NEMO – a new macro model for forecasting and monetary policy analysis

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Macroeconomic models are among the tools used to analyse the Norwegian economy and monetary policy. This article describes NEMO, a new macroeconomic model that has been developed by Norges Bank. NEMO plays a key role in designing the interest rate path. In addition to looking at how the model is constructed and quantified and how it works, we focus on why the model was chosen and the properties required. Finally, we provide examples of how the model may be used.

1. Introduction

NEMO ("Norwegian Economy Model") is Norges Bank's new forecasting and monetary policy analysis model.[1] The model is based on international research and model development over the past 10–15 years and has many features in common with similar models in other central banks.[2] NEMO has been under development since autumn 2004 and has been used previously to analyse specific developments in the Norwegian economy.

NEMO is based on the assumption that Norway with a national currency can determine its own inflation level over time. Therefore, a model requirement is that monetary policy anchors inflation expectations. This means that monetary policy is decisive in bringing inflation back to target. In the model, it is assumed that economic agents, such as households and firms, look ahead when making decisions concerning consumption, investment, wages and prices and base these decisions not only on today's economic policy but also on their expectations concerning future policy. In addition, the model builds on the experience of the 1970s and 1980s which indicated that unemployment could not be reduced permanently by accepting higher inflation. Because of price and wage stickiness, monetary policy can still influence demand and hence output and employment in the short and medium term.

Various agents' behaviour is modelled explicitly in NEMO, based on microeconomic theory. A consistent theoretical framework makes it easier to interpret relationships and mechanisms in the model in the light of economic theory. One advantage is that we can analyse the economic effects of changes of a more structural nature. In NEMO, developments in the Norwegian economy can be explained by changes in firms' technology, competitive conditions in product and labour markets, by household preferences between consumption and leisure, and by monetary policy. The structural framework makes it possible to provide a consistent and detailed economic rationale for Norges Bank's projections for the Norwegian economy. This distinguishes NEMO from purely statistical models, which to a limited extent provide scope for economic interpretations.

NEMO may be referred to as a new-Keynesian DSGE model (dynamic stochastic general equilibrium model). This model class is characterised by the bridge it builds between new classical theory (where agents have rational expectations and maximise utility/profits over time) and Keynesian theory (where imperfect competition and nominal rigidities lead to wage and price stickiness). As a result, the model takes on new classical features in the long term (supply-determined output) and Keynesian features in the short to medium term (demand-determined output).

When NEMO was constructed, particular emphasis was given to developing a model that would be a useful decision-making tool in monetary policy. Therefore, it has been constructed with a view to being transparent and manageable. Output, price-setting, wage formation and all the main demand components are modelled and

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[1] For a more detailed description of the model, see Brubakk et al. (2006).

[2] See, e.g., Adolfsson et al. (2005a,b) Bank of England (2004), Coenen et al. (2007), and Fenton and Murchison (2006).

a distinction is made between domestic and imported inflation.

It is also important, however, that the model explains the most important developments in the Norwegian economy as they appear in data. A significant part of the model construction has therefore consisted of empirical evaluation of NEMO using Norwegian data. The model is estimated as a system using a Bayesian approach.[3] The forecasting properties of NEMO are compared with those of alternative models which are based to a lesser degree on economic theory. The main conclusion is that NEMO is relatively accurate compared with competing models.

2. The model

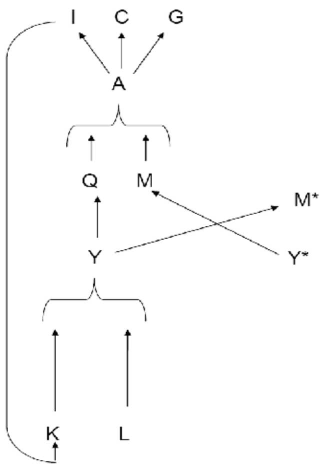
NEMO is a modern, Dynamic Stochastic General Equilibrium (DSGE) model which is an extension of real business cycle theory.[4] Dynamic means that the model solution determines dynamic paths for all endogenous variables. Developments in the variables will depend, however, on future random – or stochastic – shocks which are not known at the time agents lay their plans. This means in principle that future realisations of the variables may be described by a probability distribution, i.e. the endogenous variables in the model will also be stochastic. General equilibrium implies that market mechanisms contribute at all times to balancing supply and demand in all markets in the model. Nevertheless, NEMO provides a stylised description of the economy, and hence there are a number of markets, such as the housing market, that are not represented.

2.1 Main features

In NEMO, the world consists of two countries, home and foreign, which are interpreted as Norway and its trading partners, respectively. Apart from size, the two countries are generally treated symmetrically. We assume that Norway, as a small economy, has only a marginal effect on its trading partners. The country-specific variable is thus fully exogenous, i.e. that the Norwegian variable has no effect on the foreign variable. We will therefore concentrate our presentation on the home economy (Norway).

