as a trade-weighted sum of the interest rate of Norway's four largest trading partners (USA, EUR, SWE, GBR), quarterly and monthly data.
- (i) The three months' domestic effective nominal interest rate (NIBOR), quarterly, monthly and daily data.
- (y) Gross domestic product mainland Norway, s.a. and noise adjusted, quarterly data.
- (p) Consumer price index domestic sources, s.a. The domestic consumer price index is adjusted for changes in energy prices and taxes, quarterly and monthly data.
- (e) Real exchange rate, quarterly and monthly data.
- (s) Euro exchange rate against the Norwegian krone; NOK, daily data.
- (nw) Wage costs per hour, mainland Norway, s.a., quarterly data.

(*op*) Oil price, nominal oil price of Brent Blend in USD, monthly average of daily spot prices, quarterly data. *Source*: Telerate.

(*u*) Unemployment rate, registered unemployment rate, s.a., monthly data. *Source*: Aetat, the Norwegian Public Employment Service.

(*sp*) Oslo Stock Exchange share index (OSEBX), daily data. *Source*: Oslo Stock Exchange.

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