NORGES BANK

REVIEW OF MACRO MODELLING FOR POLICY PURPOSES AT NORGES BANK

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Contents

Executive Summary

The evaluation team was given a mandate to assess whether the current set of models employed for monetary policy analysis and forecasting purposes (i) constitute best practice in the policy arena and in relation to recent academic developments; (ii) are appropriate to answer relevant policy questions for an inflation-targeting central bank in a small open economy; (iii) and can be further developed in the years to come and in what way.

Our general conclusions are that i) Norges Bank is at the high end of the spectrum of best-practice central banks; ii) that the modelling strategy used to support the policy process is adequate and iii) that Norges Bank is conscious of recent developments at the frontier of macroeconomic modelling and is actively working in some of these areas. Nevertheless, we indicate a number of changes to the structure of the core model (NEMO) and, more generally, to the set of models used to support the policy decision process. We also present some strategic considerations on model developments for the years to come.

We believe that the policy analyses and the forecasting process are credibly and consistently conducted and well understood by staff and management. Norges Bank uses a New Keynesian DSGE model as the core model for policy analysis, forecasting, risk management and communication that is well developed, consistent, and state of the art. The model has evolved over time and is used effectively to address a variety of questions regarding policy and transmission channels. Core staff and management at Norges Bank seem confident that the current set of models and the way they have been used in the recent past are appropriate to answer policy questions. We perceived a sense of common ownership of the model used to guide the production of the interest rate path.

While we endorse the strategy of using one core model, we recommend supplementing the analysis with simple monetary policy rules and some smaller models for cross-checks, in order to avoid fine tuning policy to the core model. Moreover, we provide a list of detailed suggestions to improve the current modelling framework. NEMO should explicitly incorporate trends to allow forecasts of the level of the variables. Correlations among endogenous variables should be checked. The relative importance of various shocks should be examined and out-of-sample forecast evaluation of staff projections regularly performed. Satellite models could also be used to build credible international scenarios to analyse risks, fiscal policy and other issues that, if added, could considerably complicate the NEMO analysis.

Model development at Norges Bank seems to be organised appropriately, but we recommend more cooperation among the different units and some outsourcing of model maintenance/upgrading. We advise building a network with modelling teams from other resource-rich, small open economies and we stress the importance of documenting model development (and policy work more generally) in the form of polished and publishable policy research.

In terms of future developments, we believe that heterogeneities, non-linearities and alternative expectation formation mechanisms will be areas of research that central banks should take advantage of in the next 5-10 years. Norges Bank seems conscious of these developments and is actively working in these areas.

Introduction

In recent years, many central banks have constructed and employed dynamic stochastic general equilibrium (DSGE) models to support monetary policy analysis and the forecasting process, typically in conjunction with other time series or structural models. DSGE models are structures where agents optimise under frictions, equilibria are computed under rational expectations, and markets clear. DSGE models have evolved over time. Several features have been added to the first generation of models to answer specific policy questions: for example, to study whether financial market or labour market frictions change the transmission of relevant shocks. Other features have been added in certain countries, for example to adapt them to local conditions, such as oil or commodity-producing sectors, or pension provision and ageing issues. More recently, new solution techniques and advances in the modelling of agents' heterogeneities in income, wealth, or expectations, have introduced new expansion possibilities, currently evaluated in many policy institutions. This extension process has resulted in larger and more complicated models that give a broader view of the interdependencies present in an economy, but require considerable model building and estimation time, involve deeper identification issues, and require more effort to maintain. Many central banks are also exploring how the information contained in large micro data ("Big data" sets') can be utilised to answer policy questions more effectively.

Commentators strongly debate the success of DSGE models, the appropriateness of the extensions, and the need for new thinking about policy issues (see e.g. Wieland et al (2016), Korinek (2017), Gurkaynak and Tille (2017), Blanchard (2018), Christiano et al. (2018), Linde (2018), Reis (2018), Stiglitz (2018), among others). Still, a consensus has not yet been reached on whether models of this type should be made more flexible, relaxing some of the more restrictive assumptions such as rational expectations, reverted to hybrid formulations where general equilibrium considerations and market clearing are set aside, or simply abandoned for another paradigm, such as large-scale agent-based models.

A central bank needs models to understand how the economy functions, to evaluate the transmission channels of monetary policy and to analyse alternative monetary policy strategies and to judge the robustness of the predictions and the policy analyses to the assumptions made. The need is even more imperative in inflation-targeting central banks where forecasting inflation is centre stage. At Norges Bank, structural analysis and the forecasting process have been conducted since 2006, primarily using NEMO, an advanced open-economy DSGE model now featuring financial market frictions, banks, and an oil sector. The strategy used in the policy process has been to feed all information available at each point in time into the model to produce policy paths for the relevant variables. The Executive Board then discusses, assesses and judges these paths.

In particular, nowcasts and short-run forecasts produced via the system for averaging models (SAM), sector experts' views on short-term developments and trajectories for the variables external to the model (public expenditures, foreign variables, oil price) become conditioning information over the relevant forecast horizon. This strategy implicitly separates the analysis of short- and medium-term economic developments. This is because understanding short-term developments requires processing large information sets and the use of statistical techniques to compress this information and to evaluate the out-of-sample performance of the predicted developments. On the other hand, forecasting in the medium term is considered less data-intensive, but requires a comprehensive and theoretically consistent apparatus to interpret the outcomes, to develop narratives of the causes and the effects and to communicate monetary policy choices to the public. NEMO is used for the latter purpose: it interprets historical developments in terms of historical shock decompositions and provides medium-term forecasts of main macroeconomic aggregates.

The information NEMO produces results in medium-term forecasts for inflation and other variables and a judgemental interest rate path that aims to strike a balance between different monetary policy objectives. The uncertainty present in macroeconomic predictions is presented via fan chart forecasts, which are based on the density forecasts NEMO produces. Structural Vector Autoregressions (VAR) are at times used to complement the analysis of the transmission of shocks and policy changes NEMO provides. The insights they provide are employed either to calibrate the magnitude and the persistence of macroeconomic variables' responses to relevant disturbances in NEMO or to evaluate the transmission mechanism of different shocks, including monetary policy disturbances. Occasionally, smaller scale models are also considered to answer specific questions that may arise in the policy process and that cannot be addressed directly in NEMO.

Against this background, the evaluation team was given a mandate to assess whether NEMO and the current models employed for monetary policy analysis and forecasting purposes (i) constitute best practice in the policy arena and in relation to recent academic developments; (ii) are appropriate to answer relevant policy questions for an inflation-targeting central bank in a small open economy; and (iii) can be further developed in the years to come and in what way. To respond to these questions, we have prepared this report. The report is based on information collected during two days of meetings with Norges Bank staff and management, staff presentations on aspects of model building and policy analyses at Norges Bank and a range of supportive documents and research papers provided by the staff.

The remainder of the report consists of seven sections. The next section defines best practice for an inflation-targeting central bank against the background of its institutional size. Section 2 evaluates where the Norges Bank stands in the spectrum of possibilities. Section 3 discusses whether staff and management at Norges Bank are confident that the current model suite and the ways these models are used is appropriate to answer relevant policy questions, and Section 4 highlights areas where economic research is likely to make advances that central banks should take advantage of in the next 5-10 years. Section 5 suggests improvements to the current model suite. Section 6 defines areas for future, longer-term model development and highlights some strategic considerations. Finally, Section 7 evaluates whether model development is organised appropriately.

Our general conclusions are that i) Norges Bank is at the high end of the spectrum of best-practice central banks; ii) that the policy analyses and the forecasting process are credibly and consistently conducted and well understood by staff and management, and iii) that the modelling strategy used to support the policy process is adequate. Nevertheless, we indicate a number of changes to the structure of NEMO, and to the organisation of the policy analysis exercises, that may help to strengthen support to the policy decision process. We also provide suggestions on how to make important academic developments operational in the context of the available models, given the limited human resources and the institutional constraints Norges Bank faces.

1. Best practice for an inflation-targeting central bank against the background of institutional size

1.1. General role of models and institutional background at Norges Bank

Macroeconomic models serve a number of essential functions in modern central banks. These functions are independent of particular policy objectives, policy instruments, and institutional size. Models are required to provide specific, quantitative answers to questions that policy makers often pose to their staff such as, for example:

- How is the economy likely to develop in the foreseeable future?
- How can the central bank best fulfill its mandate?
- What are the effects of changes in the central bank's instruments on the economy?
- What are the risks or the trade-offs a central bank faces?
- What information can and should a central bank communicate to the financial community and the public at large?

A central bank without expertise in macroeconomic modelling would be a central bank that lacks key state-of-the-art skills in the practice of monetary policy. In designing and employing macroeconomic models in practice, careful attention must be paid to the goals the central bank hopes to achieve, the available instruments, as well as the effective use of central bank resources.

The law sets the institutional background for macroeconomic modelling at Norges Bank. Monetary policy shall maintain monetary stability by keeping inflation low and stable. The operational target is inflation close to 2 percent over the medium term. Norway has been operating an inflation-targeting monetary policy regime for almost 20 years. The main policy instrument is the short-term nominal interest rate. The objective is not one-dimensional and takes account of possible tradeoffs. Norges Bank's approach to inflation-targeting is forward-looking and flexible so as to contribute to sustaining high and stable growth in output and employment and to counteracting financial imbalances.