Chart 1 provides an overview of the model. The economy consists of firms, households and a government sector – which also includes the central bank. There is one intermediate sector that produces goods in the home country. Domestically produced goods (*Y*) may be both exported (*M**)[5] and used at home (*Q*), together with imports (*M*), to produce final goods (*A*)[6] that can be used to meet demand for consumption (*C*), investment (*I*)[7] and government spending (*G*).

Chart 1 A birds-eye view of NEMO



The intermediate sector consists of firms that use labour (*L*) and capital (*K*)[8] to produce differentiated products which are sold in markets characterised by monopolistic competition. This means that each firm has some degree of market power and sets prices as a mark-up over marginal costs. We assume that there are costs linked to price adjustments.[9] Price formation may thus be described as a Phillips curve where prices gradually change in pace with changes in production costs.

Households use capital markets to spread consumption optimally over time. Each household supplies labour to firms and sets wages taking into account firms' demand for labour. With regard to wage formation, we generally follow Kim (2000). We assume that wage earners have market power and thus choose a wage level that is above the free competition wage. We also assume that there are

[3] For an introduction to Bayesian econometrics, see for example Koop et al. (2007).

[4] See King and Rebelo (1999) for an overview of this theory.

[5] Foreign variables are denoted by a star. Therefore, *M** represents foreign imports (of Norwegian produced goods), i.e. our exports.

[6] Technically, this is modelled as a separate intermediate sector which uses the various goods produced as factor inputs.

[7] In the model, petroleum investment is removed as a separate demand component as NEMO is a model for the mainland economy.

[8] Capital is idiosyncratic but the utilisation rate may change over time.

[9] Technically, we follow Rotemberg (1982) and assume that firms face quadratic adaptation costs. This means that it is profitable for firms to adjust prices to a certain degree over several periods. A possible interpretation is that a firm risks losing customers if prices are changed to a new level too rapidly.

costs linked to adjusting wages and that wage earners take this into account.

Government spending is financed by a poll tax. The central bank operates an inflation targeting regime and sets short-term nominal interest rates. Monetary policy is modelled either as a simple rule (i.e. a Taylor rule) or in terms of a targeting rule where a loss function is minimised.

2.2 Some key equations

In this section, we will take a closer look at some key relationships in the model. NEMO is basically a non-linear model. Here, however, we present a log-linearised model around a given steady state. This means that all variables in the model may be interpreted as percentage deviation from long-term equilibrium.[10] For the volume variables in the model, equilibrium is measured in relation to an underlying growth path which is driven by exogenous[11] technological progress and population growth.

Households

Households maximise expected lifetime utility given budget constraints. For a representative household[12], this results in the following relationship for consumption over time:

$$(1) \quad c_t = (1-\alpha_1)c_{t-1} + \alpha_1 E_t c_{t+1} - \alpha_2 rr_t + z_t^c$$

where α_1 and α_2 are positive constants[13] and E_t is the expectations operator so that $E_t c_{t+1}$ is expected consumption in period t+1, given information at time t. Further, rr_t represents short-term real interest rates which are determined by the Fisher equation, $rr_t = r_t - E_t\pi_{t+1}$, where r_t is the nominal interest rate and π_{t+1} measures the increase in consumer prices (CPI) from period t to period t+1. Finally, z_t^c describes consumer demand shocks.

Consumption thus depends on real interest rates. This is a property of the Euler equation for optimal choice of consumption over time. With higher real interest rates, it is more profitable to save and thus more profitable to postpone consumption. Lower real interest rates have the opposite effect. Households want to spread consumption over time. This is reflected in the inclusion of expected consumption as an explanatory variable for the current period's consumption.

Consumption demand depends on consumption during the previous period, which is most often related to habit persistence in consumption. The idea originated in financial theory and is often cited as a possible explanation of the substantial difference between returns on risky and risk-free assets.[14] Habit persistence gives households an incentive to smooth consumption with the result that aggregate consumption becomes smoother.

Equation (1) can be solved forward conditional on interest rate expectations, which results in:

$$(2) \quad c_t = \alpha_3 c_{t-1} + \alpha_4 \sum_{i=0}^{\infty} E_t rr_{t+1} + \alpha_5 z_t^c$$

According to equation (2), consumption today depends not only on today's interest rate level but also on expectations of future interest rates, i.e. the entire interest rate path.

In NEMO, the labour market is characterised by monopolistic competition. This means that each household has some market power in setting wages. Firms decide how many working hours they want at given wages. This leads to the following equation for wage growth, π_t^w:

$$(3) \quad \pi_t^w = (1-\alpha_6)\pi_{t-1}^w + \alpha_6 E_t\, \pi_{t+1}^w + \alpha_7(w_t^* - w_t) + z_t^w$$

Wage growth in a given period depends on both previous and expected wage growth. Wage growth is also driven by the difference between "desired wage"[15], w_t^*, and actual wage compensation, w_t. This expression may be interpreted as an error correction mechanism. When there is a deviation between desired and actual wage, there will be a correction in wages. The direction of the correction will be determined by the sign of the deviation.

