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Review of macroeconomic modelling in the Eurosystem: current practices and scope for improvement

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Contents

Abstract

This paper provides an assessment of the macroeconomic models regularly used for forecasting and policy analysis in the Eurosystem. These include semi-structural, structural and time-series models covering specific jurisdictions and the euro area within a closed economy, small open economy, multi-country or global setting. Models are used as analytical frameworks for building baseline projections and for supporting the preparation of monetary policy decisions. The paper delivers four main contributions. First, it provides a survey of the macroeconomic modelling portfolios currently used or under development within the Eurosystem. Second, it explores the analytical gaps in the Eurosystem models and investigates the scope for further enhancement of the main projection and policy models, and the creation of new models. Third, it reviews current practices in model-based analysis for monetary policy preparation and forecasting and provides recommendations and suggestions for improvement. Finally, it reviews existing cooperation modalities on model development and proposes alternative sourcing and organisational strategies to remedy any knowledge or analytical gaps identified.

JEL codes: C5, E47, E52, E58, F4.

Keywords: econometric modelling, forecasting and simulation, monetary policy, central banking.

1 Introduction

The Governing Council established the framework for this review of the ECB's monetary policy strategy at its meeting on 23 January 2020. In this context, it decided to review practices underlying the economic, monetary and financial analysis for preparing monetary policy decisions. This paper reports the main outcomes of the work undertaken in the work stream and provides an assessment of the macroeconomic models regularly used for forecasting and policy analysis in the Eurosystem. These include semi-structural, structural and time-series models covering specific jurisdictions and the euro area within a closed economy, small open economy, multi-country or global setting. These models are actively used as analytical frameworks for building baseline projections and for supporting the preparation of monetary policy decisions.

The paper contributes to four main areas. First, it surveys the macroeconomic modelling portfolios currently used or under development within the Eurosystem. The survey documents the various models and establishes the rationale behind model selection and design. The survey also gathers information on planned modelling activities and modelling challenges. Second, it discusses the pros and cons of various macro-modelling strategies, explores analytical gaps identified in the survey and investigates the scope for further enhancements to existing models. Modelling challenges related to building forecasting and policy simulation models in an environment of low inflation and low interest rates are emphasised. The work stream also explores possible implications of climate change and the coronavirus (COVID-19) pandemic for macroeconomic modelling. Third, beyond specific model development needs, the work stream also reviews the current practice of using model-based analysis in policy preparation and forecasting and provides recommendations and suggestions. Finally, the report reviews existing information sharing within the Eurosystem and cooperation on model development. It proposes alternative sourcing and organisational strategies to remedy any knowledge or analytical gaps identified.

As concerns the first area of contribution, the paper finds that the current macroeconomic modelling strategies in use across the Eurosystem typically feature a suite-of-models approach. This balances the need for robustness across different uses (provided by model diversity) against flexible deployment of selected types of models for specific purposes. The vast majority of NCBs use large-scale semi-structural models for projections, while structural (typically dynamic stochastic general equilibrium, or DSGE) models are preferred for scenario and policy analysis. The main macroeconomic models (especially projection models) are usually operated in conjunction with a variety of other satellite tools, notably for short-term forecasts and sectoral or financial analysis.

The current approach appears significantly richer than the modelling toolkit in use at the time of the last ECB monetary policy strategy review in 2003. While the suite-of-models approach was already in use then,[1] significant advances have occurred since, increasing the variety of models routinely used for projections and policy analysis. Existing models have been enriched to give a more prominent role to elements such as financial factors, which have emerged over time as crucial for transmission of monetary policy. Focusing just on the projection tools used in Eurosystem/ECB macroeconomic projections, a comparison of the documentation reported in European Central Bank (2001 and 2016) shows that both the tools and models used by the ECB and NCBs have undergone significant changes. The ECB has replaced the previous multi-county model (MCM) with a new version (the NMCM), which, among other features, allows for forward-looking expectations. A structural DSGE model, the New Area-Wide Model (NAWM), is now routinely used for projections. NCBs have also modified their suites of models, by amending (or replacing) their main projection models to account for real-financial feedback, among other things, and developing new ones, including DSGE models for forecasting and/or scenario analyses.

The overall modelling portfolio seems adequate and provides a flexible framework for conducting projection exercises and analysing alternative policy options. The suite-of-models approach achieves a good balance between model diversity and specialisation across different uses.

Projection models (mostly semi-structural) have proved relatively resilient over the last decade. Their flexibility and the ability to swiftly add, subtract, modify or re-specify single equations or entire blocs of the model without needing to change the whole structure should be welcomed as a strength. Projection models are also amenable to the incorporation of expert views and provide a disciplining economic framework for implementing key judgements on the projection baseline. Eurosystem semi-structural projection models have been modified or replaced in recent years, notably to account for the increasingly important role played by financial factors (both as drivers of the business cycle and as amplifiers of other shocks).

Structural models used for scenario and policy analysis (such as DSGEs) constitute an important complement to semi-structural models in the overall policy process. They facilitate the construction of an internally consistent narrative around a baseline projection and, by using counterfactual scenarios, make it possible to explore the macroeconomic impact of policy announcements and instruments. In addition, they can also be used to generate projections in stand-alone mode. As in the case of semi-structural models, the DSGE models used for policy analysis have been enriched in several dimensions over the last decade in response to the changing macroeconomic environment and following the most recent advances in the academic literature.

[1] In the words of Trichet (2003): "[…] the appropriateness of a monetary policy strategy cannot be evaluated by means of just one particular model or class of models. Rather, a good candidate strategy needs to perform well across a variety of empirically plausible models […]". For a detailed description of the econometric models in use in the euro area during the last ECB strategy review, see Fagan and Morgan (2005).

At the same time, model development needs can be identified. These involve both adapting and enhancing the main projection or policy models and creating new models to complement the existing portfolio.

As far as the main macroeconomic models used for projections or monetary policy analysis are concerned, the most relevant areas for enhancement concern: specifying the expectations formation process (for both inflation and forward-looking aspects in general) and empirically validating these; accounting for the relevant transmission channels of non-standard monetary policy measures (NSMs) via expectations or the financial sector; accounting for exogenous long-term trends in growth, real interest rates, a long-term inflation anchor consistent with the ECB's price stability goal, other low-frequency but transient nominal factors related to expectations formation and factors not directly related to monetary policy such as globalisation and medium-term relative price adjustments within the monetary union; adapting to the relevant climate change-related features in the frequency of the business cycle; treating large shocks and non-linearities, including those related to the COVID-19 pandemic, in the estimation strategy.

Focusing on the main structural models, specific areas for development include: examining complementarities across instruments, the microfoundations of side effects across different NSMs and empirically validating the transmission channels for these; using advanced computational methods to account for non-linearities and multiple equilibria; incorporating a relevant role for long-term trends and accounting for their time-variation.

Development of new satellite models would be warranted in the following directions: including household heterogeneity and its implications for monetary policy transmission, e.g. along the lines of Heterogeneous Agent New Keynesian (HANK)-type models; accounting for the relevant dimensions of non-linearities in the transmission of monetary policy (from both the time-series and structural modelling standpoints); emphasising the specification of the energy sector, the microfoundations of relevant climate change-related externalities and the role of climate change mitigation policies in the global setting.

Turning to the use of models in the policy process, avenues for improvement worth pursuing relate to: improving the structural underpinning of projection models to construct a model-based general equilibrium narrative for baseline projections; increasing transparency in the use of models, in particular harmonising simulation practices and ensuring that models routinely used to assess the macroeconomic impact of monetary policy interventions are well documented and have been thoroughly evaluated; enhancing medium-term reference scenarios, possibly by systematically conducting a sensitivity analysis on monetary policy and long-term trends; making more systematic use of model-based risk metrics for the projection baseline; possibly extending some country-specific models to the rest of the euro area.

Careful consideration should be given to enhancing organisational and collaborative strategies for macroeconomic modelling. A shared infrastructure to foster knowledge transfer, facilitate efficient information flows and increase the transparency and technical accountability of model-based analysis would be beneficial. This would also encourage the build-up of a voluntary Eurosystem model repository. Recommendations for new model developments should ideally be addressed by pooling resources and skills across the Eurosystem and beyond through the standard institutional fora (e.g. the Working Group on Econometric Modelling (WGEM) and the Working Group on Forecasting (WGF)).

The remainder of this paper is organised as follows: Section 2 provides a summary of recommendations. Section 3 describes macroeconomic modelling strategies across the Eurosystem. Section 4 provides an assessment of the analytical gaps as identifies in Section 3 and the associated development needs. Section 5 provides an assessment of the model-based analysis for monetary policy preparation and scope for improvement. Section 6 assesses the cooperation across the Eurosystem. Last, Section 7 concludes.

2 Summary of recommendations

2.1 Macroeconomic modelling strategies across the Eurosystem

Overall, the modelling portfolio seems adequate as it provides a flexible framework for conducting macroeconomic projection exercises and analysing alternative policy options. The current modelling toolbox is in the vast majority of cases organised as a suite of models. Baseline projections are typically produced using semi-structural models, while scenarios around the baseline (or possibly alternative to it) are constructed using either semi-structural or structural models (the latter typically being DSGEs). Satellite models are also employed at different stages of the monetary policy preparation process, e.g. to produce a consistent scenario for foreign economies or to analyse specific policy issues. In addition, short-term forecasting models including bridge equations, factor models, Bayesian vector autoregressions (BVARs) and error-correction models are widely used. The suite-of-models approach achieves a good balance between model diversity and specialisation across different uses.

The current approach appears significantly richer than the modelling toolkit in use at the time of the last ECB monetary policy strategy review in 2003. While the suite-of-models approach was already in use then, significant advances have occurred since, increasing the variety of models routinely used for projections and policy analysis. Existing models have been enriched to give a more prominent role to elements such as financial factors, which have emerged over time as crucial for transmission of monetary policy. The projection tools and models used in Eurosystem/ECB macroeconomic projections have undergone significant changes. The ECB has replaced the previous multi-county model (MCM) with a new version (the NMCM), which, among other features, allows for forward-looking expectations. A structural DSGE model, the New Area-Wide Model (NAWM) is now routinely used for projections. NCBs have also modified their suites of models, by amending (or replacing) their main projection models to account for real-financial feedback, among other things, and developing new ones, including DSGE models for forecasting and/or scenario analyses.

Projection models (mostly semi-structural) have proved relatively resilient over the last decade, notably in facing the analytical challenges posed by the global financial crisis, the sovereign debt crisis and the introduction of non-standard measures (NSMs). More recently they have provided guidance in analysing the unprecedented pandemic emergency. Their flexibility and the ability to swiftly add, subtract, modify or re-specify single equations or blocs of the model without needing to change the whole structure should be welcomed as a strength. It allows for the introduction of additional variables and model blocs to account for previously excluded or overlooked phenomena (such as the financial-real feedback loop). Projection models are also amenable to the incorporation of expert views and provide a disciplining economic framework for implementing key judgements on the projection baseline. In practice, Eurosystem NCBs have either modified their semi-structural models or replaced them with new ones to account for the increasingly important role played by financial factors, both as drivers of the business cycle and as amplifiers of other shocks.

At the same time, semi-structural projection models may need to be complemented with other tools, such as satellite models for short-term forecasting, or others that can deliver a structural interpretation of economic phenomena in terms of underlying shocks, describe a coherent international/global macroeconomic scenario, and provide a better account of long-term trends and general equilibrium. The treatment of NSMs largely draws on satellite models.

A large number of NCBs acknowledge that the treatment of expectations in semi-structural projection models – in many cases modelled as backward-looking – is not fully satisfactory. The recent experience of the Banque de France in developing FR-BDF by following the Federal Reserve's FRB/US approach, which can account for model-consistent expectations, shows one possible way forward. The use of VAR-based expectations (currently being explored by the Deutsche Bundesbank) may be an interesting alternative. Introducing model-consistent expectations into large semi-structural models could potentially be a promising advance, but should be evaluated against the associated computational constraints and the need to maintain a flexible, data-driven set-up. New empirical evidence on the role and type of expectations in the behaviour of economic agents may provide guidance. Other gaps identified include the determinants of natural interest rates and long-run trends. The latter are only partly included, mostly as exogenous.

The structural models used for scenario and policy analysis (such as DSGEs) constitute an important complement to semi-structural models in the overall policy process. They facilitate the construction of a systematic general equilibrium narrative around a baseline projection and make it possible to explore the macroeconomic impact of policy announcements and various policy instruments by means of counterfactual scenarios. They can also be used to generate projections in a stand-alone mode. As in the case of semi-structural models, over the last decade, Eurosystem NCBs have enriched their DSGE models used for policy analysis in several dimensions in response to the changing macroeconomic environment and following the most recent advances in the academic literature. These enriched frameworks lend themselves to the quantitative assessment of non-standard monetary measures.

Nonetheless, important changes in the economic environment constraining and motivating monetary policy decisions in the Eurosystem have only been incorporated in part into the main models used for policy analysis. Despite its increasingly important role in limiting the room for manoeuvre in monetary policy, the effective lower bound (ELB) is not systematically accounted for in the construction of policy scenarios. On a similar note, NSMs are not systematically included in the majority of models, which often rely on satellites. The determinants of low natural interest rates are still under investigation from both a theoretical and an empirical standpoint and are not included. Long-run trends are only partly included, mostly as exogenous. On the empirical side, the micro-founded nature of DSGEs may limit their flexibility and applicability. While semi-structural models can be easily extended to include a very large number of variables, taking large (possibly non-linear) DSGE models to the data is not an easy task. As expectations in these models are typically rational, and therefore forward-looking, anticipation effects may be large (as in the case of the forward guidance puzzle). However, recent advances have provided convincing ways around this limitation, and the literature suggests alternative ways of bridging between fully rational and backward-looking expectations.

Compared to the experience of other peer institutions, the suite-of-models approach seems in line with common practice, both in terms of variety and model specialisation. Specifically, the use of semi-structural models for projections seems widespread, while structural models are largely used to complement baseline forecasts and perform scenario analysis. The recent experience of strategy reviews at the Bank of Canada and the Federal Reserve System confirms that semi-structural, structural and time-series models can be employed for specific types of analysis in a way that exploits synergies and complementarities.

2.2 Assessing model development needs

2.2.1 Long-term trends and macroeconomic dynamics

The main macroeconomic models used in the Eurosystem typically treat trends as exogenous or ignore them altogether. Given current changes in the economic environment, there is a need to improve the understanding and model specifications of long-term economic drivers related to the natural interest rate and GDP growth in particular. As an example, allowing for endogenous variations in productivity in the spirit of endogenous growth models helps explain deep and long-lasting recessions via hysteresis effects in total factor productivity, the missing disinflation in the downturn and the missing inflation in the upturn (see e.g. Schmöller and Spitzer, 2020). Similarly, the demographics or financial determinants of the secular decline in the natural interest rate could have meaningful implications for aggregate consumption and saving behaviour at business cycle frequency.

Recommendation for projection models: projection models should be adapted to include a relevant role for long-term trends, at least as exogenous variables, related to (i) growth determinants such as demographics, technological progress and other productive factors (including possibly energy), (ii) the natural rate, and (iii) the central bank inflation target.

Recommendation for new structural models: consideration should be given to developing medium-scale DSGE models that endogenise and incorporate economic trend drivers, following convincing achievements in the academic literature (Anzoategui et al., 2019; Bianchi et al., 2019; Moran and Queralto, 2018; Queralto, 2020).

2.2.2 Alternative expectations formation mechanisms and monetary policy transmission

The role of alternative expectations formation mechanisms, heterogeneities across economic agents and how these interact with monetary policy is still relatively unexplored in Eurosystem projection models, but more prevalent in the models used for policy analysis. Several NCBs indicate alternative expectations formation mechanisms are an important area to be explored. In particular, improving the measurement of inflation expectations across agents would increase knowledge of the role they play in economic behaviour and how they are formed. The academic literature has modified rational expectations macroeconomic models to incorporate alternative expectations formation mechanisms, such as learning (Slobodyan and Wouters, 2012), hybrid expectations (Levine et al., 2012), rational inattention (Maćkowiak and Wiederholt, 2015), and sticky information (Reis, 2009).

Recommendation for semi-structural models: FRB/US-type models can include either model-consistent expectations or VAR-based expectations. Recent work (for example at the Banque de France and the ECB) focuses on introducing such expectation formation mechanisms into large semi-structural models. These examples can be considered promising avenues of development for semi-structural projection models. Survey data can also provide guidance in modelling expectations formation.

Recommendation for structural models: the main DSGE models could be adapted to allow for simulations under alternative expectations formation mechanisms (in particular FG and makeup strategies).

The behaviour of the main models when the expectations formation mechanism is modified should be systematically investigated and empirically validated.

2.2.3 The monetary policy transmission mechanism: non-standard measures

About one-half of projection and policy models can account for NSMs, either as a fully specified bloc in the model or by using satellite tools (e.g. showing their impact on interest rates and exchange rates). DSGE models in particular have been amenable to accounting for the new instruments implementing the ECB's monetary policy stance (see e.g. Burlon et al., 2018; Coenen et al., 2020; Darracq Pariès et al., 2020). Despite abundant development of DSGE model-based analysis over the last decade more work is needed, notably regarding transmission channels, complementarities and the effectiveness of the joint use of NSMs, the role of expectations in their transmission, the impact on asset prices and side effects in the short and long run.

Recommendation for semi-structural models: further development of large semi-structural projection models to account for the relevant transmission channels of

NSMs, notably via expectations or the financial sector, is warranted. More transparency regarding the analytical protocol followed to quantify monetary policy measures in these models would be beneficial.

Recommendation for structural models: building on the progress made over recent years, the DSGE modelling agenda should focus on strategic complementarities across instruments and side effects across different NSMs. As the sample period over which NSMs have been enacted lengthens, empirical validation of their transmission channels will benefit. The findings from the work done in the FORE taskforce would constitute useful guidance for adapting models.

2.2.4 The monetary policy transmission mechanism: non-linearities

Eurosystem models do not feature a large degree of non-linearity, largely due to the associated computational and empirical challenges. The effective lower bound constraint, the non-linear Phillips curve, downward wage and price rigidities, and possibly time-varying credit and borrowing constraints are critical for the transmission of monetary and other economic policies and deserve further attention. However, non-linear modelling faces technical challenges related to solution methods and estimation techniques. This partly explains why Eurosystem NCBs do not systematically operate their main models in a fully non-linear mode. For example, while DSGE models can in principle display significant non-linearities, this is left unexploited due to the technical requirements of the estimation strategy.

Recommendation for semi-structural projection models: these models could have the flexibility to accommodate alternative non-linear specifications of selected behaviours from the empirical literature, such as price setting, financing conditions and the ELB. This should be explored.

Recommendation for structural models: the capabilities of the main DSGE models should be enhanced by actively using advanced computational methods to account for non-linearities, following relevant academic benchmarks (see e.g. Braun and Kober, 2011; Guerrieri and Iacoviello, 2015; Linde et al., 2016).

Recommendation for time-series models: some non-linearities can be explored at relatively small cost by using time-varying VARs and BVARs, smooth transition and threshold VARs, and allowing for heteroscedastic errors (see e.g. Bijsterbosch and Falagiarda, 2014; Lenza and Primiceri, 2020).

2.2.5 The monetary policy transmission mechanism: household heterogeneity

Many dimensions of heterogeneity that are relevant for policy transmission and policy effects are not captured in the main projection and policy analysis models used in the Eurosystem. One critical source of heterogeneity that can potentially affect the monetary policy transmission mechanism concerns the household sector and the labour market. Heterogenous Agent New Keynesian (HANK) models have been at the centre of a successful recent research agenda (see Kaplan et al., 2018; Auclert et al., 2020; McKay et al., 2016). The empirical evidence on the importance of different types of heterogeneity remains rather thin, however. Empirical approaches that more widely combine the macro- and microeconomic approach are required to validate HANK-type models for policy purposes. More generally, the increasing availability of granular data calls for ways to be found to exploit them in empirical macroeconomic models.

Recommendation for projection models: accounting for genuine microeconomic heterogeneity in the main projection models is not warranted at this stage given the computational constraints, the lack of clear empirical strategy and results, and uncertain benefits in terms of forecast performance.

Recommendation for new structural models: given the achievements in the academic HANK literature, central banks should venture into this area of modelling, possibly focusing first on households and labour market heterogeneity (notwithstanding other relevant dimensions) and advancing the empirical validation of those models. The Federal Reserve System has used the insights of such satellite models to inform the policy debate (see Feiveson et al., 2020). The first steps towards the use of an estimated HANK model for forecasting have already been made (Acharya et al., 2020). The work stream on employment (2021) also provided clear illustration of the scope for HANK models to shed new light of relevant policy issues.

2.2.6 Interactions with fiscal and financial policy: the design and transmission channels of fiscal policy

The Eurosystem has devoted a considerable amount of analytical work to fiscal policy and the interaction between fiscal and monetary policies. This has largely been a consequence of the monetary union framework of the euro area, with fiscal policy mainly implemented at country level. It was also encouraged by the European sovereign debt crisis. Fiscal policy is typically modelled in main models and satellite models via systematic feedback rules or shocks; these are also used in counterfactual policy analysis. However, the current pandemic and the related new fiscal policy instruments, including Next Generation EU (NGEU), climate change and related policy measures, indicate a need to fine-tune the current models. Besides further progress in modelling the interaction between monetary and fiscal policies, there is also a need to understand how alternative policy measures and policy reaction functions affect economic activity, public and private financial stability and, ultimately, inflation dynamics and the achievement of the price stability goal.

Recommendation for projection models: the main models used for projections and policy analysis should account for relevant granularity and new types of fiscal instruments (e.g. related to COVID-19 and climate change).

Recommendation for structural models: satellite DSGE models should pursue a more granular approach to fiscal policy, the analysis of various fiscal-monetary policy regimes and cross-country spillovers within the monetary union.

2.2.7 Interactions with fiscal and financial policy: the design and transmission channels of financial policy

Since the financial crisis, a widespread literature has emerged on the effects of financial instability on the aggregate economy. This has influenced developments in central bank modelling over the last decade. While the underlying mechanisms are difficult to model, particularly in medium- and large-scale models, a wide range of DSGE models used across the Eurosystem consider some form of financial frictions in their policy analysis and simulation exercises (see e.g. EAGLE-FLI, AINO 3.0, and Cozzi et al., 2020, for ECB contributions, and Júlio and Maria, 2020, for the Banco de Portugal model). Current model development plans target explicit modelling of macrofinancial linkages such as endogenous interest rate spreads, endogenous credit dynamics and other relevant items in the balance sheets of financial institutions.

Recommendation for projection models: projection models should feature a realistic design of financial intermediation, but adapting them to the latest academic benchmarks, macrofinancial interactions and macroprudential practices would be excessive. Complementing projection models with dedicated DSGE models that include a rich financial sector seems a viable solution.

Recommendation for new structural models: the burgeoning literature on a new generation of macrofinancial models should inspire the development of small-scale structural models that generate a role for banks, feature non-linear amplification effects from financial distortions, provide a structural role for macroprudential regulation (see e.g. Adrian et al., 2020; Clancy and Merola, 2017; Gertler and Karadi, 2011 and 2013; Júlio and Maria, 2020) and permit analysis of optimal monetary policy strategies in the presence of financial frictions.

2.2.8 Interactions between monetary, fiscal and financial policies

The strategic interactions between different policy areas are usually studied within small or medium-scale models, but are not yet considered within the main monetary policy analysis or projection models. Consideration could be given to embarking on a modelling avenue that would incorporate all the relevant policy frameworks for the euro area to explore the strategic complementarities between monetary, fiscal and financial policies. An example going in this direction is the recent modelling agenda of the IMF’s Integrated Policy Framework.

Recommendation for structural models: Eurosystem modellers should explore best-practice models where different options for coordinating policies can be studied and identify key potential areas of conflict for which dedicated structural models might be developed.

2.2.9 Climate change

Climate change and the related risks and policies are largely absent from the main Eurosystem models, but environmental economics literature provides relevant directions for further developments. In recent decades, macroeconomic literature has developed two main classes of environmental model: climate-related Integrated Assessment models (IAMs) and Climate-Computable General Equilibrium (CGE) models. Business cycle models have started being adopted and modified to include energy and climate channels. For semi-structural models, NiGEM is currently being adapted in the direction of IAM models. DSGE models have been successful in including selected climate change features: G-CUBED is an example. Time-series nowcasting models can also be used to introduce the short-term impact of weather-related events on inflation and output.

Recommendation on adapting current models to climate change implications: selected climate change transmission channels should be included in the projection models at business cycle frequency to account for the impact of climate-related shocks and policies on the economy. This mainly concerns sectoral dimensions (with specific energy sectors), transition policies (notably fiscal instruments affecting energy costs), the impact on financial intermediation and changes in long-run anchors.

Recommendation on a new climate-specific model: Beyond adapting existing models, a new model should be developed that emphasises the global dimension of the phenomenon, the microfoundations of the relevant externalities and the nature of climate-related global disturbances. This would help to study the optimal global policies for addressing climate change and the role monetary policy can play in mitigating climate-related shocks to the economy.

2.2.10 Large shocks and uncertainty: lessons from the COVID-19 pandemic

The ongoing experience with the COVID-19 pandemic is providing a real-time test of the ability of Eurosystem models to cope with large and unprecedented shocks. Time-series satellite models have been adapted to include new, higher-frequency data and sources of information and explore new econometric methods. Semi-structural models have been extended to capture the interplay between epidemiological dynamics, containment policies and the macroeconomy, as in the case of ECB-BASIR. Structural models can also be re-specified in this direction, providing important insights for monetary policy, as shown in Eichenbaum et al. (2020). From an analytical standpoint, the episode raises the need for a robust treatment of the heteroscedasticity of shocks in re-estimation and large shocks in density forecasts, as well as for a consistent way of handling new policy measures related to large disruptions.

Recommendation for main models: making the estimation strategy in the main models used for projection and monetary policy analysis more robust in the presence of large shocks like those experienced during the pandemic is a necessary but daunting task. Developing or consolidating higher-frequency short-term forecasting tools using alternative sets of information would be a useful complement to the main projection models during unusually large disruptions to the economy.

2.2.11 Global factors and international spillovers

Global factors and international spillovers reflect the growing integration and interdependence of the world's economies through flows of cross-border trade, finance and information and have changed the landscape in which monetary policy operates. One implication for modelling the euro area is that external factors play an increasingly important role in explaining the dynamics of inflation, the real economy and financial conditions. Global factors are found to explain at least partly the decline in the natural rate of interest and have contributed also to the slowdown in inflation and possibly the flattening of the Phillips curve. Deepening integration of financial and goods markets exposes euro area economies to tail events and contagion and strengthens foreign currency exposure and transmission of international shocks to financial conditions.

Recommendation for main models: structural, semi-structural and nowcasting models employed to produce macroeconomic projections and policy analysis need to better acknowledge the role of global factors for domestic variables, their transmission channels and international spillovers, including specific global events such as the COVID-19 pandemic. Examples already developed within the Eurosystem involve multi-country DSGE, multi-country semi-structural and nowcasting time-series models that incorporate trade and exchange rate assumptions and in some cases a rich array of global financial intermediation channels through cross-border banking and sovereign bond markets. More effort should be devoted to quantifying the relative importance of global forces impacting on the demand for safe assets, such as tail risk, uncertainty shocks, portfolio diversification, growing trade flows and the global financial cycle.

2.3 Scope for improvement in the policy use of models

2.3.1 Model-based economic narratives

Model-based economic narratives for historical developments and baseline projections are an important application of models in the policy process. Model-based decomposition of structural shocks is a standard exercise for the DSGEs and SVARs typically used as satellites, whereas producing a structural economic narrative remains more challenging for the large semi-structural models used for projections. Narrative elements are often provided through partial equilibrium exercises. Main projection models are also used to assess the role of conditioning assumptions in forecast error analysis, but economic interpretation of other sources of the forecast errors in model residuals requires bringing more structure into the models.

Recommendation on model-based economic narratives in semi-structural projection models: large semi-structural models are the workhorse analytical framework for projection purposes, and any improvements in their ability to produce convincing economic narratives are likely to be influential in the policy preparation process. Strategies should be explored to improve the structural underpinning of projection models. For example, work is underway at the ECB on ECB-BASE to structurally identify latent factors loading into its main residuals.

A model comparison exercise on the analysis of forecast errors at multi-year frequency would be instructive to foster consensus around an economic narrative. Model-based decompositions of forecast errors are clearly model-specific, but common features can be extracted from a meta-analysis across a wide range of models.

2.3.2 Model-based projections

The Eurosystem baseline projections are not purely model-based (akin to a time-series conditional forecast using a VAR for example), as experts intervene on a range of features, notably bringing external sources of information to the main projection model. Therefore the conceptual basis for disentangling the degree of expert judgement underlying the baseline projections is elusive. Some practical concepts of model-based projections might nevertheless be explored, by analogy with statistical concepts from the academic forecasting literature. These would raise the technical accountability of the baseline projections, providing a basis for extracting model-specific "implicit" judgement. They could also be incorporated in a regular review of model properties.

Recommendation on model-based projections: the conceptual framework for constructing strictly model-based projections and quantitatively or qualitatively distilling the expert judgement embedded in the projections of key macroeconomic variables should be harmonised. The availability of purely model-based projections would improve the technical preparation process for the baseline, in particular when applied to the specific models used to build it. Clear concepts of strictly model-based projections would also harmonise the way other models are used to cross-check the baseline projections.

As an illustration, the ECB produces model-based projections either as updates starting from the previous baseline, including previous judgement, or conditional forecasts, which are closer to a stand-alone model-based forecast.

Strictly model-based projections should be reviewed as part of a more general model validation and maintenance protocol. Ultimately, as strictly model-based projections become more harmonised across the Eurosystem and more appreciated as effective diagnosis tools for the construction of the baseline, they could feature more prominently in the policy process.

2.3.3 Model-based risk assessment

Risk metrics around the (B)MPE are not model-based, but in recent years increased attention has been paid to models that can better quantify the uncertainty surrounding economic forecasts. A range of empirical models are available or could be developed to complement the Quantitative Risk Analysis (QRA) of Eurosystem/ECB staff projections, which summarises staff views on the risks around the baseline projections. Traditional forecasting models can provide a full predictive density, but this is generally a by-product, while their main concern is usually the point forecast. By contrast, models such as quantile regressions are developed and estimated specifically to assess risks and uncertainty, as their focus of interest is not the mean or median, but other quantiles of the distribution. Many NCBs in the Eurosystem have developed this kind of models or are currently working on them (see for example Chavleishvili and Manganelli, 2020; Ganics and Odendahl, 2019).

Recommendation on model-based risk metrics: it is essential to subject the QRA to an empirical validation protocol for its information content and complement it with established model-based benchmarks.

Starting with projection models, their use in building up the projection baseline could be strengthened towards density forecasting, with performance evaluated on this basis. At the ECB, the NAWM II model has been used in this way and ECB-BASE is currently being developed to produce conditional density forecasts.

Beyond projection models, dedicated satellite time-series models can provide high-performing predictive densities and should be regularly reported. The model selection for such an exercise requires joint risk distributions for the main projection variables.

Model combination techniques should be better leveraged to build-up a model-based consistent statistical distribution around the baseline. These techniques make it possible to derive model-based uncertainty and risk-balance indicators around the (B)MPE baseline, using the main projection models and satellite time-series models.