Norges Bank's mandate identifies key variables of interest, with consumer price inflation as the primary objective of monetary policy. Successful policy implementation requires in-depth understanding and quantitative assessments of monetary policy transmission in the economy and ultimately inflation via the interest rate instrument. It also calls for state-of-the art assessments of the risks to economic activity and employment and to the stability of the financial system.

1.2. Key functions of macroeconomic models

There are four areas in the design and implementation of central bank policy where macroeconomic models are useful and often essential tools: forecasting, policy analyses, risk management, and communication.

1.2.1. Forecasting

The objective of central banks is to stabilise certain macroeconomic aggregates such as inflation, economic activity and employment. To achieve this, central banks need to develop forecasting tools that can enhance our understanding of how these aggregates move over time and will evolve in the future. Furthermore, inflation-targeting central

banks typically publish an inflation forecast. Macroeconomic models play an important role in producing such forecasts. A purely judgemental forecast does not make use of state-of-the-art forecasting techniques. Similarly, single equation forecasts fail to take into account the economy-wide consequences of these forecasts. By contrast, multi-equation models offer the possibility of accounting systematically for interdependencies and correlations of key macroeconomic aggregates.

Both non-structural and structural models can be used in the policy process. Academic research suggests that combining models' outputs or averaging over models' predictions can improve forecast accuracy. Non-structural models refrain from imposing theory-based restrictions or use only a minimal set of assumptions on model equations and parameters. Nevertheless, they are successful in forecasting. Structural models impose theory-based restrictions and thereby offer an interpretation of causal links between key macroeconomic aggregates. Structural models are essential if one wants to tell a story, a narrative, about the drivers behind a particular forecast of future economic developments.

Because structural models describe the relationships among only a limited set of key variables, and thus use a smaller information set, they may do worse in terms of forecast accuracy relative to larger scale, non-structural models. Yet, there are now methods that can condense large amounts of data information into nowcasts or near-term forecasts of state variables of structural models, thus resolving this shortcoming. Structural models of the size used in central banks may also be complicated to solve. Thus, it may be difficult to account for nonlinearities and regime shifts. Smaller scale structural models or non-structural models can handle these features more easily.

1.2.2. Policy analyses

Structural models are essential for policy analyses because they require an understanding of the causal linkages present in the economy. Structural models describe how disturbances are transmitted to the economy and through which channels. They also draw out the implications of policy decisions regarding the setting of a particular policy instrument for macroeconomic aggregates such as the inflation rate. Thus, since structural parameters (including the central bank's reaction function) are explicitly identified, these models can be used to show how the forecast changes if policy changes in a systematic way. They provide a setup to compute forecasts that are conditional on a specific reaction function or policy rule.

Structural models also help to draw out the implications of economic developments for the design of policy. For example, one needs a structural model to check the effectiveness of a particular policy rule or a strategy in terms of stabilising certain targets. Structural models can also be used to derive an optimal policy, that is, a policy that minimises a loss function defined in terms of the ultimate targets of monetary policy. Thus, structural models can provide well-reasoned policy recommendations.

Finally, there is substantial uncertainty about the importance of different channels of policy transmission, about parameter values, the state of the economy, and more generally the appropriate model of the economy. Different modelling approaches make use of different theoretical concepts and restrictions. To assess the extent of model uncertainty, and to evaluate the robustness of policy strategies and decisions, one can employ multiple models and derive a robust strategy that performs reasonably well across those models.

1.2.3. Risk management

Discussions concerning risk often focus on particular discrete events, which may affect the economic outlook and may require adjustments in the policy stance or even the policy strategy. Often, such risks are difficult or impossible to assess in a probabilistic sense. Examples of such events would be systemic changes such as Brexit, a sovereign default, or the outcome of a trade war. Macroeconomic models can be employed to assess the consequences of particularly risky events in the form of scenario analyses.

With the aid of scenario analyses, one can explore channels of causality through which certain events may influence key target variables.

Models can also be used to produce density forecasts, which take into account shock uncertainty, parameter uncertainty, and model uncertainty. Density forecasts illustrate to policy makers as well as to the public at large the complexity and uncertainty surrounding the economic outlook and the associated risks to the economy.

Because no single model can capture all sources of risk at once, risk management and scenario analysis need to be supported by multiple models. Central banks should allot time to develop new models that are suitable to analysing new risks as they develop.

1.2.4. Communication

The use of a structural model in the internal central bank decision-making processes helps ensure consistency over time. It also provides a benchmark to discuss different narratives and judgements over time and a language that facilitates the interaction amongst policy makers and between policy makers and central bank staff members. For example, sector specialists may develop satellite models whose outcomes can be compared with the baseline results provided by a structural model. Thus, models can play a very useful role in internal communication processes.

The time when central banks just made policy decisions, and silence or mystery about decision makers' views and intentions were considered a virtue, has long since passed. Academic research and policy practice over the past four decades have shown that openness and transparency about objectives, strategy and instruments, as well as about the central bank's assessments of current and future economic developments are essential in order to achieve good economic outcomes.

Communication takes a variety of forms: statements, speeches, reports, press interviews and press conferences. Models can play a very useful role in providing quantitative information for all those forms of external communication. Because models are a simplification of reality, they help to bring out the key drivers of certain developments or certain policies.

Inflation-targeting central banks have been at the forefront of producing detailed, quantitative information for the financial community and the public at large regarding the economic outlook, the forecast for inflation, the trade-offs faced by central banks, the implications for their policy decisions, and, to some extent, their own forecast of future policy decisions. To ensure consistency over time, it is important to have a common language, which can be provided by a core model.

1.3. What model(s) to use?

1.3.1. Core model vs suite of models

Which model should one employ? The answer depends, to some extent, on the use a model will be put to. Models are simplified representations of reality and thus are ''wrong''. However, some models are better suited than others in one of the four functions described above. Thus, an important question is whether central banks should concentrate their resources on building a core model or work with a suite of models. The core-model approach employs one single economic framework for all the functions and thus the model needs to be detailed and to include all the relevant features of the economy. Given its nature, the model is the centre stage for producing quantitative information for policy and for aggregating all types of relevant incoming information into forecasts, policy and risk analyses. The information produced by the model becomes public, indirectly, via the central bank's main communication outlets.

The suite-of-models approach instead invests in maintaining several operative models. Different models may be developed and employed to achieve different objectives, thereby optimising the model for the particular function it is devised for. Models based on competing philosophies may coexist. When used for forecasting, policy analyses and risk management, they can produce alternative outcomes for members of policy-making committees who seek robustness in their decisions.

These two approaches are at the two ends of the scale. Intermediate cases, where the outcomes of a core model are cross-checked with a number of smaller models, or a few core models are employed in the policy process, are also possible.

Both approaches coexist in the real world and have advantages and disadvantages. When the core-model approach is employed, policymakers become more familiar with the model, its key features and policy implications. In addition, a maximum degree of consistency is achieved. Modelling efforts when a new policy question emerges are not easily lost over time and become part of a sustained endeavour to obtain a better model. Finally, there is one answer to a particular question, making the policy discussion simpler. The main drawback of the core-model approach is the risk of "seeing-everything-through-one-lens". There is a danger of myopia and reinforcement of group thinking that may lead to policy strategies that lack robustness. Moreover, trying to include every aspect of interest in a core model can become more and more resource-intensive. Thus, it may not be very cost-effective when dealing with the policy challenges at hand at any given time, especially in small central banks.

The suite-of-models approach addresses some of the shortcomings of the core-model approach. This approach can better fit a particular objective, improve the degree of policy robustness, and handle new challenges more easily. Yet, in such a framework, judgment plays a more important role. For example, one has to decide when to use a particular model for what purpose. Hence, discretion may dominate other considerations and consistency over time may be lost.

Against this background, an intermediate approach seems preferable, as it balances advantages and disadvantages. In such an approach, one would build at least one large-scale model that could handle all the above functions and play a leading/core role in all of them. A large central bank might be able to have a suite of larger-scale models; for smaller central banks, one core model would probably be sufficient. In both cases, an additional set of small-scale models could be used to evaluate particular risk scenarios or new challenges that may emerge over time.

1.3.2. What type of model?

The philosophy used to develop models has changed rather drastically over the past 60 years. Rather than providing a detailed overview (available in e.g. Wieland et al 2016, Pagan, 2018, Binder et al 2019), we just list the types of model available to policymakers, focusing on those that could be included in a suite of models.

Non-structural models: As far as forecasting is concerned, it is important that the central bank's toolbox includes models that forecast well and constitute credible benchmarks to compare forecast accuracy. For this purpose, reduced form models or models employing a minimal set of theory-based restrictions could be considered. Examples of models of this type are Bayesian Vector autoregression (BVAR) or structural BVAR models, single equation models optimising the model's performance at different forecasting horizons, and regime-switching type models that help to measure the likelihood of crises or the extent of recession probabilities. The main drawback of such models is that due to their non-structural nature, the narrative behind the forecasts is harder to develop.