Alternatively, the wage equation may be written as follows:

[10] Small letters are used to indicate percentage deviation from long-term equilibrium, i.e. $x_t = \ln(X_t) - \ln(\bar{X})$, where $\bar{X}$ represents long-term equilibrium for X, the level variable.

[11] In general, we use the term exogenous to describe conditions determined outside the model.

[12] We assume the existence of a large number of households and firms, but with the same preferences and technology. The aggregate relationships in the model will therefore have exactly the same type of function and parameters as similar behavioural relationships for individual agents.

[13] To simplify, we let α_i represent gross coefficients in the model. These are in turn functions of the model's structural parameters.

[14] The reason is that with a high degree of habit persistence in consumption, households' aversion to variations in consumption increases. Thus, they demand high returns for holding risky assets.

[15] *Desired wage* means the wage level that would be realised if wages are fully flexible. This wage level is equal to the marginal substitution rate between consumption and leisure and measures households' loss of utility, measured in consumption units, as a result of working one hour extra. Households' aversion to working more will in turn depend on how much they work and consume in the first place.

$$(4)\quad \pi_t^w = (1-\alpha_6)\pi_{t-1}^w + \alpha_6 \mathrm{E}_t \pi_{t+1}^w + \alpha_8 \left(\underbrace{\alpha_9 c_t + \alpha_{10}\Delta c_t + \alpha_{11} l_t}_{\text{Pressure Indicator}} - \underbrace{\alpha_{12}(y_t - l_t) - \alpha_{13} mc_t}_{\text{Ability to Pay Wages}} \right) + z_t^w$$

In addition to its own dynamics, wage growth is driven by consumption level, changes in consumption, employment level l_t, productivity ($y_t - l_t$) and marginal cost (mc_t). The first three expressions may be interpreted as indicators of pressures, while the relationship between productivity and marginal cost indicates the ability to pay. Alternatively, wage growth may be seen as the result of a negotiation model where households' wage demands are determined by pressures in the economy, while firms' pay offers depend on their ability to pay.

Households have free access to international bond markets. For foreign loans, however, the premium accrues over and above interest costs depending on households' net asset position.[16] Optimal adjustment in bond markets results in the following modified version of uncovered interest rate parity (UIP):

$$(5)\quad s_t = E_t s_{t+1} - rr_t + rr_t^* - \alpha_{14}\, b_t^* + z_t^s$$

where s_t is the real exchange rate, rr_t^* is foreign real interest rates, b_t^* represents households' foreign bond holdings or net asset position, and z_t^s is an exogenous risk premium.

Firms

The production of goods requires labour and capital as factor inputs. In log-linearised form, the production function for a representative firm may be expressed as follows:

$$(6)\quad y_t = \alpha_{15}\, \bar{k}_t + (1-\alpha_{15}) l_t + (1-\alpha_{15})\, z_t^l$$

where y_t represents total output, $\bar{k}_t$ is capital services, l_t expresses the number of working hours and z_t^l is a temporary productivity shock. In the model, productivity will depend on capital services per working hour and the exogenous factor productivity shock.

In the short run, the physical capital is given. Nevertheless, firms can vary their input of capital services in the short run by changing capacity utilisation. Over time, developments in the physical capital, k_t, are determined in the usual way by depreciation and the investment rate. In log-linearised form, the investment rate ($\frac{I}{K}$) may be expressed as follows:

$$(7)\quad i_t - k_{t-1} = \alpha_{16}\, E_t(i_{t+1} - k_t) + \alpha_{17}(i_{t-1} - k_{t-2}) - rr_t + \alpha_{18} E r_{t+1}^k + z_t^i$$

where i_t represents investment, r_t^k is the user price of capital and z_t^i is a temporary shock to investment. The investment rate is determined by the real interest rate and expected user price of capital as well as lagged and expected investment rates. The last two terms in the equation reflect an assumption that there are costs associated with changing the investment rate. An increase in expected user price of capital means in isolation higher expected return on capital, while a higher real interest rate, by reducing the discounted value of future returns, has the opposite effect.