Where the outlook contains Knightian uncertainty or multi-modality, fully-fledged scenario analysis may be required to complement or substitute statistical risk metrics. The experience of the pandemic scenarios introduced in the June 2020 BMPE exemplifies the use of dedicated scenarios in such circumstances.

2.3.4 Model-based monetary policy analysis

Model-based monetary policy evaluation can vary across different policy processes, simulation designs and types of model. Macroeconomic models are used to assess the impact of monetary policy decisions in various contexts: (i) to construct the projection baseline and risks around it; (ii) for the scenario analysis supporting the ex-ante calibration of monetary policy measures; (iii) for the impact assessment of monetary policy decisions; and (iv) for strategic analysis of monetary policy conduct. Within monetary policy preparation, these uses are channelled to a varying degree into internal documents and presentations to decision-making bodies. In particular, the set of models and type of model-based analysis used for economic projections and stance assessment is not always the same.

Recommendation on model-based monetary policy analysis: the influence of models in monetary policy preparation should be strengthened by more consistent deployment and articulation across the various policy processes. Higher consistency across models would not mean they would all converge on a single assessment of the impact of monetary policy. The heterogeneity is also the result of the high uncertainty around assessments and should be used to inform policymakers. Indeed, the monetary policy preparation process requires robust model-based analysis. Considering improvements in the use of macroeconomic models for monetary policy evaluation would largely hinge on adapting the projection and policy analysis models in line with the recommendations put forward in Section 4.

2.3.5 Enhanced medium-term reference scenarios

Medium-term reference scenarios (MTRSs) have been run on a regular basis since the December 2010 BMPE, but there is scope to raise their influence in the policy process. Currently, the MTRS extends the baseline projections beyond the (B)MPE horizon by five years for the euro area as a whole, using the NAWM II model and focusing on a limited set of macroeconomic variables. At present, it largely reflects the mean-reversion properties of the model to steady state, which assumes historical nominal and real anchors without paying attention to possible regime changes. Consequently, its updates across projection rounds rarely entail qualitatively new messages. Given this situation, consideration could be given to improving the MTRS and developing an enhanced medium-term reference scenario with the aim of improving its impact and relevance for monetary policy preparation.

Recommendation on enhancing the MTRS: more effort should be devoted to constructing the MTRS so that it can be considered a self-consistent medium-term projection for the euro area and seen as the prime baseline for model-based sensitivity analysis, notably regarding monetary policy conduct.

The MTRS should become a fully-fledged, euro area-wide, model-based extension of the (B)MPE baseline. While a bottom-up approach in an MTRS for the Eurosystem is not feasible in the short-term, better aligning it with Eurosystem sectoral expertise would be beneficial. In particular, the supply-side review, climate-change related analysis, global trends and medium-term policy assumptions (especially for fiscal policy) should become conditioning information for the MTRS.

Regular sensitivity analysis should be performed on the MTRS, policy conduct and long-term trends. The latter should encompass growth determinants, the natural rate of interest and nominal anchors, whereas policy conduct should comprise sensitivity to monetary, fiscal and possibly other structural or financial policies. An endogenous monetary policy reference scenario could become a standard feature of the MTRS.

2.3.6 Articulating country-specific and euro area-wide model-based analysis

The combination of (or sometimes the trade-off between) a more country-specific perspective and the focus on the euro area aggregate is a major challenge for model-based analysis in the Eurosystem. The aggregate is of course much more important for monetary policy decision-making than the individual country perspective. Nevertheless, country-specific characteristics must also be taken into account. For this reason, model-based analysis should not neglect heterogeneities among countries.

Recommendation on possible extensions of country-specific projection models: for large jurisdictions, steps towards extending the main projection models to a euro area-wide set-up should be considered. This would create a level playing field for country-specific models and top-down models and increase their scope for policy analysis. Various modelling strategies should also be contrasted. For example, the main projection models at jurisdiction level could be better articulated with satellite models (multi-country DSGE models, for example). Alternatively, the main projection models could be extended to a two-region monetary union set-up. As an example, at the Banque de France the new-generation semi-structural projection model for the French economy is currently extended with a rest-of-the-euro area block.

2.4 Cooperation and organisational strategies for modelling activities

Within the Eurosystem, modelling activities entail exchange of knowledge and best practices and genuine collaborative work on model development. Under the aegis of the Working Group on Econometric Modelling (WGEM), monetary policy preparation has benefited from the expertise of a modelling community that has achieved its objectives of (i) bringing the modelling capabilities of the Eurosystem to the global institutional forefront, and (ii) exploiting relevant synergies in disseminating knowledge and sharing in the development of models and analytical frameworks. There is scope for improvement in infrastructure and information sharing and cooperation procedures. The organising framework for sharing information, data and knowledge is based on an infrastructure which works smoothly and efficiently at a local level but could be improved at a systemic level.

Recommendation on information sharing and modelling infrastructure: harmonised systems and a computational environment that meets the highest professional standards should be developed. This would be a key factor enabling the sharing of models and tools and promoting transparency across the Eurosystem and beyond.

Central ESCB infrastructure should support efficient use of a wide range of tools by making it easy to transfer data and knowledge from one bank to another. The ECB Projections Enabler Platform (PERFORM) will provide a unified user experience for ECB economists and modellers, allowing data to be shared and processed and models run to produce forecasts, visualise data and prepare reports. PERFORM is expected to orchestrate the projections process collaboratively in an access-controlled environment for decision-making, achieving traceability and reproducibility.

Incentives should be set for increasing transparency on the models used in the policy process, facilitating peer review and exchange of best practices. User-friendly, harmonised modelling infrastructure will be key to overcoming the current hurdles to sharing models. A model repository built up on a voluntary basis for common use would be a great asset for the Eurosystem. Examples of such model depositories can be found in academia, such as the Macroeconomic Model Data Base (MMB) headed by Volker Wieland at the Institute for Monetary and Financial Stability (IMFS) at Goethe University Frankfurt (see Wieland et al., 2012, for a description).

Recommendation on organisational strategies: cooperation procedures and the organisation of modelling activities across the Eurosystem should aim to pool expertise across the ESCB and beyond to benefit from economies of scale in developing new models.

The modelling hub function of the WGEM should be enhanced to cover: (i) creating IT platforms to share data, models and knowledge; (ii) generating ideas and managing model development initiatives; and (iii) networking with academia and other institutions.

The WGEM should foster its connectivity with the relevant stakeholders, notably setting up fora for exchanges with other central banks, financial institutions, data providers and universities. Sponsored modelling groups should be set up outside the ESCB to meet specific institutional needs.

Development of new models like the ones recommended in previous sections should ideally be done collectively, avoiding duplication of work and ensuring that needs are addressed efficiently. Various organisational designs should be considered, ultimately leading to shared modelling resources.

3 Macroeconomic modelling strategies across the Eurosystem

The current policy environment is characterised by low inflation and low interest rates, with consequently more restricted space for conventional monetary policy. These circumstances, in combination with the deployment of non-standard monetary policy measures, have led the Eurosystem to adjust its modelling toolkit and policy modelling practices. This section describes the macroeconomic modelling portfolios in the Eurosystem and discusses their main uses in projections and other activities related to monetary policy preparation. For benchmarking purposes, it also provides an overview of the modelling portfolios in selected institutions outside the Eurosystem.

3.1 Survey of macroeconomic models: key features and rationale behind model selection and design

The work stream has carried out a stocktaking exercise, with the aim of assessing the present macroeconomic modelling portfolios and revealing how developments spurred by two crises are reflected in the Eurosystem's current modelling strategy. Over the summer of 2020, in collaboration with the WGEM, the work stream carried out a survey of the 28 NCBs participating in the WGEM. Taking a related exercise conducted in 2017 by the WGEM as a starting point, the current survey focused on the main operational models regularly used for macroeconomic projections and scenario or policy simulations.[2]

On the basis of the survey findings, this sub-section discusses the models in the operational policy toolkit of the Eurosystem in terms of their type (semi-structural, structural, time-series, etc.), scope or jurisdictional dimension (country-specific, euro-area, global) and the underlying features (modelled economic relationships) relevant for model applications.

3.1.1 Model types

The following paragraphs provide the terminology used throughout this report to distinguish between the various types of model regularly deployed by NCBs. These models can be divided into three groups: structural, semi-structural and time-series, based on the level of microeconomic theoretical underpinning.

2 Models developed in research projects that are neither used nor expected to be used as part of the main operational modelling toolkit were therefore excluded. Among other things, the survey asked NCBs to identify major analytical gaps related to the strategy review. Specific questions concerned the incorporation of features characterising the current economic and policy environment, such as the effective lower bound and non-standard monetary policy measures, into operational policy models.

A typical example of a structural model is a dynamic stochastic general equilibrium (DSGE) model. In quantitative DSGE models used in policy analysis, the structure of equations is generally derived from microeconomic first principles. The model makes explicit the objectives and constraints of each type of agent in the economy, and macroeconomic outcomes are then interpreted as the aggregate consequences of individual decision rules resulting from the solution to constrained optimisation problems. Agents in the economy are commonly assumed to form rational expectations, i.e. they know the model economy and the distributions of shocks that perturb it, and are able to coordinate their expectations so that their subjective ex ante probability distributions coincide with the true ex post distributions of observed variables.[3] The decision rules are derived by solving optimisation problems that are supposed to describe the motivation underlying the economic agents' behaviour. This microfoundation has the advantageous property that coefficients in the model equations can be interpreted in a straightforward and meaningful way, as their connection to the deep model parameters is easily detected. The general equilibrium structure facilitates the construction of a narrative around a baseline scenario. DSGE models are one of the workhorses in the portfolios of NCBs. A large majority of NCBs in the Eurosystem maintain at least one DSGE model in their operational modelling toolkit, tailored to its specific needs. This is done either by developing a model in-house or by adopting a well-established one from the literature. Structural models are mainly deployed for scenario analysis and policy simulations. Only a small number of NCBs use a DSGE model as their main projection tool.

Semi-structural models are usually larger than DSGE models and have more detailed mapping into national accounts. They are less theory-based but feature more conceptual and empirical flexibility. Typically, this kind of model mainly incorporates theoretical considerations in the specification of long-run relationships between variables. They rest on long-run equations that are grounded in economic theory and share some features with their DSGE counterparts. For the purpose of analysing observed macroeconomic dynamics, however, equations are typically chosen to ensure a good data fit, and can rest on looser theoretical foundations. Semi-structural models may also allow for short-run deviations from theory-grounded equations to obtain a good empirical fit. This is accomplished via equation-by-equation estimation, due to constraints caused by the size of such models. Short-run dynamics then capture adjustments towards the equilibrium relationship, with other explanatory factors helping improve the empirical fit of the equations. Semi-structural models usually combine neoclassical and Keynesian properties. While the former are mainly reflected in the long-run characteristics of the model, e.g. the trend in potential output, the latter are typically mirrored in the error correction form of the equations and the demand-driven determination of actual output in the short run. In general, semi-structural models are easier to adapt than DSGE models, given the less stringent theoretical corset. This feature makes them attractive for NCBs, since it allows more straightforward model adjustment, so

[3] While rational expectations are the most common assumption within DSGE models, departures can be allowed for, as in the cases of learning (Evans and Honkapoja, 2001), rational inattention (Sims, 1998) and, more recently higher-order beliefs (Angeletos et al., 2018). See also Section 3.2.1 on alternative expectations formation mechanisms.

questions arising in the monetary policy context can be addressed in a timely manner. For instance, single blocs can be re-specified without needing to modify the whole model structure. Almost all Eurosystem NCBs maintain and develop semi-structural models, making them another key model class. A large majority of NCBs conduct their macroeconomic projections using a semi-structural model. While in many cases semi-structural models are backward-looking, they can also assign an explicit role to expectations, as in the case of the FRB/US model of the Federal Reserve Board, the LENS model of the Bank of Canada, the ECB-BASE model of the ECB and the FR-BDF model developed at the Banque de France, which also feature stronger theoretical foundations. In the case of FR-BDF, the model allows for different expectations formation processes, including model-consistent expectations. Semi-structural models typically provide a consistent framework for accommodating experts judgement. However, since they are not fully structural, the residuals of equations cannot be interpreted as structural shocks, as they can with structural models. One practical implication of this difference concerns how to interpret historical data: while DSGE models can provide historical decompositions of observed data based on structural shocks, semi-structural models only provide decompositions of observed endogenous variables based on exogenous drivers (typically interest and exchange rates, commodity prices and foreign demand).

The third category, time-series models, embraces a large variety of other models. They cover a broad range of methodologies, predominantly in the time-series framework. These models aim at optimising statistical and predictive performance to detect historical regularities and empirical benchmarks that can be exploited out of sample. Hence the structural features in the previous two categories of model are largely neglected. This category includes, for instance,[4] vector autoregressive (VAR) models, factor models and bridge equation models. The models are used as cross-checks for the main macro models, as satellites to provide additional information not covered by the workhorse models, or as short-term forecasting tools.

The analysis contained in this report does not cover short-term forecasting models.[5] According to the survey results, this class of models includes dynamic factor models, bridge equations and models for forecasting GDP and its components, mixed data sampling (MIDAS) and factor-augmented MIDAS (as recently developed at the Banque de France, for instance) and Bayesian VARs. Recent promising advances are worth mentioning in passing. The use of machine learning models (random forest, long-term short-term models), topic models based on newspaper texts, and innovative data sources such as Google Trends are currently being explored and developed by De Nederlandsche Bank. The recent experience with the COVID-19 pandemic has also stimulated the use of high-frequency disaggregated data.

[4] Several central banks also have structural vector autoregressive (SVAR) models in their toolkit. For the purpose of this report, and in order to distinguish this type of model from the main macro models, we classify these as time-series models, although SVARs can rely to a certain degree on theoretical considerations when deriving an identification scheme to detect structural shocks.

[5] See European Central Bank (2016) for references on tools for short-term inflation and GDP forecasting by the ECB and NCBs.

Finally, among other models used for recurrent activities are not covered in detail in this report, estimations of potential output and the output gap are typically produced using a semi-structural core projection model, either with additional filters or in conjunction with a suite of models (possibly including, for example, unobserved component and VAR models or the production function approach).

3.1.2 Model scope

Models vary in terms of scope, i.e. the jurisdiction(s) covered by the model. Most can be put into one of the following four categories: country-specific, euro-area, multi-country or global.

All NCBs maintain at least one country-specific model covering the home jurisdiction. The main projection models belong to this class. A country-specific model describes the key economic interactions within a country, as well as its main linkages with the rest of the world. Developments in the rest of the world are usually represented by foreign demand, foreign prices, exchange rates and commodity prices, mostly assumed to be exogenous processes. These foreign variables then affect the home jurisdiction via a trade bloc, which models exports and imports of goods and services and their respective deflators, as well as other items in the balance of payments. Because Eurosystem projections follow a country-by-country bottom-up approach, being able to assess the impact of exogenous foreign variables on the home jurisdiction is a key requirement.

NCBs also maintain models that include the euro area as a single entity (or, sometimes, as a monetary union of two or more regions including the home jurisdiction). These are often used to study issues related to monetary policy, or as a crosscheck on baseline projections. In some cases, the models extend beyond the euro area and consist of multiple blocs. Examples are: the euro area and the rest of the world, the euro area and the home jurisdiction, the euro area and the home jurisdiction plus the United States, etc. These more elaborate models can be used to analyse international policy spillovers.

The model portfolio at the ECB also includes a multi-country model (ECB-MC) covering the largest euro area countries in detail, the remaining countries as a single bloc and the trade linkages between the various countries. This is the ECB's main projection model.

Global models aim at modelling the world economy. They vary in the degree of detail. At one end of the spectrum are models in which a large set of countries is modelled individually. One well-known example is the National Institute of Economic and Social Research's Global Econometric Model (NiGEM), which belongs to the semi-structural category.[6] The Flexible System of Global Models or FSGM from the International Monetary Fund (IMF) is another (see Andrle et al., 2015). NiGEM is included in many portfolios, but NCBs do not actively develop and maintain it, as it is rather expensive. At the other end of the spectrum are much smaller models like

[6] A description of the model is available on the NiESR website.

global structural VARs (SVARs), which are much easier to maintain. In between are DSGE models that cover the key economic blocs of the world economy, such as EAGLE (see Gomes et al., 2012) and the IMF's Global Integrated Monetary and Fiscal Model, or GIMF (see Laxton et al., 2010). While not used by NCBs as their main projection models, global models are nevertheless an important tool for conducting policy analysis, as they make it possible to study important issues like international policy spillovers and trade disputes.

Table 1 provides a brief overview of the types of models in the Eurosystem and their scope and use. Table 3 at the end of this section provides detailed information and relevant references.

Table 1
Types of model in the Eurosystem, their scope and use: overview

	Projections	Monetary policy simulations	Other policy use
Geographic coverage	Country-specific Euro area (ECB)	Country-specific Euro area Global	Country-specific Euro area Global
Structural (DSGE) **Semi-structural** **Time-series**	Macroeconomic models regularly used to build the (B)MPE baseline	Macroeconomic models regularly used to assess the ECB monetary stance and effects	Macroeconomic models regularly used for other policy purposes (e.g. fiscal or global scenarios)

Source: see Table 3

3.1.3 Model features

The main macro models used by NCBs can be distinguished by different dimensions such as type, scope and use. The particular use to which models are put is a key factor in determining their specific characteristics. This explains, for instance, why most projection models turn out to represent small open economies and have weaker microfoundations than the models deployed for scenario analysis and policy simulations.

Given the distinctive forecasting process of the Eurosystem, projection models mainly embody a country-specific perspective. This essentially reflects the construction of the baseline projections, which relies on external assumptions about key international variables such as exchange rates, world demand and oil prices, and focuses on providing a coherent framework for the domestic economy. The majority of projection models therefore do not exhibit a detailed open-economy dimension, i.e. they treat the external environment as exogenous.

As international linkages are not a prominent feature, most NCB projection models do not account for the role of international monetary policy spillovers. By contrast, the interaction between domestic fiscal policy and area-wide monetary policy seems to be a much more important feature. A large number of NCBs include some form of interplay between these policies in their projection models, either via explicitly modelled rules or through shocks. The monetary/financial interaction, on the other hand, plays a minor role in this class of models. This may be justified by the specific projection procedure, whereby financial variables are mostly treated as exogenous.

The exogeneity and conditioning assumption on nominal interest rates in the Eurosystem's projections exercise also explain why only a small number of projection models incorporate the effective lower bound (ELB) on the nominal interest rate and its inherent non-linearity. As regards non-standard monetary policy measures (NSMs), roughly one-half of NCBs account for their effects, mainly by integrating exogenous shocks, while only a few models allow NSMs to be determined endogenously. Although only deployed in a few cases, satellite models seem an appropriate tool for including the estimated effects of NSMs on relevant financial variables such as long-term interest and exchange rates, which are typically assumed to be exogenous in baseline projections.

Of the other features that characterise the current environment, the possible non-linear and asymmetric effects of large shocks are virtually absent from projection models, apart from a few cases where non-linearities associated with the ELB, commodity prices and real-financial feedback are taken into account. Nonetheless, the current experience with the COVID-19 pandemic provides an interesting example of swift adaptation of projection models to analyse large, unprecedented shocks. At the start of the pandemic, no model in the Eurosystem catered explicitly for such a shock. To gauge the immediate impact of the pandemic and the associated lockdown measures, NCBs turned to alternative sources of information that were high-frequency, sectoral and on the supply side, such as electricity consumption, POS transactions, mobility indicators and newly established surveys. Some NCBs developed high-frequency GDP trackers, occasionally even extending these to a full set of demand components and labour market variables. This outside information was then used to condition the projections obtained from the standard models, as the latter were generally considered still useful and important to guarantee consistency of projections. In some cases, semi-structural models were swiftly combined with data from new sources, underlining the flexibility of this model type.

As far as some of the major analytical gaps identified are concerned, productivity trends and demographics are two features captured by several NCB projection models. These are either directly determined within the main projection model or by using satellite models. By contrast, accounting for the determinants of the natural interest rate in projection models seems to be much less relevant (or possibly less feasible) for NCBs. The role of alternative expectations formation mechanisms and their interplay with monetary transmission also remain relatively unexplored; a non-negligible number of NCBs recognise its importance, but in most cases they have not taken any concrete steps in that direction. Consequently, analysis of monetary policy under different types of expectations has to date rarely been conducted on the basis of projection models.[7] Finally, risks and

[7] Some central banks have started to go in this direction: for example, the ECB and the Banque de France carry out this type of analysis with their new projection models (ECB-BASE, ECB-MC and FR-BDF).

policies related to climate change are currently absent from the set of projection models used in the Eurosystem.

Turning to scenario analysis and policy simulations, NCB modelling toolkits often contain more than one operational model. In some cases, the same projection models are applied for this kind of analysis too, although usually in the context of scenario simulations around the baseline projection. Since a wide range of issues are discussed in the process of monetary policy preparation, NCB policy simulation toolkits typically feature a larger degree of structural heterogeneity than projection models. As an example of the use of structural models, during the current pandemic DSGE models have been deployed to produce historical decompositions of data and baseline projections into structural shocks. The experience has been mixed. Whereas some NCBs report that their models have been able to produce reasonable shock decompositions, others argue these appear unconvincing or note that they had to implement changes to their models, such as adjusting the persistence of shocks. Specific structural models have also been developed to gauge the interactions between the pandemic and the wider economy and the economic and health consequences of testing and quarantining (see Box 5 in Section 4: Decomposing sectoral inflation during the COVID-19 pandemic).

Besides domestic-economy models developed in-house, NCBs also actively deploy other models for scenario analysis and policy simulations that emphasise the open-economy dimension, such as EAGLE (possibly in a country-specific version) or NiGEM. This implies that international linkages are a much more common feature of policy simulation models than of projection models, which facilitates model-based analysis of international monetary policy spillover effects. Global models such as NiGEM and GIMF have recently been used to develop pandemic scenarios.

Another common prominent feature of NCB models used for scenario and policy simulations is the interaction between monetary and fiscal policy, which is modelled either by specifying policy rules or via additional shocks. Policy simulation models typically allow for a richer analysis of policy interactions than projection models, thanks to their stronger theoretical underpinnings. As with projection models, though, the interplay between monetary and financial policy is relatively unexplored. In light of the extensive use of government support measures during the current pandemic structural models with rich fiscal blocs were generally considered helpful, although the reliability of fiscal multipliers at the current juncture has been questioned. While the majority of NCBs recognise the importance of macrofinancial linkages, only about one-half of them explicitly model these interdependencies.

In contrast to the projection process, the ELB plays a more important role in policy simulations, although several NCBs still do not explicitly take it into account. This is the case, for instance, when NCBs use their semi-structural projection models for scenario and policy analysis, or when the structural model represents a small open economy. In both cases, monetary policy is treated as exogenous. Moreover, more than one-half of NCBs include NSM effects in their policy models, but, similar to the projection models, these are mainly implemented as exogenous shocks; only a small number of NCBs model NSMs endogenously.

Large shocks and the associated non-linearities and asymmetries are mostly ignored in scenario and policy simulation models, except in a few cases. Climate change-related mechanisms are also largely absent in this type of model, with only a very few exceptions. Nonetheless, some NCBs do attach importance to climate change modelling and plan to address the issue in the near future.

As far as analytical gaps are concerned, policy simulation models address the issue of long-term trends to a lesser extent than projection models. While some NCBs indicate that demographics and productivity trends are relevant for policy analysis and simulations, the determinants of the natural interest rate are virtually disregarded in almost all NCB models. Although alternative expectations formation mechanisms and how these interact with monetary policy are generally more explicitly specified in policy simulation models than projection models, the majority of NCBs do not account for or plan to work on this topic.

3.2 Current use of macroeconomic models for monetary policy

Models are deployed to a varying degree in policy processes. One major area is the preparation of Eurosystem macroeconomic projections, which is undertaken on a regular basis, following a well-structured procedure and involving a high degree of collaboration between the ECB and NCBs.[8] Other policy processes encompass a variety of model applications, ranging from regularly updating the monetary policy stance assessment to ad hoc use of models to address topical policy issues. This sub-section describes the different ways models are used for monetary policy purposes within the Eurosystem, with a focus on the types of model applied and the main model-based inputs to policy processes.

3.2.1 Model-based analysis in the projections process

Projection exercises conducted in the Eurosystem are largely model-based.[9] Models are used to produce and interpret the baseline, assess baseline sensitivity to underlying projection assumptions, discuss alternative scenarios around the baseline and build longer-term projections. By providing a coherent framework, models contribute to the internal consistency of overall projection numbers. As a story-telling

8 The Broad Macroeconomic Projection Exercise (BMPE) is undertaken jointly by the ECB and NCBs each winter and summer. The Macroeconomic Projection Exercise (MPE) is carried out by the ECB (with NCBs contributing short-term inflation projections) each autumn and spring. In both exercises, country-level and euro area-level (country aggregate) projections are produced. For a detailed description of the underlying procedures and modelling tools used, see European Central Bank (2016).

9 Besides the main macroeconomic projection models, a wide range of other modelling tools are regularly used to prepare projections, including various specialised satellite models, short-term forecasting tools, etc.

device, models help develop an economic rationale behind projected macroeconomic trends.

The forecasting procedures and discussions in place imply various requirements a projection model needs to fulfil to be used in the process. Given the wide range of economic indicators used to prepare projections, a forecasting model needs to provide a consistent account for a large set of data. The continuously evolving array of economic issues discussed in forecast rounds require the model to possess a rich economic structure, as well as the flexibility to incorporate novel features or structures upon demand. At the same time, models need to be built on solid theoretical foundations in order to discipline the economic discussion and interpretation of numbers.

Semi-structural macroeconometric models are the main macroeconomic projection tool used by Eurosystem NCBs. Despite recent advances in the development of DSGE models (including for forecasting, as testified by the Bank of Finland's use of a DSGE model for its projections), traditional semi-structural models remain the primary tool used for building baseline projections, thanks to their flexibility and ability to account for a wide set of macroeconomic indicators.[10] DSGE models are being increasingly used as a complementary tool to provide a structural interpretation of baseline projections and changes to projections between forecast rounds.[11]

Model-based input to baseline projections is usually complemented by expert judgement. This helps to account for factors that are not sufficiently captured by models. Specifically, experts may have additional reliable information on the main macroeconomic developments, considerably improving forecasting accuracy over a short-term horizon. Judgement may also be justified in cases where the baseline projection incorporates preannounced policy measures, for instance, or historically unprecedented events (such as the pandemic crisis).

Models are routinely used to assess uncertainty around the baseline projection. Technical assumptions are made regarding the future paths of a number of exogenous variables when preparing the baseline projection. The international environment is projected separately, and largely treated as exogenous from the euro-area perspective. Models are used to assess the implications alternative paths in technical assumptions and non-euro-area variables have for the baseline projection. Also, while fiscal policy projections are always updated in line with macroeconomic projections in an iterative manner, these only include measures that have been detailed and approved by national governments at the cut-off date.

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10 In fact, a number of NCBs have been increasingly investing in renewing this type of model, in particular enhancing their microeconomic foundations (e.g. the recent development of the FR-BDF model at Banque de France).

11 In comparison to their large semi-structural counterparts, most DSGE models used to analyse baseline projections appear relatively stylised. Practical use of larger/richer DSGE models in this context is limited largely due to rapidly rising model complexity. This reflects a high degree of interconnectedness between the different parts of the model and the effects of structural shocks, which are the ultimate source of economic fluctuations in this class of model. Nevertheless, these models are extremely useful for projection exercises; they not only generate a structural economic interpretation of the baseline projections, they also provide guidance on the effects of anticipated events or unprecedented developments, such as deployment of new policy measures or the effects of and policy responses to the pandemic.

Eurosystem staff evaluate scenarios for the most likely amount and composition of the fiscal measures needed to meet fiscal targets. Models help assess the impact of these additional fiscal measures on the baseline projection.

Basic Model Elasticities (BMEs) summarise the quantitative macroeconomic effects of changes in projection assumptions. In essence, these can be thought of as a smaller version of a multi-country model linearised around a specific baseline showing how selected endogenous variables react to shocks in certain exogenous variables. BMEs are available for all EU countries and are used to assess how assumptions contribute to projection revisions and eventually result in last-minute changes to the baseline. The tool was developed jointly and is updated annually. It is largely built on model-based reactions under specific common scenarios implemented using the ECB and NCB projection models. Besides the standard technical and external assumptions, fiscal BMEs have also been added to the toolbox to assess the impact of changes in certain categories of public expenditure and revenue. Shocks to endogenous variables like consumption and investment can be considered too.

Longer-term projections in the medium-term reference scenario (MTRS) are largely model-driven. The MTRS extends macroeconomic developments beyond the usual projection horizon (two to three years), over a period of an additional five years. Apart from an assumed path for the external environment and domestic potential output, the scenario relies on largely endogenous economic adjustment towards long-term equilibrium, including model-consistent settings for policy instruments.

3.2.2 Model-based analysis for other policy processes

Macroeconomic models are also used for monetary analysis and the regular monetary policy stance assessment. Monetary analysis systematically examines the impact of monetary policy decisions using a suite of models developed at the ECB and across the Eurosystem. The cross-checking role of monetary analysis is also performed using macro-financial scenario analysis based on state-of-the-art empirical and structural macro-financial models.

In addition to projections and the preparation of monetary policy decisions, models are actively used in other policy processes. The degree of standardisation may differ, as may the inputs used. For example, well-structured banking sector stress-testing exercises define specific simulation scenario details and lay out clear requirements regarding model-based inputs. However, model applications vary widely. They are deployed on an ad hoc basis driven by topical policy issues, and vary greatly in terms of scenario complexity and use in policy discussions.

In the past, operational policy models have been used, together with other tools, to analyse monetary policy implementation, fiscal consolidation (multipliers and policy spillover effects), external rebalancing scenarios, the implications of trade tariffs, etc. More recently, the most common use of models across the Eurosystem in 2020 was to analyse the shocks associated with the pandemic crisis and their macroeconomic impact.

Structural models complement analytical work on a daily basis. Besides facilitating quantitative assessment, as a disciplining device they also contribute to the consistency of analytical findings. Model-based inputs feature in internal policy notes and staff publications. They are often discussed in policy or consultation meetings within the Eurosystem, as well as in discussions with other domestic and international institutions (ministries of finance, the European Commission, the International Monetary Fund, etc.). Models implicitly provide a common platform for discussing differing views on economic developments and the policy recommendations implied.

The new generation of structural policy models is making an active contribution to the policy research agenda. Based at the cutting edge of theoretical advancements, these models provide a natural platform for exploring and evaluating alternative proposals aimed at policy innovation, such as implementation issues (instruments, objectives, communication, etc.) and how monetary policy interacts with other policies. These models form an effective bridge between academic and policy debates.

3.3 Benchmarking against other institutions

How does the Eurosystem compare with peer institutions? This section provides some examples of best practices in other institutions within the ESCB and beyond. The focus is on the use of models for projections and other policy-related activities. The modelling approaches typically reflect characteristic features of the economies under scrutiny; for example, in the case of small open economies, linkages with the main trade partners and exchange rate movements play a major role.

3.3.1 Benchmarking with best practices in other institutions within the ESCB and beyond

Two cases within the ESCB are worth mentioning, as they provide examples of an integrated approach to projections and monetary policy analysis. The NCBs of Sweden (Sveriges Riksbank) and the Czech Republic (Česká národní banka) have adopted a DSGE modelling framework for projections, and use this to some extent also for policy analysis. In both cases, structural models are complemented with other tools.

