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by

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A SMALL, CALIBRATED MACROMODEL TO SUPPORT INFLATION TARGETING AT NORGES BANK*

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November 2, 2004

Abstract

This note outlines a small, calibrated macromodel that can be used to support inflation targeting at Norges Bank. The model provides a stylised representation of the key flows in the macro economy, with a particular emphasis on the transmission mechanism of monetary policy. It can be viewed as the minimal model necessary to explain the nexus of output, interest rates, exchange rates and inflation, with a framework for the way monetary policy influences the real economy and inflation. The model should be viewed mainly as a pedagogical device and as a pilot model for subsequent model development at Norges Bank.

*The usual disclaimer applies. The views expressed in this note are those of the authors and not necessarily those of Norges Bank.

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1 Introduction

Since March 2001 Norges Bank's conduct of monetary policy has been oriented towards low and stable inflation. The operational target of monetary policy is annual consumer price inflation of approximately 2.5 per cent over time.

Inflation-targeting central banks must take into account that monetary policy influences the economy with long and variable lags. Norges Bank sets the interest rate with a view to stabilising inflation at the target within a reasonable time horizon, normally 1-3 years. The precise horizon will depend on the disturbances to which the economy is exposed, and how they are expected to affect the future path for inflation and the real economy. Norges Bank operates a flexible inflation targeting regime, taking into consideration both variability in output and employment, and variability in inflation.

This note outlines a small, calibrated macroeconomic model that can be used as a tool to support inflation targeting: for medium-term projections, policy and risk analysis, and communication. It is a quarterly model and provides a stylised representation of the key flows in the macro economy, with a particular emphasis on the transmission mechanisms of monetary policy. It can be viewed as the smallest model necessary to explain the nexus of output, interest rates, exchange rates and inflation, with a framework for the way monetary policy works to influence the real economy and inflation. We have started out with a small model and a simplified framework because we want the model to be simple and clear in its description of these things. This way it can provide a clear focus for debate. The model abstracts from the detailed, multiple-lag dynamics that are typically needed to describe quarterly macroeconomic time series. Thus, we do not expect it to forecast well over the short run. The model provides, however, **an organisational framework** for the forecast or projections exercise, and a **consistent story about how the short-term economic situation will evolve over the medium to long term**. While it gives a rough starting point for the medium term projections, the model is best seen as just one of many tools in the forecasting and analysis process. Our published baseline projections are based on all relevant information about the economy and on all our knowledge about how the economy works. There will always be special factors that the model cannot capture. However, it is a useful consistence check to examine what judgement is required for the model to reproduce the baseline projection. The model can then be used to study major risks and uncertainties around the projections.[1]

Section 2 provides a broad overview of the main design features and the structure of the model, and of the channels through which monetary policy works. Section 3 contains a more detailed description of the model, while section 4 discusses the calibration process. Section 5 illustrates model properties by looking at impulse responses from shocks. Section 6 offers some concluding remarks.

2 A broad description of the model (a bird's eye view)

The main design features of the model are as follows:

- The model has been **designed from a top-down perspective**, focusing on its aggregate **system properties**.

- The model has been **calibrated** rather than relying solely on econometric estimates. Calibration draws on theory and a wide range of empirical estimates to choose parameter values for the model that result in sensible aggregate properties. The Bank's macroeconomic analysis is based on specific views regarding the transmission mechanism. The model is calibrated with the aim of reflecting these views.

- **Expectations play an explicit role** in the model. With an inflation target for monetary policy, expectations of future inflation are of major importance as they will affect price- and wage-setting behaviour today. The formation of expectations is unfortunately a topic on which it is difficult to gather evidence. We are very uncertain about them, but they are crucial, so it is preferable to be explicit about assumptions and build them into the model so that the implications of alternative assumptions can be explored.

[1] A more detailed description of the forecasting and analysis process will soon be published as a Norges Bank Staff Memo.

- There is a **clear role for monetary policy** in the model. The target rate of inflation will not be produced automatically. The fundamental role of monetary policy in an inflation targeting regime is to provide the economy with a nominal anchor, i.e. an anchor for inflation and inflation expectations. Low and stable inflation will, in turn, provide a basis for stable developments in output and employment. If monetary policy is credible, future inflation will be expected to be equal or close to the inflation target. A credible monetary policy therefore contributes to stabilising inflation around the target and to stabilising the real economy. If, on the other hand, the monetary authority is seen as not committed to the inflation target, inflation expectations can become entrenched at a different level than the inflation target or become unanchored, which makes achieving the inflation target much more difficult. This, in turn, will have unfavourable implications for the real economy.

- Solution paths converge to **a well-defined steady state** (when the monetary authority fulfill its role). In our communications we convey a paradigm: that there are rigidities in the short run, that supply factors determine production in the long run, and that inflation in the long run is a monetary phenomenon. The model is in line with this paradigm. The monetary authorities cannot, in the long run, increase output beyond its potential level; there are no "free lunches".

- The model is a version of what has been called **a "gaps" model**, which aims to explain the dynamics of disequilibrium paths and how the "gaps", or deviations from equilibrium values, develop and dissipate over the medium to long term. The model has, however, nothing to say about the levels of equilibrium itself. The model user has to provide the model with equilibrium values for the real interest rate, the real exchange rate and potential output. These equlibriums have to be estimated and forecasted outside the model.