Traditional Keynesian-style models: These include, for example, models in which prices are fixed and the level of economic activity is determined by aggregate demand considerations. The latter equations could be derived from economic theory, but they

typically lack a stock-flow consistency and general-equilibrium considerations are not taken into account. Furthermore, dynamic models that feature a Phillips curve, an aggregate demand curve and financial parity conditions belong to the class of Keynesian-style models. The equations typically feature arbitrary lags of the dependent and the independent variables, and expectations are adaptive and backward-looking. There may be separate equations for aggregate demand components, a production function representing the supply side, a foreign sector and, at times, multiple countries. There are small-scale but also large-scale macro-econometric variants of these models. Small- to medium-scale versions are still used in policy institutions because they fit the data reasonably well. In general, dynamic Keynesian-style models impose more structure than structural BVARs, but they do not necessarily improve on their forecasting ability. However, they help to develop narratives and can be useful for robustness analysis in policy design. The main drawback of these models is that they ignore the possibility that parameters change when the policy strategy changes (the Lucas critique). Such changes could be due to forward-looking, optimising behaviour.

First-generation New-Keynesian models: The New Keynesian approach to macro modelling responded to the Lucas critique by integrating into traditional Keynesian-style models forward-looking expectations, nominal rigidities due to staggered wages and prices or menu costs, and policy rules. There are small-, medium-, and large-scale single country models of this type; multi-country models are also possible (see e.g. Taylor 1993, Isard (2000), etc.). Perhaps the most prominent model of this class that is currently employed as a core model at a central bank is the FRB-US model of the Federal Reserve Board. Recently, the European Central Bank has developed a euro area version of this model (ECB-base). These models are generally built using an equation-by-equation approach, but typically have a well-defined steady state. They offer some flexibility as far as adding new features, for example institutional aspects, new details about the financial, fiscal or energy sectors, or allowing extensions focusing on the risks faced by the central bank. They also offer some flexibility in terms of modelling expectation formation. Typically, models of this type are solved using rational expectations, although these expectations can be replaced with adaptive expectations or VAR learning, if needed. For example, the FRB-US model uses VAR learning in the forecasting and policy process, but studies on policy design employ rational expectations.

New-Keynesian DSGE models: These models build on a consistent optimising-behaviour-general equilibrium setup pioneered in the real-business-cycle literature. To construct monetary models of this type, it was necessary to add imperfect/monopolistic competition to the original paradigm and thereby market power and optimal price setting. This increased the modelling complexity considerably but strengthened theoretical consistency relative to the first-generation New Keynesian models. There are small-, medium- and large-scale variants of these models today. Prominent examples are the New Area Wide Model (NAWM-I and II) of the ECB, the SIGMA model of the Federal Reserve Board, Ramses of the Sveriges Riksbank, Totem of the Bank of Canada, the QUEST model of the European Commission and the GIMF model of the International Monetary Fund.

Following the 2008 crisis, researchers in academia and central banks have extended the baseline DSGE models used for policy to include financial frictions, housing, and banking. Others have added commodity and energy sectors to the original specification. Finally, fiscal policy considerations have also been included in many models to evaluate the monetary–fiscal policy mix and the various options available to policy makers. In general, it is more difficult to extend a core central bank DSGE model than an FRB-US type model because the complexity increases more rapidly. While the presence of cross-equation restrictions in the DSGE models may decrease forecast accuracy and model fit, these models seem to be doing as well as non-structural models in these regards. Partly, this is due to the inclusion of serially correlated shock processes. NEMO (Norwegian Economy Model), the main model used by the Norges Bank, belongs to this class.

We believe that investing human resources in building a large-scale traditional Keynesian-style model is not necessary or advisable, in particular since stock-flow consistency and general-equilibrium considerations are neglected. Small- to medium-scale dynamic Keynesian-style models are still used in policy institutions because they fit the data reasonably well and can be helpful for robustness checks. First-generation New Keynesian models are suitable as core models, as they can cover all functions relevant to central banks. However, they do not make full use of recent advances in modelling design or estimation techniques. New Keynesian DSGE models are also appropriate to serve as core models at central banks. Nowadays many central banks use them for forecasting, policy analyses, risk management and communication purposes.

Summary
Macroeconomic models form an essential element of best practice in monetary policy. Models are needed to support forecasting, policy analysis, risk management and communication. They are essential to produce quantitative information on the transmission channels of monetary policy, alternative policy and risk scenarios and the performance of policy strategies. Using one medium- to large-scale core model is possible if supplemented with smaller models for cross checks. Alternatively, a suite-of-models approach could be used. With regard to the choice of the core model, either a first-generation New Keynesian model or a New Keynesian DSGE model would be advisable.

2. Evaluation of the current status at Norges Bank

2.1. Norges Bank's leadership role and key macro modelling choices

Norges Bank has been and still is a leading central bank in several areas of monetary policy strategy. The Bank practises a high degree of openness and transparency regarding monetary policy design and implementation. It stands out among inflation-targeting central banks in its long-held practice of publishing not only forecasts of inflation and economic activity but also of future policy rates. The forecasts of economic aggregates are not conditioned on exogenous or market-based monetary policy paths. The procedure used at Norges Bank makes sure that future policy paths are consistent with the forecasts. It ensures that policy is thought of as a strategy resulting in a reaction function, rather than just a particular sequence of one-off decisions.

Forecasts and uncertainty bands presented in the regular monetary policy reports are produced with the aid of the core macro model. Thus, Norges Bank has provided key leadership to the central banking community on how to use models for public communication of quantitative information regarding objectives, forecasts and policy strategy. Allowing public scrutiny of this information appears to have had mostly beneficial effects for the conduct of monetary policy. In sum, the Norwegian experience has provided very valuable input to the development of communication strategies at other central banks.

With regard to the use of macro models, Norges Bank has opted for the core-model approach. In fact, it stands out in terms of the consistency and stringency with which this approach is applied. NEMO is a central element in forecasting, in economic and policy analyses and in communication. This ensures a high degree of consistency across the processes of information production and dissemination.

Information from other sources is filtered and aggregated through NEMO. This is different from some other inflation-targeting banks, such as the Riksbank, which employ a suite-of-models approach. The model used by the Norges Bank is state-of-the art and belongs to the class of New Keynesian DSGE models. Norges Bank was among the first central banks to put such a model at the core of their forecasting and policy analysis system. The model is used in all four functions discussed in Section 1.

Using a DSGE core model requires strong ownership of the model-based analysis by both the staff and the policy makers. On the side of the staff, this includes not only the modellers, but also the sector specialists, the policy division, and others involved. How to maintain ownership when the new monetary policy committee is introduced from 2020 is an issue to keep in mind for the future.

Norges Bank does not rely exclusively on NEMO for all four functions. In particular with regard to nowcasting and short-term forecasting, it has developed the System of Model Averaging (SAM), which provides real-time and short-term forecasts for GDP and inflation. Jointly employing SAM and NEMO allows Norges Bank to combine state-of-the-art empirical methods to analyse the near-term outlook using a structural model focused on understanding the narrative behind medium-term developments, where data is less informative, but theory can help.

Norges Bank also stands out in terms of the use of the model for policy design. Rather than using a feedback rule or reaction function to capture the systematic, forecastable component of monetary policy, it aims to compute the model-consistent optimal policy, using a technically quite advanced optimal control approach. The loss function

employed aims at making operational the central bank mandate. Thus, the Norges Bank, in defense of its policy, can state that it does the best it can, even measured against state-of-the-art optimal control and modelling techniques. Moreover, NEMO is used to decompose the change in the policy path due to different shocks driving the economic and inflation outlook. This enhances the story-telling about what drives changes in policy.

The drawback of feeding all the information into NEMO is that the policy recommendations and the interest rate path coming out of such an exercise are very model-dependent, that is, policy is "fine-tuned" to a particular model and not necessarily robust to model uncertainty. If the causal linkages in the economy differ substantially from those assumed in the model, then the policy that appears optimal in the model may perform quite poorly in practice.

There are a number of ways to robustify the recommendations the model delivers. For example, one could evaluate simple policy rules in order to find one or more that perform reasonably well in NEMO, but are not too model-dependent. Once these rules are found, they should also be examined for robustness in other models, possibly smaller-scale models, derived under different assumptions and estimated to Norwegian data. Such small-scale models can also be used to cross-check the forecasts.

2.2. Adaptability and extensions

The Norges Bank core model approach is well thought out and consistent. However, relative to a suite-of-models approach, it may take longer to adapt the modelling framework to new questions and new issues emerging in policymaking and that are not covered by the main model. Over time, this could become a problem as more features are added to the model and none of the older special features, no longer useful, are removed. So far, the model development team has dealt very successfully with this challenge.

The original structure was enlarged in quite a successful and timely manner to cover two issues of relevance for the Norwegian economy: the analysis of the housing market and the modelling of oil-related issues. These extensions were introduced in a reasonable way, focusing on the most salient features and adjusting the framework where needed, without complicating the structure of the model too much. Adjustments included moving away from rational expectations to extrapolative expectations to capture house price persistence.

The attention paid by Norges Bank modellers to Heterogeneous Agents New Keynesian (HANK) models also seems appropriate. It is based on a sound rationale, that is, the importance of liquidity-constrained households in the Norwegian economy and the availability of micro data to refine the analytical process. It may provide an alternative model that can be employed for robustness and cross-checking purposes.

Summary
The Norges Bank approach using a New Keynesian DSGE model as core model for policy analysis, forecasting, risk management and communication is well developed, consistent and state of the art. It has been adapted and used effectively in addressing a variety of questions regarding policy and transmission channels. It is recommended to supplement the core-model approach with simple monetary policy rules and some smaller models for cross-checks and robustness analysis in order to avoid fine tuning policy to the core model.