Sveriges Riksbank uses two types of macroeconomic models in the monetary policy preparation process: an empirical Bayesian VAR (BVAR) and a medium-scale DSGE model. The latter (called MAJA) is a two-country model in which both Sweden and the foreign economy are modelled as structural economies (see Corbo and Strid, 2020, for details). The domestic economy is a small open economy, while the foreign economy is assumed to be closed. The model is linear and currently does not include an ELB, nor does it assign any role to non-standard monetary policy measures. However, it includes global technology growth among the determinants of the natural interest rate, which implies that global savings demand and supply are important in determining real interest rates. This reflects the fact that Sweden is a small open economy and Swedish interest rates are highly correlated with foreign interest rates. The model is estimated using Bayesian techniques. The foreign bloc represents the two main trading partners of Sweden (the euro area and the United States) and is estimated using a weighted average of the two. Compared to past experience with modelling the external sector at Sveriges Riksbank, the introduction of a structural foreign economy has improved the role of trade spillovers and enriched the identification of structural foreign shocks. As some sectors are not included in MAJA (e.g. housing, banking), other DSGE models are sometimes employed in policy analysis.

A range of BVAR models has also been developed for forecasting Swedish inflation, with substantially better forecasting performance than professional forecasts and benchmarks.

Česká národní banka has recently developed a new core macro forecasting model called g3+, which is regularly used in forecasting rounds. This is a two-country DSGE model that provides a detailed description of the domestic economy, while the foreign economy represents the "effective" euro area, based on international trade weights for the Czech economy (see Brazdik et al., 2020, for a detailed description). It is a fully micro-founded model for the domestic economy featuring an intermediate goods production function using labour and capital, final goods production that includes energy, domestic intermediate and foreign goods, monopolistic competition, nominal rigidities, a forward-looking monetary policy rule, a simple fiscal rule and two types of households (Ricardian and non-Ricardian). The foreign-economy bloc takes the form of a small semi-structural model consisting of four equations: an IS curve, a Phillips curve, a monetary policy rule and an uncovered interest parity condition. The model is linear and therefore does not take the ELB into account. However, a tool has been developed that captures the effects of it via a mix of anticipated shocks. The baseline forecast incorporates endogenous responses based on the monetary policy rule for the foreign economy. The forecast is also conditional on foreign outlooks, the domestic fiscal outlook and one-quarter ahead forecasts for the exchange rate and inflation. The model accounts for non-standard monetary policy measures in the euro area by including a shadow interest rate (in addition to three-month EURIBOR). For scenario simulations of the external environment, Česká národní banka produces consistent external assumptions using NiGEM; this features a detailed description of global economic dynamics and provides flexibility with regard to a wide range of shock types and source. External assumptions are complemented and supported with satellite models, and the full conditioning set is interpreted via the foreign bloc of the core model.

Outside the ESCB, the Federal Reserve System uses a wide range of models for forecasting and policy analysis, with a large role still played by judgement (see Giannoni, 2016 and Roberts, 2019). Judgemental forecasts typically amount to including “add factors” in model equations, and are needed to provide a narrative explanation of current developments and the outlook (including nowcasting). Model-based forecasts make use of semi-structural models (FRB/US, described in Braytn et al., 2014), structural models (DSGE) and empirical time-series models such as VAR and factor models. FRB/US is interesting from both a modelling perspective and a communication and dissemination standpoint. It is a large-scale estimated model of the US economy with a neoclassical core that combines a production function with endogenous and exogenous supplies of production factors, and rigidities that apply to households' and firms' decisions, allowing the model to generate gradual responses in macroeconomic variables to exogenous shocks that are in line with the data. FRB/US allows for two alternative assumptions on how agents form expectations: the latter can be either fully model-consistent or based on projections from estimated small-scale auxiliary VAR models. It also allows for a zero lower bound on nominal interest rates. To facilitate communication of the model and its properties to the public, the FRB/US documentation and sample simulation programs can be downloaded from the Federal Reserve System's website. Documentation is also publicly accessible for the Estimated Dynamic Optimization-based Model (EDO), a DSGE model of the US economy used for forecasting and policy analysis (see Chung et al., 2010). The main international/global DSGE model routinely used at the Federal Reserve Board of Governors is SIGMA (see Erceg et al., 2006), a multi-country open-economy model.

The Bank of England's recently developed forecasting platform is another interesting case. This consists of four components: a structural DSGE model named COMPASS (Central Organising Model for Projection Analysis and Scenario Simulation); a suite of models used to provide cross-checks on the forecast; a macroeconomic modelling and projection toolkit called MAPS (Model Analysis and Projection System); and EASE (Economic Analysis and Simulation Environment), a user interface. Burgess et al. (2013) provide a detailed description. The platform has been in use within the projections production process since the end of 2011. COMPASS is a New Keynesian general equilibrium model, similar to those used by other central banks and policy institutions. It is employed to produce forecasts for key macroeconomic variables. In terms of modelling trade-off strategies, the level of complexity of COMPASS was chosen based on a cost-benefit analysis. The suite of models includes 50 separate models covering different aspects, including shocks and channels omitted from COMPASS and additional variables (e.g. energy, the financial sector). MAPS and EASE form part of the IT infrastructure. MAPS is a MATLAB toolkit built and maintained by economists at the Bank of England, similar to other MATLAB-based modelling toolboxes like DYNARE. It allows for Bayesian estimation of linear state-space models. The Bank of England's approach is to modify the structure of COMPASS and the composition of the suite of models as modelling progresses and the questions about the economic landscape change.

The Bank of Canada mostly relies on both a main structural and semi-structural models for policy purposes. ToTEM (Terms-of-Trade Economic Model) is a large-scale multi-sector DSGE model (for a description, see Murchinson and Rennison, 2006, and Dorich et al., 2013). As such, its micro-foundations make it suitable for policy analysis as well. Recently, the Bank of Canada has developed a large-scale semi-structural model called LENS (Large Empirical and Semi-structural, see Gervais and Gosselin, 2014) to complement ToTEM in projections and policy analysis. The structure of LENS is similar to that of FRB/US.

Table 2 provides a summary of the types of model at selected institutions outside the Eurosystem and how they are used.

Table 2

Types of model outside the Eurosystem, their scope and use: details

Country	Projections	Other policy use	References
CZ	G3+ [D]	G3+ [D] NiGEM [S]	Brazdik et al. (2020), NIESR
SE	MAJA [D]	MAJA [D]	Corbo and Strid (2020) Villani (2009)
US	FRB/US [S] EDO [D]	FRB/US [S] EDO [D] SIGMA [D]	Brayton et al. (2014) Chung et al. (2010) Erceg et al. (2005)
UK	COMPASS [D]	COMPASS [D]	Burgess et al. (2013)
CA	ToTEM [D] LENS [S]	ToTEM [D] LENS [S]	Murchinson and Rennison (2006) Dorich et al. (2013) Gervais and Gosselin (2014)
IMF	GPM [S]	GEM [D] GIMF [D] FSGM [S] IPF [D]	Carabenciov et al. (2013) Laxton and Pesenti (2003), Pesenti (2008) Kumhof et al. (2010) Andrle et al. (2015) Adrian et al. (2020)
EC	QUEST III [D] GM [D]	QUEST III [D] GM [D]	Ratto et al. (2009) Albonico et al. (2017)

Note: S=Semi-structural; D=Structural.

Among non-central bank institutions, the IMF provides an interesting example of the use of multiple models in forecasting and policy analysis. The forecasts regularly published in the IMF's *World Economic Outlook (WEO)* are produced using a bottom-up approach. Global assumptions are formulated about interest rates, exchange rates and commodity prices, in addition to country-specific assumptions. Individual country teams then use country-specific models to produce projections, and the WEO team aggregates the latter and checks consistency in an iterative process. The Global Projection Model (GPM) employed to assist country desks in the WEO projection exercise is an important analytical tool developed at the IMF (see Carabenciov et al., 2013). The GPM stands in an intermediate position between a fully structural DSGE model and a time-series, quarterly projection model. The Global Economic Model (GEM) by Laxton and Pesenti (2003) and Pesenti (2008) and the Global Integrated Monetary and Fiscal Model (GIMF) described in Laxton et al. (2010) are two key examples of DSGE models developed by the IMF. In addition, the IMF has developed a suite of macroeconomic models called the Flexible System of Global Models (FSGM; see Andrle et al., 2015). This contains three core modules, each of which fully encompasses the global economy. Each module has 24 countries/regions. FSGM modules are semi-structural; some key elements, like private consumption and investment, have micro-foundations, while others, such as trade, labour supply, and inflation, have reduced-form representations. More recently, the IMF has developed an Integrated Policy Framework that provides conceptual and quantitative approaches aimed at assessing the policy trade-offs many emerging markets and small open economies face.

The European Commission (EC) develops and maintains several macroeconomic models for forecasting and policy analysis. QUEST is a macroeconomic model routinely used to analyse the state of the EU economy. The current version, QUEST III, has been in use since 2007 (see Ratto et al., 2009). This is a structural DSGE model that includes frictions in goods, labour and financial markets. It is used to produce structural shock decompositions, for example to assess the main drivers of growth and imbalances. Its main areas of application are monetary and fiscal policy analysis. There are also model variants covering housing and collateral constraints, and a banking sector. All model versions are employed using different country disaggregations, focusing on the euro area or the European Union as a whole, other global regions, or individual member states. A variant of QUEST that includes semi-endogenous technological change is also available, and is typically used to analyse the effects of structural reforms. Recently, the EC has developed the Global Multi-country model (GM) to complement QUEST in supporting the macroeconomic surveillance, monitoring and forecasting activities of the EC (see Albonico et al., 2017). The GM is regularly used to identify the model-based drivers of GDP forecasts. It is a structural DSGE model and builds on QUEST, but with a few main differences: the euro area is split into two sub-regions, and the trade sector incorporates oil imports, which are used for to generate domestic total output. To compute the output gap the EC applies a Cobb-Douglas production function approach, which looks at short-term deviations of labour and total factor productivity from their potential (see Havik et al., 2014).

3.3.2 The experience of other central banks with a strategy review

The Bank of Canada has renewed its monetary policy several times since its early adoption of an inflation targeting framework in 1991. The two most recent renewals took place in 2011 and 2016, and the next one will be completed in 2021. In preparation for the 2011 renewal, staff research focused on the possible benefits of a lower inflation target. However, as noted in Amano et al. (2020a), most of the studies relied on models that abstracted from the ELB, as did much of the wider literature at the time. In the 2016 renewal, model-based simulations included both the ELB – which had already proven to be a constraint on monetary policy in many jurisdictions – and unconventional monetary policy tools. As reported in Bank of Canada (2016), analyses made use of ToTEM and LENS, among other tools. In the context of the ongoing review process, model-based analysis produced by Bank of Canada researchers used, for instance, DSGE models to analyse the performance of an average inflation targeting regime when the short-term policy rate is close to its ELB (see Amano et al., 2020).

In 2019, the Federal Reserve System launched a comprehensive and public review of its monetary policy framework, which ended in August 2020 when the Federal Open Market Committee (FOMC) released a revised Statement on

Longer-Run Goals and Monetary Policy Strategy. The review process highlighted the role of models in supporting the monetary policy preparation process. As reported in Altig et al. (2020), the studies prepared in the strategy review were intended to provide a foundation for: assessing the prospective performance of the flexible inflation-targeting framework; exploring the need for and the desirability of modifying the overall monetary policy framework; and examining issues related to the robustness of the main conclusions to alternative assumptions. The review made extensive use of both FRB/US and various DSGE models to support the analysis of alternative monetary policy strategies and their implications for the US economy (see, among others, Arias et al., 2020 and Hebden et al., 2020). The distributional consequences of alternative monetary policy strategies have also been analysed with the use of a HANK DSGE model in Feiveson et al. (2020).

Table 3

Eurosystem models: details

		Monetary policy simulations			Other policy use			
	Projections	Country-specific	Euro area		Country-specific	Euro area		References
BE	NONAME [S], BE3C [D]	NONAME [S]	BE3C [D], (B)EAGLE [D]	NONAME [S], BE3C [D]	NONAME [S], 3D version [D]	BE3C [D], (B)EAGLE [D]	BE3C [D], (B)EAGLE [D]	Jeanfils and Burggraeve (2005) de Walque et al. (2017)
DE	Macro-econometríc model [S]	Macro-econometríc model [S], 3-region model [D]	TANK [D], Kuehl model [D]	Macro-econometríc model [S]	Macro-econometríc model [S], 3-region model [D]	TANK [D], Kuehl model [D]	NiGEM [S]	Haertel et al. (2021) Hoffmann et al. (2020) Gerke et al. (2020) Kuhl (2018)
EE								
IE	Econometric model [S]	Econometric model [S], DSGE [D]	EAGLE version [D]	Econometric model [S]	Econometric model [S], EAGLE version [D]	DSGE [D]	NiGEM [S]	
GR	Macro-econometríc model [S]	BoGGEM [D], EAGLE version [D]	3D [D], EAGLE version [D]	Macro-econometríc model [S]	BoGGEM [D]	3D [D]	EAGLE version [D]	Zonzilos (2004) Papageorgiu (2014)
ES	MTBE [S], JoSE [D]	MTBE [S], JoSE [D]	JoSE [D], ELMo [D]	MTBE [S], JoSE [D]	MTBE [S], JoSE [D]	JoSE [D], DSGE [D]	NiGEM [S]	Arencibia et al. (2017)
FR	FR-BDF [S]	FR-BDF [S]	FREAM [D]	FR-BDF [S]	FR-BDF [S]	FREAM [D]	IMF-GIMF [D] IMF-FSGM/NiGEM [S] Devulder-Lisack	Lemoine et al. (2019) Castelletti et al. (2018) Laxton et al. (2010) Andrle et al. (2015) Devulder and Lisack (2020)
IT	BIQM [S]	BIQM [S]	DSGE [D]	BIQM [S]	BIQM [S]	DSGE [D]	DSGE [D]	Bulligan et al. (2017) Bartocci et al. (2017) Cova et al. (2020)

	Projections	Monetary policy simulations			Other policy use			References
		Country-specific	Euro area		Country-specific	Euro area		
CY	Semi-structural model [S]	Semi-structural model [S], CY-EAGLE [D]	CY-EAGLE [D]	Semi-structural model [S]	Semi-structural model [S], EAGLE version [D]	CY-EAGLE [D]	CY-EAGLE [D]	
LV	Main DSGE for forecasting [D]	Main DSGE with fiscal sector [D]		Main DSGE for forecasting [D]	Main DSGE with fiscal sector [D]			Bušs (2017) Bušs and Gruning (2020)
LT	Semi-structural model [S]	Semi-structural model [S], EAGLE version [D]	EAGLE version [D]	Semi-structural model [S]	Semi-structural model [S], EAGLE version [D]	EAGLE version [D]	EAGLE version [D]	
LU	Semi-structural model [S]	LU-EAGLE [D], LED [D]	LU-EAGLE [D], LED [D]	Semi-structural model [S]	LU-EAGLE [D], LED [D], LOLA [D]	LU-EAGLE [D], LED [D], LOLA [D]	LU-EAGLE [D], LED [D]	Garcia and Moura (2019) Moura (2020), Marchiori and Pierrard (2015)
MT	STREAM [S]	MEDSEA [D]	MEDSEA [D]	STREAM [S]	MEDSEA [D]	MEDSEA [D]		Grech and Rapa (2016) Rapa (2016)
NL	DELFI [S]	DELFI [S]	EAGLE [D]	DELFI [S]	DELFI [S]	EAGLE [D]	NiGEM [S]	Berben et al. (2018)
AT	AQM [S]	AQM [S]	AQM [S]	AQM [S]	AQM [S]	AQM [S]		Leibrecht and Schneider (2006)
PT	“M” [S]	“M” [S], PESSOA [D]	PESSOA [D]	“M” [S]	“M” [S], PESSOA [D]	PESSOA [D]	EAGLE version [D]	Júlio and Maria (2017)
SI	Semi-structural model [S]	EAGLE version [D]		Semi-structural model [S]	EAGLE version [D]			Gomes et al. (2012) Clancy et al. (2016)
SK	NBS main macro model [S]	NBS main macro model [S], PReMISE [D]		NBS main macro model [S]	NBS main macro model [S], PReMISE [D]		ECB-Global [S], EAGLE [D]	Výškrabka et al. (2019)
FI	Aino 2.0 [D], SVAR [R]	Aino 2.0 [D], SVAR [R]	DSGE [S], SVAR [R]	Aino 2.0 [D], SVAR [R]	Aino 2.0 [D], Aino 3.0 [D] SVAR [R]	DSGE [S], SVAR [R]	IMF- GIMF [D]	Kilponen et al. (2020) Laxton et al. (2010)
ECB	ECB-BASE [S], ECB-MC [S], NAWM II [D]	ECB-MC [S]	NAWM II [D]	ECB-BASE [S], ECB-MC [S], NAWM II [D]	ECB-MC [S]	NAWM II [D], BVAR [R]	ECB-Global [S], DSGEs [D]	Angelini et al. (2019) Coenen et al. (2019) Dieppe et al. (2017)

Note: S=semi-structural; D=structural; R=time-series.

4 Assessment of analytical gaps and associated development needs

This section elaborates on the pros and cons of various macro-modelling strategies and the room for further enhancements to existing models in the Eurosystem. It makes use of survey responses, wider academic literature and the experience of Eurosystem central banks and the ECB in addressing gaps in monetary policy modelling as seen through the lens of policy modellers.

Modelling needs related to the other MPC work streams and the strategy review discussion in general will be assessed, and recommendations made on the feasibility, scope and prioritisation of activities to develop new models. The section is divided into six thematic sub-sections, relating to: long-term trends and macroeconomic dynamics; the monetary policy transmission mechanism; interactions with fiscal and financial policies; climate change; large shocks and uncertainty (with a focus on the COVID-19 pandemic); and global factors and international spillovers.

4.1 Long-term trends and macroeconomic dynamics

This sub-section explores the key challenges in capturing long-term trends such as productivity and demographics, and how these affect growth and the real natural rate of interest in the canonical macroeconomic and macroeconometric models routinely used for forecasting and policy analysis. It reviews different modelling strategies and frameworks, paying attention to different approaches to extracting trends from the data.

It also builds on the findings of other strategy review work streams (digitalisation, globalisation, inflation measurement and climate change, 2021) and the expert group on productivity, innovation and technological progress (2021). These work streams have put forward various hypotheses on long-term determinants of growth, natural rates of interest and factors which can have persistent effects on inflation, but conclusions on the effect and impact these have on monetary policy transmission and strategy require further analysis and modelling to increase robustness (see Baqaee et al., 2021).

4.1.1 Measurement and econometric challenges

Many macroeconomic variables exhibit long-term trends, which can be understood as variations in the long-term averages of a variable which may arise due to structural changes. For example, real GDP exhibits long-term growth, with one of its main determinants being technological progress. Inflation has also experienced long-term historical trends, mainly due to convergence on low inflation targets set by central banks in the 1990s. Recently, inflation and inflation expectations have been significantly below the target of close to but below two percent in the euro area. While long-term inflation is ultimately a monetary phenomenon under the control of the monetary authority, de-anchoring inflation expectations and very persistent (albeit transient) structural factors can trigger persistent inflation dynamics that are observationally equivalent to changing trends for the econometrician.

Research has shown that the natural rate of interest has been declining in recent years. This is most likely related to demographic and technological developments, possibly also to globalisation due to increased trade and financial integration, which has broadly coincided with the fall in the natural rate (for details, see work stream report on globalisation, 2021).

There is a broad consensus in the profession that long-run trends are mainly influenced by supply-side factors, while cyclical variations around trends are mainly driven by demand-side factors. Decomposing key macroeconomic target variables into trend and cycle components is therefore crucial, since different policy conclusions and economic narratives emerge depending on whether the movements observed in, say, output and inflation, are driven by the trend or the cycle. As an example, the slower than expected real recovery (and low inflation) from global financial crises is difficult to rationalise without accepting the possibility that there has been feedback from crises and the associated policy response to supply-side factors in the economy. Similarly, whether a decline in inflation and inflation expectations is believed to be the result of a string of negative cyclical surprises, policy, or very persistent (albeit transient) structural factors gives rise to different policy conclusions and recommendations and different forecast narratives and expected inflation.

Quantifying long-term trends is far from straightforward and vast amount of research has been devoted to the theme since the seminal work by Beveridge and Nelson (1981). One approach is to use time-series models in which trends are assumed to be an unobserved component that generally follows an exogenous unit root, making it possible to capture low-frequency movements in the different variables and permanent shifts in the data. This approach has been used in univariate and multivariate models in which the intercepts are allowed to vary over time. Canova (1998) provides a survey of the various filtering methods and outlines the quantitative differences between them. Importantly, different decomposition techniques extract different types of information from the data; the appropriate technique may depend on the question at hand.

Empirical models can be successful in providing a good representation of the dynamics of the data, as well as improving forecasting. However, these are pure data-driven methods. They ignore the economic drivers of a movement and can be very sensitive to assumptions about the initialisation of the model and the variance in trends. It is difficult to use them to evaluate the potential future impact of structural economic changes and policies on households' and firms' expectations. If a policy that changes potential output growth is implemented (for example, some types of labour market reforms), statistical models will not capture the change in the trend until data becomes available several quarters later. Similarly, if a change in monetary policy strategy shifts expectations, this cannot be captured by purely backward-looking methods. Judgement consequently needs to be incorporated into the trend, and structural estimates of the elasticities of trends to the policy change are needed.

A classic example of a multivariate model with time-varying trends (and other coefficients) is Primiceri (2005). Other strands of models introduce some economic structure to pin down the trends. Laubach and Williams (2003) is one of the seminal works on this. They link the evolution of trends to movements in other variables (for example, the natural rate of interest might co-move with the real GDP growth trend). One of the main advantages of this type of approach is that it can still be estimated using linear techniques which are not computationally expensive. However, the trends cannot be considered structural, as they are just capturing low-frequency movements in the different variables and their possible correlation, not the theory-based drivers behind them. In other words, the models will yield time-varying potential GDP growth, but will not be able to say anything about the underlying causes of these movements.

Structural models, which are mainly DSGE models, do not generally account for endogenous changes in trends, except for exogenous changes in technology potentially having a permanent impact on real GDP (as in Smets and Wouters, 2007, and Christiano et al., 2005). While in principle this could be achieved by introducing time-varying structural parameters into the model, which would in turn introduce time-varying steady states that evolve over time, this is far from easy. First, DSGE models need to be stationarised before being solved and the introduction of several trends would make this task daunting. More importantly, as both the steady state of a DSGE model and the matrices that determine its dynamics are generally complicated non-linear functions of the structural parameters, estimating DSGE models with trends would require computationally expensive methods that need to be able to handle a large amount of state variables.[12] On the other hand, model-implied detrending imposes tight restrictions on the long-run properties of data which are unlikely to hold (e.g. a balanced growth path). As a result, deviations from the imposed structure have to be captured by the shocks driving the transformed model and some long-run properties are left unexplored. However, if properly modelled in terms of technology, risk aversion and the labour market (among many other factors) the DSGE framework would be an ideal laboratory for exploring how structural trends have evolved over time, and for running scenarios to evaluate how macroeconomic trends might change in response to different economic policies. One possible solution could be to use the method proposed by Canova (2014), which permits various time-series patterns for non-model-based trend components.

In all class of models, trends (either statistical or structural) are modelled as exogenous processes. It therefore remains a challenge to understand and generate endogenous trends in macroeconomic models. However, the literature provides a number of examples, such as models with endogenous growth and overlapping generations (OLG) models, capable of generating endogenous

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[12] For recent advances in machine learning to handle such problems, see for example Fernández-Villaverde et al. (2019).

movements in long-term growth trends and the natural rate of interest. These are discussed below.

4.1.2 Endogenous and exogenous drivers of long-term growth

The traditional macroeconomic models routinely used for policy and forecasting mostly ignore endogenous drivers of long-term growth. Most estimated DSGE models are assumed to be stationary around a balanced growth path. To allow for temporary deviations, a shock can be introduced which affects the technology level, leading to permanent shifts in macroeconomic variables. This shock is targeted to impact the growth of the technology process and is purely exogenous in nature (see Smets and Wouters, 2007, for example). Technological growth eventually returns to the balanced growth path, depending on the persistence of the shock. In these canonical models, money is typically neutral in the long run.

However, there is some evidence that monetary policy may not be neutral and may impact productivity growth through various channels. Policy accommodation can stimulate investment in productivity-enhancing technologies and alter the pace of technology diffusion and adoption, or favourable financing conditions may increase corporate profitability, raising firm entries and decreasing firm exits. It is also possible that favourable financing conditions can reduce the incentives for firms and banks to carry out necessary restructuring and balance sheet repairs, with adverse effects on resource allocation (see the expert group on productivity, innovation and technological progress, 2021). One way of introducing endogenous variations in the technology level is to let firms decide on investment in research and development (R&D), eventually influencing the technology stock and therefore productivity (see for example Romer, 1990).

There are, however, only a limited number of papers in the literature that fully endogenise movements in productivity in a model capturing business cycle fluctuations (for example, Comin and Gertler, 2006). Besides the focus on explaining asset price movements (Kung and Schmid, 2015), models have been used recently to explain persistent features of the economy with the help of endogenous variations in the technology level. These recent models (Anzoategui et al., 2019; Bianchi et al., 2019; Moran and Queralto, 2018; Queralto, 2020; and Elfsbacka Schmöller and Spitzer, 2021, for the euro area) underline the role of hysteresis effects and demand-side shocks in changes in total factor productivity. Anzoategui et al. (2019) build a model with endogenous variation in the technology level and R&D adoption in which the build-up of technologies and their actual use can have a time lag. In this set-up, demand-side shocks can cause a slowdown in productivity, which was seen as a major driver of the slow recovery following the Great Recession. Although Anzoategui et al. (2019) focus on a demand-side shock, they argue that their shock might also capture developments from the financial sector, as it affects the spread over the policy rate. Queralto (2020) makes a similar point by explicitly drawing on a model with a banking sector. Using data from the South Korean 1997 financial crisis, he concludes that financial frictions reinforced the slowdown of productivity growth. Endogenous variations in the technology level caused by demand or financial factors can therefore deepen a recession.

The same argument as above, explaining business cycle movements without explicitly discussing the impact of policy on productivity, holds for Bianchi et al. (2019), who look more deeply into the effects of financing investment. They introduce a borrowing constraint related to the capital stock, tying the scope for investment to the volume of debt. For the United States, they are able to show that equity shocks mainly explain R&D investment, with consequences on the economy's technology level; whereas shocks to the borrowing constraint, influencing the debt level, mainly drive physical investment.

The results from Bianchi et al. (2019) indicate that policy affecting corporate financing conditions can automatically also have an impact on the technology level via endogenous propagation channels on productivity. The policy dimension can be manifold in this respect. Apart from thinking about the transmission of prudential measures, one straightforward question is how standard and non-standard monetary policy can influence the productivity of an economy. For example, Garga and Singh (2020) study optimal monetary policy under endogenous growth using R&D and output hysteresis. Gil and Iglésias (2020a) are one example showing there are long-run relationships between inflation and the economic growth rate, the real interest rate and R&D.

Elfsbacka Schmöller and Spitzer (2020) focus on monetary policy at the zero lower bound. They study the performance of lower-for-longer strategies from the perspective of a medium-scale DSGE model featuring endogenous total factor productivity dynamics similarly to Moran and Queralto (2018) and Anzoategui et al. (2019). In their model, money is not neutral in terms of total factor productivity. One key finding of their paper is that the losses associated with the zero lower bound may be even larger than usually calculated using exogenous growth models and Taylor rules. The main reason is that standard Taylor rules do not consider underutilisation on the technology margin, leading to premature tightening of monetary policy and generating permanent output losses.

One central analytical gap that can be identified concerns the interaction between monetary policy and the endogeneity of an economy's productivity, which may also affect the natural rate of interest. It is not clear whether allowing for endogenous variations in productivity has only a quantitative impact on business cycle dynamics (see Box 1). Monetary policy impulses may be amplified or attenuated through these feedback effects, in both the short and the long run. It is also possible that the transmission channel of monetary policy could change, which would be even more important when looking at non-standard measures and the costs of the zero lower bound. An investigation of monetary policy measures and their impact on the technology level of an economy could depend heavily on the framework used. The related analytical questions are naturally exposed to model uncertainty, which requires strong empirical backing or at least an elaborate sensitivity analysis.

For projections, the benefit of understanding the structural drivers of long-term growth is probably more relevant to economic narratives than forecast accuracy per se in the very short run. However, recurrent forecast mistakes in certain directions may be a symptom of models' attraction points or long run equilibria being systematically biased, models not sufficiently capturing the persistence of shocks due to missing feedback mechanisms or erroneous assumptions on policy transmission mechanisms.[13]

4.1.3 The natural rate of interest

The real rate of interest in the euro area has been estimated to have declined from about 2% in the early 2000s to zero or even a negative level in the late 2010s. According to the Eurosystem's analyses, the decline has been the result of higher saving due to population ageing, declining productivity growth and an increased demand for safe assets since the global financial crisis. A decline in r* severely limits the central bank's conventional policy space. A trend like this, which typically can only be assessed ex post, makes it significantly harder to assess the monetary policy stance and analyse the medium-term outlook for the economy.

The effect of long-term trends on the natural rate of interest in the main macroeconomic models used by Eurosystem central banks is typically either not modelled explicitly or modelled as exogenous. Most central banks use either semi-structural or DSGE models where the natural rate is exogenous. Similarly, some of the variables that affect the natural rate, such as demographics or technology growth, are typically also exogenous in the main models too (see Section 4.1.2). There are, however, satellite models available to assess developments in the natural rate (for an informative overview and examples of models used, see Brand et al., 2018). These models can be either empirical, DSGE, or OLG models.

The omission of explicit modelling of the natural rate from the main models is particularly pressing at the current juncture, since the low natural rate and fluctuations therein reduce room for manoeuvre in the monetary policy rate and increase the frequency of hitting the effective lower bound. Since fluctuations in the natural rate are due to a long-term trend that can be estimated with sufficient precision and are predictable, augmenting existing models with the level of the natural rate from empirical or other satellite models is feasible and desirable. The omission is even more relevant for the monetary policy if fluctuations in the natural rate are linked to cyclical factors such as credit crunches (Guerrieri and Lorenzoni, 2016) or shocks to preferences over assets (Haavio et al., 2019, Rannenberg, 2021), and also when the natural rate may no longer be exogenous to monetary policy (see Section 4.1.2), as this could affect the effective lower bound at cyclical frequencies. Such fluctuations in the natural rate could affect structural

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13 See Kontogeorgos and Lambrias (2019) and Granziera et al. (2021) for an analysis of bias in and efficiency of Eurosystem and ECB inflation projections and Heathcote et al. (2020) for the hysteresis effects of recession through loss of skills during long spells of unemployment.

interpretation of the monetary policy stance at frequencies that are important for the conduct of monetary policy and, ultimately, monetary policy strategy.