The model is highly aggregated and consists of just four "behavioural" equations :

1) An IS or aggregate demand equation for an open economy that expresses the dynamic relationship between real output, the real interest rate, the real exchange rate and world output;

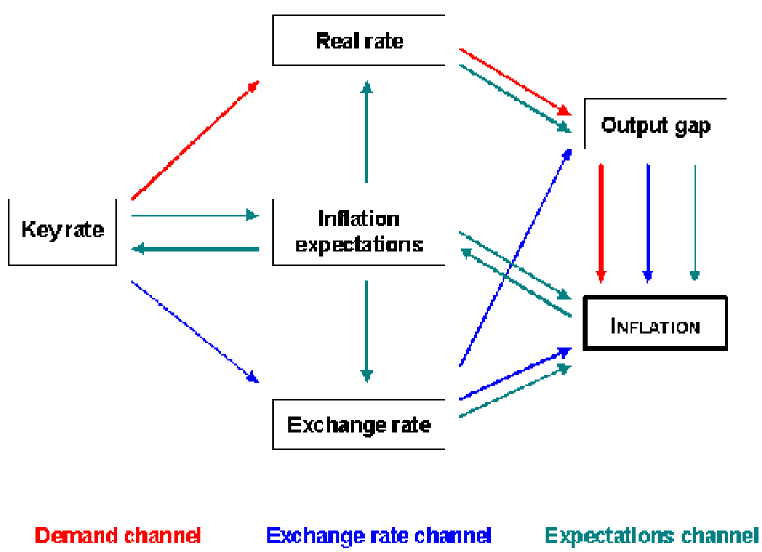
2) An aggregate supply (Phillips Curve) or price-setting equation characterising the dynamic response of inflation to inflation expectations, the output gap (i.e. output relative to potential) and the real exchange rate;

3) An uncovered interest parity (UIP) equation expressing the dynamic relationship between the exchange rate and the spread between domestic and foreign interest rates;

4) A monetary policy rule, describing how the monetary authority sets interest rates in order to balance the short run trade off between stabilising inflation around target and stabilising developments in the real economy.

Interest rate changes affect the real economy and inflation with long and variable lags. In addition, the effect will vary in strength. Figure 1 illustrates the effects of a change in the key policy rate (nominal interest rate) in the model. Broadly, we can discriminate between three main channels:

Figure 1. The transmission mechanism



The demand channel

The red arrows illustrate the traditional demand channel of monetary policy. A change in the key policy rate (nominal) also changes the real interest rate due to nominal rigidities. An increase in the real interest rate has a negative direct effect on output, since higher rates discourage expenditure. Lower demand pressures and output, in turn, have a negative impact on price inflation. This effect can work both through lower wage inflation and downward pressure on profit margins (not modelled explicitly).

The exchange rate channel

The blue arrows illustrate the exchange rate channel. Higher nominal interest rates relative to abroad cause the currency to appreciate, all else equal. This has both a direct and an indirect effect on inflation. When the currency appreciates, imported goods become cheaper and inflation at home falls (direct effect). But a stronger krone also has a negative effect on demand and output. First, lower inflation from the direct effect raises real interest rates and dampens demand. Second, we can think of both an expenditure switching effect (a stronger krone shifts demand away from goods produced domestically towards imported goods), and an effect via reduced competitiveness for industries that compete with firms internationally. Lower demand and output reduces price inflation, as discussed above.

The expectations channel

The green arrows illustrate the inflation expectations channel, which plays a important role. Inflation expectations influence wage demands and firms pricing decisions. The real interest rate depends on inflation expectations. It is difficult to be certain about how expectations are generated. Confidence in the inflation target may provide an anchor. Past inflation rates may also influence what we think inflation will be in the future. There is thus an interaction between inflation expectations and actual inflation. If monetary policy is credible, inflation will be expected to be equal to or close to the inflation target. This in itself contributes to stabilising inflation around the target. The expectations channel thus amplifies the effects of monetary policy.

3 The model

The main equations of the model can be written as:

Definitions

$$\pi_t = p_t - p_{t-4} \tag{1}$$

$$i3m_t = i_t + risk_{i3m} \tag{2}$$

$$r3m_t = i3m_t - E_t\pi_{t+1} \tag{3}$$

$$r12m_t = \frac{\sum_{i=0}^{3} E_t r3m_{t+i}}{4} \tag{4}$$

$$r36m_t = \frac{\sum_{i=0}^{11} E_t r3m_{t+i}}{12} \tag{5}$$

$$q_t = s_t + p^f - p \tag{6}$$

$$y_t = y_t^* + ygap/100 \tag{7}$$

"Behavioural"

$$\begin{aligned} ygap_t \;=\;& \delta_0 ygap_{t-1} \\ &+\delta_1 \left[\psi_1(i3m_{t-1} - i^*) + \psi_2(r12m_{t-1} - r^*) + (1 - \psi_1 - \psi_2)\left(r36m_{t-1} - r^*\right)\right] \\ &+\delta_2 \left(q_{t-1} - q^*\right) + \delta_3 ygap_{t-1}^f + \varepsilon_y \end{aligned} \tag{8}$$

$$\begin{aligned} \pi_t \;=\;& \alpha_0\pi_{t-1} + \alpha_1\pi^* + (1 - \alpha_0 - \alpha_1)E_t\pi_{t+4} \\ &+\alpha_2 ygap_{t-1} + \alpha_3\Delta ygap_{t-1} + \alpha_4 \sum_{i=2}^{5} \beta_i \Delta q_{t-i} + \varepsilon_\pi \end{aligned} \tag{9}$$

$$s_t = E_t s_{t+1} - \left(i3m_t - i3m_t^f\right) + \varepsilon_s \tag{10}$$

$$\begin{aligned} i_t \;=\;& \rho_0 i_{t-1} \\ &+ (1 - \rho_0)\left[r^* + E_t\frac{\sum_{i=5}^{8} \pi_{t+i}}{4} + \rho_1 \left(E_t\frac{\sum_{i=5}^{8} \pi_{t+i}}{4} - \pi^*\right) + \rho_2 ygap_t\right] + \varepsilon_i \end{aligned} \tag{11}$$

This system includes eleven equations and an equal number of endogenous variables: output (y), the output gap ($ygap$), consumer prices (p), inflation (π), the nominal exchange rate (s), the real exchange rate (q), the key policy rate (i), the nominal 3 month interest rate ($i3m$), the real 3 month interest rate ($r3m$), the real 1 year interest rate ($r12m$) and the real 3 year interest rate ($r36m$). The model also contains exogenous variables and shocks. The exogenous variables are potential output (y^*); equilibrium values for the real exchange rate (q^*) and the real interest rate (r^*); the inflation target (π^*); a risk premium on short-term nominal interest rates ($risk_{i3m}$); and foreign variables, such as the output gap $\left(ygap^f\right)$, consumer prices $\left(p^f\right)$ and the nominal short-term interest rate $\left(i3m^f\right)$ among our trading partners. The exogenous shocks are shocks to aggregate demand (ε_y) and inflation (ε_π), a risk premium shock (ε_s) and a monetary policy shock (ε_i).