3. Core staff and management at Norges Bank and their confidence in the use of models for policy analysis

In this section we evaluate whether core staff and management, including the governor and the deputy governors, are confident in the ability of models developed at Norges Bank to answer relevant policy questions. Our assessment is based on meetings with Governor Øystein Olsen, Deputy Governors Jon Nicolaisen and Egil Matsen, Executive Director for Monetary Policy Ida Wolden Bache and the heads of several units within the Monetary Policy Department (PPO).

The general impression is that core staff and the management of Norges Bank are confident that the current set of models and the way they have been used in the recent past are appropriate to answer policy questions. The top management displays a very collegial attitude and trusts staff members who are ultimately the main users of models. We perceived a sense of common ownership of the model used to guide the production of the interest rate path.

One positive experience associated with the use of the policy model has been the publication of the interest rate path. Norges Bank started publishing its own interest rate path in 2005, one of the first central banks to do so. Other policy makers and central banks have expressed skepticism as to whether markets could understand the conditionality of interest rate paths and whether monetary policy committee members would be able to agree on a common path (see, for example, Weber (2007)). The Norwegian experience seems to indicate that these worries are not warranted.

Another positive experience was associated with the recent extensions of the core policy model (NEMO) to include a separate housing sector and a detailed oil sector. The extensions turned out to be useful to understand developments of the Norwegian economy such as the house price boom of 2016 and the decline in oil prices in 2014-2015.

Clearly, many challenges remain. The top management expressed skepticism as to how financial stability considerations are dealt with within the main policy model. The situation in 2016 was particularly problematic when house prices were booming while the policy model was suggesting that interest rates should be lower. More generally, we perceived that policy makers at Norges Bank were concerned about the trade-off between inflation stabilisation and financial stability considerations, with recurrent references to house price dynamics. While the model has been extended to include a housing and banking sector, further work to discuss financial stability aspects is needed. The issue of normalising the level of interest rates, which is related to the current level of the natural rate of interest in Norway, and the role of star variables (natural rate of interest, potential output, and natural rate of unemployment) were also mentioned as key topics in which model-based support is expected to be needed.

The meetings highlighted two other issues that concerned the policymakers: the way expectations are modelled in NEMO and the lack of heterogeneity within the main policy model. Both issues are at the frontier of academic research and we highlight in the next few sections how to potentially address them. Our impression is that the set of projects currently developed seem well suited to addressing these concerns.

Finally, we discussed the strategy of channelling the policy discussion through the lenses of only one policy model. Our impression is that the top management fully supports the current strategy. While some interest in having a suite of models to analyse specific questions was expressed, the limited size of the staff does not seem to allow for the development and maintenance of more than one full-scale policy model. A

special appreciation was expressed for the SAM system, which has turned out to be extremely useful over time for short-term forecasting purposes.

While it seems clear that the top management is confident about and appreciates the current modelling system, it will be interesting to see if this continues to be the case with the new comittee structure implied by the law approved by the parliament in June 2019. The new law prescribes a monetary policy committee composed of three internal members and two external experts. Will new members understand the policy process? Would they agree on the strategy of channelling the discussion into the policy model? Would they want to tie their hands to a model? How would the creation of a committee influence the way the process works? These are important questions, which point to the need to develop models for cross-checks. A robustness approach also addresses the possibility that a new committee member would question the whole process, because he or she has a different core model in mind, helping to strengthen the credibility of the strategy.

Summary
Core staff and management at Norges Bank seem confident that the current set of models and the way they have been used in the recent past are appropriate to answer policy questions. We perceived a sense of common ownership of the model used to guide the production of the interest rate path. A possible trade-off between inflation stabilisation and financial stability considerations emerged as a key challenge for policy makers.

4. Advances in areas of economic research likely to be relevant for central banks

Academic research is active in many subfields of macroeconomics, and there have been substantial, measurable advances over the past 15 years. Over the next 5-10 years, we expect significant contributions in at least three areas. First, we believe there will be progress in handling nonlinearities and asymmetries due to zero lower bounds, borrowing constraints, structural breaks, regime shifts, or skewed disturbances. Linearised versions of DSGE models abstract from these features. However, more complicated solutions, where the nonlinearities are retained for inference and policy analyses, are still hard to implement for models of the size currently employed in central banks. The exploration of alternative approximation methods is underway. Second, we foresee significant advances in the way expectations are modelled, bringing into the picture heterogeneities, learning, psychological and behavioural aspects that are ruled out by the rational expectation assumption. Finally, we expect considerable progress in solving and analysing realistic heterogeneous agent models. All these advances will bring realism to the current wave of structural models and allow researchers to study the role of non-convexities when analysing the reaction of the economy to aggregate shocks.

The insights emerging from research on non-linearities, alternative expectation formation mechanisms and heterogeneity have not yet been incorporated in models routinely used for policy purposes. Nonetheless, it is conceivable that at least some aspects of this research will be relevant for policy in the future, and Norges Bank seems not only to be conscious of these developments, but is also actively working in some of these areas.

In terms of heterogeneous agents modelling, Norges Bank is at the forefront of policy innovation. An ambitious project linking state-of-the-art macroeconomic modelling and detailed micro-data is in place. The focus on household heterogeneity has been well motivated, and the initial results from the project are promising. Many key policy questions, such as the mechanics of monetary policy transmission as well as the fiscal multipliers, have been dealt with quite successfully already with two-agent models (TANK). Nonetheless, a HANK model is needed when discussing issues related to, for example, inequality, and the rich micro data available in Norway make its calibration possible.

We see two risks associated with such an ambitious project. The first risk is related to the fact that the presence of heterogeneity comes at great cost, as far as solution technicalities and computational needs are concerned. We believe it will be important to proceed in a stepwise fashion, focusing first on small-scale partial equilibrium models to understand the main mechanisms in detail, evaluating the gains from different options, and focusing model development only on the aspects deemed relevant. Such a process avoids the problem of building models that are too large and too complex to be used in the practical monetary policy preparation process. In this context, it is important to get insights from representative agent models with preferences that allow for risk (as in Caballero, 1990) and models with a few agents to measure the incremental value of heterogeneous agent models.

The second risk is associated with the fact that the project is in the hands of a small team of experts. Given the relatively high turnover of PhD economists at Norges Bank, we see a risk that the project may be discontinued if its main developer should leave. To avoid this outcome, we recommend building a team where at least two other people are fully aware of the development strategy and of the codes. The modelling unit has proven to be able to attract good economists, genuinely interested in a policy-oriented job, both from the domestic market and from the international market. The ability to hire

talented PhD economists on the national and international market is an advantage that can smooth issues due to members of the current staff leaving as a result of normal turnover.

The presentations offered during the visit to the committee did not include the recent work on non-linearities. However, we are aware of a project on GDP at risk, based on the work by Adrian et al. (forthcoming). The RISE platform, developed by Junior Maih, who is employed at Norges Bank, was not discussed during our visit. RISE collects, in a user-friendly environment, state-of-the-art methods currently used at the frontier of the academic literature and can handle non-linearities in a straightforward way. Having the advantage of being in close contact with the developer of the platform makes us think that Norges Bank will continue to be at the forefront in this field in the years to come.

Finally, some preliminary effort has been made to consider alternative expectation formation mechanisms, for example in the housing market block within the main policy model and in some Norges Bank Working Papers (see Gelain et al., 2018, among others). Additional suggestions on how to introduce alternative expectation formation schemes are presented in Section 5.

In general, our impression is that Norges Bank is already close to the frontier in areas where we expect significant progress in the near future. Central banks should follow what is going on at the research frontier and also have some researchers that do frontier work themselves. They should certainly continue to develop their own methods and handle issues that are dormant in the academic literature. However, small central banks, in particular, may not be able to keep up with the frontier in all central-banking related fields. Given the scarcity of resources, it makes sense for Norges Bank to prioritise and stay close to the frontier where its staff has a comparative advantage. In many cases, small central banks could act more like consumers of academic products. Policy units should work in cooperation with the research unit and with academic consultants and visitors. A number of examples of academic products, which could be easily implemented by central banks and could lead to sharper policy analyses are given in Section 5. Another example is the use of learning in macroeconomic models, where a lot of directly applicable work already exists. For example, a number of models in the Model Database www.macromodelbase.com can be simulated and their implications analysed under both adaptive learning (choosing the appropriate gain parameter) and rational expectations. This database offers a wealth of resources that Norges Bank modelling team could consult.

Summary
We believe that introducing heterogeneity into macroeconomic models, modelling non-linearities and considering alternative expectation formation mechanisms will be areas of research that central banks should take advantage of in the next 5-10 years. Norges Bank seems conscious of these developments and is actively working in some of these areas.

5. Areas of improvement in the current model suite

The models available at Norges Bank could be improved in a number of ways. We first suggest modifications/additions to NEMO and then discuss how other models could be strengthened or made more useful for policy purposes.

5.1. NEMO

NEMO is more than a decade old, but its structure and features make it close to the frontier models used in policy institutions. Still, there are a number of improvements that could make NEMO a better tool for policy analysis and forecasting and reposition it at the frontier of the policy models without excessive costs in terms of modelling and estimation.