There have been recent developments in both theoretical and empirical academic literature that explain the structural driving forces behind the natural rate of interest and the measurement of its levels and trends. From the empirical side, the Laubach and Williams (2003) methodology has been the main method for estimating the natural rate: they define the natural rate of interest as the interest rate that would prevail in the economy in the absence of shocks. In contrast, general equilibrium models define the natural rate of interest as the interest rate needed to close the output gap in the absence of nominal rigidities in the economy. Under this definition, the theoretical natural rate of interest is in fact in constant flux as it reacts to the business cycle and other factors. Among other improvements to this approach, there have recently been suggestions to broaden the set of countries due to mobility of capital (Rachel and Summers, 2019). The methodology itself has also recently been questioned and improvements suggested (Buncic, 2020).

Holston, Laubach and Williams (2016) and Vilmi (2017) provide examples of the Laubach and Williams (2003) semi-structural method for the euro area. Holston et al. (2016) find that the rate has fallen into negative territory, while Vilmi (2017) shows that estimates of the natural rate of interest are very sensitive to modelling and estimation assumptions. Vilmi (2017) estimates provide two competing interpretations for the economic environment in the euro area. According to the first set of results, the shocks generating slack in the euro area real economy are large and persistent cyclical shocks that die out only gradually and could be attributed to financial market and demand shocks. In the second specification, the economic slack is explained by large, near-permanent changes in the long-term natural rate of interest, which falls to around 1%. Such changes could be attributed to a near-permanent slowdown in expected productivity growth. His example shows vividly that there can easily be competing but plausible narratives to explain the same observed trends and cycles, with different policy conclusions. If slack is mainly the result of large cyclical shocks, strong policy measures should gradually close the output gap and return inflation closer to its long-term average. However, if the long-term natural rate of interest has dropped significantly, achieving price stability would require low interest rates well below pre-crisis levels. The analysis by Brand et al. (2018) suggests that, in addition to domestic factors, there are multiple international factors that affect the natural rate too, such as trade globalisation (which has pushed the natural rate up) and financial globalisation (which has pushed it down); demographic factors remain the dominant explanation in many studies (see also Section 4.6).[14]

From the theoretical perspective, there have been several developments concerning the natural rate. Incomplete markets literature has shown the importance of the link between risk (either aggregate or idiosyncratic), wealth distribution and the associated saving behaviour, and the implications this may have on the natural rate. Research has advanced using DSGE models (e.g. Rannenberg, 2019, Rungcharoenkitkul et al., 2019, De Fiore and Tristani, 2011 and Bonam et al., 2018). Mian et al. (2020) have argued that an increase in debt levels,

[14] See also Borio et al. (forthcoming).

with segmented borrowers and savers, can lead to a decrease in the natural rate. Even in more standard DSGE models, if assets are valued by households, the shocks to preferences over such assets have implications for the natural rate (Haavio et al., 2017), leading to fluctuations at cyclical frequencies (see Brand et al., 2018). Using a closed-economy DSGE model estimated for the US and the euro area, Neri and Gerali (2019) show that risk premium shocks, which capture changes in agents' preference for safe assets, have been the main driver of the fall in the natural interest rate in the euro area. In the United States, shocks to the efficiency of investment, which may capture the functioning of the financial sector, and to the risk premium have played a major role.

The most likely way to include long-term trends in the main models used in the policy process is by augmenting the treatment of exogenous levels of the natural rate. This implies that long-term trends in the level of natural rate would be assessed using satellite models (either empirical or theoretical), and these estimates could then be used to inform the main models. To some extent, including fluctuations in the natural rate would be possible by adding a safe asset to the utility function and allowing shocks to preferences over such an asset. The validity and relevance of such an approach would first have to be thoroughly examined.

There is scope to use other models to analyse the effects of changes in the natural rate for specific situations. For instance, models with incomplete markets could be used to analyse fluctuations in the natural rate when aggregate uncertainty or wealth distribution have changed. Alternatively, the effects of factors such as ageing[15] or migration on the natural rate could be assessed using satellite models designed for this purpose. The resulting findings could be used to modify the exogenous level of the natural rate in the main models.

4.2 The monetary policy transmission mechanism

This sub-section explores recent theoretical and empirical evidence on the monetary policy transmission mechanism, especially in a low interest rate and low inflation environment. Household heterogeneity, alternative expectation formation mechanisms and transmission of unconventional monetary policy will be highlighted. It also builds on the findings of the expert group on inflation expectations (2021), as well as the work done for the strategy review seminar on monetary policy instruments and the work stream on the price stability objective (2021).

4.2.1 Alternative expectations formation mechanisms

One important transmission channel of monetary policy is how it affects expectations. First, it is important for central banks that long-term inflation expectations be anchored around their inflation target. Second, the effectiveness of several monetary policy strategies relies on: (a) agents understanding the central

15 See e.g. Carvalho et al. (2016).

bank's policy rule; (b) monetary policy conduct being credible; and (c) agents being forward-looking. These aspects have become even more important since the financial crisis, as central banks have started to incorporate policies such as forward guidance and asset purchases in their portfolio of monetary policy instruments. For example, a monetary policy intervention where central banks announce a future path for either short or long-term nominal interest rates requires agents both to understand why the policy is in effect and also to pay attention to future events. If agents are myopic and only consider past information when forecasting future events, forward guidance announcements could become ineffective, or at least less powerful than with forward-looking agents.

Recent literature has focused on the stabilising properties of interest rate rules that are history-dependent, also called make-up strategies. In these rules, past inflation affects the determination of the short-term policy rate. This approach differs from how monetary policy is thought to be conducted, i.e. in a purely forward-looking way, with past shocks to the economy being irrelevant for the conduct of today's monetary policy. Two noteworthy examples of history-dependent rules are price level targeting (PLT) and average inflation targeting (AIT). Under PLT, the central bank aims for a price level that grows at a pace equal to the inflation targe; under AIT, the central bank focuses on an average inflation rate over a specified number of quarters or years, rather than just on the short-term inflation rate. Both rules imply that the central bank will tolerate the inflation rate overshooting the target sometimes to make up for past inflation shortfalls. These rules have been analysed extensively in the strategy review work stream on the price stability objective (2021).

If these rules are well understood by the private sector, they can provide superior outcomes relative to an inflation targeting rule in terms of hitting the inflation target and output being close to potential, while at the same time providing more stable inflation and output. As in the case of forward guidance, the main transmission mechanism is expectations. Under a make-up strategy, if inflation falls during a recession, agents will expect the central bank to keep the policy rate lower for longer, to compensate for the inflation shortfalls. If households and firms are forward-looking they will expect higher inflation and lower rates in future, i.e. a reduction in the real rate, helping the recovery of both output and inflation.

A significant portion of the literature on structural models has assumed full-information rational expectations – in other words, agents fully understand the model and are entirely forward looking. Growing evidence from psychology and behavioural studies suggests, however, that people neglect some of the information available in their decision-making process – that is, they do not update probabilities as new information arrives, as an agent adhering to rational expectations would. There is an increasing number of experimental studies[16] aiming at understanding the expectation formation process. These generally find biases in expectation

[16] The results of Mankiw and Reis (2002) and Coibion and Gorodnichenko (2012, 2015) suggest informational rigidities in inflation expectations, while studies by Abarbanell and Bernard (1992) and Bouchaud et al. (2018) suggest that there is an under-reaction in near-term earnings forecasts. Debondt and Thaler (1985) document biases in expectations of corporate earnings and stock returns. See also Evans and Honkapohja (2001) for models and evidence on learning behaviour.

formation, and the rational expectations hypothesis is typically rejected by the data both for most individual participants and for the average forecast, with little evidence of convergence with rational expectations over time. Moreover, expectations tend to be influenced by previous forecasts (stickiness) and to exaggerate the impact of the most recent shocks (extrapolation).

Current literature does not provide strong conclusions about exactly how economic agents form expectations. There is evidence in favour of a departure from rational expectations, suggesting that these departures seem to converge with rational expectations over time and that people learn from their mistakes. Yes, data cannot explain how exactly expectations are then formed. Insights from consumer surveys can help in understanding more about how agents form their expectations.

Macroeconomic models have been modified to incorporate expectations formation mechanisms other than rational expectations. Among these alternatives, researchers have proposed learning (Slobodyan and Wouters, 2012), hybrid expectations (Levine et al., 2012), rational inattention (Maćkowiak and Wiederholt, 2015), sticky information (Reis, 2009) and bounded rationality (Gabaix, 2014). Under learning, agents do not know the structure of the economy but make decisions using optimal or nearly optimal decision rules based on estimated subjective forecasting models in real time. Needless to say, the model results, and hence the transmission of monetary policy, are sensitive to the specification of the forecasting model. Hybrid expectations mechanisms allow forward-looking agents to be combined with basic learning schemes. Under rational inattention, agents have a limited ability to process all the information available, so they update their information and make optimal decisions frequently (every period) but incompletely. Under sticky information, agents face a cost of acquiring and processing information and making decisions and plans based on that information. As a result, they update their information and make optimal decisions sporadically but completely.[17] Box 2 provides some illustrative examples of how different expectation formation mechanisms can impact the transmission of monetary policy.

Finally, there is no general consensus on the best way to model expectations in macroeconomic models. Therefore, a robust recommendation would be to explore how different models react when the expectations formation process is modified, and provide a set of results based on those different mechanisms.

4.2.2 Macroeconomic transmission channels of the ECB's non-standard measures

ECB monetary policy conduct over the last decade has entailed adopting non-standard measures (NSMs), due to a secular decline in the natural rate of interest and large adverse shocks leading to a higher probability of hitting the lower bound for the nominal interest rate and persistently low inflation. The policy toolkit has been extended to include four types of unconventional measures:

[17] Some NCBs have already experimented with DSGE models with such features; for instance Banco de España uses a model with adaptive expectations and learning, based on Vazquez and Aguilar (2021).

(i) negative interest rate policy (NIRP); (ii) forward guidance (FG); (iii) purchases of private and public sector securities under the asset purchase programme (APP) and more recently the pandemic emergency purchase programme (PEPP); and (iv) long-term refinancing operations, both targeted and untargeted (TLTROs and PELTROs). NSMs like the above are likely to become part of the ordinary toolkit of central banks.

Survey evidence shows that roughly one-half of projection models include NSMs as exogenous shocks or satellite models. A similar picture holds in the case of models used for counterfactual analysis.

There is an important body of literature which documents that the APP can affect asset prices (and ultimately the real economy[18]) by three main channels: signalling, portfolio rebalancing and direct pass-through. Capturing all these channels in Eurosystem models would enable an assessment of their relative importance and an investigation into the extent to which they mutually reinforce each other. As an example, the signalling effect of the APP and the impact it has on the long end of the yield curve can reinforce FG; together, these are the key to anchoring policy rate expectations, with significant effects on growth and inflation.

Standard theoretical monetary policy models rely primarily on sticky prices and intertemporal substitution of monetary policy in the New Keynesian tradition, and are not able to capture the full effects of central bank asset purchases because they typically assume perfect substitutability across assets. Assets purchases mainly have a real effect where the principle of perfect arbitrage between asset classes and maturity buckets does not hold. For this reason, theoretical models need to assume imperfect substitutability among assets for central bank asset purchases to have non-trivial effects on the real economy.[19] Essentially, the common friction shared by these frameworks is related to some form of limited arbitrage.

Asset purchases can stimulate real economic activity and boost inflation via two main channels: direct effects on (a) consumption and (b) investment. For consumption the channel is akin to standard monetary policy. Agents hold assets and earn the return on these. Lowering the expected returns on household portfolios triggers an expenditure switch which first stimulates consumption. Further effects on investment can arise through the abilities of households to affect investment. When the focus is on investment, a borrowing constraint in the financial intermediaries sector is often at the centre of considerations. Non-financial firms borrow from capital-constrained banks, for example; since the assets held by banks, i.e. loans to the non-financial sector and government bonds, are imperfect substitutes, central bank purchases of government bonds reduce their expected return, leading banks to rebalance their portfolio and grant more loans. If firms use these loans to finance investment projects their borrowing costs decrease, which stimulates investment.

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[18] Asset price fluctuations affect agents' wealth, cost of borrowing and bank lending, which in turn impact on spending and investment decisions in the economy and ultimately the inflation rate. For early literature see Krishnamurthy and Vissing-Jorgensen (2011), Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014).

[19] See Andrés et al. (2004).

Two frameworks are widely used in the theoretical literature to introduce limits to arbitrage across assets. In one case, this arises in the banking sector through leverage constraints; in the other, market segmentation is assumed to be the main friction.

Gertler and Karadi (2011, 2013) and Carlstrom, Fuerst and Paustian (2017) introduce limits to arbitrage through leverage constraints and portfolio adjustment costs in a New Keynesian model. The assets held by banks are exposed to the leverage constraint to different degrees. When leverage constraints bind financial intermediaries, their inability to increase borrowing/leverage implies an external finance premium equal to the difference between the risk-adjusted returns on long-term assets (capital) and the risk-free asset (short-term government bonds). Changes in holdings of government bonds must be accompanied by changes in expected returns. The latter will therefore induce rebalancing on banks' balance sheets, in which case they will increase the supply of loans to the non-financial sector. As a consequence, lending rates will fall, easing firms' financing conditions. The lower returns from asset purchases are thus transmitted into lower borrowing costs, which makes it possible to boost investment.

Chen et al. (2012) modify an otherwise standard New Keynesian model by introducing exogenous limited participation to the financial market framework. This form of market segmentation arises from a "preferred habitat" motive. Some households are unrestricted and have access to all financial markets, including short- and long-term sovereign bond markets. Others have restricted access, specifically: (i) they only have access to long-term sovereign bond markets; and (ii) they can only invest in physical capital. Restricted households are key to central bank purchases of long-term sovereign bonds having real effects. The central bank buys long-term sovereign bonds, raising their prices and reducing the long-term interest rate. Thus, restricted households have an incentive to move out of long-term bonds, where returns have decreased, into investment in physical capital and consumption. Higher demand for investment in physical capital and consumption induces firms to increase production and prices. Ultimately, the APP has expansionary effects on economic activity and favours inflation (e.g. Kortelainen, 2020, uses the Chen et al., 2012, model to study the effectiveness of both unconventional monetary policy and fiscal policy in the euro area, focusing on yield curve control).

The above models focus on imperfect asset substitutability between short- and long-term bonds, which gives rise to a term premium. Nevertheless, in principle the effects can be generalised to other dimensions of asset classes, giving rise to credit risk premia or exchange rate effects. For instance, the frameworks illustrated can be extended to an open economy, allowing international trade in key financial assets denominated in different currencies. In this way, central bank asset purchases could potentially have a direct non-trivial effect on the nominal exchange rate and hence international relative prices (the APP can affect the nominal exchange rate too, via general equilibrium effects, if the central bank does not buy foreign assets directly).

The macroeconomic effectiveness of expansionary non-standard monetary policy measures in a regulated banking environment is an important debate in central banking circles. Based on an estimated DSGE model incorporating risk-taking motives of banks and bank capital policies, Darracq Pariès, Körner and Papadopoulou (2019) explore the interactions between central bank asset purchases and bank capital-based financial policies (regulatory, supervisory or macroprudential) through their influence on banks' risk-shifting motives. They find that weakly-capitalised banks display excessive risk-taking, which reinforces the credit easing channel of central bank asset purchases at the cost of a higher probability of bank default and risks to financial stability. In such cases, adequate bank capital demand through higher minimum capital requirements curtails excessive lending and restores a more efficient propagation of central bank asset purchases. As supervisors can impose further capital requirements, uncertainty about oversight provokes precautionary motives for banks. They build up an extra capital buffer, attenuating non-standard monetary policy. Finally, in a weakly-capitalised banking system, countercyclical macroprudential policy attenuates banks' risk-taking and dampens excessive persistence of non-standard monetary policy impact. In fact, in a well-capitalised banking system, the macroeconomic stabilisation of central bank asset purchases outweighs the marginal financial stability benefits of macroprudential policy.

Another widely studied non-standard measure is forward guidance. As shown by Laseen and Svensson (2011) and Verona et al. (2013), FG can be captured in standard DSGE models using anticipated monetary policy shocks. These reflect deviations in the short-term interest rate from the historical policy rule that are anticipated by the public. One key challenge in the earlier literature has been the forward guidance puzzle: why do key macroeconomic variables show unreasonably large responses to central bank announcements about future interest rates? The phenomenon seems to be due to the excess sensitivity of consumption to both current and far distant interest rate changes and the front-loading associated with the New Keynesian Phillips curve.

Several solutions to the FG puzzle have been proposed in the literature. McKay et al. (2016) show that aggregate consumption in a model with heterogeneity and borrowing constraints does not suffer the same pitfall as in standard representative agent models. Precautionary savings considerations limit the individual response to future shocks. Moreover, they find that discounting expected future consumption in the aggregate Euler equation can generate responses in a medium scale DSGE model that are similar in magnitude to those in the heterogeneous agents' economy. Del Negro et al. (2012) show that incorporating a perpetual youth structure into the benchmark provides a possible resolution to the puzzle. Kiley (2016) focuses on the other key ingredient in the forward guidance puzzle, namely the front-loading implicit in the New Keynesian Phillips curve, and suggests that sticky information models (Mankiw and Reis, 2002) are less susceptible to the puzzle.

It would be easy to quantify the effects of non-standard monetary policy measures with a complete structural model of the economy, but there is no such generally agreed framework capturing different instruments, how they

interact and their side effects. Consequently, much of the literature on non-standard measures resorts to empirical, less structural approaches.

There are several academic papers that estimate the impact of QE measures on key asset prices. Among others, Dedola et al. (2020) use local projection methods to estimate the impact of US and euro area quantitative easing programmes on the EUR/USD nominal exchange rate. Bluwstein and Canova (2016) use Bayesian mixed-frequency structural vector autoregressive techniques to examine the effects of unconventional monetary policy measures by the ECB on nine European countries that have not adopted the euro.[20] Levin and Loungani (2019) claim that during periods of financial distress APP can have significant effects, but as financing conditions ease markets become more efficient, leaving limited scope for balance sheet actions to have any real effect.

Non-structural analyses come with their own analytical problems, often related to identification and endogeneity issues. Unconventional tools have made the identification issues even harder due to joint use of instruments, as central banks intend to impact on several margins at the same time.

Identifying exogenous movements in financial market prices and subsequent transmission to the real economy after monetary policy announcements requires combining very high-frequency financial market data and specific policy announcements with lower-frequency macroeconomic data and constructing relevant counterfactuals. Fortunately, there is a large and growing literature, starting with Kuttner (2001) and Cochrane and Piazzesi (2002), followed by, among others, Gürkaynak et al. (2005), Gertler and Karadi (2015), Nakamura and Steinsson (2018a), Rostagno et al. (2019), Altavilla et al. (2019) and Jarociński and Karadi (2020), who address endogeneity and identification issues related to non-conventional measures.

Many central banks in the Eurosystem have enriched their suite of DSGE models to better assess the effects of APP and FG. Among others, such examples can be found in Burlon et al. (2018), Coenen et al. (2020), Darracq Pariès et al. (2020) and Lemoine et al. (2019). Box 3 provides a description of the macroeconomic impact of the APP based on a DSGE model developed at Banca d'Italia to analyse non-standard measures. Another example is Darracq Pariès and Papadopoulou (2020), which explores country-specific transmission of selected non-standard measures from the ECB using a global DSGE model with a rich financial sector and including credit and exchange rate channels for central bank asset purchases. They perform a comprehensive evaluation of the ECB's non-standard measures since 2014, more explicitly the public sector purchase programme (PSPP) and the second series of targeted longer-term refinancing operations (TLTRO II). Beyond the credit impact of the liquidity operations, global portfolio frictions also open up an exchange rate and trade channel. As euro area banks increase their holdings of domestic sovereign bonds and sovereign spreads narrow, the rest of the world sheds its exposure to euro area bonds, triggering exchange rate depreciation.

[20] For a survey of both the theoretical and empirical literature on non-standard measures, see Bhattarai and Neely (2016).

The expenditure-switching effect of this depreciation boosts euro area exports, and imported inflationary pressures arise.

One of the key analytical gaps here is that it is difficult to examine the effects of different instruments simultaneously and understand their potential complementarity. Analysis of side effects is also typically more qualitative than quantitative in nature, opening another gap. Furthermore, even identifying monetary policy shocks remains a daunting challenge in current empirical and semi-structural models.

For counterfactual policy analysis, DSGE models are effective and tractable tools to assess the macroeconomic effects of non-standard monetary policy measures. Central banks could exploit this model set-up and the adjustments previously described (discounting expected consumption) for the FG puzzle.

Models like DSGE and VAR designed to investigate the effects of a given non-standard policy measure can be used to provide information about the likely responses of the main interest rates and the nominal exchange rate. These insights could serve as inputs for the main models, add to the narrative or help clarify which non-standard policy measure is the most effective. One limitation of having models focused on only a single non-standard policy measure is that they study this tool in isolation and do not account for interactions and potential synergies or anomalies across measures. However, they offer improved tractability and provide enhanced understanding of a specific channel of the transmission mechanism.

Systematically introducing non-standard measures into projection and other models would allow them to better assess the transmission, effectiveness and side effects of monetary policy and how it interacts with other policies (e.g. fiscal or macroprudential). Non-standard measures mainly enter the forecasting process via satellite models for long-term rates and the nominal exchange rate, but overall simulation strategies have not been harmonised. It would be useful to understand the extent to which estimates in central banks' models are similar to each other and what the possible sources of difference are. Caution should be used in comparing satellite model-based results with those from DSGE and VAR models, since the transmission channels of the different classes of models can differ.

Modelling non-standard measures would require reassessing the transmission channels of monetary policy and modifying the specification of the monetary, financial and real blocks within models and their interlinkages. There would be benefits in terms of transparency for counterfactual policy analysis, because it would be possible to disentangle the contribution of non-standard measures to the macroeconomic performance of an economy both qualitatively and quantitatively. DSGE models could also be re-specified to solve the forward guidance puzzle.

4.2.3 Non-linearities in the monetary policy transmission mechanism

The current macroeconomic outlook is characterised by considerable non-linearities, e.g. the effective lower bound on the policy rate, the non-linear

Phillips curve and other types of occasionally binding borrowing constraints such as credit restrictions in recessionary periods. Some of these, such as the ELB, will most likely remain for the near future; others, such as the state dependence of the Phillips curve, which is critical for the transmission of monetary policy, deserve further attention as they are permanent features of the economy. In particular, non-linearities will affect the transmission of both standard and non-standard monetary policy measures as well as the interaction between monetary and fiscal policy. They are also critical for properly designed macroprudential policy.

Survey results (see Section 3) show that a large majority of central banks do not have a lower bound on the policy rate in their projection models, most likely because they have country-specific models and hence the policy rate is an exogenous variable. Some allow for non-linear effects from large shocks (to the exchange rate, commodity prices and financial variables) in models used for projections, but the main models operate largely in a linear mode. No central bank uses a fully non-linear model that would account for idiosyncratic or aggregate risk or occasionally binding constraints as its main model.

Some central banks use DSGE models in a non-linear form to perform deterministic simulations for policy analysis. In these experiments, non-linearities play some role for large shocks and credit and borrowing constraints, for example. Within this framework, the endogenous lower bound on the interest rate (or any bound on any other variable) can be taken into account too. The main use of these models is for counterfactual scenario analysis and to construct densities around key macroeconomic variables.

When the policy rate hits the ELB, the central bank cannot reduce it any further in response to deflationary shocks. The real rate therefore increases, amplifying the negative effects of the shocks on inflation and economic activity. Similarly, an occasionally binding borrowing constraint can affect the marginal propensity to consume out of income and, therefore modifies the transmission mechanism of monetary policy. For example, a binding borrowing constraint makes consumption more sensitive to current income changes induced by an increase in the policy rate, among other things.

Non-linear price and wage inflation Phillips curves also pose challenges for the design of monetary policy. Non-linearities in the Phillips curve could arise due to state dependence in firms' pricing strategies, for example. In the case of the wage inflation Phillips curve, it may be the case that the sensitivity of wage growth to labour market tightness decreases more if labour market slack is very high. In this situation, a given monetary stimulus would have a lower impact on inflation (and a higher impact on employment). The opposite would happen in the case of overheating. The Phillips curve also becomes non-linear in the presence of downward rigidities in nominal wages. Byrne and Zekaite (2020) use reduced-form methods to estimate the sensitivity of wage growth to labour market tightness in the euro area. They show that the estimated euro area wage Phillips curve is convex. When labour market slack is elevated, wage growth does not respond to changing labour market conditions. This finding may explain in part the so-called "missing wage growth" as the labour market tightened between 2013 and 2016, and why stronger wage growth has been evident since 2017. There is also evidence that nominal wages are downwardly rigid. For example, Schmitt-Grohe and Uribe (2016) document that in several European countries, downward nominal wage rigidities are pervasive and have significant effects on the unemployment rate.

Models that incorporate these types of rigidities seem to capture better the key dynamics of wages and the labour market in general and generate longer recessions, which raise challenges for monetary policy. Non-linearities in the price- and wage-setting mechanisms could also imply significant changes in the size of the fiscal multiplier compared to their linear counterparts, and therefore change the predictions for inflation and employment and the appropriate response of monetary policy.

Downward wage rigidities can be practically introduced in structural models using asymmetric menu costs or using more elaborated decision problems. Lindé and Trabandt (2019) show that models which introduce additional strategic complementarities in the price- and wage-setting processes using a Kimball aggregator imply significantly different dynamics for inflation and wages when the model is solved accounting for non-linearities.

Non-linearities can be especially important if financial aspects of the economy are explicitly taken into account. Leverage of non-financial corporations and financial intermediaries typically introduces additional non-linearities that affect the transmission of shocks. This becomes especially important if shocks are large. The level of leverage can affect the effectiveness of monetary policy transmission. Typically, the transmission of a monetary policy shock through the banking sector (or more broadly the financial sector) is weaker if financial intermediaries are close to the minimum capital constraint. The literature is extensive on this aspect: some examples can be found in Beck et al. (2014), Bruno and Shin (2014) and Angeloni and Faia (2013). Moreover, there can be a threshold below which further lowering of interest rates can become contractionary, as in Brunnermeier and Koby (2020).

From the perspective of the policymaker, it is also important to understand the source of the disturbances that are driving the business cycle (supply vs. demand factors). Models that do not account for the possible sources of non-linearities would provide biased estimates of those sources and therefore be misleading for the design of monetary policy.

From the theoretical and computational points of view, there are several approaches to deal with occasionally binding constraints within structural models. These include extended path, piecewise-linear solutions, anticipated shocks, projection methods and regime-switching methods. Among others, Braun and Kober (2011) show how to use the extended-path method. The advantage of the extended-path algorithm is that it can handle non-linear perfect-foresight models with many state variables. However, the initial conditions have to be good, i.e. they have to favour algorithm convergence. Moreover, the occasionally binding constraint introduces a kink in the model derivatives which are at the heart of the algorithm. The extended path can therefore have problems solving the model at the kink. If the model is linearised, an extended-path algorithm would give the same path for endogenous variables as a piecewise linear algorithm. Guerrieri and Iacoviello (2015) develop a piecewise linear solution and discuss its pros and cons. This method cannot capture precautionary saving linked to the possibility that the constraint will become binding in future, but because it is a first-order perturbation approach it is computationally fast. Lindé et al. (2016) impose the ZLB constraint in expectation, using anticipated shocks. This approach does not allow for agents changing behaviour in the neighbourhood of the ZLB, even when it is not binding. Projection methods have been used by Gust et al. (2017) to estimate a non-linear version of a widely-used model in macroeconomics.

The computational burden of non-linear methods can be quite heavy, which limits the number of state variables and hence the size of the model that can be solved using these methods. Binning and Maih (2017) advocate regime-switching methods. According the authors, these solution methods allow agents to be aware of the regime in which the constraint binds and form expectations accordingly, and also indicate that the constraint binding could be a recurring event. In the vicinity of the constraint binding, agents assign a significant probability of switching to the binding regime, so the constraint impacts the system even when it is not binding.

Non-linearities can be handled in small- and medium-scale DSGE models, either fully non-linearly, using the extended-path method or with piecewise linear approximation (see Guerrieri and Iacoviello, 2015). These models feature non-linearities and can be used to provide external information to “feed” the main semi-structural linear models. This information concerns the macroeconomic implications of the break in empirical regularities for the interaction between real, monetary and financial variables. Such details associated with crisis events (rather than ordinary periods) are rarely found in historical data.

To better guide policymaking, models should naturally be applied to data. With the development of Bayesian methods and increases in computational power a vast number of estimated DSGE models appeared in the literature, most of them relying on log-linearised versions, for several reasons. First, this approach allows the researcher to use linear tools that are well developed in the time-series literature. Second, for small-size shocks that seemed relevant before the financial crisis, non-linearities were second-order. Third, non-linear tools are not yet very well developed in the literature or require very complex tools. Finally, they may not be computationally feasible for larger models.

Nevertheless, some literature on the subject has emerged in recent years, providing approaches for dealing with non-linearities in the estimation of structural models. One way to proceed is to use particle filters, which is potentially not feasible in large-scale models due to the tremendous computation loads, but still practicable in more stylised versions. This is precisely the approach used by Gust et al. (2017), who show that non-linearities in the model play an important role in inferences about the source and propagation of shocks. The authors find that the zero lower bound presented a significant constraint on monetary policy that exacerbated the recession and inhibited the recovery. They also show that linear methods perform poorly for moderately sized innovations, and that this poor performance is rooted not just in the zero lower bound, but also in investment adjustment costs and the Euler equation. Specifically, there are terms in the model that the linear approximation around a non-stochastic steady state neglects, but that arise in a non-linear approximation and become important for explaining macroeconomic dynamics for moderately sized innovations.

A different approach is provided in Guerrieri and Iacoviello (2017), who use full-information methods to estimate a DSGE model with occasionally binding constraints on housing wealth. The authors conclude that collateral constraints became slack prior to, and binding during, the financial crisis. Jensen et al. (2020) take yet a different approach, estimating a model with collateralised borrowing and occasionally binding credit constraints through the simulated method of moments. The authors argue that business cycles have become increasingly skewed, with booms becoming progressively smoother and more prolonged than busts, a result stemming from slack collateral constraints during expansions that turn binding during recessions. Some algorithms for solving models with occasionally binding constraints have now started to flourish (Guerrieri and Iacoviello, 2015), but the literature is still scarce and the way ahead unclear. These alternatives also lack testing in larger models with hundreds of equations.

From a more empirical perspective, possible breaks in historical data associated with large shocks can be handled with models featuring time-varying parameters and stochastic volatility, like for example Threshold VAR (TVAR). These models should fit data plagued by non-linearities, even if their structural interpretation is less clear. The assumption of Gaussian distribution of the shocks can be relaxed, allowing, for example, non-Gaussian distributions with fat tails.

Lenza and Primiceri (2020) illustrate how to handle a sequence of extreme observations – such as those recorded during the COVID-19 pandemic – when estimating a VAR. They show that the ad hoc strategy of dropping these observations may be acceptable for the purpose of parameter estimation. However, disregarding recent data is inappropriate when forecasting the future performance of the economy, because it vastly underestimates uncertainty.

VAR models with time-varying parameters can be exploited to inform the large linear models used in the projection exercise. For example, based on Primiceri (2005), Bijsterbosch and Falagiarda (2014) estimate a time-varying parameter VAR with stochastic volatility using euro area data, and identify the structural credit supply shocks by imposing sign restrictions on impulse response. The results suggest that credit supply shocks have been an important driver of business cycle fluctuations in euro area countries, and that their effects on the economy have generally increased since the great financial crisis.