Equations 1 to 7 are definitions. In equation 1, p_t is the log of CPI-ATE (consumer prices adjusted for taxes and energy) in period t (the periodicity is quarters), and π_t is the year-on-year rate of inflation in per cent in period t. Equation 2 defines a link between the key policy rate (i_t) and the 3 month money market rate ($i3m_t$). Equation 3 defines the real short-term interest rate in period t ($r3m_t$) as the difference between the nominal 3 month interest rate in period t ($i3m_t$) minus expected inflation in period t+1, where E_t is the mathematical expectations operator. This reflects the assumption of rational, or model-consistent, expectations, conditional on all (model) information up until period t. Equation 4 and 5 defines the 1-year/3-year real interest rate as the average of expected short-term real interest rates over the next 4/12 quarters, respectively. Equation 6 defines the log of the real exchange rate (q). s is the log of the nominal trade-weighted exchange rate, and p^f is the log of consumer prices among our trading partners. A lower q (s) implies an appreciation of the real (nominal) exchange rate. In equation 7, y is the log of real GDP Mainland Norway, y^* is the log of potential output, and $ygap$ is the output gap. The scaling converts the gap units to per cent (of potential output).

Equations 8 to 11 describe the core macroeconomic system. These equations are not identities, but behavioural equations (albeit at a high level). It is appropriate to think of these equations as quasi-reduced-form descriptions of the macroeconomy, not as literal descriptions of agent behaviour, i.e. the model is not derived explicitly from optimising agents. Rather, we have taken a pragmatic approach to model design. Still, the model has a considerable theoretical content. Both in the academic literature and in central banks around the world, many small models have been developed that in spirit are the same as the one described in this note, starting from the classic small-scale open-economy model by Dornbusch (1976). A distinguishing feature of this model is its fairly simple specification of price-setting behaviour, where inflation is assumed to be proportional to an excess demand term. More sophisticated price and wage-setting specifications for closed economies can be found in Taylor (1980) and Fuhrer and Moore (1995); the more recent of these models also allow for inflation persistence. More recent simple open-economy models in the same class include Svensson (1998), Ball (1999), Batini and Haldane (1999) and Leitemo and Røisland (2002).

Equation 8 corresponds to the aggregate demand equation in the basic structure outlined in Section 2. Interest rates have a negative direct effect on output ($\delta_1 < 0$), since higher rates discourage expenditure. Modern theory argues that expectations about the future are important when consumption, saving and investment decisions are being made. These decisions are made intertemporally. In line with this, the output gap responds not only to current interest rates, but also to future expected interest rates. Monetary policy can thereby affect output today by affecting expectations about future interest rates. We have chosen to model this expectations channel explicitly as a weighted average of the previous period's nominal short-term interest rate, the 1 year real interest rate and 3 year real interest rates (all expressed as deviations from equilibrium, where r^* is the equilibrium real interest rate and $i^* = r^* + \pi^*$ is the corresponding equilibrium nominal interest rate). A weight on the nominal short-term interest rate in equation 8 can be rationalised by credit rationed or rule-of-thumb consumers.

Output in equation 8 also depends on the real exchange rate gap and foreign output gap. An appreciation of the real exchange rate (i.e. a decrease in q) produces a decline in output ($\delta_2 > 0$), because it reduces the attractiveness of exports to foreign purchasers, while making imports less costly for domestic purchasers. A fall in output abroad also lowers output at home ($\delta_3 > 0$). These effects are in line with standard textbook theory. Output today also depends on its lagged value (with coefficient $0 < \delta_0 \leq 1$). The theoretical rationale for such an effect could be habit formation in consumption, and adjustment costs and time-to-build effects in investment. The disturbance term (ε_y) can be interpreted as an exogenous demand shock, picking up non-modelled effects (government purchases, shock to preferences etc.)

Equation 9 is an open-economy aggregate supply equation. It can be interpreted as an expectations-augmented Phillips Curve, or a variant of the new Keynesian Phillips Curve that assumes that the pricing of goods sold domestically takes place through some sort of staggered contracts, or that there are adjustment costs related to changing prices. According to equation 9, inflation depends on both its own lagged and expected value, in addition to (possibly) the inflation target. An important feature of equation 9 is the homogeneity restriction on the parameters for inflation, i.e. the coefficients on inflation on the right-hand side of equation 9 sum to unity. This specification implies a vertical long-run Phillips curve. There is no long-run trade-off between output and inflation in this model. The influence of excess demand is captured through the one-quarter-lagged value of the output gap. The specification also allows for a possible speed limit effect through the inclusion of the lagged change in the output gap.[2] In addition to these domestic effects, lagged real exchange rate changes appear in the equation with a positive sign ($\alpha_3 > 0$). This captures the direct effect on inflation from changes in the exchange rate and foreign prices. The disturbance term ε_π represents shocks to inflation from all other sources.

Equation 10 is the uncovered interest parity (UIP) condition: higher interest rates today relative to abroad will tend to produce an exchange rate appreciation today, leading to an expected depreciation in the future. In essence, the UIP condition is an arbitrage condition that says that investors will act to equalize expected rates of return on investments in different currencies, allowing for any country-specific risk premiums. The disturbance term ε_s in equation 10 can be interpreted as an exogenous risk premium on NOK.