5.1.1. Trends

One area where NEMO lags behind similar models used in policy institutions is in the treatment of trends. Currently, NEMO features only transitory dynamics around a deterministic steady state, and trends are eliminated from the data prior to parameter estimation. Trend estimates are constructed using a variety of procedures ranging from sector experts' long-term forecasts and standard statistical filters to infrequent projects trying to measure long-term developments in the Norwegian economy. This variety of procedures calls into question the consistency of the trend estimates. Furthermore, while the approach of building models featuring only transitory dynamics and filtering trends out of the data used for estimation was common in the past, it is suboptimal, throws away potentially useful information and impedes the production of model-based forecasts for the level of data (right now only gaps are forecasted and trends added ex-post). This approach creates an artificial separation between trend-induced fluctuations, which are determined outside the model, and cyclical fluctuations which are, instead, at the centre of the core-model-based analysis. There is substantial evidence that fluctuations in the trend of relevant macroeconomic variables (e.g. potential output) are not necessarily independent of cyclical fluctuations. Indeed, both transitory and permanent shocks may affect macroeconomic conditions. This could easily occur, for example, when the economy features R&D or investment in intangibles. In this case, transitory shocks affect not only the cyclical pattern of macroeconomic variables: through their effects on R&D, patents, or intangible capital they may also influence the potential long-run path of the economy. Similarly, because of optimisation and intertemporal substitution, permanent shocks may influence both the potential and the gap. Thus, the separation of the movements in the observable macro-variables into trends and cyclical fluctuations may lead to incorrect policy conclusions.

Many structures used by academics and a number of models employed in policy institutions nowadays account for both permanent and transitory fluctuations, where the former are typically driven either by technological improvements (a combination of TFP and investment-specific technological progress) or by preference shifts. Models with these features imply balanced growth path restrictions, where certain real variables grow at the same rate. However, such restrictions need not hold in many countries. There are interpretation gains in allowing NEMO to capture the stochastic trends present in the data and analysing the channels through which permanent disturbances generate business cycle-like fluctuations in small open economies (along the lines of Aguiar and Gopinath, 2007). However, we also see advantages in having flexible trend specifications, which allow deviations from balanced growth in estimation, when forecasting in the medium run and when performing scenario analyses, and can easily adapt to changes when they occur.

One simple way to introduce flexibility in a policy model was suggested in Canova (2014). Such an approach has been successfully used at the Riksbank and the Bank of Canada to account for those trends present in the data that the model cannot capture. Researchers in the modelling unit should also acquaint themselves with the work of Kulish and Pagan (2017), which allows models to be solved and estimated when there are predictable structural breaks due, e.g., to policy announcements or policy-induced permanent regime switches. The technology they develop is particularly relevant for an economy like Norway and expands the range of counterfactuals that could be performed and analysed within NEMO. For example, the methodology allows researchers to analyse what would happen in the transition period when a central bank announces a credible switch between an inflation and a price level-targeting regime, or when a particular inflation target is adjusted over time in an anticipated, predictable, but not always fully credible manner.

5.1.2. Correlations and prior specification for the parameters

It is nowadays standard to check how policy models perform in-sample by reporting correlations between endogenous variables and between estimated exogenous shocks. It would be advisable to do the same in NEMO. In particular, it would be useful to know if endogenous variables are comoving along the business cycle in a way that is consistent with prior views about cyclical fluctuations in Norway. In addition, while shocks are assumed to be uncorrelated over time and across shocks, estimated shocks rarely satisfy such an assumption. Deviations from the uncorrelatedness assumption provide evidence of misspecification, and this information can be useful when respecifying certain aspects of the model.

Currently, the parameters of NEMO are estimated with Bayesian methods and the prior for the parameters is endogenously specified. Because such a prior specification is designed to match the variability of the endogenous variables, it may be possible that cross correlations among variables are not matched well. It would be useful to know if this is the case and whether important distortions occur. If this is the case, we recommend using both variabilities and correlations to set up an endogenous prior for the parameters. In general, the role of the endogenous prior and its exact specification should be carefully evaluated via sensitivity analysis and the results compared with those obtained with standard exogenous prior specifications. It is also highly advisable to specify endogenous priors using a training sample of data to make sure that the prior and the likelihood contain separate information. Such a training sample could be the pre-inflation targeting period. If, for some reason, data from this regime cannot be used, data for other resource-rich, small open economy inflation-targeting countries could be employed.

In general, given that, for policy purposes, all available information is filtered, it is important to perform reality checks so that the narrative the model delivers is credible and sustainable. Reporting posterior moments and correlations could help in this respect. Tracking over time the real-time forecasting performance for output and inflation could also enhance the trustworthiness of the structure.

5.1.3. Sources of fluctuations

Currently NEMO is estimated with 26 observable variables and 26 shocks. As we discuss later in the report, the use of a large information set in estimation is desirable, since it helps to reduce standard errors, forces NEMO to capture a wide array of cyclical dynamics and makes policy counterfactuals more realistic. However, it is unlikely that there are truly 26 important independent structural disturbances driving the Norwegian economy. It is more likely that many of the estimated shocks simply absorb the misspecification present in the structural relationships, error-in-variables (particularly relevant in the case of star variables) and noise present in the data. These shocks have no structural interpretation; still, if they are left unrestricted, they may account for a large portion of the variability of the endogenous variables, making policy analyses difficult to interpret. We see two ways to deal with the problem. One recently suggested by Ferroni et al. (2017) is to allow the prior variance for the shocks to be zero. A posteriori, some

shocks will be inactive (will have zero variance) and only the remaining shocks will explain the variability of the endogenous variables. In this way, one lets the data decide which of the 26 shocks should truly be in the model. However, it is possible that shocks have non-zero variance because they enter an equation that is misspecified. An alternative approach is to treat disturbances of relatively minor policy interest explicitly as measurement errors and bound the proportion of the variance of major macroeconomic variables explained by these shocks with a tight prior specification. The latter approach can effectively limit the misspecification captured by the shocks and provides a unified framework for using additional information in estimation (see later on).

One additional concern comes from the fact that supply shocks do not play an important role in NEMO. The focus on the gap variables and the elimination of trends from the data used in estimation may be a reason for this fact. However, since in Norway the unconditional correlation between GDP growth and domestic inflation is negative, supply-type shocks must be important. Rebalancing the relative importance of demand and supply disturbances in the model and presenting estimated in-sample correlations to measure the estimation outcomes could help to more realistically anchor estimates and policy prescriptions.

5.1.4. Forecast evaluation

For internal purposes, it would be desirable to construct a real-time evaluation of the forecasts produced by NEMO. To do this, it is necessary to store vintages of data and versions of the model available at the time forecasts are made. Internal forecast evaluation exercises are common in policy institutions, may enhance the credibility of the policy model used, and provide useful information if systematic biases appear. At times, the results of such investigations are made public, see e.g. Iversen et al. (2016). Similarly, the Bank of Canada has recently released two working papers (one of them published in an academic journal). In the first paper, Champagne et al. (2018a) evaluate the real-time performance and the forecasting properties of the staff's estimate of the output gap. In the second paper, Champagne et al. (2018b) provide a systematic evaluation of the staff's forecasts for GDP, inflation and interest rates. An internal document evaluating the staff's estimate of the Norges Bank output gap has been produced and is currently being transformed into an academic paper. We recommend that the quality of the staff's projections at Norges Bank should also be documented.

5.1.5. Bounded rationality

In NEMO, as in the vast majority of general equilibrium models used in policy institutions, agents have rational expectations and the equilibrium of the model strongly relies on this assumption. The rational expectations paradigm is appealing because it requires consistency between perceived and actual laws of motion for the endogenous variables, and avoids myopic behaviour, persistent mistakes, and counterintuitive conclusions in response to policy changes. However, the rational expectations assumption is a tight corset in many practical situations: it does not permit waves of exuberance or pessimism among market participants, nor does it allow for inattention to certain news. In addition, as is well known by now, rational expectations generate puzzling dynamics in response to forward guidance policy announcements. To the extent that the forward guidance puzzle appears to be less of a problem in NEMO, it would be interesting to explore which feature of the model makes the issue less important, both from an academic and a policy point of view. Some preliminary analysis, which could be refined and transformed into a paper, is provided in Bergholt et al. (2019).

It is also worth exploring how alternative expectation formation schemes would impact on the dynamics produced by exogenous shocks and on the policy conclusions that are derived. For example, least squares or Bayesian learning could be considered, and the work of Slobodyan and Wouters (2012) and the Model database (www.macromodelbase.com) could constitute the starting point for the investigation. Learning tends to generate additional persistence in the dynamics of the endogenous

variables. Thus, realistic persistence in the responses of macroeconomic variables to shocks can be obtained without forcing unrealistically persistent exogenous processes. Learning can be easily incorporated in NEMO without affecting parameter identification or complicating estimation and policy analyses. Learning, however, is not designed to solve other shortcomings of representative agent models, such as that consumption decisions depend only on the real rate and not on wealth or income.

In academia, the macroeconomic literature has also started using models where agents have bounded rationality or are inattentive. Bounded rationality could account for exuberant aggregate behaviour and/or eliminate puzzles in response to policy announcements. The bounded rationality literature has, for a long time, been theoretical and its implications for macroeconomic analysis elusive. However, operational behavioural new Keynesian models where agents have bounded rationality have started to appear in recent years. These models are appealing because differences in rational behaviour are summarised in one parameter (see, e.g. Acemoglu and Jensens (2018); Gabaix, 2018). Bounded rationality of this type could also be easily integrated into a version of NEMO. The addition would not compromise its current structure nor require profound changes in the way it is estimated and could help to provide crucial inputs in the policy process, for example when discussing housing market dynamics.