Firms have some monopoly power with regard to the pricing of their products. Therefore, they will set prices as a mark-up over marginal cost. We assume that firms exercise a degree of price discrimination between domestic and export markets, which is determined by demand in the two markets. As in the case of wages, we assume that prices change gradually as a result of adaptation costs. Optimal adaptation gives us the following Phillips curve for domestically generated inflation, π_t^q :

$$(8)\quad \pi_t^q = (1-\alpha_{19})\pi_{t-1}^q + \alpha_{19} \mathrm{E}_t \pi_{t+1}^q - \alpha_{20}\,(p_t^q - mc_t) + z_t^q$$

where mc_t refers to marginal cost, whereas p_t^q expresses the real price for domestically produced and utilised goods. The term ($p_t^q - mc_t$) may be interpreted as an expression of a firm's profit margin or earnings and functions as an error correction mechanism. When margins are higher than normal (>0), there will be downward pressure on prices. When margins are low (<0), firms will want to increase prices. Since there are costs connected with changing prices, it will not be optimal for firms to change prices in pace with changes in marginal cost. As a result, a firm's earnings will vary through business cycles. Whether margins are cyclical or countercyclical will depend on exogenous factors.[17]

However, it is not only earnings in the current period that are decisive for the rise in prices. This is easier to understand if we solve equation (8), conditional on the margins:

$$(9)\quad \pi_t^q = \pi_{t-1}^q - \alpha_{21} \sum_{i=0}^{\infty} \alpha_{22}^i\, E_t(p_{t+i}^q - mc_{t+i}) + \alpha_{23} z_t^q$$

[16] This may be interpreted as an endogenous risk premium. The interest margin domestic agents pay for foreign loans depends on total foreign debt. High debt means higher risk and thus a higher premium.

[17] In general, demand shocks will result in a negative correlation between profit margins and the output gap, whereas supply-side shocks lead to a positive correlation. A key premise underlying these results is an assumption of sticky prices. A positive demand shock will, for example, lead to higher output and increased production costs. Since we assume that firms can only change prices to a limited degree in the short run, firms will not be able to fully pass on cost increases to prices. As a result, margins decline.

where α represents gross coefficients. We see from (9) that firms set prices on the basis of expected earnings.

Both export and import prices are modelled as in (6). Here, however, the real exchange rate will also be of importance. The rise in import prices π_t^m, may therefore be expressed as follows.

$$(10)\quad \pi_t^m = (1-\alpha_{24})\pi_{t-1}^m + \alpha_{24}\mathrm{E}_t\,\pi_{t+1}^m - \alpha_{25}[(p_t^m - s_t) - mc_t^*] + z_t^m$$

where mc_t^* expresses foreign firms' marginal costs, s_t is the real exchange rate, p_t^m represents the level of import prices and z_t^m is an exogenous shock to import prices. Conditional on developments in foreign firm's earnings, $(p_t^m - s_t) - mc_t^*$, we can write the equation (10) as:

$$(11)\quad \pi_t^m = \pi_{t-1}^m - \alpha_{26}\sum_{i=0}^{\infty}\alpha_{27}^i E_t[(p_{t+i}^m - s_{t+i}) - mc_{t+i}^*] + \alpha_{28} z_t^m$$

In other words, imported inflation will depend on foreign firms' expected earnings (measured in foreign currency). In the model, total inflation is shown as a weighted sum of domestic and imported inflation.

Differentiated domestically produced goods are combined to become an aggregate of domestically produced goods which in turn are combined with an aggregate of differentiated imported goods to become an aggregated final good. This aggregated good may be used for investment, consumption and government spending. Therefore, we can write aggregate domestic demand as follows:

$$(12)\quad a_t = c_t + i_t + g_t$$

where the variables a_t, c_t, i_t and g_t represent total domestic demand, consumption, investment and government spending, respectively. Note that a_t expresses total demand and thus includes both domestically produced and imported goods. The general budget equation in turn describes total demand for domestically produced goods and services and is related to a_t as follows:

$$(13)\quad y_t = a_t + s_t p_t^{m^*} m_t^* - p_t^m m_t$$

where y_t is total production of domestic goods and services, which must be equal to total demand a_t, corrected for net exports $s_t p_t^{m^*} m_t^* - p_t^m m_t$. Inserting a_t from the equation above will give us the aggregate resource constraint as it usually appears. It is also important to note that NEMO provides a consistent description of flow and stock variables. Changes in capital may therefore be related to investment and capital consumption. Similarly, there is an explicit relationship between changes in foreign assets and the current account balance (net exports plus net interest and transfers).

The fiscal and monetary authorities

Government spending is determined exogenously and is financed by lump-sum taxes. This is, of course, a gross simplification. The central bank operates an inflation targeting regime and sets the interest rate based on a further specified rule. Here, we can choose between simple rules, such as the Taylor rule, or more general rules where the central bank's loss function is minimised. An example of a simple rule would be:

$$(14)\quad r_t = \lambda r_{t-1} + (1-\lambda)(\alpha_{29}\pi_t + \alpha_{30}y_t) + \varepsilon_t$$

where ε_t represents an exogenous shock to monetary policy. According to this rule, the interest rate in a given period will be determined by the interest rate in the previous period, overall inflation and output.