The model is closed by a monetary policy rule (equation 11). This can take various forms. For example, monetary policy could be assumed to follow a rule similar to that set out in Taylor (1993), where the nominal interest rate

[2] There are at least two reasons for building in such an effect. First, inflation can start to pick up even if the output gap is negative, if the output gap is closing fast. Second, given that estimates of the level of the output gap are uncertain, having the change in the output gap (which is less sensitive to assumptions) in the Phillips Curve make the forecasts for inflation somewhat more robust.

is set each period in response to a weighted combination of the deviation of inflation from target and of output from potential. It could also be specified in terms of a loss function. To approximate the idea of targeting a forecast of inflation, in this version of the model, policy responds to the averaged expected inflation five to eight quarters ahead[3] as well as to the current output gap. The interest rate rule also includes a weight on lagged interest rates. This can be viewed as interest rate smoothing. In the steady state, nominal interest rates equals to the equilibrium real interest rate (r^*) plus the expected rate of inflation.

4 Calibration

To match the properties of the model to the Norwegian economy, we have to complete it with specific parameter values. The calibration has been based on economic theory and available empirical evidence. An overriding concern and constraint is to ensure that the model has a dynamically stable solution. The focus has been on the properties of the simultaneous system of equations as a whole. We have had a particular emphasis on the transmission mechanism of monetary policy. The calibration process has not been based on any formal methods.

The calibrated parameters chosen must be seen as a starting point, and not as representing any fixed view. We have tried to choose parameter values that give responses in line with the official view on the transmission mechanism, as this has been presented to the public. The box in Inflation Report 4/00 and later refinements regarding the pass-through from exchange rate changes to prices (Inflation Report 1/04), which were based on empirical evidence, have been key guides. We have also compared our model to an estimated structural VAR model. However, available empirical evidence is by no means conclusive. Judgement must, in the end, be imposed. We will comment more on this below.

[3] One should not presume that because only the expected rate of inflation five to eight quarters ahead is considered explicitly that this is the only horizon that matters. Since the model is forward looking in several other aspects, the entire future path of inflation matters for interest rates today.

Table 1 shows the parameters chosen for the aggregate demand equation (equation 8) and the aggregate supply equation (equation 9).

Table 1. Calibrated parameters

Aggregate demand ($ygap$)
$\delta_0 = 0.9$ (lagged output gap)
$\delta_1 = -0.15$ (interest rate effect)
$\psi_1 = \frac{1}{3}$ (weight on short nominal rate)
$\psi_2 = \frac{1}{3}$ (weight on 1 year real rate)
$\delta_2 = 0.03$ (real exchange rate)
$\delta_3 = 0.1$ (foreign output gap)
Aggregate supply (π)
$\alpha_0 = 0.6$ (weight on lagged inflation)
$\alpha_1 = 0.05$ (weight on inflation target)
$\alpha_2 = 0.07$ (output gap)
$\alpha_3 = 0.1$ (change in output gap)
$\alpha_4 = 0.15$ (change in real exchange rate)
$\beta_2 = 0.2, \beta_3 = 0.2, \beta_4 = 0.3, \beta_5 = 0.3$

In the baseline calibration of the model, the aggregate demand equation has a coefficient of $\delta_0 = 0.9$ on lagged output. The high parameter value on the lag ensures a fairly slow-moving output gap, in line with our estimates. The coefficient on the real interest rate, δ_1, was calibrated to -0.15. The weights attached to the short nominal rate, the 1 year real rate and the 3 year real rate were each set to $\frac{1}{3}$. Together, these assumptions produce a relationship between interest rates and output broadly in line with empirical evidence for the Norwegian economy. The implied real interest rate elasticity is also comparable to the evidence found for the UK. The elasticity of output with respect to the real exchange rate, δ_2, was set to 0.03, implying a MCI-relation between the real exchange rate and the real interest rate of 1:5 (that is, a one per cent change in the real interest rate has the same effect on output as a 5 per cent appreciation of the real exchange rate). The elasticity of output with respect to foreign output was set to 0.1. This implies that a good 30% of a sustained output gap abroad will be reflected in the domestic output gap after 4 quarters (all else equal). After 8 quarters, the effect will be slightly over 50%.

On the supply side, α_0 has been set equal to 0.6, implying a fairly high degree of inflation persistence. In the baseline calibration we have also attached a weight α_1 of 0.05 on the inflation target (implying that the forward looking term has a weight of 0.35). The weight on the inflation target can be viewed as a credibility effect.[4] The impact of the output gap on inflation, α_2, was set at 0.07. In addition we have calibrated an effect from the change in the output gap ($\alpha_2 = 0.1$). The calibration of the Phillips curve implies a much weaker effect from output to inflation than what is built into the new macromodel of the Bank of England, but more in line with evidence found for Norway.[5] Finally, we have set the overall coefficient on the effect from lagged real exchange rate changes to inflation, α_3, to 0.15. Combined with a lag structure of 4 lags, this specification matches the model properties to recent empirical research on the pass-through from exchange rates to prices.

Calibration of the monetary policy rule (equation 11) normally comes from studying model properties. If, for example, the parameter on the difference between the forecast of inflation and the target rate is set very high, monetary policy is extremely aggressive in responding to shocks. The economy may be hit very hard and inflation may overshoot, with secondary cycling as a result. On the other hand, too little response may imply unrealistically long adjustment periods. For the simulations presented in Section 5 later on, we have chosen parameter values that imply that the inflation target is approached within 3 years for most types of shocks (including a change in the inflation target). The parameterisation and specification of the policy rule is, however, an active area of research and discussion.

A key objective in the calibration process has been to match the impulses of different shocks in the model to the published view on the transmission mechanism and available empirical evidence for Norway. Figure 2a show the effects on output of a change in nominal interest rates of 1 per cent lasting for 2 years in the model compared with Norges Bank's view as stated in

[4] Having a small weight on the inflation target does not mean that the inflation target will be reached automatically, but it will make the job for the monetary authority easier (see more on this in section 5).