We are aware that Norges Bank has started exploring agent-based models, where a fraction of the agents of the economy do not optimise intertemporally and instead act on the basis of simple rules. Agent-based models may also help to account for exuberant/pessimistic behavior. Our impression, however, is that such a framework of analysis requires significant changes to NEMO. Thus, we believe that the role of agent-based modelling for macroeconomic dynamics could be more fruitfully examined in a smaller-scale satellite model.

5.1.6. Using additional information for estimation and forecasting

As mentioned, NEMO is currently estimated using 26 observable variables, which include all the main macroeconomic and financial aggregates, prices, and trade variables. However, important variables such as stock and bond prices, consumers' and firms' survey expectations, flash estimates of inflation or production, or other information that may help Norges Bank to assess in real time the state of the economy is not used. We recommend the modelling unit to consider adding this information in both the estimation and the forecasting process and make use of mixed frequency devices to combine quarterly data and higher frequency information. In particular, data on agents' future expectations, first releases, nowcasts, and daily financial market information can be used to improve real-time estimates and reduce standard errors in forecasting, even though these variables do not explicitly appear in the model. To do so, it is sufficient to append reduced form equations linking the states or the observables of the model to the available data using a data-rich approach.

Let x(t) denote the endogenous variables and let x(1t) denote those capturing the state of the economy and let them be measured at the quarterly frequency. Then, any informational variable z(t) can be used in estimation by positing, for example, a linear relationship with the states, $z(t)=a+ bX(1t) +u(t)$, where b measures the information content of z(t) and u(t) is a measurement error. Joint estimation of the parameters of the model, of b and of the variance of u(t) would allow information about z(t) to be incorporated into parameter estimates and forecasting. Furthermore, estimates of b for different z(t) variables would allow researchers to evaluate the relative importance of different pieces of information for the state of the economy, and the variance of u(t) the relative noise present in different z(t) measures. Researchers at the Federal Reserve Bank of New York have shown that such an approach is useful to incorporate additional variables in the model and sufficient, for example, to account for the information financial markets provide for macroeconomic purposes without explicitly modelling the macro-financial links (cf. Del Negro and Schorfheide, 2013, and Gelfer, 2019) .

The same approach can be used to combine data coming at different frequencies and/or irregularly sampled. In this case, z(t) is a high frequency signal (say monthly or weekly)

providing noisy information about the state of the economy. The approach can also be employed when multiple indicators of the same model quantity, for example multiple measures of the output gap or of inflation, are available. Here, z(t) is a vector of variables which is related to a subset of the endogenous variables x(t). Enlarging the information that NEMO uses in estimation is easy, since it only involves appending linear equations to the current structure and does not require modification of its core. Using additional information is likely to produce more precise, real-time estimates of the state of the economy, reduce posterior parameter uncertainty and, in general, make it easier to derive policy conclusions and to forecast in the medium term.

A similar setup can also be employed to incorporate into NEMO the wealth of micro information collected by Statistics Norway. Here, z(t) could be the deciles of income distribution, measures of wealth, income or wage inequality. Using micro data in estimation would not only bring new information into the estimation/forecasting process; it would also help to measure the effects of macroeconomic shocks on microeconomic aggregates without explicitly modelling the micro-macro interactions. Thus, the approach would make the model more flexible, allowing it to capture the information present in the available data, without requiring a modification of its core. Models of this type (''practical DSGEs'') may be superior to semi-structural specifications for two reasons. They maintain the optimisation features and the general equilibrium implications present in standard models; they are modular so that variables can be introduced or eliminated when not needed. Policy models should be more flexible than academic models because policy institutions need to have a bird's eye view of the whole economy, while academics can concentrate on an aspect or sector to highlight particular mechanisms that may be present in the data. However, flexibility should not come at the cost of compromising the core relationships. The approach we suggest satisfies both concerns.

5.2. Other models

The other models used in the framework of policy analysis are adequate, but upgrading is probably advisable for some of the existing tools. The SAM package was developed a number of years ago and has not been fully adjusted to reflect the type of models used by academics and/ or other policy institutions. For example, BVARs, models with stochastic volatility or time-varying coefficients are not included; neither are dynamic multicountry panel specifications. It may be appropriate to extend not only the set of models but also the way they are estimated to better take into account sampling and specification uncertainty. We also recommend pursuing further the use of simple mixed frequency BVAR models (see Aastveit et al., 2014) as they can effectively combine high frequency information coming from financial and survey variables and macroeconomic aggregates. Alternative weighting schemes, based on log-scores or linear and nonlinear opinion pools, could also be further explored (see Bjørnland et al., 2011).

Given the abundance of microdata for Norway, we believe there is room to better integrate the information that micro and macro data provide for nowcasting purposes, perhaps employing recently developed big data machine learning techniques.

The new SMART system offers the advantage of easy access to real-time data vintages and corresponding real-time forecast evaluation in a systematic manner. Given the limited amount of resources, however, there may be tension between investing in upgrading the models and the way weights are computed, which is important, and investing in a new platform to compute combinations.

Summary
NEMO should explicitly incorporate trends to allow forecasts of the level of the variables. Correlations among endogenous variables should be checked. The relative importance of various shocks should be evaluated and out-of-sample foreast evaluation of staff projections regularly performed. Additional data should be used for estimation of NEMO. The model could be expanded to potentially deal with agents featuring bounded rationality. SAM should be upgraded.

6. Areas of future, longer-term model development

We divide our recommendations regarding the areas of future longer-term development in three parts. First, we provide suggestions on how to robustify policy prescriptions and cross-check the policy and forecasting information NEMO provides. Second, we highlight three topics that could be investigated in satellite models. Finally, we consider some strategic issues.

6.1. Additional models and robustness analysis

As already mentioned, although there are advantages in having a single comprehensive model when performing counterfactual exercises and communicating policy conclusions to the public, we see benefits in endowing the modelling unit with a number of additional models to cross check the credibility of the conclusions derived from NEMO, to investigate questions NEMO is currently not designed to answer, or to provide more in-depth analyses about aspects of the economy that could become important in certain states of the world. These models could be used in policy analyses, forecasting, and risk assessment exercises. A standard toolbox could include multivariate time series models as well as structural BVARs, structural factor and/or structural Markov switching models. While all these frameworks may be less appealing from a story-telling point of view, as they are silent about agents' interactions and expectations, they relax important cross-equation restrictions structural models impose on the data and are generally more robust to misspecification of the structural relationships, omission of variables and sectors, improper assumptions, or incorrect parameterisations of adjustment costs or nominal rigidities. Many central banks routinely compare the forecasts, the historical decomposition exercises, and the counterfactual experiments of their baseline framework with those produced by one or more of these models. Bayesian SVARs are particularly appealing for this purpose: they are simple to build and estimate, can be made relatively large without overwhelming computational costs, require minimal maintenance once they have been tuned up to the local needs, and have a long-lasting record of good performance for different variables, in different countries, and in different states of the world. Moreover, Bayesian SVARs can be useful for structural analysis: they can provide answers on the effects of shocks that are not included in NEMO (for example, an immigration shock) or to discuss the transmission mechanism of selected shocks on variables that are not included in NEMO (for example, the effect of an oil shock on the labour force participation rate). Many Bayesian SVARs have been estimated over time (and published in international journals) by researchers at Norges Bank for forecasting purposes and for structural analysis. We recommend developing and maintaining one or more such models and using them routinely in the policy process. Collaboration between policy units and research seems particularly fruitful in this area. Given the high level of expertise available at the Norges Bank, Markov switching models could alternatively be considered for cross checking NEMO outcomes.

We also see advantages in building small structural models designed to address specific questions that may arise in the policy process. While there are obvious general equilibrium gains when aspects previously missing are fully integrated in an existing model and their role understood and quantified, we believe that for certain questions it is worth building smaller scale models that examine only certain aspects of the economy and may not take into account general equilibrium interactions. The HANK project is an example. Once the model is fully operational, it could enhance our understanding of housing market developments in Norway, how monetary policy decisions influence the debt burden of different types of households, and how income and wealth inequality may evolve in response to macroeconomic shocks. These exercises provide disaggregated information to policymakers, which complements the aggregate view that NEMO provides, without affecting the regular policy rounds and the forecasting

exercises that would still be based on NEMO. Work concerning the effects of immigration on labour market outcomes, wage structure, and inequality is another theme of great policy interest that could be examined in a satellite model. Here, the details of the Norwegian labour market could be carefully accounted for while the macroeconomic effects of labour market adjustments could be summarised with a small set of parameters that have a counterpart in NEMO.

We also view favourably the idea of building simple models to evaluate the reasonableness of NEMO policy recommendations on a case-by-case and ad-hoc basis. For example, the idea of comparing the interest rate paths predicted by the model against those produced by simple interest rate rules is sound and useful. Similarly, examining the interest rate paths generated by robust control exercises in simple models could give policymakers stronger confidence in the choices they have to make.

Ideally, one would also like to know how the addition of the oil or the financial sectors to NEMO have changed the way macroeconomic disturbances are transmitted, the content of historical decomposition exercises, or policy conclusions reached in particular episodes. To examine such an issue, it is necessary to keep alive different versions of NEMO and analyse historical episodes with the vintage data. Such an exercise would also help to assess if all the features of the current version of the model are truly needed to derive the best policy conclusions and to have the best overview of the Norwegian economy.