In the model, the role of monetary policy is to provide an anchor for inflation expectations. This means that the central bank must set the interest rate so that inflation expectations over time are consistent with the inflation target. This places certain restrictions on the interest rate rule. The interest rate rule must ensure among other things that interest rate changes are sufficient in situations where inflation deviates from the target. Typically, this means that the change in the interest rate is greater than the change in inflation, i.e. that $\alpha_{29}>1$ in equation (14).

2.3 Quantifying

The model is estimated on data for the period 1981–2007. We have used quarterly figures for GDP, consumption, investment, employment, real wages, inflation, imported inflation, the real exchange rate and the nominal interest rate. For the foreign variables in the model we have used trade-weighted data for GDP, inflation, the nominal interest rate and wage costs, bringing the total number of variables to 13. We have used a relatively large number of variables in order to be able to estimate the largest possible number of parameters. Nevertheless, some parameters in the model are impossible to estimate, given the information set. These parameters have been calibrated on the basis of results from international studies and our own assessments of the transmission mechanism.

We have used a Bayesian approach to determine the parameters in the model. In general, this means that we update our initial estimates of the model parameters on information derived from the data. Our initial view, or our priors for the probability distribution of the parameters, is based on previous assessments and experience of the functioning of the economy. The final product is a probability distribution of the parameters, conditional on the data observed. The Bayesian framework provides a basis for quantifying the forecast uncertainty in the

Chart 2 The monetary policy transmission mechanism

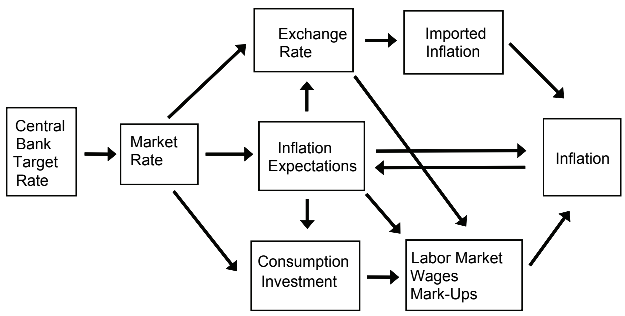
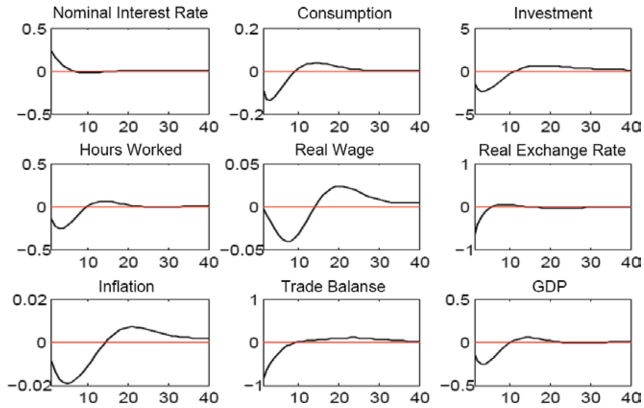


Chart 3 Impulse responses to a monetary policy shock



model which may be used, among other things, to make the fan chart which illustrates the uncertainty surrounding the projections.

2.4 The transmission mechanism

In a small open economy like Norway, monetary policy operates primarily through five channels:[18] (1) the direct exchange rate channel to inflation, (2) the real interest rate channel to aggregate demand, (3) the exchange rate channel to aggregate demand, (4) the demand channel to inflation, and (5) the expectations channel to inflation.[19] Chart 2 illustrates the transmission mechanism.

We will consider the effect of an interest rate increase by Norges Bank. The result is an increase in short-term (nominal) money market rates and owing to sticky prices and wages, the real interest rate also rises. For a given exogenous level of external real interest rates, the real interest rate differential increases. The result is therefore a real appreciation of the Norwegian krone. The *direct exchange rate channel* to inflation implies that with an appreciation of the krone, imported goods become cheaper measured in NOK. Thus, inflation also falls. The impact on inflation will depend on how fast and to what extent import prices are adjusted as a result of a change in the exchange rate (exchange rate pass-through). In addition, higher real interest rates and a real appreciation of the krone affect aggregate demand: increased real interest rates reduce consumption and investment demand, and a real appreciation of the krone curbs demand for domestically produced goods and services since foreign goods become relatively inexpensive. This is the *real interest rate channel* and the *foreign exchange channel* respectively to aggregate demand. Lower demand will in turn put downward pressure on inflation. This is referred to as the *demand channel to inflation*. In NEMO, expectations concerning future developments in key macroeconomic variables, not least the interest rate, play an important role.[20] Since the central bank's response pattern is modelled explicitly in NEMO, it is possible for economic agents to make qualified projections about future developments in the interest rate. This implies in turn that monetary policy will influence the current level of inflation, output and employment also indirectly through expectations. This is called the *expectations channel to inflation*.