[5] We have compared the result of a monetary policy shock in Model 1a to what the Bank of England has built into its new macromodel BEQM (documentation available on request). While the response from interest rates to output is about the same, the inflation response is about 3 times as high in BEQM than in our model. This illustrates that by international standards, the output-inflation link in our model is on the weak side.

IR 4/00. The results presented in IR 4/00 were based on avilable empirical evidence at the time, various assumptions on the effect from interest rate changes to exchange rate changes, and on judgement. The results cannot be compared one to one, since the model described in this note is forward looking and has a monetary policy rule that kicks in after 2 years in this experiment. Nevertheless, we see from figure 2a that the initial effect on the real economy is fairly similar to the effects presented in the box in IR 4/00. However, output bottoms at a higher level and returns somewhat faster towards the control level after the two year shock. This is partly because once monetary policy is allowed to respond after 8 quarters, the short-term nominal interest rate is reduced under the control level to restore equilibrium. In the experiment in IR 4/00, the nominal interest rate was exogenous and simply returned to control after 8 quarters. In addition, the agents are forward looking in the model and see up front that the monetary authority will have to loosen policy considerably after 8 quarters to restore equilibrium. This dampens the effect of the shock compared to a case where the agents are purely backward looking.

To illustrate the effect of forward looking agents and that the length of the monetary policy shock matter, also in the short run, Figure 2b shows the effects on output when holding interest rates 1 per cent away from control for 4, 8, 12 and 16 quarters, respectively. We see that if the agents believe that interest rates will be held away from control for 16 quarters, the effects on output the first 8 quarters is fairly similar to the view presented in IR 4/00.

The effect on inflation from the interest rate shock lasting for eight quarters is well inside the uncertainty band presented in IR 4/00, see Figure 2c. Given the effect on output, it is fair to say that the link between output and inflation seems somewhat stronger in the model than what was presented in IR 4/00. It is not, however, easy to compare the results from such a persistent shock one to one. This has to do with the forward-looking nature of the model and how inflation expectations become successively more entrenched away from target the longer interest rates stay away from the model solution. This amplifies the effect on inflation, as pointed out in section 2.

Figure 3 compares the "isolated" effect on inflation of a 5 per cent appreciation of the krone lasting for 2 years (then back to control) in Model 1a versus the views presented in Inflation report 1/04. By the "isolated" effect, we mean that we have forced the interest rate and the output gap to stay constant for 4 years. We see from Figure 3 that the model matches the latest empirical evidence on pass-through from exchange rate changes to inflation pretty well.

We have also compared the calibration to a structural VAR-model (SVAR-model). The SVAR is estimated on quarterly data from 1993 to 2003 and contains five variables: output, short-term interest rates, the trade-weighted exchange rate, core inflation and wage inflation (2 lags of each variable). Figures 4a-d compare the impulse responses from the SVAR to those from the model under a monetary policy shock. Interest rates are shocked one percentage point for 1 quarter and are endogenous thereafter. In this exercise, we have calibrated the monetary policy rule in the model such that the interest rate path is as close as possible to the one coming out of the SVAR; see Figure 4a. Figure 4b shows that the exchange rate responses are small and fairly similar. We are able to match the dynamics of the output response from the SVAR well (see Figure 4c). Output bottoms at a higher level, though, compared to the SVAR model. This may again reflect the forward-lookingness as discussed above. Figure 4d shows the effect on inflation. Given the differences in output responses, figure 4d indicates a fairly similar link between output and inflation in our model and the SVAR.

5 Properties of the model

A good way to communicate the properties of a model is to examine how key variables respond to specific shocks. The shocks are considered one at a time, and they are of brief duration. We start from a baseline solution of the model in equilibrium. In reality, shocks do not arrive one at a time, and they do not arrive when everything is in equilibrium. To study model properties, however, it is helpful to keep things as simple as possible and look at one issue at a time.

5.1 Changes to the inflation target

In this experiment, the authorities decide to lower the target rate of inflation by one percentage point, from 2.5 per cent to 1.5 per cent. We start with inflation at the 2.5 per cent target and then introduce a new target, one percentage point lower (see the solid lines in Figures 5a-d).

To lower inflation permanently by one percentage point, the monetary authority must shift inflation expectations down. To do so, it increases nominal short-term interest rates. This also serves to increase the real interest rate and thereby lower aggregate demand. Further, the increase in interest rates causes the exchange rate to appreciate. This also contributes to lower demand. A negative output gap gradually opens up. The lags and inertia in the system imply that the initial effect on output is small, but this gradually builds so that after 8 quarters the output gap bottoms at about -1 per cent.

The combined effect of the appreciation and the negative output gap works to gradually pull down inflation and, consequently, inflation expectations. There is considerable inertia in the inflation rate, however. It takes around 2 years to get the bulk of the reduction and about 3 years to approach the new target.

After three quarters, the monetary authority begins to lower the key policy rate. This reduction of rates is necessary to prevent inflation from decelerating more than one percentage point below its previous level. Measured by the real interest rate, monetary policy is approximately neutral again after 4 years. Note that since this shock is a purely nominal shock, and since the model is super-neutral, there is no change to any real equilibriums. In the end, when a new equilibrium is in place, all nominal variables are lowered by 1 percentage point. The output gap is closed, as is the real exchange rate gap.

The sacrifice ratio is an often used measure of the cumulative effects of the disinflation on the level of output. In this model, the sacrice ratio is around $2\frac{3}{4}$, that is, it takes a cumulative loss of output of close to 3 per cent of one year's potential output to lower inflation by a percentage point. This number is somewhat higher than those seen in other models of industrial economies.