6.2. Examples of satellite models

6.2.1. International aspects

Currently, international scenarios are generated externally to the modelling unit and the unit for policy and analysis by economists in the international unit. These scenarios are constructed using models external to the Norges Bank and developed at the IMF. Since IMF models are used in many countries for this purpose, reliance on such models has the advantage of making consistent world projections for all countries. However, it also limits the possibility of integrating NEMO into a model of the world economy and of explicitly accounting for the channels of transmission of international disturbances that affect the Norwegian economy. A number of policy institutions have moved away from using external inputs in their policy process and have instead tried to develop a coherent framework where domestic and international channels of transmission of disturbances are contemporaneously modelled. Nesting NEMO into a model of the world economy could be complicated. A feasible alternative would be to produce world scenarios using structural time series models, such as a structural BVAR or a structural Bayesian FAVAR. Such a set-up can explicitly account for foreign-domestic interactions and for important channels of transmission without an explicit structural model of the world economy. The staff in the research unit could contribute to developing such models and compare their performance to the IMF models. However, if successful they could be routinely run, maintained and upgraded by researchers in the international unit.

6.2.2. Financial stability considerations

Since the onset of the 2008 financial crisis, several central banks have included a financial sector in their policy models to evaluate the importance of macro-financial linkages. In addition, they have started measuring the effects of monetary policy decisions on financial stability, and some have included financial stability concerns into the central bank objective function. NEMO does not currently feature an explicit financial sector interacting with the world economy, but it does have a housing sector and credit considerations are taken into account. Given the importance of housing and the role of credit expansions for the Norwegian economy, this seems to be the first priority. However, we believe that a thorough analysis of the consequences of monetary policy choices on banks and non-bank financial institutions' balance sheets is an important step in assessing the risks to financial stability when particular interest rate paths are chosen. Furthermore, financial considerations play no direct role in the loss function

used to derive optimal policy and the Taylor mimicking rule. They are captured by a constant term in the interest rate rule. Financial fragility is important for monetary policy because it creates downside risks for GDP and inflation. Given that the central bank mandate is to employ flexible inflation-targeting to promote stable output and employment and to counteract the buildup of financial imbalances, alternative ways of including financial stability considerations in the loss function could be explored (e.g. targeting credit growth). In addition, the role of macro-prudential policies should be carefully evaluated and the interaction between monetary and macro-prudential policies fully fleshed out. It seems also useful to integrate macro stress-testing exercises and risk analyses into the routine policy process. The CISS indicator developed at the ECB could serve as a starting point. Recent work by Adrian et al. (forthcoming) provides a simple framework to evaluate GDP at risk.

Since taking into account financial fragility may involve drastic changes to the structure of NEMO to allow for asymmetric shocks and, possibly, extreme events, we recommend examining financial fragility issues in a smaller satellite model, where nonlinearities can be taken into account and different risk aspects examined. A first step in that direction is constituted by the paper published by Gerdrup et al. (2017).

6.2.3. Fiscal policy and the oil fund

Fiscal policy as a stabilisation tool is currently disregarded in NEMO, and the sovereign oil fund plays no role other than helping to ensure that an equilibrium exists through the net foreign asset position of the economy. While monetary policy still has plenty of ways to affect the real economy, stabilise inflation and promote growth, one could conceive likely situations where external causes would drive the nominal interest rate at the zero bound. In these situations, the economic stimulus that expenditure programs and/or tax cuts provide would need to be carefully evaluated. The first step in this type of exercise would be the calculation of simple multipliers and an analysis of the relative power of expenditure increases vs. tax cuts in stimulating aggregate demand. Evidence from the literature on fiscal policy in small open economies suggests that the fiscal stimulus could have smaller effects on aggregate demand than expected and that supply-side policies could be more effective than demand-side policies. In general, contingent information about the role of fiscal policy in zero lower bound situations could help policymakers to better understand the available options.

Similarly, the oil fund provides an important buffer stock that can be used to stimulate or stabilise the economy in case dramatic situations develop. For this reason, it is important to evaluate how the presence of the oil fund reduces the effects that uncertainty disturbances may have in the economy. Such an investigation could help policymakers to better assess the quantitative risks that Norway faces when stressed situations develop in the world economy.

6.3. Strategic considerations

The models used in academia are continuously evolving over time and often in different directions. A number of alternatives are explored simultaneously, and consensus on how to model certain features of the economy emerges only after some time. Consensus is typically reached faster if simple additions are found (see e.g. Calvo pricing, habit in consumption, etc.). However, it is somewhat difficult for policy institutions to measure in real time the gap between their models and the academic frontier, precisely because the frontier is a fuzzy concept. Thus, from an operational point of view, it is important that policy institutions take stock of academic advances that could help them understand better how the economy works, but not necessarily jump on existing bandwagons. In particular, being at the frontier in the policy process does not necessarily mean dressing their models in the latest academic fashion. Instead, it requires adaptation of those developments to local needs.

Central banks should be pragmatic and try to incorporate in their models issues at the frontiers of economic research either by clever choices (as, for example,

was done in the case of long-term assets) or by collaborating with academics on developments that are truly needed. The interaction between central banks and the academic world is crucial for both partners, and while academics may offer tools or solutions to problems, policy institutions should highlight the problems and the incongruences of academic models when applied to real world monitoring.

Thus, we advise modellers at the Norges Bank to keep an eye on academic developments and on opportunities for easy adoption of model features that have received substantial support in the profession. When there are issues that are critical for making models useful to policy makers that have not been developed sufficiently in the available literature, it is a good idea to involve academics or researchers from other institutions as consultants and visitors that can help the modelling team make progress.

It is typical in policy institutions to enlarge the models used in the forecasting round over time with new aspects previously neglected or to build satellite models to address specific questions that arise in the policy process. However, increased size comes at a cost: model solution and estimation become more complicated, the transmission mechanism of shocks is often obscured, and income and substitution effects are not clearly separable. Furthermore, it is well known that in forecasting simple models are comparable, if not preferable, to larger ones. For all these reasons, it is conceivable that policy models can also shrink. Features deemed unimportant to draw policy conclusions can be substituted with simpler ones or with some special ad-hoc choices and features that neither benefit nor hinder forecasting should be slowly phased out. The recent example of the Riksbank, where search and matching frictions were introduced into RAMSES at one stage and taken out a few years later, because the reality of labour markets in Sweden strongly deviates from the suggested paradigm, and replaced with a wage bargaining framework, is a good example of model simplification. Similarly, following the financial crisis, there has been an effort to model the link between financial markets and the real economy. However, when it comes to forecasting, having a detailed structure or simple reduced form equations linking relevant financial variables with real variables and inflation appears to be sufficient. For example, the Federal Reserve Bank of New York now maintains two versions of the model they use for policy purposes: one with the detailed macro-financial linkages, another where the main core is augmented with ad-hoc relationships associating the two sides of the economy. We recommend the modelling unit to consider proceeding in the same way with NEMO. Simplifications that maintain the main thrust of the existing structure and do not compromise on interpretation or forecasting performance should be attempted in order to focus the model to a greater extent on the important features of the Norwegian economy. Different versions of the model should be kept alive to check the robustness of the policy conclusions and the main insights of the economic analysis.

Summary
Norges Bank should develop models for cross checks and build credible international scenarios. Satellite models could also be used to analyse risks, fiscal policy and other issues that could considerably complicate the analysis using NEMO, if added. NEMO could also be simplified and features deemed not crucial eliminated. It is important to use human resources in the most effective way and concentrate model development only on the issues of first importance. Collaborations with the academic world and with other central banks is advised.

7. Organisation of model development

7.1. Current organisation of modelling activities at the Norges Bank

Seven units are involved in the use and development of models at Norges Bank (see Table 1). The PPO/FST Modelling Unit (MG) is the main unit responsible for developing the Forecasting and Policy Analysis System (FPAS) and its two core models: the policy model (NEMO) and the short-term average model (SAM) (see Chart 1). The MG is part of the monetary policy wing (PPO), but also serves the financial stability wing (FST). For example, it is developing models of growth at risk to predict financial vulnerabilities, which can serve as an input in macroprudential policy, as well as a Markov-Switching version of NEMO to analyse the optimal response of monetary policy to increasing financial imbalances. The MG has seven employees working on monetary policy models.

The main user of the FPAS is the PPO unit for policy and analysis (PA), which has 18 employees. The PA is responsible for monetary policy preparation including the Norges Bank forecasts. As such, it is responsible for running SAM and NEMO and is the main counterpart of the MG. The PA interacts with the MG in a number of domains. First, it interacts on the development of NEMO and the modelling infrastructure more generally. Second, when running the model it makes use of the MG as a helpdesk. It also develops and runs models for domestic subsectors, which are used to cross-check NEMO's analysis. One ongoing MG project is building SMART (System for Model Analysis in Real-time), an integrated Mat lab/Java-based toolbox that compares and evaluates forecasts from different models within an integrated database and user interface.

There are three additional units providing inputs in the forecasting and policy preparation process. The PPO's international unit (INT) is responsible for developing and running empirical models for the international economy. This includes forecasts for the main trading partners of the Norwegian economy. The INT unit has nine employees, six working with international analysis including oil market analysis, three with IMF-related issues, and uses the IMF's Global Projection Model (GPM++) and the IMF's Global Integrated Monetary and Fiscal Model (GIMF) for projections and scenarios, respectively. It is a member of the GPM network. Attempts at building a GVAR from scratch to get a model that is up to date and includes Denmark (an important trading partner of Norway not covered in the GPM) were not considered sufficiently convincing.