Chart 3 shows the effect over time on a number of variables of an unexpected shock to nominal interest rates. Initially, an increase in nominal interest rates will lead to higher real interest rates as result of sticky prices in the short run. Higher real interest rates will lower both consumption and investment demand. When firms experience a fall in demand, they will in isolation want to reduce production. This leads in turn to lower demand for both labour and capital inputs. This exerts downward pressure on real wages and the user price of capital. Cheaper factor inputs will lead to a decline in marginal costs and domestic firms will reduce prices for products on both domestic and export markets. Price changes will come gradually, however, because as assumed in NEMO there are costs associated with adjusting prices.

An unexpected increase in the interest rate will also generate appreciation pressures on the krone exchange rate. Import prices will decline, amplifying the fall in overall inflation. Demand for imports will decline, however, due to a reduction in domestic demand. Changes

[18] Channels refer to mechanisms in the Norwegian economy through which monetary policy operates.

[19] Another channel is the *credit channel* for monetary policy, on the assumption of imperfect credit markets which can enhance the effects of monetary policy. The current version of NEMO disregards this aspect. Another version of the model is currently being developed however. Here, some households are assumed to be credit-constrained.

[20] See for example equation (2) which shows how the current level of consumption depends on real interest rate expectations.

Chart 4 What drives inflation 2001–2007? Percentage points contribution

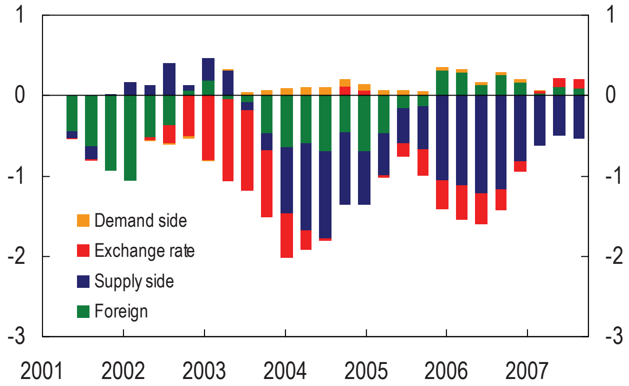
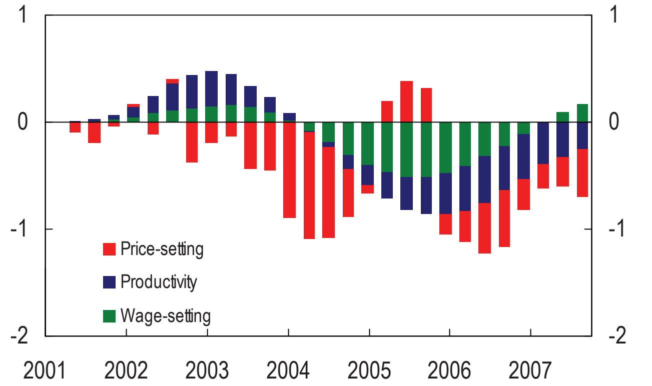


Chart 5 The supply side factors behind inflation 2001–2007. Percentage points contribution



in the exchange rate also affect export prices. In NEMO, a stronger krone will in isolation result in higher export prices, measured in a foreign currency, and contribute to curbing foreign demand for Norwegian goods. All in all, an unexpected increase in nominal interest rates leads to deterioration in the balance of trade. The result is a clear decline in output.

So far, we have focused on the short-term affects of an unexpected shock to interest rates. As economic agents adjust nominal variables to new desired levels, the economy will gradually return to its original steady state. One of the properties of this steady state is that all real variables are unchanged (relative to the underlying growth path).

3. Applications

The model may be used both for identifying underlying forces in the economy and for forecasting purposes. These two applications are closely connected. Identifying exogenous forces is decisive to making accurate projections. The model will also be useful in evaluating the published projections. The structural framework allows the decomposition of the relative contribution of different shocks to forecast errors for different variables.

3.1 Identifying driving forces

One of the advantages of NEMO is that the exogenous shocks in the model are given a structural interpretation. This means that we can use the model to identify structural conditions that are driving forces behind cyclical developments. NEMO can, for example, help us understand why inflation has been so low in recent years.

The solution of NEMO in compact form can be expressed as follows:

$$(15)\quad Y_t = AY_{t-1} + B\varepsilon_t$$

where Y is a vector of endogenous variables and ε is a vector of structural shocks. The elements in ε summarise variations in exogenous relationships, related for example to productivity, product or labour market competition or fiscal policy. A and B are coefficient matrices that are functions of the structural parameters in the model.

It follows from (15) that the contribution from the structural shocks to developments in the endogenous variables in the model is expressed by:

$$(16)\quad B\varepsilon_t = Y_t - AY_{t-1}$$

Equation (16) states that the prediction error, $(Y_t - AY_{t-1})$, is equal to the contribution from the vector of structural shock ($B\varepsilon_t$). When we know the forecast error for a given variable, we can use equation (16) to calculate the contribution from the different exogenous factors. It is important to emphasise that the driving forces that are identified will be conditional on the model.