The size of the sacrifice ratio is determined by the Phillips curve. The stronger is the link between output and inflation, the lower the sacrifice ratio. The more credible monetary policy is, or the more forward looking the agents are, the lower is the sacrifice ratio. To illustrate the effect of credibility, the broken lines in Figures 5a-d shows the effects of the inflation target shock in a version of the model where the weight on the inflation target in the Phillips curve is instead placed on the lagged inflation term (everything else unchanged). We now see that the monetary authority must work harder to reduce inflation permanently, with a bigger cost to the real economy as a result. The sacrifice ratio is raised by $\frac{3}{4} - 1$ percentage point compared to the baseline calibration.

5.2 A shock to aggregate demand

In the next example, we study the effect of an autonomous positive shock to aggregate demand lasting for eight quarters (see Figures 6a-d). Under the assumption that the central bank knows immediately that the shock has occurred, and reacts promptly, the shock raises the output gap by 1 per cent after two years. The shock puts upward pressure on inflation. The job of the central bank is to counter the inflation pressure by raising nominal interest rates by more than the increase in inflation, in order to raise the real interest rate. Together with an appreciaton of the currency, this curbs demand. Eventually, a small negative output gap opens up. This will put downward pressure on inflation, as will a stronger krone. When the central bank knows the shock and reacts immediately, inflation is never allowed to raise much, see Figure 6d.

We have also studied the effects of a delayed policy response. Let us assume that the central bank is not aware of the shock and delays the response by two years. Short term rates are fixed at the control level for eight quarters. For the sake of argument, we have also fixed the nominal exchange rate at the control level for eight quarters.[6] In this case, without the immediate policy

[6] As the agents in the foreign exchange market are forward looking, they see that the central bank will have to react sooner or later to the shock. Therefore, the exchange rate will appreciate immediately. We have assumed that the agents in the foreign exchange market have the same information as the central bank, and nothing happens with the exchange rate before the central bank reacts to the shock.

response, there is much more build-up in inflation and inflation pressures. Therefore, the central bank has to do more when it finally responds. The resulting cycles are more pronounced. The longer the central banks delays its response, the more inflation pressure will build up and the more pronounced will be the cycles.

5.3 A shock to prices

In this shock, we suppose there is a negative shock to prices that lasts for four quarters and brings inflation down by $1\frac{1}{2}$ percentage point (see Figures 7a-d). We assume that the central bank knows about the shock immediately and responds without delay. In this example, the central bank cuts rates by close to 4 percentage points (in steps due to interest rate smoothing), and then begins to move rates back towards the control level. The currency depreciates as a negative interest rate differential vis-a-vis our trading partners opens up. Deflation pressures are curbed by both a weaker currency and the fact that a positive output gap builds up. As monetary policy is relaxed, the output gap closes and inflation approaches the target.

6 Concluding remarks

There are clear advantages with a small model like that outlined in this note that focuses on the central mechanisms of inflation. However, it contains very few variables and shocks, and is insufficient to address many of the issues and questions that arise in a central bank. The model therefore has to be viewed mainly as a pedagogical device and as a pilot model for subsequent model development at Norges Bank. That said, no model, no matter how complex, can describe "the truth" or forecast the future perfectly (even in the absence of unanticipated shocks). All models are simplifications and abstract from details that we know matter at some level for understanding what is going on in the economy. The assumptions and simplifications in the model presented here are extremely heroic in this respect. Nevertheless, we believe the model can be useful for our purposes. A properly-designed model, albeit simple, that captures the salient features of the economy can be a useful tool to support inflation targeting.

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Figure 2a

Effects on **output** of 1 percentage point increase in interest rates for 8 quarters. Per cent.

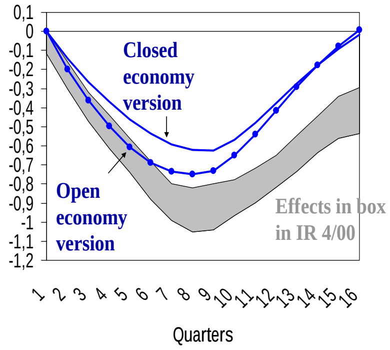


Figure 2b

Effects on **inflation** of 1 percentage point increase in interest rates for 8 quarters. Percentage points

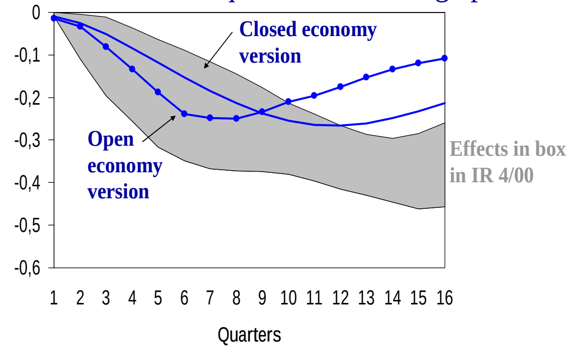
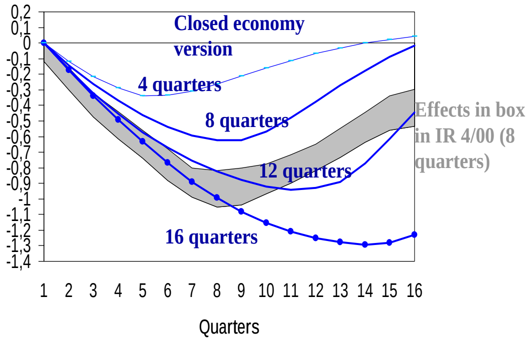


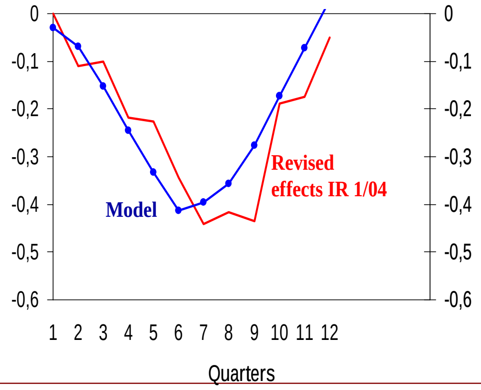
Figure 2c

Effects on **output** of 1 percentage point increase in interest rates for x quarters. Per cent.