4.2.4 Heterogeneity

Many dimensions of heterogeneity relevant for policy transmission and policy effects are not captured in canonical representative agent models. One critical source that can potentially influence the monetary policy transmission mechanism is household heterogeneity.

Heterogeneity is one of the ways to improve the microfoundations of macroeconomic models, but has typically not been explicitly addressed in modelling work. This has largely been due to the fact that models where the heterogeneity of agents is endogenous have been difficult to solve. The survey evidence (see Section 3) shows that most NCBs in the Eurosystem do not use models with endogenous heterogeneity. Five central banks have identified heterogeneity as an analytical gap, of which one is already in the process of addressing it, while two institutions plan to do so within the next two-three years. Some NCBs already use models with hand-to-mouth consumers, or saver-borrower structures (TANK models).

When the first methods to solve heterogeneous agent models were developed in the 1980s and 1990s, one of the findings was that they can be reasonably approximated with a representative agent model (see for example Imrohoroğlu, 1989; Bewley, 1983; Huggett, 1993; Aiyagari, 1994; den Haan, 1996; Krusell and Smith, 1998). This has changed significantly in recent years, especially in a setting with sticky prices where changes in demand have stronger effects on quantity.[21] Issues related to the distribution of income, wealth, household balance sheets, borrowing constraints and differences in marginal propensity to consume have become important. A typical finding is that wealth and income distributions matter for macroeconomic outcomes (see Moll, 2018).

This section examines the analytical gap between typical current modelling infrastructure and state-of-the-art heterogeneous-agent New Keynesian (HANK) models with endogenous heterogeneity, incomplete markets and hence uninsurable (idiosyncratic and aggregate) risk. The work stream on employment (2021) also provided clear illustration of the scope for HANK models to shed new light of relevant policy issues.

The main analytical gap can be summarised as the role of wealth inequality and its effect on marginal propensity to consume in the transmission mechanism of both monetary and other policies and of shocks in general. While most models used by central banks in the Eurosystem feature some heterogeneity, typically as a fraction of constrained households, there is little or no role for wealth and its distribution across households, the composition of wealth in liquid or illiquid assets or the implications of income risk for wealth distribution and marginal propensity to consume.

HANK models can make a difference to the interpretation of transmission mechanisms of economic policies and shocks in general. The main difference compared to standard models is that HANK models have an endogenous wealth distribution and therefore an endogenous distribution of marginal propensity to consume, too. These distributions depend on the risk which agents are exposed to and the constraints they face. As a result, issues such as which agents in an

[21] This paragraph draws on Moll (2018) and Gulan (2018).

economy receive income during a boom or lose it in a recession, how close to the constraint they are, how liquid their wealth is and what insurance is provided by the social welfare network become important in explaining the transmission mechanism.[22]

It has been argued that monetary policy affects different types of income and asset value differently. In a typical HANK model, those affected are exposed to different income effects and asset valuations, and also have different marginal propensities to consume (Auclert, 2019). The interaction between these which is a feature of HANK models provides a framework for more detailed and comprehensive analysis of monetary policy transmission channels than traditional models. As transmission channels of monetary policy in HANK models are richer, there is scope to investigate both how different wealth distributions affect shock transmission and how monetary policy affects the wealth and income distribution (see Slacalek et al. 2020, for an application to large euro area countries and Mäki-Fränti et al., 2021, for Finland).

For example, in Kaplan et al. (2018) the transmission mechanism of monetary policy and other shocks is mainly via the income effect rather than through intertemporal substitution. The reason for the predominance of the income channel is the calibrated distribution of liquid wealth across households. According to empirical evidence from the United States, regardless of overall wealth level (i.e. whether they are rich or poor) households with low liquid wealth have a higher marginal propensity to consume out of transitory income; these are a non-negligible fraction of overall households (around 30%). The approaches pursued in HANK-type models take a step towards addressing the criticism made in Muellbauer (2020), for example, who points to microeconomic evidence that the marginal propensity to consume varies with the household balance sheet. He suggests that balance sheet effects such as the redistribution of wealth can play an important role in the response to shocks, and goes even further to argue that these differences can make the responses destabilising.

These features imply that standard monetary policy may have stronger effects when households have more illiquid assets. They suggest that short-lived but larger discretionary monetary shocks may have greater macroeconomic effects than smaller but more persistent ones (Kaplan et al., 2018). Finally, they also imply that forward guidance may be less effective if a larger proportion of households have few assets or are otherwise constrained (McKay et al., 2016).

In terms of forecasting with HANK models this issue has been mostly unexplored so far, although this is likely to change. The first steps towards using an estimated HANK model for forecasting have already been made (Acharya et al., 2020).

These analytical gaps could be addressed by drawing on various models that have been developed in academia and at central banks over recent years looking at monetary policy issues in general (e.g. Kaplan et al., 2018; Auclert et

[22] For a non-exhaustive list see e.g. McKay et al. (2016), McKay and Reis (2016), Kaplan et al. (2018), den Haan et al. (2018), Auclert et al. (2020) and Bayer et al. (2020a, 2020b).

al., 2020) and specific issues such as forward guidance (e.g. McKay et al., 2016; Hagedorn et al., 2019) and the interaction between monetary policy and labour markets (e.g. den Haan et al., 2018; Ravn and Sterk, 2017). There have been applications to fiscal policy (e.g. McKay and Reis, 2016; Ferriere and Navarro, 2018; Bayer et al., 2020b), and many other issues.

Slacalek et al. (2020) provide evidence for the euro area about the distribution of marginal propensity to consume across households and the composition of wealth between liquid and illiquid assets and their cross-household distribution. Blomhoff et al. (2021) investigate the transmission of monetary policy to household consumption using detailed administrative data on Norwegian households. They find that both low- and high-liquidity households show relatively strong consumption responses to interest rate shocks, supporting the importance of financial frictions, cash flow channels, and heterogeneous effects of monetary policy.

A number of the main models in the toolboxes of central banks use ex ante heterogeneity (typically two types of agent), which can bring some of the features of the transmission mechanisms present in HANK models into the analysis. A typical example is the presence of a fraction of liquidity-constrained households that have a high marginal propensity to consume. According to Debortoli and Galì (2018), a simple Two-Agent New Keynesian (TANK) model with a constant share of constrained households and no heterogeneity within either type approximates the implications of a HANK model for the effects of aggregate shocks on aggregate output reasonably well.

It is not feasible to use endogenous heterogeneity driven by uninsurable idiosyncratic and/or aggregate risk in one of the large estimated main models used for policy analysis. A typical model used for policy analysis is large in terms of state variables, which makes it hard or impossible to solve when there is heterogeneity driven by uninsurable idiosyncratic risk. Taking this risk into account requires non-linear approaches and global solution techniques. The inherent non-linearity of the solution procedure also implies that full estimation (i.e. the estimation of the steady state and the dynamics around it) needs to be done using a particle filter (see Acharya et al., 2020). There are models where the steady state takes idiosyncratic risk (which is not estimated) and the dynamics around the steady state into account, but this does not allow for the effect of aggregate risk on the steady state of the model (see for example Bayer et al., 2020a).

One key challenge is therefore to take both aggregate and idiosyncratic risk into account, which is computationally much more intensive than for idiosyncratic risk only. A proposed approach by Reiter (2009) treats idiosyncratic risk fully non-linearly, while the aggregate risk (which is typically smaller than idiosyncratic income risk) is approximated. Recent work has proposed improvements in these methods (Ahn et al., 2017; Auclert et al., 2019; Bayer and Lütticke, 2020; Boppart et al., 2018; Ragot, 2018; Winberry, 2018). Operationalisation of heterogeneous agent models through satellite models for policy analysis is feasible. Some central banks have already used insights from such satellite models to support the policy debate (e.g. Feiveson et al., 2020, was used to inform the review of the Federal Reserve System's monetary policy strategy). It seems also feasible to develop and use parsimonious HANK models to study a particular issue. Recent developments in the academic literature (see above) can be used as a source and starting point for such developments.

Used in conjunction with main models, HANK models can shed light on specific transmission channels that are not explicitly modelled in the main models. This would notably be the case for the transmission channels that are important for the policy action considered. The forecasting process can also benefit from the insights of HANK models. Modellers can test whether both conditional and unconditional forecasting performance improves when model equations are specified so as to relate, even in a parsimonious way, aggregate marginal propensities to consume and to invest to measures of cross-agent income and wealth distribution, as suggested by HANK models.

4.3 Interactions with fiscal and financial policies

This section focuses on the interaction between monetary policy and fiscal and financial policies in Eurosystem models. It also provides a brief review of the most recent academic literature and attempts to address issues related to fiscal dominance, financial frictions, macroprudential policy and financial intermediation. It also builds on the findings of the macroprudential policy, monetary policy, financial stability and the non-bank financial intermediation work streams (2021).

4.3.1 The design and transmission channels of fiscal policy

According to the survey in Section 3, a large number of central banks include some form of interaction between monetary and fiscal policy in their projection models. It is either explicitly modelled via systematic feedback rules or via shocks and is a predominant feature of almost all models used for counterfactual policy analysis.

Furthermore, many central banks do not consider the design and transmission of fiscal policies to be a major analytical gap in their models. The central banks of the Eurosystem have in the past done considerable work on fiscal policy and its interaction with monetary policy. This has largely been a consequence of the monetary union framework of the euro area, where fiscal policy is mainly implemented at country level, and the European sovereign debt crisis.

Most countries have the ability to analyse fiscal multipliers, often in conjunction with constrained monetary policy (see Coenen et al., 2012, for a comparison of the effects of fiscal stimuli in structural DSGE models; also Kilponen et al., 2019, for a comparison of results on fiscal multipliers, both with and without the effective lower bound). There has also been work on investigating fiscal multipliers when there is forward guidance and quantitative easing (Burlon et al., 2017). These models often include a relatively rich array of fiscal policy instruments, typically several types of taxes, transfers to different types of households and various forms of government expenditure, such as government consumption and government investment. Policies that involve several fiscal policy instruments, such as fiscal devaluation or optimal financing of government investment, have also been considered. A non-exhaustive list of this work would cover Burlon et al. (2017), Clancy et al. (2016), Gadatsch et al. (2016), Gomes et al. (2016), Hickey et al. (2020), Jacquinot et al. (2018), Thomas and Stähler (2012) and Kilponen (2016).

However, some analytical gaps remain and further ones may arise as the macroeconomic outlook evolves (for example, following the pandemic shock) and policy responds. One potential analytical gap relates to the importance of the type and allocation of fiscal policy action. Therefore, there is scope to analyse the more granular allocation of government spending and its implications for the size of fiscal multipliers and price stability. This point has been made by Cox et al., 2020; see also Bouakez et al., 2020). There may also be scope to investigate regional fiscal multipliers within the monetary union (Chodorow-Reich, 2019) to gain more insight into the transmission of fiscal policies and their spillover across countries. Moreover, government and European Commission bonds may be valued by households as an asset that provides liquidity, which opens new channels of transmission and affects existing ones (Rannenberg, 2021). Finally, if fiscal policy is used to tackle climate change, more work will be needed to analyse the implications of such actions. (Some work on this already exists, e.g. Bartocci and Pisani, 2013.) Any application of such models will be related to the creation of the new temporary centralised budget of the European Commission (the "Next Generation EU"), which will need to be incorporated into main or satellite models to analyse the effects of the programme.

It has been shown recently that fiscal policy can matter more and its transmission mechanisms may be different when heterogeneity is taken into account (see for example Dupor et al., 2018, and Section 4.2.4). A more granular approach to fiscal policy could be applied using satellite models, while some gaps could be incorporated into the main models. Next Generation EU is one such example. Inclusion of sectoral or regional aspects in the main models should consider the trade-off between the importance of such features and the complexity of models.

It is also important to take into account the fact that a large percentage of sovereign bonds is held by the Eurosystem. This, along with significantly higher debt levels, opens up additional questions, which may not be easily analysed using a regular central bank model toolkit. Darracq Pariès, Müller and Papadopoulou (2020) introduce sovereign default in a DSGE model as a consequence of the government's inability to raise the funds necessary to honour its ex ante debt obligations.

Modelling the interaction between monetary and fiscal policies would be relevant to understanding the macroeconomic effects of alternative policy measures and policy reaction functions on economic activity, public and private financial stability and, ultimately, inflation dynamics and achievement of the price stability goal. In the new economic environment of non-linearities associated with high levels of debt and balance sheet composition it may be relevant for properly describing the transmission of macroeconomic shocks (see Section 4.2.3 on non-linearities and Section 4.3.3 on fiscal, financial and monetary policy interaction).

4.3.2 The design and transmission channels of financial policy

Since the financial crisis, a broad literature has emerged on the effects of financial instability on the aggregate economy, highlighting transmission channels from the former to the latter. Bank defaults, bankruptcy rules, fire sales, non-linearities, even systemic risk, all seem to have played an important role in financial instability. Box 4 provides an overview of the rise of novel financial frictions and a summary of the main instruments and objectives of monetary, macroprudential and microprudential policies, continuing with a description of their respective transmission mechanisms and a stylised conceptual framework for their interactions.

These mechanisms are naturally difficult to model, even more so when medium- and large-scale models are required for policy analysis. Many DSGE models used by NCBs consider some form of financial frictions in their policy analysis and simulation exercises. In some cases, frictions are on the demand side, in others the focus is on the supply side. Some of these models feature an explicit role for banks, but not all consider the interplay between monetary and financial policy (including regulation and macroprudential policy). Some NCBs are focusing their ongoing or planned research and model development on modelling credit or housing market financial frictions or including a comprehensive model of the full balance sheet of financial institutions.

Some projection models have also been developed in this direction, including financial frictions either directly or via satellite models. However, the role of financial variables is deemed less relevant here, probably because they are mostly exogenous to projections. A large majority of NCBs use satellite models to address specific issues or questions that are not treated with a sufficient level of detail in the main models used for projections and policy analysis. Model development plans target explicit modelling of macrofinancial linkages, such as endogenous interest rate spreads, endogenous housing investment and prices and endogenous credit, or of different parts of the balance sheet of financial institutions.

To pinpoint the banking system as a key player in a financial crisis we need to understand how banks come to endogenously adopt high balance sheet risk exposure in the first place. In the model of Gertler et al. (2012), banks opt for high leverage if risk perceptions are low, at the cost of increasing the vulnerability of the economy to a crisis. This creates scope for intervention by the monetary authority, for instance through a large-scale asset purchase programme aimed at stabilising financial markets. The situation triggers moral hazard, since banks will adopt a riskier balance sheet if they anticipate this policy, creating a need for a macroprudential policy aimed at keeping risk-taking by banks under control. The role of banks in the supply of credit is emphasised in Gerali et al. (2010), who construct and estimate a model for the euro area economy and conclude that they contribute significantly to propagating shocks to the real economy.[23] Shocks originating in the banking system explain a considerable part of the contraction in economic activity since the financial crisis, a conclusion common to most models where banks are placed at the centre of financial intermediation.

On the borrower side, most models highlighting asymmetric information and costly state verification. The influential article by Christiano et al. (2014), for instance, includes the Bernanke et al. (1999) financial accelerator mechanism in an otherwise standard DSGE model, but estimates the model for US data allowing the volatility of cross-sectional uncertainty to fluctuate over time. The risk shocks are shown to imply a countercyclical credit spread and procyclical investment, consumption, employment, inflation, stock market and credit, fitting the US business cycle very well. The originality of the approach lies in the way it combines risk shocks with news, with agents receiving both current and future information on risk innovations. Both features are key to obtaining the results in the paper.

The role of the housing market is addressed in Iacoviello and Neri (2010) and Berger et al. (2018). The former estimate a DSGE model for the United States and conclude that housing demand and technology shocks explain one-half of the volatility in housing investment and prices – which they argue is a key driving force behind business cycle fluctuations. The latter build a model of housing that links consumption to house price changes, departing from the permanent income hypothesis that underlies most DSGE models to date. The model is therefore able to match a number of data on wealth distribution, leverage and housing.

Another issue that has come to the forefront of the economic discussion is what policy players can do to minimise the impacts of adverse shocks and stabilise business cycle fluctuations. Some of the models above, by introducing frictions in the intermediation system where banks play a central role, lay the groundwork for macroprudential policy too. Usually, moral hazard or asymmetric information issues are at the centre of these frictions, and the aim of the monetary authority is to keep such market failures under control. Related to this, Gertler and Karadi (2011, 2013) develop a model to address the role played by unconventional monetary policy and quantitative easing, in a set-up where financial frictions again play a central role. Financial intermediaries face balance sheet constraints and may not be able to meet demand for loans due to moral hazard. Under this set-up, unconventional monetary policy can ease balance sheet constraints and increase the flow of credit to the economy, at the cost of being less efficient in the intermediation of funds than the private sector. In this context, large-scale asset purchases can boost economic recovery and have a sizable effect on output compared to a laissez-faire allocation, even under the zero lower bound.

The excessive risk exposure in the banking system that laid the foundations for the financial crisis and hindered the subsequent economic recovery has alerted policymakers to the need for stricter regulation. The Basel III reform, more stringent capital and liquidity regulations and countercyclical capital buffers are

[23] Kilponen et al. (2016), using a similar model of the banking sector, find shocks induced by the financial markets play a relatively small role in the Finnish economy.

the most visible part of the reforms that have taken place at this level. Several articles model a specific aspect of Basel III endogenously. For instance, Benes and Kumhof (2015) build a model of risky bank lending where part of the interest rate spread is endogenously driven by the Basel capital requirements. The authors also use the model to stress the role of macroprudential policy, illustrating how the countercyclical capital buffer can be an important tool to increase welfare. Clancy and Merola (2017) show that countercyclical capital regulation can help attenuate boom-bust cycles, whilst Clerc et al. (2015) develop a DSGE model to analyse the normative and positive aspects of macroprudential policies, highlighting the interplay between borrowing households, entrepreneurs and banks in a set-up where the later have to comply with Base III-type capital requirements. Gertler et al. (2012) also use their model to address how macroprudential policies can help to offset the incentives for risk taking. Other articles on the topic include Darracq Pariès et al. (2011) and Lozej et al. (2018).

Some of the models discussed above extend their analysis by allowing risk-weighted assets to be determined endogenously and dynamically. For example, Darracq Pariès, Jacquinot and Papadopoulou (2016) allow corporate exposure risk weights to be determined based on the Basel II formula. The weights are risk-sensitive and depend on the one-year-ahead probability of default, the loss given default on corporate exposures and the asset value correlation which parameterises cross-borrower dependencies. If loss given default is constant, the only time-varying component in the risk weighting is the one-year-ahead probability of default, and the resulting risk curve is concave. This dynamic dependency and more stringent regulatory requirements in periods of higher risk creates an additional accelerator mechanism on the supply side in credit markets. It leads to higher commercial lending rates, a reduction in leverage and credit supply constraints, an increase in loan-deposit margins and a decline in investment.

The large stock of non-performing loans (NPLs) on banks' balance sheets has been a persistent legacy for several euro area economies in the aftermath of the financial crisis. Both institutional work (Aiyar et al., 2015; Constâncio, 2017) and academic studies (Gerali et al., 2010; Darracq Pariès et al., 2011; Benes and Kumhof, 2015; Gertler and Kiyotaki, 2015) have emphasised the link between credit defaults and credit supply restrictions in amplifying output fluctuations. The DSGE modelling literature often deals with credit default flows by assuming that they are fully covered by a state-contingent interest rate (Bernanke et al., 1999), immediately recognised as impairment losses and written off (Benes and Kumhof, 2015; Clerc et al., 2015), or somehow embodied in an exogenous shock to the value of bank capital (Gerali et al., 2010; Darracq Pariès et al., 2011).[24]

One influential class of models that has recently emerged links the roll-over crisis in the shadow banking sector with fire sales (Gertler and Kiyotaki, 2015; Gertler et al., 2016). Suppose that in each period banks can decide to finance long-term assets by either issuing short-term debt (debt roll-over) or selling assets. In normal circumstances banks roll over debt, and this is compatible with agents' beliefs. However, there are cases where individual creditors believe that not all other

[24] For an alternative discussion of this topic see Segura and Suarez (2019).

creditors will extend new credit to banks, and bankers are forced to hold a fire sale of assets to pay off their debt, wiping out their equity in the process. The result is a system-wide failure of banks that leads to a roll-over crisis where creditors prefer to buy assets at fire-sale prices rather than extend credit to a bank with zero net worth. This model can generate a systemic crisis from a relatively small shock, which addresses one of the main criticisms of older models. Extending it to an estimated version would be challenging because financial crisis are rare events, but could signal the probability of a roll-over crisis, conditional on the state of the economy.

Some of the most recent models illustrate the importance of non-linearities in economic allocations. In the models of Gertler and Kiyotaki (2015) and Gertler et al. (2016), non-linearity arises endogenously when a roll-over crisis hits the economy, an event with a very small probability. In another class of models, Christiano et al. (2016) and Gust et al. (2017), amongst others, emphasise the role of the zero lower bound. Studies show that the interaction between financial frictions and the effective lower bound can account for the bulk of movements in aggregate real economic activity during the Great Recession (see Section 4.2.3. for a detailed discussion of non-linearities).

Work has also been done at NCB level. Júlio and Maria (2020) fill in some of the gaps identified in the literature by developing an occasionally binding version of the balance sheet constraint in Gertler and Karadi (2011, 2013), and bringing it together with a Benes and Kumhof (2015)-type of model where Basel-regulated banks act as financial intermediaries. On top of this the authors add a mechanism that is able to generate defaulted loans, which linger in banks' balance sheet and create costs that have to be dealt with, sometimes by recognising impairment losses. The authors show that most of the time the balance sheet constraint is slack and the cost of funds is driven solely by banking frictions, which is the rationale for the Basel requirements. However, if negative financial events occur, the constraint binds and the costs related to defaulted loans rise. Even a small-sized financial shock can be sufficient to disrupt the supply of credit. Banks are then forced to cut the credit they make available to the economy and increase lending spreads, creating both a quantity and a price effect and greatly magnifying the impact of the financial shock. The model demonstrates powerful asymmetric amplification effects, because the restriction is slack during expansions). It can easily be extended to consider policy issues such as the effects of asset purchase programmes and macroprudential policy in a context where they may play a key role in changing the state of the economy and the severity and duration of quantitative credit restrictions. The model also generates both symmetric behaviour under non-financial shocks (which cannot cause disruptions in the supply of credit) and non-linear behaviours under financial shocks (which cause disruptions on the downside).

The AINO 3.0 model (Silvo and Verona, 2020) considers housing and credit-constrained households in a set-up where banks are subject to capital requirements and macroprudential regulation. The model can be used to study the effects of several macroprudential policies, as it includes countercyclical capital requirements, risk weighting on mortgage loans, a loan-to-value ratio requirement on mortgage loans and different mortgage repayment schedules. The model also allows in-depth analysis of the monetary policy transmission mechanism in the presence of credit-constrained households.

The EAGLE-FLI model (Bokan et al., 2016) incorporates financial linkages in EAGLE (a New Keynesian multi-country DSGE model of the euro area) by including financial frictions and country-specific banking sectors; these are key to studying monetary and financial stabilisation in a monetary union. The model includes a real estate sector that provides housing services to households and a stock of collateral to borrowers and is used as an input in production. Region-specific banks collect deposits from domestic savers, raise capital subject to a regulatory requirement and lend both to domestic households and entrepreneurs. Novel shocks to, for example, the loan-to-value ratio, the amount banks are willing to lend in the interbank market and the bank capital requirement enhance the stochastic properties of the model.

The New Area-Wide Model II (Coenen et al., 2019) which is an extended version of the ECB's micro-founded model for forecasting and policy analysis, incorporates a rich financial sector. It has the threefold aim of: (i) accounting for a genuine role for financial frictions in the propagation of economic shocks and policies and the presence of shocks originating in the financial sector itself; (ii) capturing the prominent role of bank lending rates and the gradual interest rate pass-through in the transmission of monetary policy in the euro area; and (iii) providing a structural framework useable for assessing the macroeconomic impact of the ECB's large-scale asset purchases conducted in recent years.

The 3D model (Clerc et al., 2015) incorporates three layers of default, embracing all classes of borrowing from household to bank deposits in a set-up where banks act as intermediaries of funds from savers to borrowers. The mechanisms within the model create distortions and cause financial amplifications, creating an ideal environment for analysing macroprudential policies. Millard et al. (2021) propose a DSGE model incorporating financial frictions, leverage limits on banks, loan-to-value limits and debt service ratio limits on mortgage borrowing. They use the model to examine the effects of different macroprudential policies and their interaction with monetary policy.

Cozzi et al. (2020) examine the interactions between macroprudential and monetary policies through the lens of a range of macroeconomic models used at the ECB. They find that in the long run a 1% increase in the bank capital requirement has a small impact on GDP, but in the short run it declines by 0.15-0.35%. Under a stronger monetary policy reaction, the impact falls to 0.05-0.25%. They also examine how capital requirements and the conduct of macroprudential policy affect the monetary transmission mechanism. First, higher bank leverage increases both the economy's vulnerability to shocks and monetary policy's ability to offset them. Second, macroprudential policy diminishes the frequency and severity of financial crises, thereby eliminating the need for extremely low interest rates. Last, countercyclical capital measures reduce the neutral real interest rate in normal times.

Darracq Pariès et al. (2011) analyse the role of credit market frictions in business cycle fluctuations and in the transmission of monetary policy

through the lens of a closed-economy DSGE model for the euro area with financially constrained households and firms which embeds an oligopolistic banking sector facing capital constraints. They examine the monetary policy implications of the various financial frictions to credit supply and demand and examine the real economic implications of increasing capital requirements and introducing risk-sensitive capital requirements. In addition, they examine the potential for introducing countercyclical bank capital rules and aligning macroprudential tools with standard monetary policy tools. The model results particularly highlight the importance of operating with a protracted implementation schedule for new regulatory requirements to smooth out the transitional costs to the economy arising from a more capital-constrained banking sector.

The main focus of NCBs' development efforts should be on simpler models of the financial frictions that generate a role for banks, the amplification effect from financial distortions and the effectiveness of macroprudential regulation. On the one hand, these need to be complex enough to generate a supply of credit potentially susceptible to disruptions while still respecting the key guidelines in the Basel III regulatory framework, including macroprudential policy rules. At the same time, they should be simple enough to be modelled without unreasonable effort; this could be achieved through more reduced-form specifications, even if these are not fully micro-founded. More complex models covering fire sales or embodying some type of non-linearity are important, but probably inefficient from a cost/benefit standpoint.

The models used by NCBs and the ECB described above are steps in this direction, and their development and dissemination by NCBs should be an action point in future research. They constitute important improvements in the macro toolkit and policy advice, and make it possible to study a vast number of policy issues. For instance, regulatory requirements (such as the capital requirement), macroprudential rules (such as the counter-cyclical capital rule), quantitative easing, large scale asset purchase programmes and the zero lower bound can all be introduced in small models at reasonable cost and their effects studied both in the steady state and when the economy is facing an underlying shock that triggers disruptive credit conditions. When combined with advanced perturbation techniques that allow for stochastic simulation under occasionally binding constraints in a medium-scale model, they could be an important tool for assessing how policy options might hasten the transition to a non-disruptive equilibrium and foster healthy bank balance sheets. It is also straightforward to extend these models to consider weighted capital ratios or housing (durable goods), making it possible to ask questions about the effects housing prices have on the banking system, for instance.

Including these newest mechanisms in projection models is a daunting task. Some NCBs are opting to use satellite models as a way of introducing a degree of financial frictions in their projections. This is probably the best way forward, as long as the effects from financially-based models can be combined with projection models.

4.3.3 Strategic interactions between monetary, fiscal and financial policy

Although monetary, financial and fiscal policy pursue different objectives and use different instruments, from a conceptual point of view there are numerous areas of strategic interaction between them that create scope for synergies by sharing information and expertise. All policies influence monetary and financial conditions, so the question arises as to how they may influence each other's effectiveness in reaching their respective objectives. Changes in the various instruments used by each policy may be transmitted through similar channels and affect the same financial instruments or economic sectors, implying that the three policies are likely to interact in a dampening or amplifying manner. Macroprudential measures affect credit supply and aggregate demand, affecting inflation in the medium term. They also change the behaviour of the banking system, thus potentially affecting the credit channel of monetary policy and the pass-through of interest rates in the economy. Monetary policy, on the other hand, can affect the way macroprudential measures are transmitted to the real economy. By stimulating or discouraging bank risk taking, changes in interest rates could also change the desired stance of macroprudential policy. Monetary policy measures can mitigate impediments to fiscal policy meeting its stabilisation objectives, including when financial fragmentation risks hamper the effectiveness of fiscal interventions.

There is a growing body of literature assessing the interactions between monetary policy and fiscal and financial policy and potential areas of conflicts. Leeper (1991) laid the groundwork for understanding the principles of the interaction between monetary and fiscal policy. He showed that the interplay has a major effect on the stability of the economy if the government is indebted and the sustainability of debt becomes a target its own right. Monetary and fiscal policy can be either active or passive. Active monetary policy means the central bank pursues the objective of price stability, which requires raising interest rates by more than the increase in the rate of inflation and vice-versa (i.e. the Taylor principle holds). If the central bank is too loose in responding to inflation, it becomes passive. Fiscal policy is said to be passive if it stabilises debt sufficiently to preserve intertemporal solvency by adjusting taxes. Active fiscal policy is where there is no intertemporal balancing of budgets.

There are four possible combinations in total, but only two of them guarantee the stability of the economy (with a well-defined equilibrium). Monetary dominance describes the situation where monetary policy is active and fiscal policy passive. Under this configuration, monetary policy controls prices. By contrast, an economy is operating under fiscal dominance when fiscal policy is active and monetary policy passive. Under this configuration, the price level is largely a fiscal phenomenon. In this situation, prices adjust to preserve intertemporal debt sustainability. This regime is usually characterised by a higher volatility in inflation.

Economies have well-defined equilibria under both regimes, monetary and fiscal dominance, but the transmission channels within them may differ. According to Leeper and Leith (2016), the rate of inflation under fiscal dominance can behave differently than under monetary dominance for specific shocks, because with fiscal dominance wealth effects start playing a more important role. The discussion of monetary-fiscal interaction can therefore have two dimensions: either it is directed to one of the two stable regimes and the way the propagation of shocks will be affected by slight changes in policy (keeping the regime), or there is a discussion about switching regimes. For policy purposes, once the relevant regime has been identified it is important to investigate the monetary-fiscal interaction within it. Some of this work will be undertaken in the work stream on monetary-fiscal interaction (2021).

Strategic interaction between different policy areas can be studied in small or medium-scale structural models. There is no systematic approach to incorporating these considerations into monetary policy analysis or projections. A key dimension that needs to be systematically studied is the interplay between different policy areas and the impact of fiscal and financial policy on monetary policy transmission.

Basu et al. (2020) develop a model of optimal monetary policy, capital controls, foreign exchange intervention and macroprudential policy. It incorporates many shocks and allows countries to differ in currency of trade invoicing, degree of currency mismatches, tightness of external and domestic borrowing constraints and depth of foreign exchange markets. The analysis is able to map these shocks and country characteristics to optimal policies.