We have used NEMO to identify exogenous forces driving inflation since 2001. Chart 4 presents the results. During the first part of the period, inflation seems generally to be driven by exogenous factors related to the exchange rate and import prices. These factors are primarily changes in external interest rates and the risk premium as well as the shift towards imports from low-cost countries. In recent years, however, domestic supply-side factors have been primarily responsible for the fall in inflation.

Chart 5 illustrates a decomposition of the contributions from various supply-side shocks. We find that the significance of the supply-side factors has varied over the period. According to NEMO, lower inflation in 2003 and 2004 was largely due to increased competition in product markets. This is in line with earlier assessments presented in Norges Bank's *Inflation Report*. From 2004, increased labour market competition and improved productivity in particular explain the low rate of increase in consumer prices. During this period, there was a sharp increase in labour migration from new EU member states, primarily Poland.

Chart 6 Recursive forecasts for 1999q1–2007q1

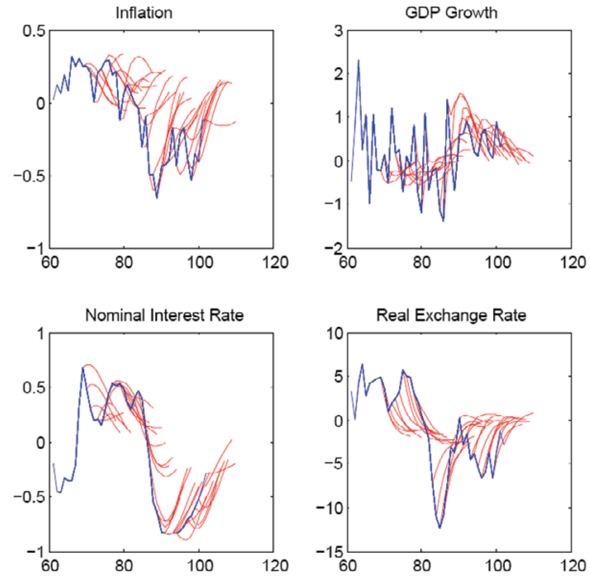
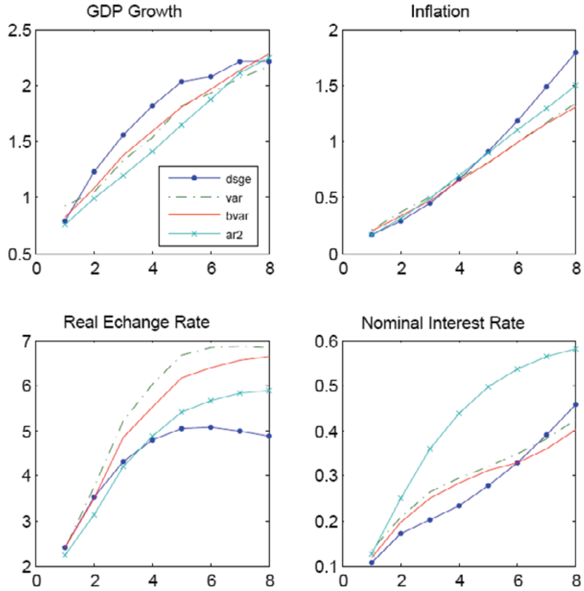


Chart 7 Forecast errors for different models and horizons



Root Mean Squared Error (RMSE) for different models and horizons

3.2 Forecasts

Chart 6 shows the quarterly NEMO-based forecasts for different horizons over the period Q4 1998 – Q4 2006 for four key variables. At each time during this period, a forecast is made for the next eight quarters. The model is estimated recursively so that in principle we do not use more information in the estimates than would have been available at the time the projections were made.[21] All variables are measured as deviations from their respective averages.

The GDP growth forecasts indicate that NEMO is fairly accurate as to underlying developments. The model is less accurate in projecting short-term movements. We also see that NEMO would have been of limited use in predicting the fall in inflation from 2002. The interest rate forecasts seem to be broadly in line with actual developments. The model also seems to capture the main developments in the real exchange rate.

We have compared the NEMO-based forecasts with forecasts from alternative models recommended in the literature to evaluate the model's forecasting properties: a VAR (2) with no parameter restrictions, a BVAR (2) and a set of univariate AR (2) models.[22] The accuracy of the models for a given variable and horizon has been measured by the root mean squared error (RMSE)[23]. Chart 7 shows the RMSE for some of the domestic variables over different horizons. The main impression is that NEMO is on a par with the competing models included here. The NEMO-based GDP forecasts are approximately as accurate as the forecasts from the alternative models in the long term. In the short run, however, the NEMO-based forecasts seem to be less accurate than the forecasts from its competitors. The opposite is the case for inflation forecasts from NEMO. Here, NEMO is less accurate in the long run. The forecasts for the nominal interest rate are in line with both the VAR and the BVAR models. Finally, we find that NEMO-based real exchange rate forecasts are relatively accurate at the longest horizons.