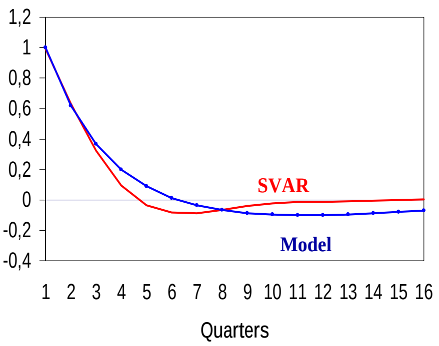
Norges Bank Monetary Policy

Figure 3
Isolated effect on inflation of a 5 per cent appreciation of the nominal effective exchange rate lasting for **two years**



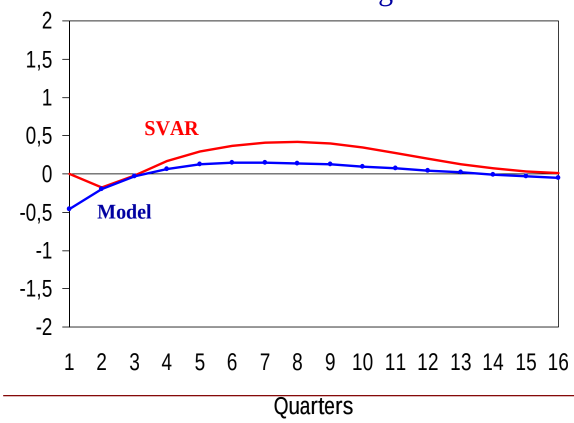
Norges Bank Monetary Policy

Figure 4a
Nominal interest rate



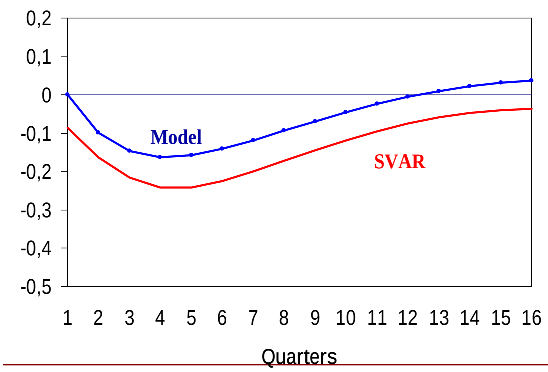
Norges Bank Monetary Policy

Figure 4b
Nominal exchange rate



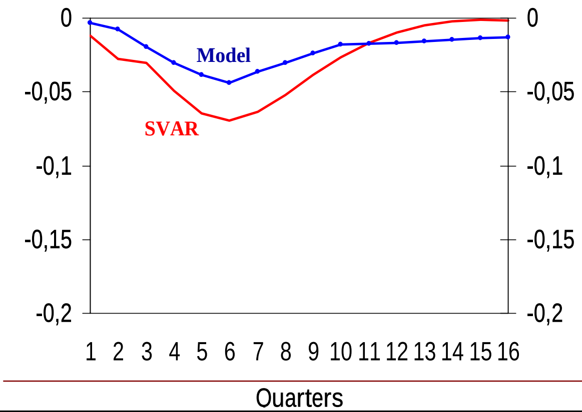
Norges Bank Monetary Policy

Figure 4c
Outputgap



Norges Bank Monetary Policy

Figure 4d
Inflation



Inflation target shock

Figures 5a-d

Figure 5a
Short-term interest rates

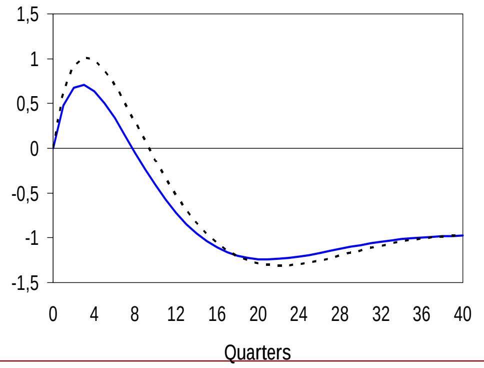


Figure 5b
Inflation

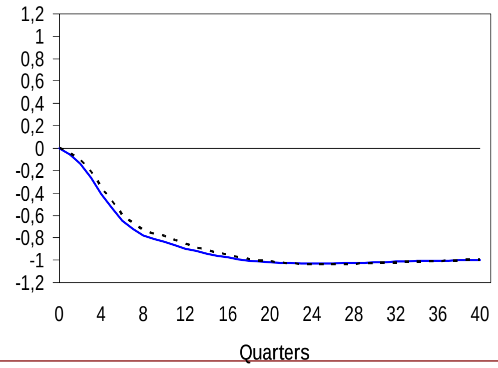


Figure 5c
Real exchange rate

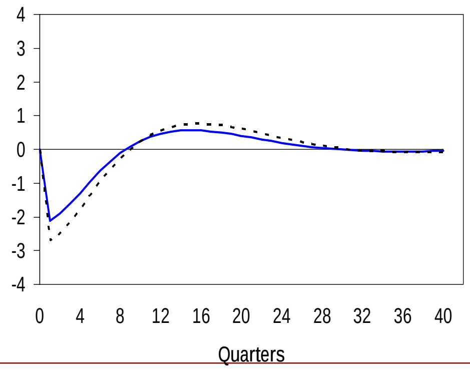
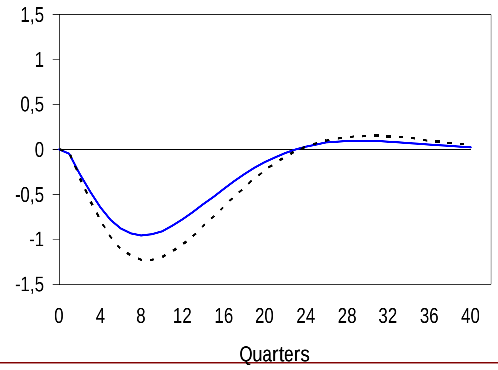