Adrian et al. (2020) develop an empirically oriented New Keynesian model to evaluate and quantify how using multiple policy tools can potentially improve monetary policy trade-offs. The New Keynesian small open economy model embeds non-linear balance sheet channels and includes a range of empirically relevant frictions. They show that foreign exchange interventions and capital flow management tools may improve policy trade-offs under certain conditions, especially for economies with less well anchored inflation expectations, a substantial foreign currency mismatch and more vulnerability to shocks.

Darracq Pariès, Müller and Papadopoulou (2020) use a DSGE model to investigate the magnitude of fiscal multipliers under several scenarios, including an economy with financial fragmentation risk and interactions with monetary policy measures. In this model, an endogenous sovereign-bank nexus arises via two channels. First, through the sovereign exposure channel: sovereign risk triggers adverse valuation effects on bank holdings of government bonds, which weakens bank capital positions and raises bank default risks. Second, through the safety net channel: sovereign risk weakens the direct or indirect government guarantees securing the functioning of the financial system, thereby exposing banks to large deposit withdrawal risks. The specification of the sovereign-bank nexus in the model opens up a transmission mechanism between sovereign risk, bank risk and bank lending conditions to the real economy. More explicitly, they show that monetary policy can mitigate impediments to fiscal policy fulfilling its stabilisation function.

4.4 Climate change

Climate change affects macroeconomic outcomes, financial markets, and financial institutions through two broad categories, namely physical and transition risks, yet there is a huge degree of uncertainty when it comes to the economic effects of climate change. Physical risks emerge through more frequent extreme weather events and persistent global warming; transition risk can feature in the economy through government policy actions, technological developments and changes in consumer and investor sentiment.

Government climate policies aimed at reducing carbon emissions may lower GDP growth, increase inflation, lower stock prices and increase interest rates in the short term. Policymakers might be forced to take stringent measures to reduce carbon emissions, leading to an increase in the effective carbon price and pushing up coal, oil, and gas prices. Higher energy costs increase production costs, resulting in lower profitability, bringing down investment and equity prices. In response, firms may increase the prices they charge to consumers, having a negative impact on households' disposable income. In normal times, when interest rates are not constrained by the effective lower bound, an increase in the price level leads to contractionary monetary policy, while higher inflation expectations lead to higher long-term interest rates. Policymakers can potentially mitigate the adverse macroeconomic consequences of an increase in the carbon price by returning the receipts, either by reducing non-carbon taxes or by increasing government subsidies (e.g. to renewable energy industries). Therefore, the effect on GDP, inflation and interest rates depends on how carbon tax receipts are rebated to the economy.

Technological developments boosting the percentage of renewable energy in the energy mix are expected to lead to short-term losses, while the long-term effects on potential output remain ambiguous. Investment in renewable energy generation and storage boosts the percentage of renewable energy in the energy mix and creates the potential for technological breakthroughs that make production less fossil-fuel intensive. Higher investment demand initially boosts GDP in the short run, but in the medium run GDP growth slows due to the capital stock write-offs that result from creative destruction and the reallocation of production factors in the economy. While potential output may increase since energy is cheaper, the long-term effects of investments shifting from R&D to repair and replacement after extreme weather events leave the impact on potential output ambiguous.

The transition vulnerability risks are expected to impact financial markets through equity and bond prices. Equity returns are expected to change most in industries where the final goods and services require substantial carbon emissions in the production process. Bond prices will potentially be impacted, due to the change in the risk-free interest rate and the credit risk spread. The more vulnerable the industry to climate risk, the larger the increase in credit risk.

The impact on financial assets can be divided into exposures to selected carbon-intensive industries, exposures to other industries and changes in the risk-free interest rate. Loans are measured in accordance with IFRS 9, which require banks to increase provisions when the probability of default increases.

Changes in the risk-free interest rate are expected to change government bond yields, impacting bank balance sheets via the sovereign-banking nexus. In the end, all these factors are expected to impact supervisory ratios. The higher a bank's risk exposure amount, the greater the hit to regulatory capital and the larger the risk that the institution's assets might not be sufficient to meet its obligations (see for example Vermeulen et al., 2018).

Climate change could also affect the conduct of monetary policy via the interest rate, asset prices, credit supply, the exchange rate and expectations. First, transition risks increase uncertainty and thus raise risk premia and volatility, impacting interest rates. Furthermore, a decrease in the equilibrium real interest rate could reduce room for monetary policy manoeuvre by pushing the interest rate close to the effective lower bound. Second, financial losses may reduce borrowers' net worth and collateral, resulting in reduced credit supply. Third, climate change is likely to shift demand between sectors and regions, leading to stranded assets, increase risk premia and financial market volatility. Fourth, climate-related changes may lead to border carbon adjustments and disrupt trade routes and global value chains. Finally, time-inconsistent transition policies reduce monetary policy credibility and effects.

The fact that climate change itself is already subject to very large uncertainty, poses a huge challenge for central bank modellers. Yet, there are various approaches already developed in the literature which are discussed briefly in what follows.

Climate-related integrated assessment models (IAMs) describe how climate and economic developments interact with each other from a microeconomic perspective. They provide reduced-form aggregate representations of the carbon cycle through detailed energy models linked to simple macroeconomic models with intertemporal welfare maximisation, subject to general or partial equilibrium constraints. Examples of such models include DICE/RICE (Nordhaus, 2013, 1992), PAGE (Hope, 2006), FUND (Waldhoff et al., 2014), REMIND (Leimbach, 2010) and MESSAGE (Messner, 2000). Although IAMs can be usefule for informing optimal climate policy and can be simple enough if needed, they tend to be weak due to the limited realism of their optimisation assumptions, the low number of variables included and the fact that they cannot be used directly for macrofinancial and monetary policy analysis or temporal resolution.

Climate-computable general equilibrium (CGE) models are used to explore the long-run impact of different policies on the energy system and the economy. They can be used to simulate core economic interactions across agents, sectors and regions. Unlike other models, they have a high degree of sectoral granularity and are linked to input-output tables or social accounting matrices. One such example is the MIT EPPA model (Jacopy, 2006) model. This class of models exhibits the most detailed sectoral and regional disaggregation, and therefore can be used for analysing policy and international trade. However, they are weak in their ability to include market frictions, rendering them inappropriate for considering inflation and unemployment trends or conducting forward-looking analysis.

DSGE models have started to be adapted to include climate change features too. These are stochastic based on optimal decision rules of rational economic agents and can capture the business cycle, monetary dynamics and forward-looking behaviour. They can be used for medium- and long-run analysis and explore both transition and physical risks of climate change. Examples include G-CUBED (McKibbin, 1998) and Acemoglu et al. (2012).

Climate-related risks should be included in central bank workhorse models to capture their interactions with other, more standard risks within the usual monetary policy horizon. Currently, there are various statistical and structural approaches to integrating climate-related dynamics in macroeconomic models. The standard models that are widely used by central banks have started to be adapted and modified to include energy and climate channels. These can be used for forecasting and other macroeconomic analysis, e.g. international spillover effects. An example of such a model is NiGEM, which is used by the Banque de France and De Nederlandsche Bank; this has been modified to integrate with IAM models and includes different monetary and fiscal rules and financial frictions. Although these models can be used for business cycle and monetary analysis, they contain no optimisation assumptions and their energy representation tends to be limited and less detailed.

According to the survey, only few central banks have started adapting their models to include climate-related features. However, there are several satellite avenues for integrating macroeconomic and climate tools into the main areas of the typical modelling arsenal of a central bank for forecasting and policy analysis.

Time-series nowcasting models can be used to introduce the short-term impact of weather-related events on inflation and output. There are several ways to do this; first, based on how extreme weather events affect food prices; second, based on how weather events affect energy demand and supply and therefore prices; third, looking at how weather developments affect the dynamics of other macroeconomic variables beyond food and energy prices.

Semi-structural models, which are the main workhorse class for Eurosystem members, can also be used to include new blocks for climate change. This class of model is typically modular and flexible by design, and therefore can incorporate the differential temporal impact of different shocks when analysing climate change issues over varying horizons. In addition, when semi-structural models are multi-country, they explicitly incorporate the international spillovers and potential spillbacks of climate policies. One approach is to allow carbon taxes, and thus energy prices, to affect total factor productivity (TFP) in a Cobb-Douglas production function with capital and labour. The second approach includes energy directly as a separate factor of production.[25] In the NiGEM model, potential output takes the form of a constant in which a constant elasticity of substitution (CES)

[25] This is for example the case for the semi-structural models of De Nederlandsche Bank and the Deutsche Bundesbank, where the aggregate production function combines capital, labour and energy input in a two-level nested CES structure. The Deutsche Bundesbank has recently used its model to study the effects of the climate package introduced by the German government (see Deutsche Bundesbank, 2019).

bundle of capital and labour is nested in a Cobb-Douglas function with energy and labour-augmenting productivity. The energy component is further decomposed into the output intensity of fossil fuels and renewables (NIESR, 2020). The final approach to modelling long-run output is more empirically determined and does not impose a particular theoretical structure on the relation between output and inputs. This allows for the incorporation of greater detail on output determination, particularly in relation to various energy inputs and technologies. Where there is detailed treatment of both domestic and international macrofinancial linkages in semi-structural models, this renders them suitable for analysing the impact of transition risks arising due to a sudden change in the expectations of consumers, firms, or financial market participants from reasons to do with the climate.

The semi-structural model NiGEM is already used by the Banque de France and De Nederlandsche Bank for climate change related simulations. The model has been modified to integrate with IAM models and includes different monetary and fiscal rules and financial frictions. Although these models can be used for business cycle and monetary analysis, they contain no optimisation assumptions and their energy sector representation tends to be limited and less detailed.

DSGE models with environmental aspects have the potential to become the new workhorse models of central banks for scenario analysis, although the literature still needs to develop much further. There are no estimated DSGE models with climate change elements in use at central banks, therefore they have had to start adapting DSGE models to incorporate both physical and transition risks of climate change to simulate carbon taxes, emission caps with trading of pollution permits and emission intensity targets. These models can also be used to explore how the conduct of monetary policy can influence the effectiveness of climate change policy. In addition, DSGE models with sovereign, banking and financial frictions can be used to assess the impact of transition risks from climate change on the macroeconomy and the banking, sovereign and financial sectors.

4.5 Large shocks and uncertainty: lessons from the COVID-19 pandemic

The emergence of the COVID-19 pandemic introduced considerable challenges for modelling at central banks. The modelling apparatus was not well equipped to deal with either the unprecedented large shock or the specific nature of the pandemic propagation mechanism. Several areas have been in focus in the year following the shock and merit future development: (i) short-term nowcasting and forecasting; (ii) the effects of large shocks for current modelling, ranging from new and robust methods for estimation to better capturing tail events; (iii) understanding the short-term nature of the shock; and (iv) structural modelling of the pandemic's propagation mechanisms, notably over the long term, and the optimal policy response.

In the initial stages of the crisis it became crucial to have timely information on how the pandemic shock was propagating and the economic consequences it

would have. Models using higher frequency data and alternative data sources had to be developed. Time-series models led the way in incorporating higher frequency data into the information set, due to their flexibility and relatively low development cost compared to semi-structural and structural models. A good example is a model developed by Lewis, Mertens and Stock (2020) at the Federal Reserve Bank of New York. Eraslan and Götz (2020) of the Deutsche Bundesbank constructed weekly economic indices: WEI for the United States and WAI for Germany. These were developed to track the rapid economic developments associated with the onset of and policy response to the coronavirus in those two countries. Both indices use various high-frequency data to track overall economic performance, including novel indicators such as mobility indexes and credit card spending.

Exploiting new data sources and integrating them into time-series models was also the main strategy at the ECB. After the first lockdowns, it quickly became clear that these have to be part of the information set for nowcasting and forecasting following the pandemic shock. Battistini et al. (2020) proposed a simple approach to exploit the information content of the different containment measures implemented across countries. A pooled panel regression known as the pandemic cross-country model gauges the relationship between containment measures, as measured by the Oxford Stringency Index (OSI), and real GDP. Forecasts based on this model are one of the main inputs for constructing alternative scenarios during the forecasting rounds used to gauge the uncertainty surrounding the baseline forecast. New data sources with higher frequency such as weekly credit card payments have also been included in standard nowcasting models (Bańbura and Saiz, 2020) and potential non-linearities from such extreme events considered too (see Battistini et al., 2020). The main time-series models like big BVARs will also have to be adjusted to handle mixed-frequency data and alternative data sources, possibly connecting machine learning techniques with more standard macro time-series models. As an illustration, Box 5 shows how combining sectoral data and time-series models can help to understand the structural drivers of the subcomponents of inflation during the pandemic.

The large economic slump following the pandemic has led to estimation instability in current models, raising the question of whether and how to capture information in the pandemic period and deal with the uncertainty related to such large-tail events. Several issues arise when including extreme COVID-19 observations in model estimates, be they time-series models like a standard VAR, structural DSGE models or semi-structural models. Generally, these models are estimated assuming a constant covariance matrix and coefficients. Including large outliers from high-volatility episodes in the data might bias the estimated coefficients and disrupt the estimated historical relationships between the different variables in the model. Estimators normally use a quadratic loss function, which will be disproportionally affected by a large outlier and give a large weight to a single observation. The latest developments are therefore focused on making estimators more robust by changing the assumptions about the distributions of the stochastic errors (using t-distribution instead of normal distribution), explicitly modelling the heteroskedasticity of errors or ignoring observations altogether. Box 6 describes how extreme observations can be taken into account in estimation in the popular VAR model, building on an approach proposed by Lenza and Primiceri (2020) and Carriero et al. (2021). Similar techniques have to be developed for estimation in structural and semi-structural models. Large swings in economic activity also imply a need to revisit the methods used to produce density forecasts. Methods have to be adjusted using non-normal distributions, allowing for larger tails that are able to capture extreme events like the ongoing pandemic. It will also be important to review the weighting given to observations from the pandemic for future forecasts.

Understanding the nature of the pandemic shock is key for assessing the longer-term economic consequences and calibrating economic policy. The COVID-19 pandemic can be characterised as both a supply and a demand shock, which poses a challenge to inflation-targeting central banks, since these tend to move inflation in opposite directions. A variety of models can be used to understand the exact decomposition between supply and demand shock, but to a large extent all tools rely on conditional correlation between the drop in output and the movement in inflation. DSGE models and SVAR models have been applied and each found that the shock was characterised by both demand and supply effects. Box 5 uses SVAR analysis; the shock decomposition exercise reveals that the pandemic has led to substantial negative supply shocks. These contributed positively to inflation and dominated the initial disinflationary effects arising from negative demand shocks. The results also show that the impact of the pandemic has been felt differently across sectors, with some more supply-constrained than others. The outcome of the exercise illustrates the relative importance of supply and demand shocks and could serve too as an input for macroeconomic models and scenario analysis.

Structural modelling can accommodate the novel mechanisms of the pandemic and offers a testing lab for the effects of different policies. Time-series models were the first to be adjusted for the new economic landscape, due to their flexibility and relatively low cost of development. However, by construction these rely on historical patterns and may therefore not be the best suited for studying the unprecedented nature of the pandemic shock. Only structural models can provide an environment for producing the counterfactuals required for sound policymaking. One of the most influential works in this vein has been a DSGE model developed by Eichenbaum, Rebelo and Trabandt (2020). They incorporate the canonical epidemiology model in a macroeconomic model to study the interaction between economic decisions and epidemics. Their model is one of the first attempts to study optimal containment policy and concludes that, given competitive equilibrium is not socially optimal, the optimal policy is to use lockdowns that increase the severity of the recession but have better health outcomes.

ECB-BASIR is a semi-structural model to study the interplay between epidemiological fundamentals, containment policies and the macroeconomy. ECB-BASIR (Angelini et al., 2020) is an extension of the ECB-BASE model (Angelini et al., 2019) which addresses specific features of the COVID-19 crisis by combining a standard pandemic susceptible-infected-recovered (SIR) model with a semi-structural large-scale macroeconomic model. The advantage of the semi-structural nature of the model is that the extension was implemented relatively fast and that the model was estimated and thus followed the data closely. The empirical relevance of the model has enabled it to be used at the ECB both for forecasting and for counter-factual analysis. As well as assessing the demand versus supply nature of the shock, the model has also been deployed to give forecast updates implied by the course of the pandemic, to analyse scenarios studying the effects of vaccine discovery and the efficiency of implementation, and to give a better description of the uncertainty surrounding the baseline projections. Several of those uses are described in more detail in Box 7.

In summary, the disruption caused by the pandemic has confirmed the usefulness of the suite-of-models approach. The flexibility of time-series models was a boon in the initial stages of the crisis, while later developments in semi-structural and structural models enabled us to evaluate policy options better. Following the outbreak of the crisis, it became clear that the estimations of all models have to be made more robust, moving away from the assumption that data is normal. It has become clear that in future models will need to be flexible enough to take on board non-standard data, primarily by allowing them to be informed by mixed-frequency data and connecting standard macroeconomic models with modern machine learning techniques.

4.6 Global factors and international spillovers

Global factors and international spillovers reflecting the growing integration and interdependence of the world’s economies through cross-border trade, finance and information flows have changed the landscape in which monetary policy operates. Since the last ECB monetary policy strategy review in 2003, globalisation has affected the properties of business cycle dynamics, the sensitivity of activity, inflation and financial conditions to external factors, and the propagation of domestic and external shocks. This has contributed to the emergence of a factor underlying key economic structural trends such as persistently low inflation and interest rates and weakening global productivity. More specifically, global factors may have contributed to the decline in the natural rate of interest, the flattening of the Phillips curve and persistently low inflation by strengthening competitive pressures, amongst other things. In addition, international spillovers associated with the global financial cycle have complicated and changed the channels through which monetary policy is transmitted across euro area countries and the rest of the world.

The new landscape emerging from globalisation is accompanied by several analytical modelling gaps in terms of the role of global factors on projection exercises. Global factors which might have played a role in shaping the decline in headline inflation may need to be more explicitly taken into consideration in future. A better understanding of the exchange rate channel for the relevance of valuation effects on external balance sheets and the sensitivity of domestic financial conditions to the exchange rate is needed. In addition, our understanding of the magnitude and determinants of exchange rate pass-through in global value chains, changes in trade flow composition, invoicing currency patterns and competitive pressures in export markets needs to be improved (Ortega and Osbat, 2020). More efforts should also be devoted to quantifying the relative importance of the different global forces that underpin the growing demand for safe assets, including greater tail risks, the rising sensitivity to uncertainty shocks such as global credit booms, greater portfolio diversification, growing trade flows and the global financial cycle. Global issues such as COVID-19 and climate change have opened up further analytical gaps when it comes to incorporating the specific shocks accompanying them into projection and policy models. In addition, more attention should be paid to analysing the different channels of transmission for spillovers and spillbacks, measuring the magnitude of these effects and testing the symmetricity of positive and negative shocks.

Analytical gaps in multi-country modelling have also emerged around policy questions in the Eurosystem. First, policy questions relating to monetary policy, transmission of conventional and unconventional measures and the monetary policy strategy review (e.g. asymmetric effects of non-standard monetary policy across euro area countries, forward guidance, alternative monetary policy rules) warrant deeper analysis. Second, issues relating to policy mix such as fiscal policy and monetary policy interactions, global monetary policy normalisation and fiscal policy coordination, fiscal multipliers and fiscal spillovers need to be examined. (One example of this relates to Next Generation EU (NGEU) funds.) Third, issues relating to global imbalances, trade wars (tariffs and global value chains) and possibly energy-related topics such as climate change need to be considered. Finally, issues relating to demographics (e.g. the sustainability of the pension system, ageing populations, migration) that imply the introduction of finite-horizon economic agents require investigation.

On the semi-structural front, central banks are using large-scale, estimated multi-country models for forecasting and policy simulation. Examples include ECB-BASE (Angelini et al., 2019), developed by the ECB (which covers the euro area, with ECB-MC for individual countries), FRB/US (Brayton, 2014) developed and maintained at the Federal Reserve System and the LENS model (Gervais and Gosselin, 2014) developed and maintained at the Bank of Canada. ECB-BASE was developed by the ECB to account for the relationship among key macroeconomic variables, including foreign trade and exchange rate assumptions, in a systematic manner in order to provide input to the complex process of macroeconomic forecasting, scenario analyses and policy simulations. Although the model provides an explicit role for the financial sector, international spillovers can emerge only through trade, not financial assets. An augmented version of ECB-BASE called ECB-BASIR (Angelini et al., 2020), which includes the predictive dynamics of the SIR model, has also been developed to assess the interplay between epidemiological fundamentals, containment policies and the macroeconomy. One application of this model is to analyse the macroeconomic consequences of the COVID-19 pandemic. Another example of a semi-structural model used for forecasting and policy analysis is NiGEM, a global macroeconomic model used by both policymakers and the private sector across the globe for economic forecasting, scenario and simulation purposes. This is currently being modified to allow integration with IAM models for climate change analysis.

With respect to multi-country DSGE modelling, a joint effort by ESCB experts developed the EAGLE model to provide a coherent framework for evaluating euro area-wide and country-specific policy measures across NCBs from global factors. Similar models include the Global Integrated Monetary and Fiscal model (GIMF) (Derek et al., 2013), a multi-region, forward-looking DSGE model developed by the IMF for policy analysis and international economic research, and QUEST III (Ratto et al., 2008), an estimated open-economy DSGE model of the euro area with fiscal and monetary policy developed by the European Commission. EAGLE (Gomes et al., 2012) is a multi-country model shared by ESCB experts through the EAGLE network to address policy issues effectively and efficiently, mainly in monetary and fiscal policy, and to evaluate international spillovers.

Significant contributions by the EAGLE model to the policy debate include work on the transmission of non-standard monetary policy measures in a monetary union (forward guidance), the interaction between the single monetary policy and fiscal measures in individual member states, and the interaction between euro area policies and those implemented in European countries not belonging to the euro area or in the other main regions of the world. EAGLE has also been used for country-specific scenario analysis simulations to assess the macroeconomic impact of non-standard monetary policy measures (forward guidance) on the euro area economy. The version of EAGLE that includes financial frictions, EAGLE-FLI (Bokan et al., 2018), is described in Section 4.2.2.

Darracq Pariès, Jacquinot and Papadopoulou (2016) present a global DSGE model with a detailed banking system and a rich set of financial frictions which pays special attention to financial variables (in particular lending rates), financial cross-country heterogeneity across euro area countries and international trade and financial spillovers across Germany, France, Italy, Spain, the rest of the euro area and the rest of the world. The model describes the credit intermediation process, showing that sources of impairments in the monetary policy transmission mechanism can arise from four distinct segments, related both to the demand and the supply of credit, namely: (i) the market-funding cost spread; (ii) bank capital charges; (iii) compensation for expected losses; and (iv) the competitive wedge, representing specific types of financial frictions. Cross-country heterogeneity in the financial structure specified in the model affects the real-financial amplification mechanism of the various financial wedges and the importance of financial and trade spillover effects across euro area countries. The granularity of the model with its detailed banking system and rich set of financial shocks provides a consistent framework for evaluating the macroeconomic effects of key financial shocks usually analysed by the literature in isolation, such as a narrative of the recent financial crisis.

With respect to monetary policy analysis, Darracq Pariès and Papadopoulou (2020) explore the country-specific macroeconomic transmission of selected non-standard measures from the ECB by using a global DSGE model with a rich financial sector which includes credit and exchange rate channels for central bank asset purchases. They find that domestic transmission of the asset purchase programme (APP) through the credit intermediation chain is significant and relatively heterogenous across the largest euro area countries. The introduction of global portfolio frictions on euro area government bond holdings by international investors amplifies the depreciation of the euro, which rotates the transmission mechanism from bank-based channels towards trade. The interaction between international and domestic channels affects the magnitude and the cross-country distribution of the impact of APP. Furthermore, the international transmission of asset purchases from one jurisdiction to another within the monetary union is significant, since cross-country spillovers are high and mostly driven by trade channels.

Box 1
Endogenous total factor productivity, hysteresis and monetary policy

This box summarises the main results from a model with endogenous total factor productivity (TFP) dynamics for the euro area (Elfsbacka Schmöller and Spitzer, 2021). The model features the possibility of hysteresis effects in total factor productivity as the result of adverse spillovers from weak aggregate demand to technology growth and thus aggregate supply, which can render recessions deep and long-lasting. Monetary policy is non-neutral as it can influence investment in research and development (R&D) and technology adoption and thus total factor productivity growth. As a result, costs induced by the effective lower bound (ELB) are larger than conventionally assessed, as the procyclical deceleration in TFP is intensified. The model also predicts a dampened inflation response over the business cycle resulting from the interaction of inflation and productivity dynamics.

Model description

TFP evolves endogenously in a general equilibrium setting, departing from the standard assumption of exogenous TFP driven by technology shocks only. The model follows Anzoategui, Comin, Gertler and Martinez (2019) and is estimated on euro area data using Bayesian methods.

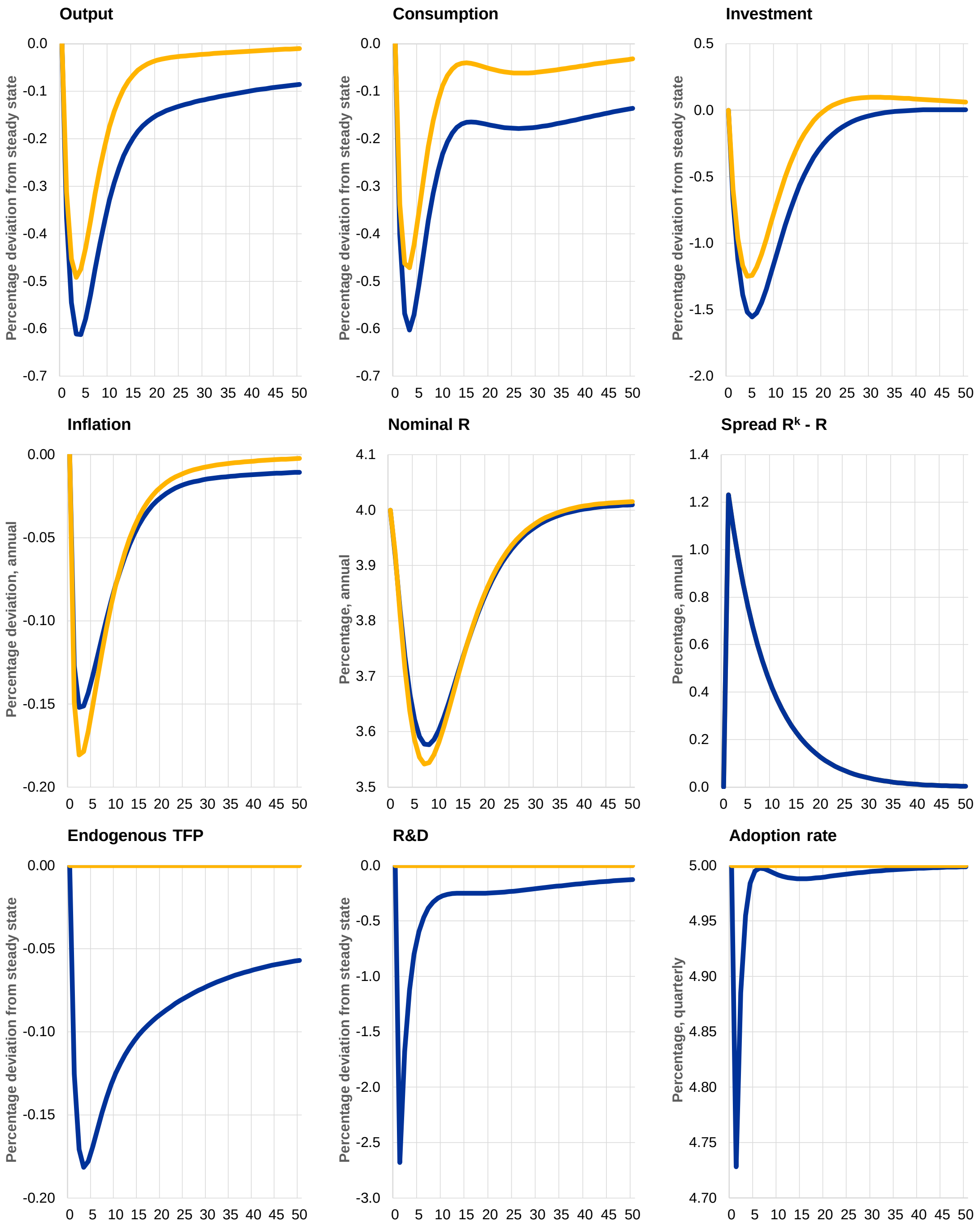
The framework is a medium-scale New Keynesian DSGE model in the spirit of Christiano et al. (2005) and Smets and Wouters (2007). In addition, the model features an endogenous TFP mechanism as proposed by Comin and Gertler (2006). Total factor productivity growth evolves in a two-stage process: R&D and technology adoption, where innovations occur in the form of the expanding-variety approach in endogenous growth in intermediate goods (Romer, 1990). In the first stage, new technologies are invented by innovators through investment in R&D, adding to the total stock of technologies. In the subsequent stage, competitive adopters render these technologies usable in production. Hence, R&D only results in productivity gains when innovations diffuse to the wider economy and are incorporated in firms' production processes. As a result, TFP is not only driven by technology shocks, it is also subject to endogenous fluctuations.[26] The model is otherwise subject to standard DSGE model features, with Calvo price and wage rigidities. Monetary policy is modelled in the form of a standard Taylor rule and may be constrained by the ELB. The model features skilled labour employed in the R&D sector and the technology adoption process, as well as unskilled labour used in production.

[26] TFP is thus the combination of the standard technology shock θ_t and the endogenous TFP component A_t ($TFP=\theta_t A_t$^(ϑ-1)), where ϑ refers to the elasticity of substitution in intermediate goods.

Chart A

Business cycle amplification and persistence under endogenous TFP

(x-axis: quarters)



Source: Elfsbacka Schmöller and Spitzer, 2021.
Note: Impulse response to a one standard deviation liquidity demand shock.

Macroeconomic dynamics under endogenous TFP

Chart A shows the macroeconomic dynamics under the endogenous TFP model (the blue line) and a model with exogenous TFP (the grey line)[27] in response to a one standard deviation liquidity demand shock.[28] The shock raises the demand for safe asset holdings at the expense of consumption. The spread between safe and risky assets increases, accompanied by a fall in capital investment. Crucially, the endogenous TFP model displays a substantially higher degree of business cycle persistence, with a more pronounced and long-lasting drop in key economic variables relative to the exogenous TFP setting. The underlying cause are hysteresis effects in TFP, resulting from the spillover from weak aggregate demand to technology growth, which is absent in standard macroeconomic frameworks. The recession reduces firm profits and expected gains from investment in R&D and technology adoption, inducing an endogenous fall in productivity-enhancing investments and a deceleration in total factor productivity. The model can generate deep and long-lasting recessions via hysteresis effects in TFP, explaining both the severity and persistence of past euro area recessions, and the simultaneous intensification of the euro area productivity slowdown.

The endogenous TFP mechanism also dampens the inflation response over the business cycle as a result of the interaction between inflation and productivity dynamics. As in standard DSGE models, contractionary demand shocks lower inflation. However, a downturn simultaneously induces a deceleration in productivity, which in turn raises marginal costs and price pressures, dampening the disinflationary effect. In an expansion, the increase in inflation is alleviated as inflationary pressures are partly offset by procyclical increases in TFP, reducing marginal costs. As a result, the alleviated inflation response under endogenous TFP dynamics can also contribute to explaining the phenomenon of missing (dis-)inflation in the euro area.