To provide a more formal overall impression of the forecasting properties of the different models, we have also calculated two different multivariate measures based on a weighting of the accuracy of each variable.[24] Chart 8 shows the results for the four key variables. Both measures indicate that NEMO is generally more accurate than the alternative models in the long term.

21 We disregard the real-time aspect linked to data revisions.

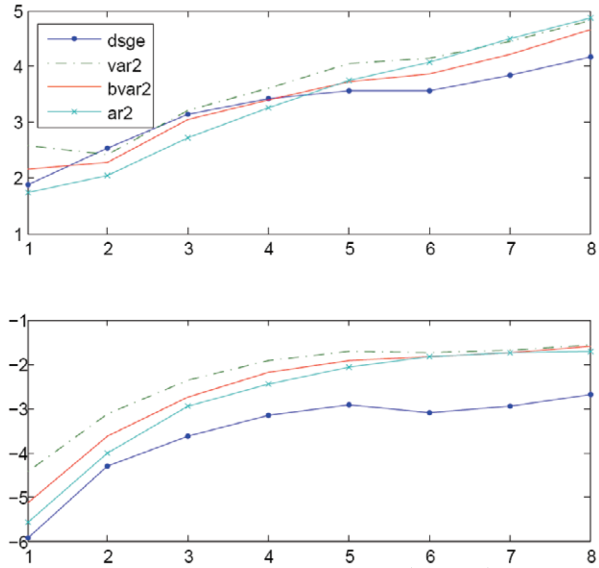
22 Vector autoregressive models, both without parameter restrictions (VAR) and with a priori parameter spreads (BVAR), are purely statistical models that describe developments in a set of variables as multivariate autoregressive processes. An AR model is a univariate autoregressive process. BVAR models in particular have been found to have very good forecasting properties.

23 This is a measure of forecasting accuracy which is calculated by taking the square root of the mean square forecast error for a given variable (and horizon).

24 Both measures are based on the mean square error (MSE) defined as: $MSE_M(\mathrm{h}) = \frac{1}{\mathrm{N_h}} \sum_{t=T}^{T+N_h-1} (Y_{t+h} - \hat{Y}_{t+h|t})\Omega^{-1}(Y_{t+h} - \hat{Y}_{t+h|t})$

where $(Y_{t+h} - \hat{Y}_{t+h|t})$ is the forecast error for a given horizon h, $\mathrm{N_h}$ indicates the number of projections with horizon h while Ω is a scaling matrix. We consider $\ln|MSE_M(\mathrm{h})|$ (log-determinant) and $tr(MSE_M(\mathrm{h}))$ (trace).

Chart 8 Comparing weighted forecast errors from different models and horizons



Upper panel shows $\ln|MSE_M(\text{h})|$ and lower panel shows $tr(MSE_M(\text{h}))$.

4. Conclusion

In this article, we have presented Norges Bank's new macro model for the Norwegian economy. The model contains the most important channels in the Norwegian economy through which monetary policy operates. In developing the model, a clear objective has been to balance clarity and realism. This means that we have oversimplified in some areas, for example in modelling fiscal policy and financial markets. Nevertheless, the model seems to provide a satisfactory description of the most important developments in the Norwegian economy as presented in the data. It cannot be overlooked, however, that there were problems when estimating the model on data from periods with different monetary policy regimes. The estimated parameters must therefore be interpreted with caution. The model's success will ultimately be assessed on the basis of its usefulness to Norges Bank in the formulation of monetary policy.

NEMO is one of several models used in the conduct of monetary policy. In order to obtain a more accurate picture of today's situation and of developments over the next few quarters, we rely heavily on various short-term models. Such models can capture time series properties in data and correlations that in many cases feature a fairly high degree of accuracy without the model relationships following directly from economic theory. In order to forecast somewhat further ahead, however, we must gain more insight into the forces at work and how they are affecting the economy. Statistical forecasting models will not be particularly helpful here. A solid basis in economic theory is required to shed light on causal relationships. NEMO's strength is that it provides a consistent description of the relationship between monetary policy and cyclical developments that lends itself to economic interpretation. The model formalises to a large extent Norges Bank's view of the key relationships in the Norwegian economy. Thus, it contributes to a consistent framework that gives structure to both internal discussion and external communication.

A model always involves simplifications and will never be able to provide an exhaustive description of reality, but a good macro model can and should be a framework for ratiocination. In this way, the model plays an important role in the rationale for interest rate setting. At the same time, it is important to remember that in the conduct of monetary policy, we must always supplement model-based results with discretionary assessments.

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