Figure 5d
Output gap



Demand shock

Figures 6a-d

Figure 6a
Nominal interest rates

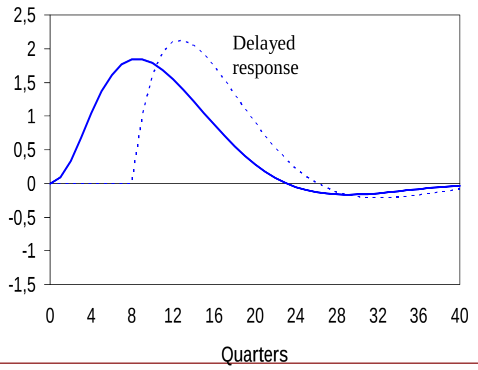


Figure 6b
Inflation

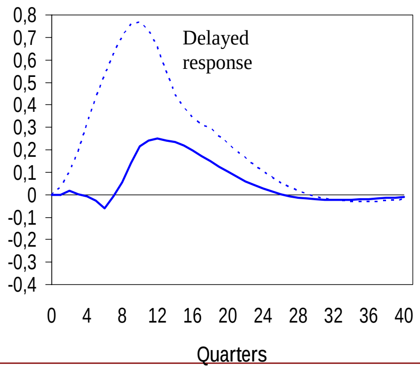


Figure 6c
Real exchange rate

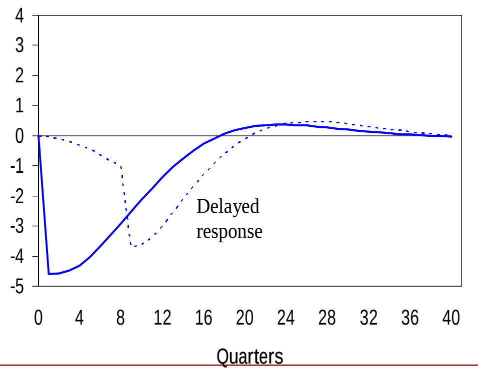
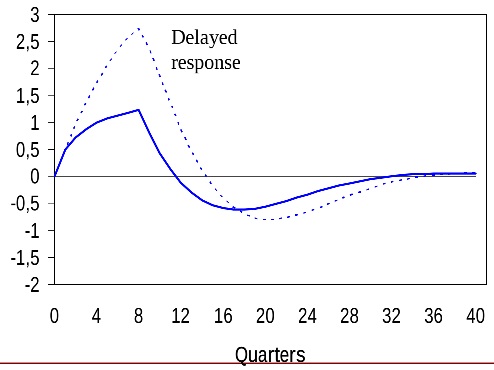


Figure 6d
Output gap

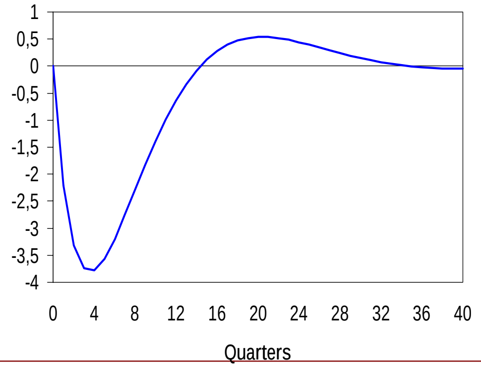


Inflation shock

Figures 7a-d

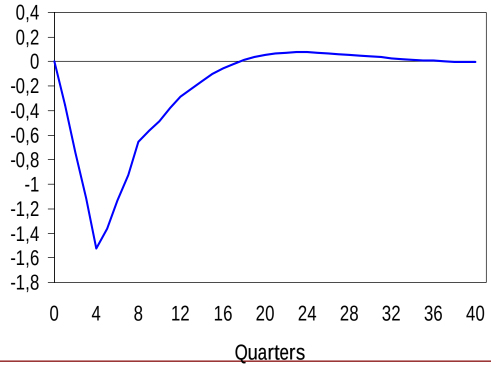
Norges Bank Monetary Policy

Figure 7a
Nominal interest rates



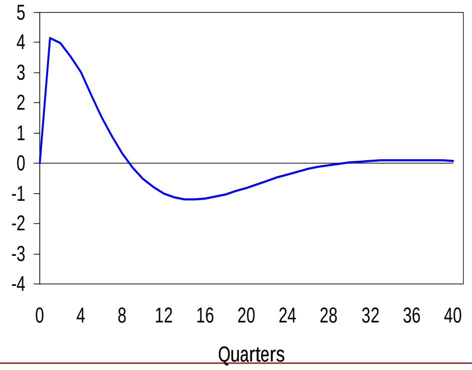
Norges Bank Monetary Policy

Figure 7b
Inflation



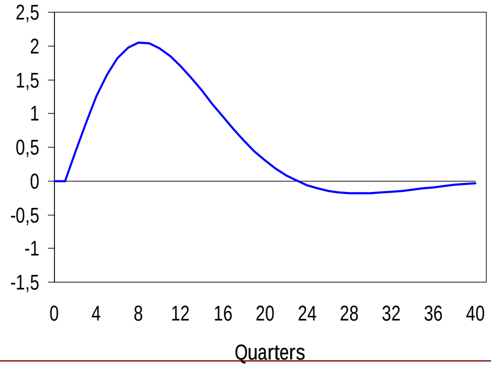
Norges Bank Monetary Policy

Figure 7c
Real exchange rate



Norges Bank Monetary Policy

Figure 7d
Output gap



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