Some of the financial variables in the forecast are provided by units in the financial stability wing. Forecasts for bank interest rates are provided by FST's banking unit, and forecasts for house prices and credit are provided by FST's macroprudential unit. One of the main developments in NEMO following the great financial crisis was the incorporation of a housing sector with a long-term mortgage debt market and a behavioural model of house price forecasts. In this effort, the MG has taken on board some of the requirements coming from those FST units.

Finally, there are two additional units in the monetary policy wing developing models and providing model-based input in the policy process. On the one hand, PPO's research unit (FA), which consists of 12 economists, serves both the monetary policy and financial stability wing. The research unit provides research-based support, devoting 50 percent of its time to directed research, which is defined and evaluated by the policy units. For example, the FA was recently instrumental in developing the oil sector block of the expanded NEMO model in 2017. It has also developed a number of BVAR tools that can be used to cross-check some of the core NEMO analysis. On the other hand, the monetary policy strategy unit (UP) has six employees. This unit provides alternative small-scale models for monetary policy analysis and policy rules, thereby providing robustness checks of the main forecasting and policy process. The search for

a robust policy rule for Norway is still ongoing after disappointments with simple rules following the financial crisis. This unit also has the ambition to build a number of smaller-scale macroeconomic models (BVAR, semi-structural models) that can be used on the one hand for reality checks and on the other for robust policy analysis.

7.2. Assessment and proposals

Given the above, is model development at the Norges Bank organised appropriately? Given the central role the main policy models (SAM and NEMO) play in the forecasting and monetary policy preparation process, the organisational set-up, whereby the development and the use of the main models in the FPAS are separated into different units, seems appropriate. It ensures that the modelling unit can focus on the longer-term development of the FPAS without being unduly distracted by the quarterly policy cycle. At the same time, it makes clear that the unit for policy and analysis "owns" the FPAS as its main user for forecasting and monetary policy analysis. Such an arrangement requires regular interaction and feedback between the users (PA) and the developers (MG). This happens naturally during the policy cycle as the MG serves as a helpdesk for the PA. What is less clear is how the user requirements for the medium-term development of the FPAS are specified. Recent developments in NEMO and SAM stem from priorities elicited from the users (e.g. the extensions of NEMO with a housing sector and oil sector). However, is there an explicit model development strategy, possibly as part of the overall strategic objectives of Norges Bank? If not, we believe it would be desirable to set up such a strategic process.

Second, the modelling unit is quite small (seven out of 54 employees in PPO), which implies that, in addition to the necessary maintenance work, only a few development projects can be entertained at any time. Current examples of such development work are the HANK models, SMART, MS-Nemo, and analysis of forward guidance in Nemo. At the same time, modelling activities are quite dispersed across various units in PPO. This raises a number of questions. First, is the allocation of resources devoted to modelling activities appropriate? Second, how are the modelling activities coordinated across units? Our visit did not clarify how the modelling activities are coordinated. For example, the modelling unit is developing a HANK-type model, which is well-motivated from a policy perspective, but it is not obvious why this is done in MG and not in the research unit, where this state-of-the-art research at first sight would fit better and could lead to synergies with other researchers. Another example is the work on a small-scale BVAR with long-run priors and sign restrictions to robustify the medium-term forecasts in the monetary policy strategy unit. This is very useful from a cross-checking perspective, but it was unclear to what extent this BVAR differs from those developed and used in the research unit. Moreover, was there an interaction with the MG and the PA to decide the most useful specification?

In order to optimise resource allocation to modelling activities, avoid overlaps, and encourage synergies, it may be worth considering some of the following proposals. First, to the extent that the monetary policy strategy unit has the ambition to develop a suite of BVARs and less structural tools, something that we would encourage to robustify the forecasting and policy recommendations coming from NEMO, it could be useful to better integrate the resources devoted to model development activities in both units (MG and UP), for example, in the form of joint projects. A further possibility could be to integrate the two units into one. This could promote feedbacks between structural and other less structural models and stimulate synergies in monetary policy analysis (like forward guidance). However, larger central banks have a policy strategy division separate from the modelling division for good reasons. For a smaller central bank, these reasons need to be balanced against the allocation of limited resources. An advantage of having a separate strategy unit could be to have a group that focuses on questions of policy strategy using a variety of models and tools, while the modelling unit has a natural tendency to focus on questions that can be handled with the core model, or extensions of that model.

Second, it may be worth setting up a Model Development Group coordinating model development across Norges Bank. This group could develop a suite-of-models strategy, encourage information sharing about model development activities across units, discuss policy requirements in the various areas, and monitor the deliverables of such modelling activities.

Third, in order to devote more time to model development activities, it may also be worth thinking about how to outsource aspects of model maintenance. As a rule, owners of the model should maintain them. However, in order to relax resource constraints, one might envisage outsourcing some of that maintenance to externals, such as PhD interns or selected visitors.

It is essential to formulate a general development strategy for the years to come, stressing medium- and long-term goals, identifying avenues of development that are more likely to give a larger payoff, and assigning existing human resources to model development, to maintenance and to upgrading of existing tools and facilities. A better integration of the modelling unit with the monetary policy strategy and research units is likely to provide significant externalities that can reduce the human resource constraint. For example, the monetary policy strategy unit could build and maintain models used for cross-checks, and the research unit could be in charge of developing satellite models, either as a part of their directed research or as their own research output. Board seminars could also help the management to get a better feel of the potentials of various projects and developments. Similarly, academic and research visitors should be exploited to construct satellite models, to provide training for local staff and to upgrade existing facilities. PhD interns could also be employed for this purpose. The experience students acquire in the process would be far-reaching, giving them valuable skills and providing the conditions for long-lasting relationships. Norges Bank has already a well-established PhD internship programme with the explicit goal of producing research papers. A policy version of the programme could be a relevant experience for many candidates (both local and foreign-based) with a genuine interest in policy issues.

Building networks with modelling teams from other (commodity-producing) small open economies could also ease the human resource problem. The networks that have been created, for example of central bank researchers in the euro area, have proved to be a good way to exchange information and codes, to engage in collaborative efforts on specific themes of interest and to conduct effective cross checks of policy exercises. Modelling issues are quite specific to the structure of a small open economy with an important commodity sector like Norway. Thus, model development requirements might be quite different from those needed for large, relatively closed economies, such as the euro area or the United States. It may therefore be advisable to develop and maintain a network of modellers in small open economies. Norges Bank could take the lead in organising networks of this type and then rely on international institutions, such as the BIS or the IMF, to enlarge the scope of the initiatives. The conference scheduled for the autumn of 2019, to be organised together with the Bank of Canada, Reserve Bank of Australia, Reserve Bank of New Zealand and Riksbank could be a seed in the development of such a network (see https://www.riksbank.se/en-gb/press-and-published/conferences/2019/business-cycles-in-small-open-economies---call-for-papers/). Model team representatives of each central bank could use this occasion to share experiences and codes in a day-ahead event. The current group could be extended to other countries like Chile and Peru, which have an important commodity sector and active researchers. International institutions such as the BIS or the IMF could also be invited.

Finally, Norges Bank's researchers could use publicly available models for the analysis of particular model assumptions and implications for the transmission of policy changes. There are many free resources that could considerably reduce the human resource costs of building models used for cross checks.

We offer two final considerations. While the work done in the modelling unit is of high academic quality, efforts to disseminate the output through international journals have been limited and more concentrated on SAM. While policy research has different outlets

from academic research, it cannot be relegated only to working papers. It is imperative for the international visibility of the Norges Bank that policy notes are transformed into polished and publishable research, that the output is presented at international conferences, and that the tools developed by the unit get proper credit. We believe such an approach would also facilitate recruiting, connect the modelling unit more closely to the academic world, and give valuable returns to the institution as a whole.

We also believe that periodic external evaluations, say every five years, would help to keep model development activities focused and allow the improvements over different vintages of policy models to be examined. Recurrent deadlines would also give incentives to researchers in the modelling units to document as far as possible the advances made, providing valuable input in the policy process, especially when the format or the members of the monetary policy committee change. They would also help to provide a stimulus to compile a forecast record of different models for the main macroeconomic variables that would give quantitative content to the external evaluation process.

Summary
Model development at Norges Bank is organised appropriately, but we recommend more cooperation among units and some outsourcing of model maintenance/upgrading. We advise building a network with modelling teams of other resource-rich, small open economies. We stress the importance of documenting model development (and more generally policy work) in the form of polished and publishable policy research.

Table 1: Responsibilities for models at Norges Bank

Unit	DSGE/policy models	Forecasting models
PPO Research unit (FA)	Research based support	Research based support
PPO/FST Modelling unit (MG)	Responsible for developing NEMO. Project on developing heterogeneous agent model ("HANK")	Responsible for developing and running SAM
PPO Monetary policy unit (PA)	Responsible for running NEMO (and iterating with MG on development). Responsible for the final forecasts.	Responsible for developing and running empirical models for domestic developments. Responsible for the final forecasts.
PPO International unit (INT)		Responsible for developing and running empirical models for international developments.
FST Banking unit		Forecasts of bank interest rates.
FST Macroprudential unit		Forecasts of house prices and credit
PPO Development and project unit (UP)	Theoretically-oriented models for policy analysis	

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