Output hysteresis and the ELB

Chart B shows the macroeconomic response to a large recessionary shock that induces the ELB to bind. When monetary policy is constrained by the ELB (the blue line), the hysteresis effects in TFP are substantially amplified relative to a model version without the ELB (the grey line). Due to the non-neutrality of monetary policy in this setting, a binding ELB intensifies the hysteresis effects in TFP and the depth and persistence of the recession. Specifically, a binding ELB magnifies the initial output drop and the fall in firm profits, which further weighs on the value of unadopted and adopted technology. The resulting amplified drop in investment in R&D and technology adoption intensifies the deceleration in TFP. As a result, hysteresis effects in TFP will further decrease output and protract the recovery. Hysteresis effects arising under endogenous productivity dynamics thus render the costs of the ELB more severe owing to its adverse effects on technology growth and the supply side of the economy.

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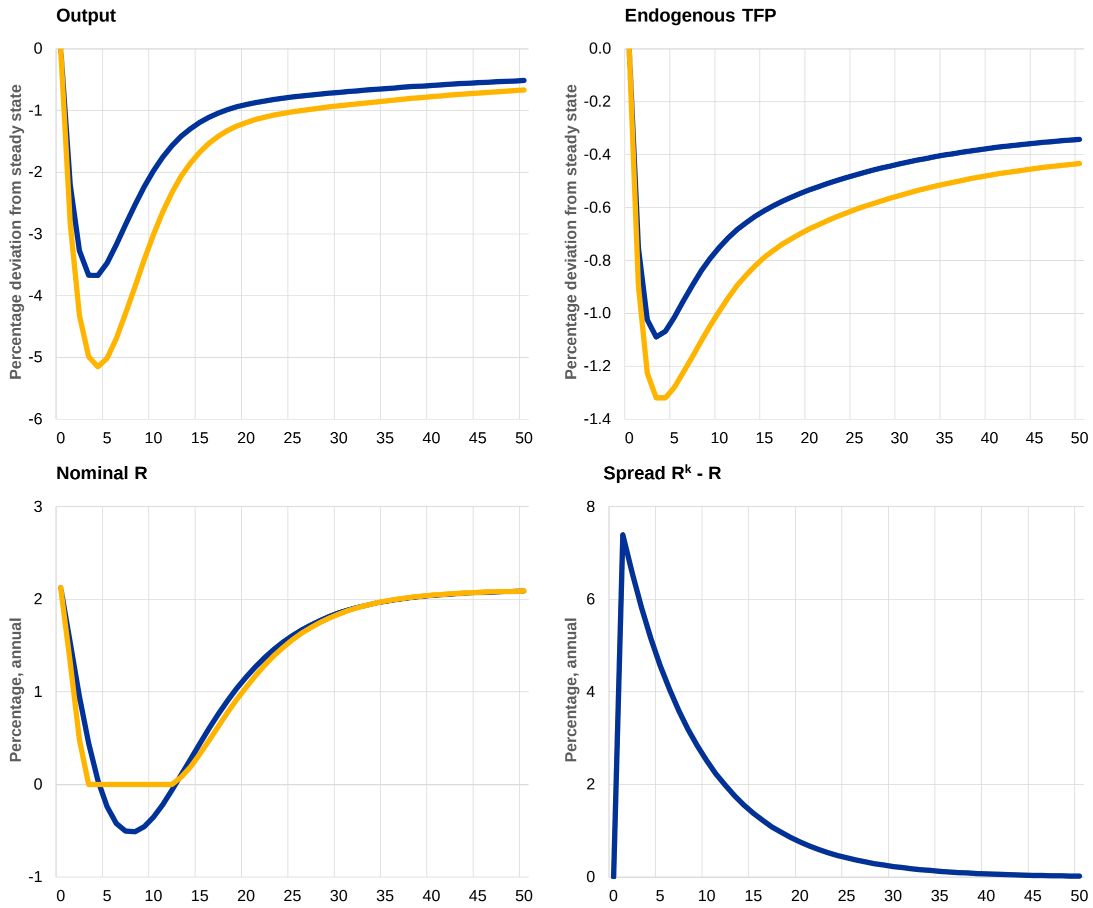
[27] Apart from the presence of the endogenous TFP mechanism, the models are identical with respect to model assumptions and parameterisation.

[28] We focus on the liquidity demand shock as it triggers the typical business cycle co-movement in economic variables and emerges as the central shock in explaining economic fluctuations. The liquidity demand shock is modelled via bond holdings in the utility function, where a positive shock to liquidity demand raises safe asset holdings at the expense of consumption. Fisher (2015) shows that the liquidity demand shock constitutes an explicit formulation of the Smets and Wouters (2007) risk premium shock, and we also verify empirically a close co-movement of the liquidity demand shock and euro area credit spread measures.

Chart B

The role of the ELB in business cycle amplification

(x-axis: quarters)



Source: Elfsbacka Schmöller and Spitzer, 2021.
Note: Impulse response to a liquidity demand shock which causes the ELB to bind.

Box 2

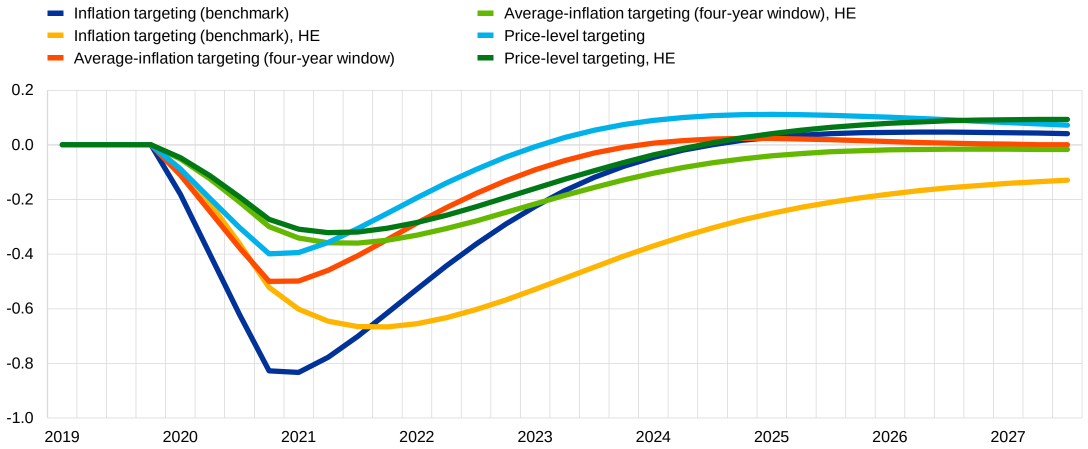
A comparison of responses to monetary policy shock under different expectation formation mechanisms

Chart A illustrates how different expectation formation mechanisms can impact the transmission of monetary policy. The solid lines show the impulse response of the harmonised index of consumer prices (HICP) after a negative demand shock around a December 2019 BMPE extended baseline under forward-looking rational expectations, and under different monetary policy rules. Make-up strategies such as average inflation targeting or price level targeting can effectively mitigate the negative impact due to the expected reversal in future inflation. The dashed lines represent the case where inflations are not purely forward-looking and there is a learning component (hybrid expectations or HE). In this situation, under all three possible rules inflation becomes more persistent and the recovery arrives significantly later, posing major challenges for monetary policy.

Chart A

Impact of an adverse demand shock on HICP inflation under different monetary policy strategies

(y-axis: percentage points deviation, annual)



Source: ECB calculations based on NAWM.
Notes: The chart shows the marginal impact on annual inflation of a negative demand shock around the December 2019 BMPE extended baseline (MTRS). The model is simulated under rational and hybrid expectations, and takes into account an ELB set to -0.5%

Chart B illustrates the impact of the transmission of an anticipated monetary policy shock – a forward guidance announcement – in the Aino models of Suomen Pankki – Finlands Bank (the Aino 2.0 model of Kilponen et al., 2016, and the Aino 3.0 model of Silvo and Verona, 2020). The experiment consists of a simulated scenario in which the central bank announces that the nominal interest rate will decrease by 50 basis points and stay at that level for six quarters (and then go back to its steady state). We run the simulations in the model with a standard sticky prices (SP) Phillips curve and its sticky information (SI) counterpart (implemented as in Chung et al., 2015).

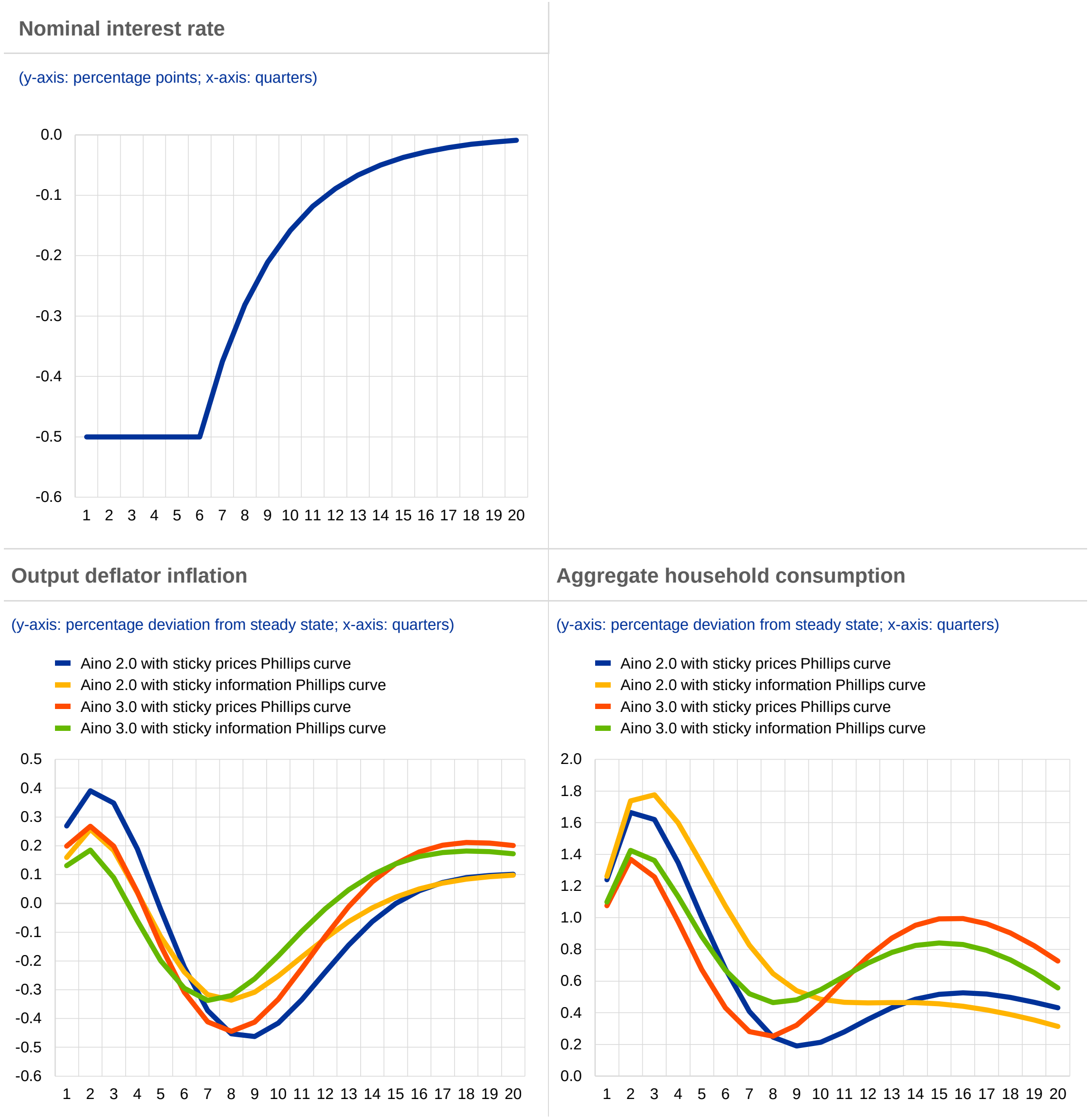
Qualitatively, the responses are similar across models and across different specifications for the Phillips curve. The effects of forward guidance in Aino 3.0 (the solid lines) is more muted than in Aino 2.0 (dashed lines). The reason is that Aino 3.0 features household heterogeneity in the form of savers and constrained borrowers (as in Iacoviello, 2005), and the presence of constrained households mitigates the impact of forward guidance (as pointed out by McKay et al., 2016).

What drives the differences in the responses between SP (the black lines) and SI (the blue lines) is the dynamics of the real interest rate. Households forecast the entire future path of the real interest rate and make their optimal decisions according to a standard Euler equation. Inflation in the SI models reacts by less. Hence, the higher consumption in the models with SI is due to the fact that the undiscounted sum of expected real interest rates falls by more in the SI models than in the models with SP (even though the initial fall in real rates is larger in the SP models).

Overall, replacing the standard SP Phillips curve with its SI counterpart in a model with household heterogeneity makes inflation less volatile, at the expense of a more volatile real economy following a monetary policy forward guidance announcement.

Chart B

Impact of a forward guidance announcement under sticky price and sticky information Phillips curves



Sources: Aino 2.0 and Aino 3.0.

Box 3

Evaluating the macroeconomic effects of the ECB asset purchase programme using a New Keynesian model

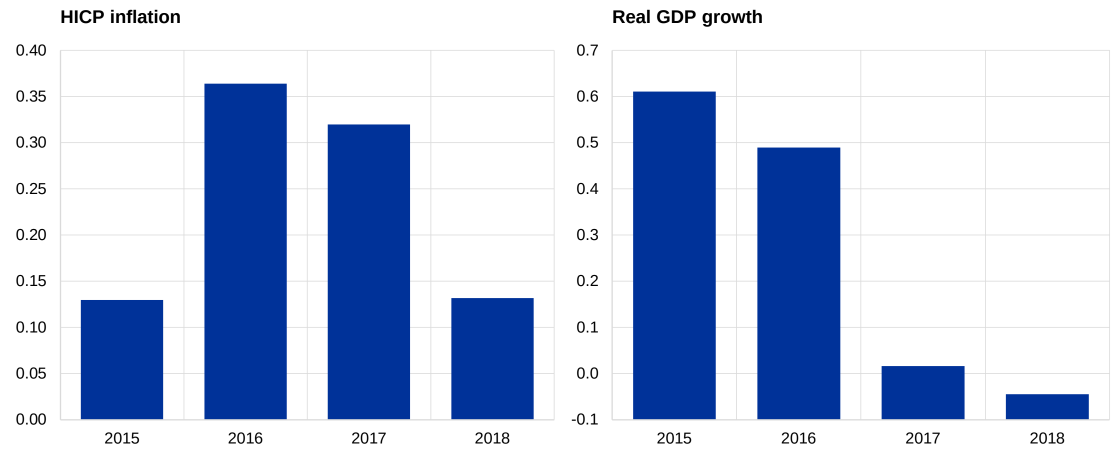
In January 2015 the ECB announced the launch of an expanded asset purchase programme (APP), which consists of purchases in the secondary market for private securities and euro-denominated investment-grade securities issued by euro area (EA) governments and institutions. The announcement of the APP spurred a debate about its transmission channels.

Burlon et al. (2015) develop a New Keynesian model calibrated to the EA (modelled as a two-region monetary union) and the rest of the world to evaluate the macroeconomic effects of purchases of long-term sovereign bonds by the central bank of the monetary union. Following Chen et al. (2012), in each of the two EA regions the assumption of financial market segmentation holds. More precisely, some households (labelled "unrestricted") have ample access to financial markets, while others (labelled "restricted") have access only to domestic long-term sovereign bond markets and are co-owners of domestic physical capital producers. Central bank purchases of long-term government bonds induce an increase in the price of the bonds and a corresponding reduction in long-term interest rates. These developments activate a "portfolio rebalancing" channel, by which restricted households react to the lower profitability of government bonds by selling them to the central bank and increasing investment in physical capital and consumption.

Chart A

The macroeconomic impact of the January 2015 APP

(percentage points)



Source: Burlon et al. (2015).

Counterfactual simulations suggest that the APP is effective in stimulating inflation and economic activity through this channel.[29] Chart A shows the responses in euro area inflation and output to the first wave of ECB purchases of sovereign bonds announced in January 2015 (amounting to €1,140 billion). Relative to the no-purchase baseline scenario, in the first four years EA consumer prices increase by 0.9 percentage points and real GDP by 1.1 percentage points.[30]

Box 4

The rise of novel financial frictions and policies

This box provides an overview of the rise of novel financial frictions and a summary of the main instruments and objectives of monetary, macroprudential and microprudential policies, continuing

[29] The simulations assume that the central bank keeps the policy rate at its baseline level during the APP.

[30] See Burlon et al. (2015). Counterfactual simulations of versions of the model illustrated have been run to evaluate the macroeconomic impact of the central bank's reinvestment policy for assets purchased, the impact of purchases on financial stability, the interaction with macroprudential policy, public investment multipliers and the macroeconomic impact of the corporate sector bond purchasing programme. See Burlon, Gerali, Notarpietro and Pisani (2017 and 2018), Burlon, Locarno, Notarpietro and Pisani (2017), and Bartocci, Burlon, Notarpietro and Pisani (2020).

with a description of their respective transmission mechanisms and a stylised conceptual framework for their interactions.

Financial frictions and financial policy have been topics of increasing importance in recent years. The 2007-09 international crisis created shockwaves in the economics profession that are far from settled. In the euro area, interactions between financial and non-financial institutions during the 2010-12 sovereign debt crisis called for in-depth examination in both the empirical and theoretical literature. Failures in financial markets were again pushed to the forefront by many economists, just as when Irving Fischer and J. M. Keynes examined the causes behind the Great Depression.

A key criticism of dynamic stochastic general equilibrium (DSGE) models has been their inability to identify the cumulative vulnerabilities before the crisis period (Christiano et al., 2018), let alone signal meaningful policy warnings. The depth of the recession was either outside the predictive density of standard pre-crisis models (Del Negro and Schorfheide, 2013) or only explained by a “cocktail of extremely unlikely shocks” (Lindé et al., 2016). The inability of financial frictions-based models to properly take rare or extreme events into account and provide a convincing improvement over simpler and more standard alternatives suggests work is needed to enhance our understanding of the size, persistence and asymmetry of business cycle fluctuations.

Pre-crisis models were revealed to be largely ineffective in predicting or explaining the events of the Great Depression. Two of the most influential studies on financial frictions as amplification and propagation devices, viz. Bernanke et al. (1999) and Kiyotaki and Moore (1997), inspired a vast literature on the subject. However, theoretical and empirical evaluations of such devices provide some support for the insufficiency of such mechanisms, suggesting no clear and compelling improvement over the standard New Keynesian benchmark (Brzoza-Brzezina and Kolasa, 2013; Brzoza-Brzezina et al., 2013), or that additional non-linear features are required to account for business cycle fluctuations properly (Lindé et al., 2016). Models based on collateral constraints have been found to be quantitatively insignificant (Kocherlakota, 2000; Cordoba and Ripoll, 2004).

Models failed because they did not include the relevant kind of financial frictions in their analysis, or at least the frictions that mattered to address recent macroeconomic weaknesses. Several models have arisen in recent years to address these issues, some associated with the introduction of non-linear features (see Section 4.2.3), others accounting for frictions not considered in older models. In general, models of financial frictions can be divided in two classes: those that focus on frictions originating inside financial institutions, and those that focus on frictions arising outside those institutions, looking at the people who borrow. Developments in the former are associated with theories about bank runs, rollover crises, credit restrictions and new types of banking frictions, whereas the latter focus on collateral-constrained borrowers. Most models that have been developed in recent years can be classified as extensions of Bernanke et al. (1999) or Kiyotaki and Moore (1997) to include more complex structures in banks and capture disruptions in intermediation, usually associated with some form of non-linearity.

As novel financial frictions emerged, central banks needed to enrich their policy toolkit to deal with financial and banking instabilities from both a micro- and macroeconomic perspective. Discussions on how all these policies interact moved to the forefront of policy and academic circles.

Beyer et al. (2017) provides an overview of monetary, macroprudential and microprudential policies, starting with their main instruments and objectives, continuing with a description of their respective transmission mechanisms and a stylised conceptual framework for their interactions. The monetary policy objective of most major central banks has been defined in terms of price stability, which some combine with an objective of balanced economic growth and full employment. They stipulate an operational framework for implementing their monetary policy consisting of a number of instruments, typically including key rates, open market operations, standing facilities and potentially also reserve requirements.

Apart from this standard toolkit, central banks have developed various non-standard measures to influence market interest rates and the availability of central bank money in periods when nominal interest rates move closer to the effective lower bound. Financial (i.e. micro- and macroprudential) policies, by contrast, aim to ensure the financial system is resilient and works smoothly, limiting the probability of a misallocation of funds, sharp corrections in financial markets and the associated sharp downturns in economic activity. Financial policies are categorised into three broad areas, depending on whether the instruments affect capital, assets or liquidity. The main objective of macroprudential policy is to contribute to the stability of the financial system, safeguarding it against the build-up of systemic risk. Therefore its focus is on all entities and their interactions as a whole. This is achieved by monitoring at least four broad categories of vulnerability in the system: (1) mispricing of risk; (2) overleverage; (3) maturity mismatches and liquidity transformation; and (4) excess interconnectedness and complexity. The objective of microprudential policy is to contribute to the safety and soundness of individual entities and thereby contribute to the stability of the system as a whole. A microprudential authority considers several risk factors: risks to capital (credit risk, market risk, interest rate risk and operational risk); risks to liquidity and funding; risks stemming from interdependencies. The paper concludes that from a conceptual point of view there are numerous areas where policies interact, which are summarised in Table A. These create scope for synergies which can be reaped by sharing information and expertise across the various policy areas.

Table A

Interactions between policies and monetary transmission channels

Transmission channel	Monetary policy	Macroprudential policy	Microprudential policy
Interest rate	All	X	X
Money			
Exchange rate			
Asset prices and wealth		X	X
Bank lending		Liquidity coverage ratio Net stable funding ratio Large exposure limits Sectoral risk weights (in the residential and commercial property sectors) Intra-financial sector exposures	Liquidity coverage ratio Net stable funding ratio Large exposure limits
Bank capital		Minimum capital requirements Countercyclical capital buffer Capital conservation buffer Leverage ratio	Minimum capital requirements Capital conservation buffer
Firms' balance sheet and profitability		General equilibrium effects of LTVs/LTIs/LTDs are likely, i.e. a slowdown or contraction in asset prices affects balance sheets.	General equilibrium effects of LTVs/LTIs/LTDs are likely, i.e. a slowdown or contraction in asset prices affects balance sheets.
Risk-taking		Capital surcharge on systemically important institutions	
Expectations			

Source: Beyer et al. (2017).

Box 5
Decomposing sectoral inflation during the COVID-19 pandemic

The COVID-19 pandemic can be characterised as both a supply and demand shock, which poses a challenge to inflation-targeting central banks since these tend to move inflation in opposite directions. The immediate impact of the pandemic and the associated lockdown measures has been different across sectors. This box shows that the use of sectoral data and time-series models can help us better understand the driving forces behind the subcomponents of inflation. In particular, they allow timely estimation of the relative importance of supply and demand and other shocks in driving sectoral inflation during the pandemic.

The empirical analysis is based on a shock decomposition of sectoral inflation employing a Bayesian VAR model accounting for stochastic volatility and data from the first quarter of 1998 to the second quarter of 2020 for the euro area. The model includes the following variables: sectoral gross value added, the sectoral implicit price deflator, the nominal exchange rate (against 42 trading partners), the shadow interest rate (following Krippner, 2013), and the high-yield bond spread (which is a proxy for financial conditions in the euro area). Using sign restrictions, we decompose sectoral inflation into demand and supply shocks. In particular, we impose the condition that, on impact, positive demand shocks raise inflation, output and the interest rate, while supply shocks move inflation and output in opposite directions. To account for financial market forces that may affect inflation via the demand side of the economy, we also impose restrictions to identify three other shocks: exchange rate, risk premium and monetary policy shocks (the accompanying sign restrictions are standard and follow the literature).

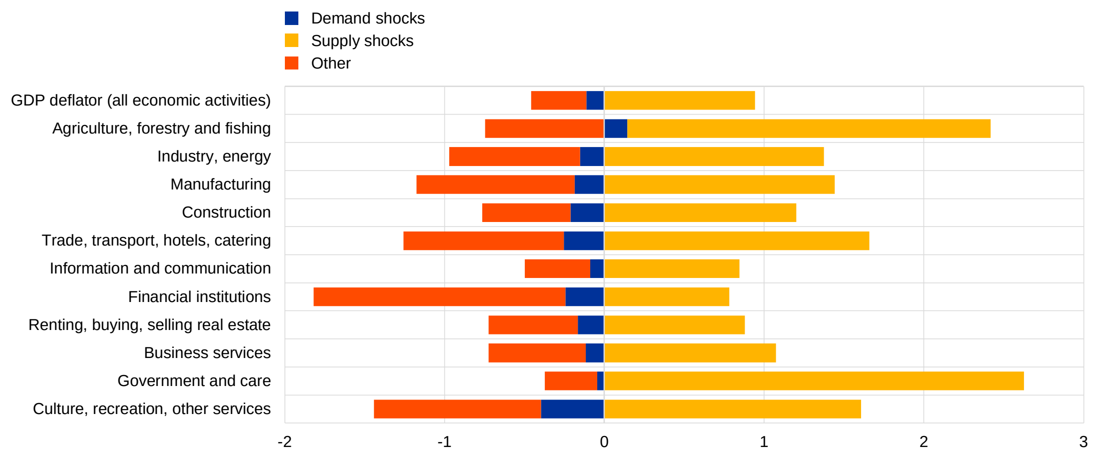
Chart A shows the shock decomposition of euro area inflation in the second quarter of 2020 and reveals a substantial amount of heterogeneity across sectors. In most, inflationary supply shocks dominate disinflationary demand shocks. The most sizable inflationary supply-side contributions are found in government and care, trade, transport, hotels and catering, and culture and recreation. Whereas the first of these experienced large supply contractions due to healthcare shortages, the latter two were particularly constrained by government-imposed lockdown measures. Most sectors experienced disinflationary pressures arising from positive exchange rate and risk premium shocks, reflecting the impact of the exchange rate appreciation and a tightening of financial conditions (as captured by the high-yield bond spread). Finally, at the aggregate level (the top row), inflationary supply shocks also considerably outweighed disinflationary demand shocks in driving inflation, again reflecting the significant disruptive effect of the pandemic on the supply side. However, the other shocks had a sizable impact on aggregate inflation as well.

The exercise reveals that the pandemic led to substantial negative supply shocks, which contributed positively to inflation and dominated the disinflationary effects arising from negative demand shocks. The results also show that the impact of the pandemic was felt differently across sectors, with some being more supply-constrained than others. The outcome of the exercise illustrates the relative importance of supply and demand shocks, and could also serve as input for macroeconomic models and scenario analysis.

Chart A

Shock decomposition of euro area inflation (second quarter of 2020)

(percentage deviation from historical mean)



Source: Eurostat, ECB's SDW, author's estimations.

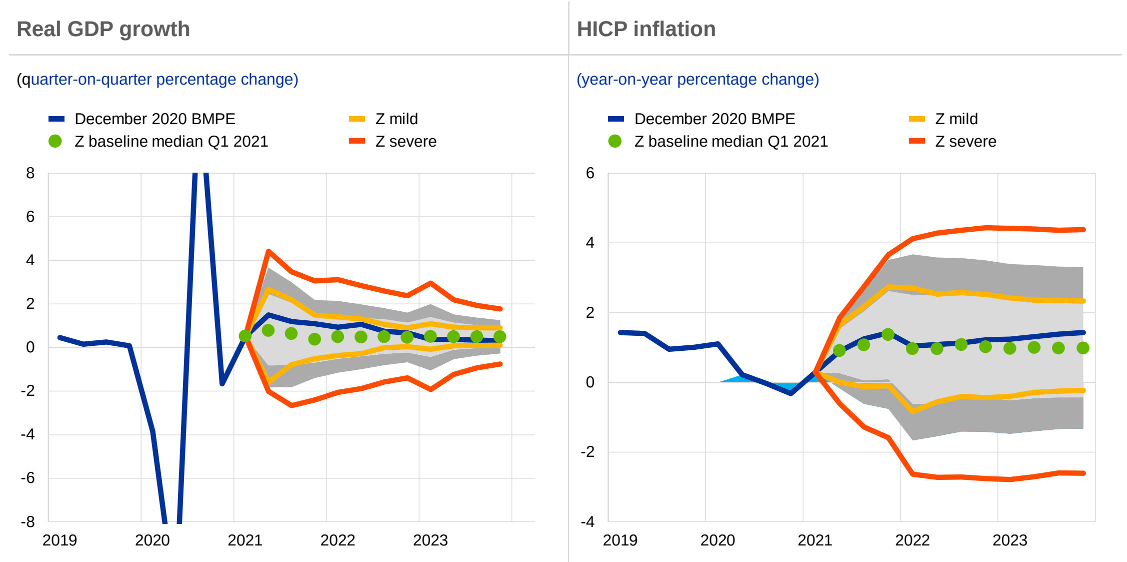
Box 6
VAR-based risk analysis during the COVID-19 pandemic

The outbreak of the COVID-19 pandemic has led to unprecedented variation in many key macroeconomic indicators. Several variables, such as GDP, unemployment, consumption and industrial production (among many others), have experienced unprecedented changes due to significant shifts in consumer behaviour and the measures taken to combat the pandemic (the "Great Lockdown"). The magnitude of these shocks and their propagation through the economy constitute a considerable challenge for estimations of the most popular time-series models used in central banks, vector autoregression (VAR).

When it comes to inference, several issues arise when including extreme COVID-19 observations in a model such as a standard VAR. Generally, these models are estimated assuming a constant covariance matrix and coefficients or a stochastic volatility model with a random-walk assumption for changes in the variance-covariance matrix. In the first case, including big outliers from high-volatility episodes in the estimation sample might bias the estimated coefficients and disrupt the estimated historical relationships between the different variables in the model. In the second case, a persistent model might not be a reasonable choice for producing density forecasts, as volatility should be kept constant over the projection horizon due to the nature of the random walk. For example, the estimation of a model that incorporates data related to the COVID-19 pandemic will contain significant changes in volatility between the first and third quarters of 2020 (see Chart A). However, it is unreasonable to think that these volatility changes are going to have such a large impact on uncertainty permanently. Most of the change in volatility would have come from the lockdowns imposed in several countries, which in principle will be temporary. If one assumes that volatility will remain elevated when producing forecasts for key macroeconomic variables over the subsequent quarters, the resulting scenario might be distorted.

Chart A

Statistical risk metrics: predictive densities across models



Source: ECB projections database.
Notes: Calculations based on Z model (BVAR with heteroscedasticity modelled as a function of predicted paths for VIX and the Oxford stringency index). Forecasts and scenarios for the stringency index provided by DG/E-BCA.

In what follows, we present alternative specifications for modelling time-varying uncertainty when projecting macroeconomic variables which address the previous concerns while avoiding over-fitting, i.e. not allowing parameters to change too much to handle the extreme observations resulting from the volatility spikes in our variables. Some of the approaches are close in spirit to those in recent literature (see e.g. Lenza and Primiceri, 2020 and Carriero et al., 2019 and 2021).

The standard BVAR model can be written as

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \cdots + B_p Y_{t-p} + \lambda_t \varepsilon_t$$

where $\varepsilon_t \sim IIN(0,\ \Sigma_t)$, $t = 1, \ldots, T$, λ_t is the heteroscedastic factor and Σ_t a possibly time-varying covariance matrix.

We define three alternative proposals for modelling uncertainty as follows:

Fat-tails T-model: $\lambda_t = IG(\nu/2, \nu/2)$, $\varepsilon_t \sim t_\nu(0, \Sigma)$, and $\Sigma_t = \Sigma$.

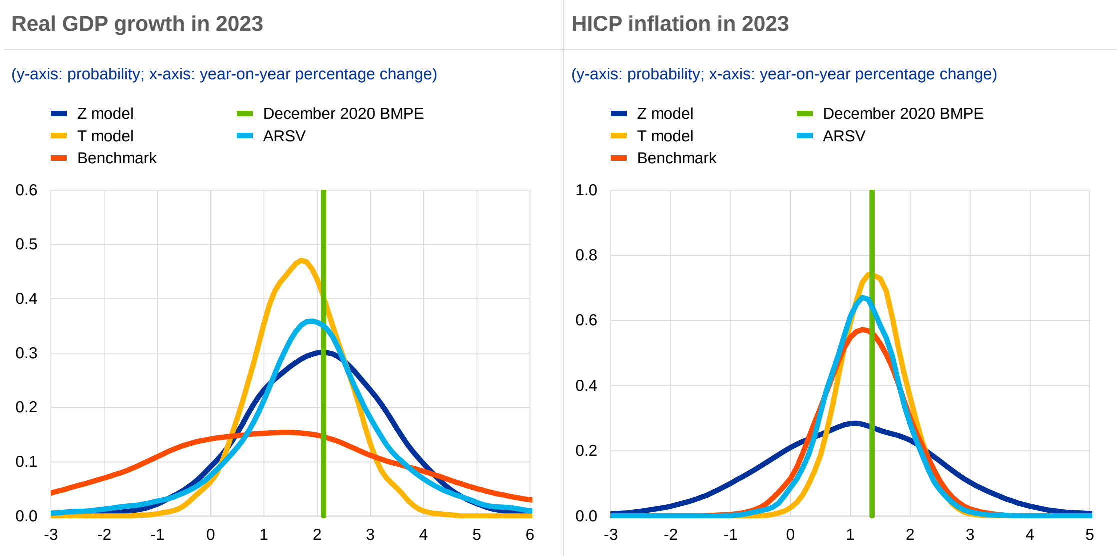
Autoregressive stochastic volatility model: $\lambda_t = 1$ and $\Sigma_t = A^{-1}\Lambda_t(A^{-1})$, $\Lambda_t = diag\left(\sigma^2_{H,1,t},\ \ldots, \sigma^2_{H,n,t}\right)$ and $\log \sigma^2_{H,i,t} \sim AR(1)$ with $\rho_1 = 0.7$

Heteroscedastic Z model: $\lambda_t = exp(Z_t'\alpha)$ and $\Sigma_t = \Sigma$, $Z_t' =$ (composite indicator of systemic stress (CISS), Oxford stringency index)

Two main approaches can be followed to deal with these issues: one can rely on a statistical model which by construction remains agnostic about the future behaviour of volatility, or one can adopt a more flexible specification that conditions future uncertainty on external information about the economy.

Chart B

Statistical risk metrics: predictive densities across models



Source: ECB projections database.
Notes: Calculations based as follows: Benchmark: BVAR with constant coefficients and volatilities; AR-SV: BVAR with an AR(1) process for stochastic volatility; Z model: BVAR with heteroscedasticity modelled as a function of predicted paths for VIX and the Oxford stringency index; T-model: heteroscedasticity via fat tails, t-student distributed errors.

Chart B illustrates an example of these different proposed techniques. The standard BVAR with a constant variance-covariance matrix and coefficients is labelled the benchmark model. We suggest modelling heteroscedasticity either via fat tails (t-student distributed errors, the "T model"), or with a stochastic volatility model where the volatility follows an AR(1) ("ARSV") process rather than a random walk. These models allow us to capture changes in volatility based purely on the variation in the endogenous variables used to estimate the VAR model. When producing density forecasts, volatility will decay naturally in the case of the stochastic volatility model rather than staying constant, due to the AR(1) component. In the case of the model with t-distributed errors, the changes in volatility are in principle independent over time[31].

To increase the accuracy of the density forecasts we suggest that it is reasonable to use external information related to future economic uncertainty to condition on future volatility paths, so in the last model we propose exploiting external information to estimate time-varying volatility and condition its behaviour over the projection horizon. We call this the Z model: it models time-varying variance as a deterministic function of uncertainty indicators such as CISS and an index of lockdown measures during the pandemic (the Oxford stringency index[32]). This directly predicts future uncertainty behaviour with external information, potentially making it possible to carry out conditional uncertainty forecasts depending on different scenarios for the future evolution of the COVID-19 pandemic (see Chart A).

[31] To introduce a smooth change in volatility over the projection horizon in the T model we add a further modification that introduces volatility decay to our forecasts, with the path of the volatility modelled as an AR(1) process with an autoregressive parameter equal to 0.7.

[32] Forecasts and scenarios for the stringency index were provided by DG/E-BCA, while for the evolution of CISS over the forecast horizon used in the different scenarios we matched the growth rate of CISS to be the same as projected for the Oxford stringency index.

Box 7
Model-based risk analysis during the pandemic with ECB-BASIR

This box describes how the ECB-BASIR model is used to complement the standard tools in summarising the risks around the baseline forecast.

The ECB-BASIR model

ECB-BASIR (Angelini et al., 2020) is an extension of the ECB-BASE model that addresses specific features of the COVID-19 crisis by combining a standard pandemic susceptible-infected-recovered (SIR) model with a semi-structural large-scale macroeconomic model. An SIR model – a compartmental model introduced by Kermack and McKendrick (1927) – divides the population into groups and, using differential equations, predicts how a disease will spread on the basis of the number of susceptible, infected, recovered or deceased individuals. We extend that model by incorporating two additional categories: (i) quarantined individuals; and (ii) people who have been vaccinated (who are assumed to be immune to the virus).

We postulate that economic behaviour will affect the transmission of the disease (with declines in consumption and work activity reducing the probability of people getting infected, for example), establishing a channel from the macroeconomic model to the epidemiological model through the sensitivity of transmission to economic interaction between people. The channel running in the opposite direction, from the epidemiological model to macroeconomic behaviour, is established by assuming that different groups of agents modelled in the epidemiological component have differing abilities to work, consume and invest. For example, agents who are constrained by lockdown can only consume part of what unconstrained agents consume, with those differences between the consumption of constrained and unconstrained agents being estimated on the basis of data for the first and second quarters of 2020. These effects then propagate through the macroeconomic linkages in the model.

As we have observed over the latest period, the interaction between the severity of infection rates and the lockdowns imposed to curb the pandemic is the main driver of macroeconomic dynamics. The infection rate in the model is based on several factors, one of which is the containment measures implemented (including lockdowns). Lockdowns are endogenous in the model and based on a decision-making rule for containment measures. The rule assumes that policymakers seek to ensure infection rates do not result in hospital admissions exceeding hospital capacity, while minimising economic costs.

Uncertainty and pandemic

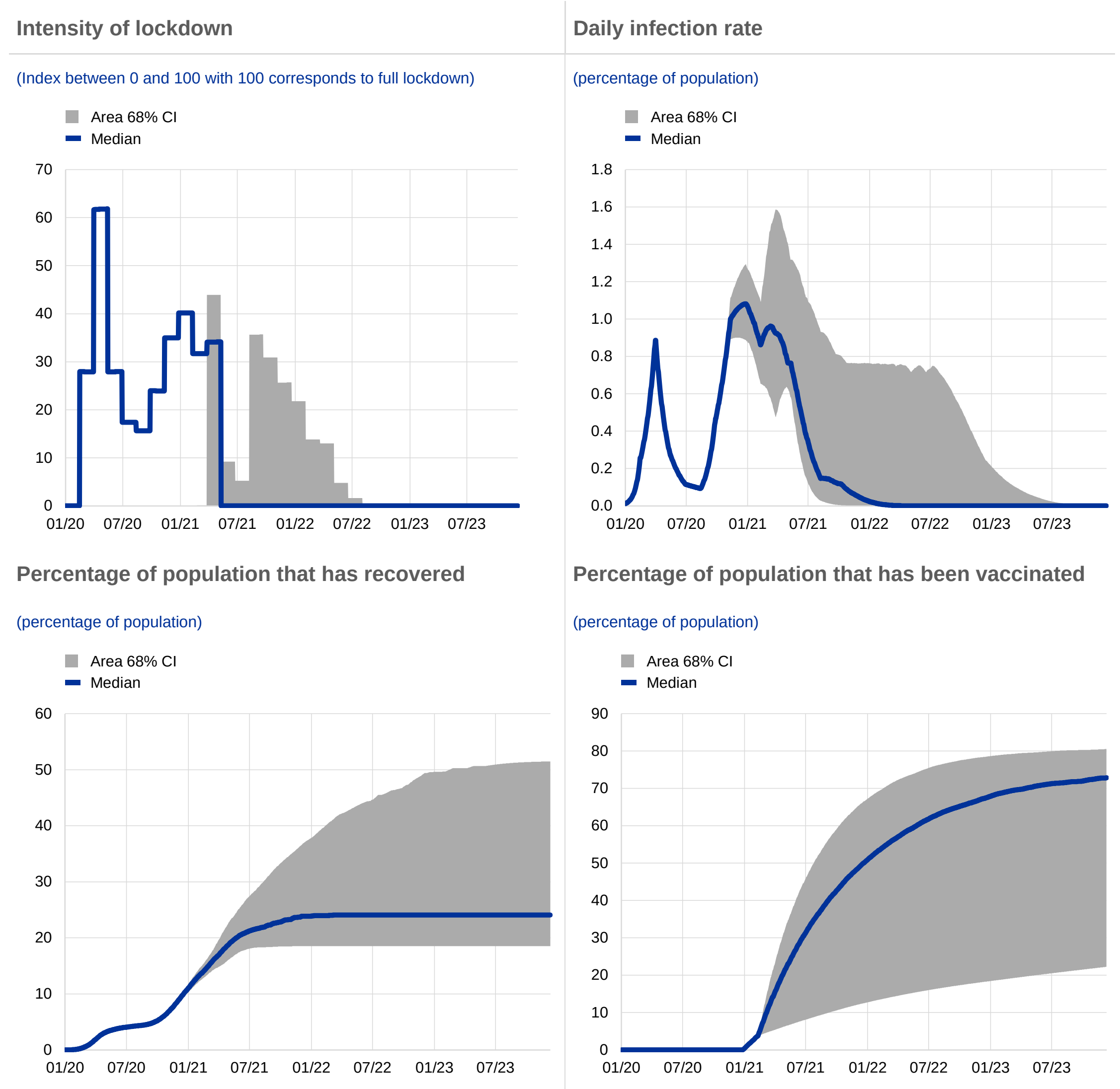
Models usually rely on historical data to capture uncertainty around forecasts. More precisely, time-series, semi-structural and structural DSGE models use historical errors and uncertainty in the estimated parameters to evaluate forecast uncertainty. However, a pandemic is an unprecedented event and therefore historical patterns can be of little use. Given that the pandemic mechanisms are absent in the structure of those models, it is not possible to estimate how parameter uncertainty will evolve.

ECB-BASIR explicitly models the development of the pandemic. It uses a mixed-frequency approach to estimate the underlying pandemic process using daily data. This makes it possible to use the uncertainty in estimates to capture the uncertainty of pandemic developments.[33] We can also use the structure of the model to design a set of probabilistic scenarios, for example considering different realistic efficiency and speed of vaccination, which can then be mapped onto the structural parameters of the model.

Chart A

Uncertainty surrounding pandemic-related developments

(y-axis: percentages; x-axis: number of days after 31 December 2019)



Source: ECB calculations.
Note: The daily infection rate indicates the percentage of the population that has the virus on a given day. Intensity of lockdown is an index ranging between 0 for no lockdown and 100 for a total lockdown.

ECB-BASIR can be used to assess a combination of economic and pandemic-related risk factors. Chart B, for example, shows a composite measure of risk density combining: (i) the standard historical uncertainty captured in the residuals of the model; (ii) uncertainty about the efficiency of

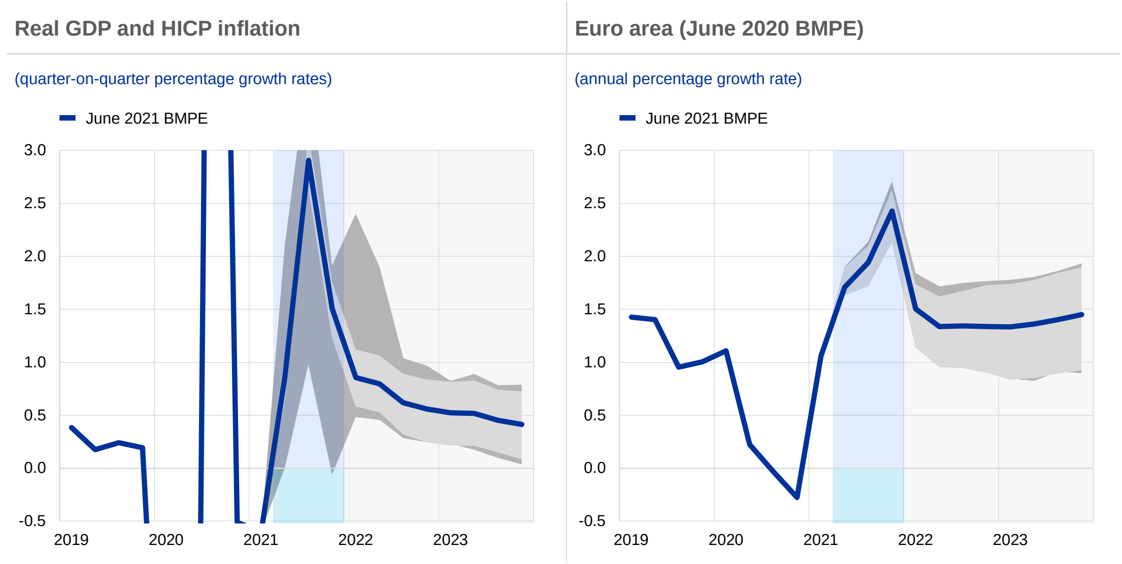
33 Currently we take parameter uncertainty from the estimated SIRQ (suspected-infected-removed-quarantined) model into account, while residual and model uncertainty is ignored.

vaccine implementation; and (iii) uncertainty about the fundamentals of the pandemic (the estimated epidemiological parameters).

The percentage of the population that will be vaccinated and the related intensity of the lockdowns are key pandemic-related risk factors. In the bottom-right panel of Chart A we can see that differences in the efficiency of implementation of vaccines result in differences in the percentage of the population that is vaccinated.

Chart B

Estimated bounds around the June BMPE forecast with ECB-BASIR



Source: ECB/NCB projections database and ECB/NCB calculations.
Notes: The grey areas represent the 68% confidence intervals from the ECB-BASE forecast and the ECB-BASIR forecast. These are centred around the June BMPE. The darker intervals correspond to ECB-BASIR. In the ECB-BASE model, the density forecast is computed using a bootstrap method that re-samples the in-sample residuals of the model. The forecast value of an endogenous variable is calculated by adding the re-sample residual to the value forecast by the model; the distribution is obtained by repeating the process 500 times.

In different stochastic simulations we draw on different vaccination rates based on realistic scenarios. For example, a more optimistic draw results in the vaccinated population exceeding 60% by summer 2021, while a negative draw might foresee the same rate as at the beginning of vaccination campaign. The exact intervals from which vaccination rates are drawn are therefore based on realistic external information. We can only follow this approach when the epidemiological model is included within the macroeconomic model, as we also have a feedback loop from macroeconomic outcomes to health outcomes.[34] Similarly, estimating the epidemiological module gives us tools to asses the uncertainty related to the evolution of the pandemic, which is also captured in Chart A. The final building block is more standard and relies on the historical residuals of the model and considers standard macroeconomic uncertainty.

This combined uncertainty results in uncertainty in the economic outcomes. Chart B shows the uncertainty bands around the baseline forecast, together with model-based forecasts. The light grey band represents the standard uncertainty obtained using historical residuals, while the dark grey area is the uncertainty that combines all three sources of uncertainty as explained above. We can draw three main conclusions from comparing confidence bands obtained using the standard

[34] As explained above, the decline in consumption and work activity will lead to fewer contacts between people and therefore reduce the probability of people getting infected.

method with those obtained considering pandemic-related risks too. First, pandemic risks are large, and therefore the uncertainty in forecasts is larger than we would estimate using just the historical observations without pandemic events. Second, the difference is particularly large in the short term, which is related to the fact that we expect pandemic risks to slowly fade away from the second half of 2021 onwards. Thirdly, pandemic risks transmit largely into uncertainty for GDP, while the uncertainty for the inflation forecast increases more moderately. This asymmetry between GDP and inflation is the consequence of the propagation mechanism of the pandemic, which has a low real-to-nominal link.

5 Assessment of model-based analysis for monetary policy preparation and scope for improvement

This section reviews the use of model-based analysis in monetary policy preparation and puts forward suggestions for possible improvements. The macroeconomic models considered in this report have been developed to serve dedicated institutional objectives and processes. Therefore they are by design fit for purpose and reflect the choices made to optimise the trade-off between academic standards and operational needs for real-time policymaking. Overall, current practices in the Eurosystem give ample scope for models to be influential in forecasting or policy analysis. At the same time, improvements can be identified to reap the full benefits of the models' capabilities, both in their current uses and for new areas of application.

We first assess the role of models in projection activities. Models are instrumental tools for shaping a quantitative economic narrative of historical developments and projections. Progress towards greater interpretative power for the main projection models would be helpful. Models have become the organising device to discipline the use of sectoral assessments and expert judgement in the projection process, whereas their use as stand-alone statistical projection tools is less mature. The use of models for fully-fledged scenario analysis is deemed appropriate, but there is room to deploy statistical models to construct model-based risk metrics that perform well, alongside the Quantitative Risk Assessment (QRA) of the ECB/Eurosystem projections which summarises staff views on risks around the baseline projection.

Model-based evaluation of monetary policy conduct is also reviewed. This could become a regular sensitivity analysis around an "enhanced" medium-term reference scenario. The segmentation of the models used for the different policy processes, notably for stance assessment or Eurosystem projections, would benefit from stronger harmonisation of simulation protocols and a comparison exercise to validate the relevant range of models deployed for this purpose. Given that the medium-term orientation of the ECB's monetary policy and current pronouncements on its instruments may extend beyond the projection horizon of the broad macroeconomic projection exercise (BMPE), the medium-term reference scenario (MTRS) might be an adequate framework for quantitatively exploring the macroeconomic implications of alternative monetary policy conduct. Model-based sensitivity analysis would be even more relevant if the MTRS were strengthened as a more realistic extension of the BMPE baseline.

Finally, considerations are brought forward on the use of country-specific and euro area-wide models across the Eurosystem. In practice, NCB projection models are country-specific and designed as a small open economy, while policy analysis tools may have a euro area-wide set-up. At the ECB, the monetary union is modelled either as a multi-country system or for the euro area as a whole, both for projection purposes and for policy analysis. Analytical strategies can be explored to use the country-specific models in a euro area-wide context too. The allocation of euro area-wide and multi-country models across policy uses could be revisited.

5.1 Model-based economic narrative: structural interpretation of macroeconomic dynamics and outlook

Current practice

Interpreting historical developments and the projection baseline in terms of structural economic drivers is a prime use for models in the monetary policy preparation process. A plausible economic narrative on the relative role of demand and supply factors or identifying impairments in the monetary policy transmission mechanism provides a basis for calibrating policy measures and appropriate communication. Similarly, a fully-fledged economic narrative for baseline projections is instrumental to improving relevance, transparency and accountability for policymakers. During the projection process, an economic narrative also helps initiate new projection rounds by providing a starting point for assessing the importance of economic developments and framing the quantitative implementation of the key judgements applied in the construction of the baseline. The usual practice in the Eurosystem is to use satellite models such as DSGE or SVAR to derive the structural shocks underlying the sample history and the projection baseline; a few countries (Finland, Latvia) use DSGE models directly to construct and interpret the baseline. These types of model make it possible to uncover structural relationships and innovations consistent with the conventional characterisation of macroeconomic shocks.[35]

As an example, the ECB's workhorse DSGE model, NAWM II, is regularly used to provide a structural interpretation of the projection baseline. Box 8 illustrates such an analysis, focusing on the December 2020 BMPE: the NAWM II structural decomposition suggests that inflation is expected to stay below the inflation target over the projection horizon, mainly on the back of weak domestic demand and international disinflationary pressures. At the same time, the COVID-19 crisis implies that supply shocks are expected to have a neutralising impact on inflation by absorbing some of the drop in activity that would otherwise be fully reflected in the slack use of resources. The economic policies embodied in government demand and monetary measures are expected to gradually drive inflation towards the target at the end of the horizon.

The use of satellite structural models to provide the narrative behind the projection baseline is also a common practice within NCBs. As an example of a case where an existing model shows itself useful in this regard, after the COVID-19

[35] Macroeconomic shocks can be defined as innovations orthogonal to other disturbances and economic developments with a meaningful economic interpretation.

shock the Bank of Spain used the Joint Spain-Euro Area model (JoSE), a DSGE model estimated with data for Spain and the rest of the euro area, to assess the relative importance of demand and supply shocks during the first two quarters of 2020, as shown in Box 9. There is a large supply-side shock caused by closing retail and many service sectors, supply-chain issues and shortages of certain goods, but according to the model its effects are smaller than those coming from the negative demand shock generated by the curfew, the fall in household income and increase in precautionary savings and delays or cancellations to investment plans. The expected effects of the crisis on future inflation crucially depend on the balance between a negative supply shock and a negative demand shock. In terms of the forecast process, using the JoSE model to assess historical developments and the projection baseline provides useful insight and assurance that current projections are plausible in the sense that the relative responses in quantities and prices are in line with the data from the initial stages of the crisis.

Purpose-built SVAR models can also provide this kind of insight. For example, Nocera and Roma (2020) recently used a Bayesian stochastic search variable selection SVAR model to investigate the heterogeneous impact of housing demand shocks on the macroeconomy and the role of house prices in monetary policy transmission across euro area countries. Their variance decomposition exercise shows that house prices play an important role in the availability of loans. They also find a significant and highly heterogeneous effect of monetary policy on house price dynamics.

Nevertheless, the commonly employed practice of using satellite structural models to provide an economic narrative behind the projection baseline does potentially come at a cost. The main rationale for employing satellite structural models alongside the main semi-structural projection models comes from the limited ability to interpret innovations in projection models (e.g. residuals) in terms of structural macroeconomic shocks. This inherently implies a break between the main projection models used for designing the baseline and the models used to interpret it. Linking assessments from satellite models to the main projection model faces several challenges, partly related to potential conceptual inconsistency between the different classes of models and mismatches between the sets of observables used in each model.

In the case of the semi-structural models used for projections, producing a structural economic narrative remains challenging. Narrative elements are often provided through partial equilibrium exercises, examining a given economic behaviour (e.g. consumption, investment, trade or labour demand) through the lens of selected equations from the large semi-structural models. For example, inflation forecasts from Phillips curve equations, which are conditional on growth projections, are often used to cross-check the inflation baseline without considering the roles of the demand and supply shocks underlying the growth outlook, potentially disregarding the general equilibrium implications of different shocks. The main projection models are also used to assess the role of conditioning assumptions in forecast error analysis, but these exercises have clear limitations: the assumptions are most commonly treated as exogenous factors in the models, ignoring their interdependence with domestic conditions. In addition, any economic interpretation of other sources of forecast errors covered by model residuals would require bringing more structure into the model.

Macroeconomic models can be usefully employed to construct counterfactual scenarios, for example to evaluate the economic impact of events such as a major crisis, by artificially replacing actual developments with alternative hypothetical assumptions (a "no crisis scenario"). This allows a better understanding of the channels by which the crisis is propagated. Box 10 provides an example of a counterfactual exercise performed using the Banca d'Italia semi-structural model to investigate the impact of the COVID-19 pandemic on the Italian economy.

Scope for improvement

The first direction for improvements, without developing new models, should aim at a better articulation between the signals from satellite structural tools and semi-structural projection models. Two types of satellite tool could support the economic narrative from semi-structural models: first, sectoral models that can interpret developments in a segment of the macroeconomic allocation, and second, DSGEs or SVARs providing a consistent structural perspective on growth and inflation. Articulation with sectoral models often brings some structural perspective to variables usually treated as exogenous in projection models (e.g. the oil price, the exchange rate, financing conditions). The emphasis should be on connecting the structural drivers most closely linked to euro area domestic developments with the innovations in semi-structural models: for example, if long-term interest rates are interpreted by satellite tools as stemming from better real macroeconomic news in the euro area, this assessment should be compared to the conditional forecast errors in the semi-structural projection model, in particular innovations in the demand equations. Turning to articulation with satellite DSGE or SVAR models, evaluation from these tools could either inform the projection models of the relevance of missing channels (e.g. the role of credit supply factors), or hint at specific disturbances they do not cover (e.g. temporary productivity shocks that may be reflected in price and wage setting, labour demand residuals or potential output).

Steps can be taken to strengthen the structural underpinning of the main semi-structural projection models. Typically, these are not estimated using full information methods or system-wide inference strategies. Therefore innovations, or residuals, from the estimated behavioural equations in a model should not be interpreted as structural shocks. In practice, those models display a large set of residuals with significant cross-correlations. Bringing more structure to the model could be achieved by aiming to "summarise" these residuals into a small number of structural sources of cyclical fluctuation (e.g. product market demand and supply shocks, labour demand, supply shocks, financial shocks). One strategy could be to impose a small-scale factor-model structure to shrink the information content from the covariance matrix of the residuals. Time-series identification techniques could then be employed to orthogonalise and provide a structural interpretation of the factors within such an auxiliary model. This is currently being explored in the ECB-BASE model.

Addressing the challenges posed by the endogeneity of forecast assumptions in semi-structural projection models would enhance their use for developing an economic narrative and assessing forecast errors. In most cases, some of the forecast assumptions are also exogenous variables. Let us assume first that those exogenous variables meet a weak-exogeneity econometric criterion to the rest of the model (i.e. they have no further contemporaneous information content for the residuals). Even in this case, changes in financing conditions, global trade or commodity prices may respond to common drivers across the global economy. One could therefore aim to endogenise the international environment in projection models to account for global real, nominal and financial factors. This would imply that the apparent macroeconomic elasticities to a given assumption become sensitive to its structural driver: for example, transmission of higher global activity to the euro area in a "demand-like" scenario would be associated with global inflationary pressures, including higher commodity prices and tighter international financing conditions.

In practice, however, forecast assumptions may not be weakly exogenous and can be correlated with the residuals in a projection model. These correlations may reflect genuine empirical features of the macroeconomic landscape, like global sentiment shocks affecting both the euro area and the rest of the global economy. They may also mask model mis-specifications, possibly stemming from missing macroeconomic propagation channels. Taking the example of the yield curve, treating forecast assumptions on interest rates as exogenous variables condemns projection models to a negative correlation with real GDP, for example, which is counterfactual to unconditional historical regularities (not least due to the presence of demand shocks). Advanced modelling of the yield curve within semi-structural projection models (for the euro area at least) would therefore be worth pursuing. This is part of the ECB-BASE development workplan.

A model comparison exercise analysing forecast errors on an annual/biennial frequency would be instructive for fostering consensus around an economic narrative. Model-based decompositions of forecast errors are clearly model-specific, but common features can be extracted from a meta-analysis across a wide range of models.

5.2 Model-based projections

Current practice

"Judgement-free" model-based projections are not explicitly reported in the forecast process, in part due to the elusive conceptual basis for disentangling the degree of expert judgement underlying the baseline projections. From an econometric standpoint, one may define model-based projections as a statistical object corresponding to the conditional forecast of the projection model with a varying conditioning set (e.g. assumptions, incoming data). However, in practice projection models operate more as an organising and disciplining device for bringing together findings from dedicated satellite tools such as high frequency short-term forecasting models, sectoral models and long-term supply-side models. Experts intervene in a range of features, mainly bringing external sources of information to the main projection model. More generally, any interventions in model properties or simulation procedures could also be interpreted as judgement.

In the institutional projection process a qualitative narrative therefore aims to distil the key judgements underlying the baseline projections, which in practice rely on a wide range of quantitative judgemental interventions. A regular exercise consists of decomposing revisions in the projection baseline both for the euro area and its member states into the impact of new assumptions, the carry-over of incoming data and an “other” category which might proxy in a crude way the role of expert judgement. By contrast, the use of satellite models and alternative quantitative tools forms the basis for judgemental interventions implemented in country-specific models in constructing the baseline.

Scope for improvement

Some practical concept of model-based projections might still be explored, by analogy with statistical concepts from the academic forecasting literature. These would raise the technical accountability of the baseline projections, providing a basis for extracting model-specific “implicit” judgement. They could also be incorporated in regular reviews of model properties. As an example, the ECB regularly produces purely model-based projections. Box 11 takes the example of ECB-BASE to illustrate the simulation protocol underlying model-based projection updates and model-based conditional forecasts.

Model-based projections may indirectly provide an organising framework for mapping judgemental interventions in model simulations and ultimately delivering the baseline numbers. They can be seen as a sequence of simulations that process assumptions, incoming data, short-term forecasting information and long-term anchors. At each step, some judgement may be applied on the basis of external information or to alter a given property of the projection model. Key judgements in the construction of the baseline can also be articulated through “scenario-type” interventions, possibly quantified using a satellite model (e.g. adding judgement to reflect the anticipation effects of an announced VAT increase in a backward projection model). These best practices are followed to varying extents by forecast teams across the Eurosystem.

It would be beneficial to harmonise the conceptual framework for constructing strictly model-based projections and measures of “implicit” judgement. The availability of purely model-based projections would improve interpretation of the baseline, in particular when applied to the specific models used to build the baseline. Clear concepts of model-based projections would also provide a sound basis for other models to cross-check the baseline projections. As an illustration, and taking the analytical protocol described in Box 11 as an example, purely model-based projections could fall into two categories:

- model-based projection updates (shown more regularly in the projection process), which would start from the previous baseline, including previous judgement, and update it with (i) the impact of changes in assumptions, (ii) news from incoming data and short-term forecasts, and (iii) changes in other quantitative conditioning factors;
- conditional strictly model-based forecasts, which would get closer to a stand-alone model-based forecast conditional on (i) assumptions, (ii) incoming data and short-term forecasts, and (iii) other quantitative conditioning factors.

It is worth reviewing strictly model-based projections as part of a more general model validation and maintenance protocol. Ultimately, as strictly model-based projections become more harmonised across the Eurosystem and more appreciated as effective diagnosis tools for constructing the baseline, they could feature more prominently in the policy process.

5.3 Model-based risk analysis

Current practice

The risk assessment around the (B)MPE baseline is not derived from a statistical model. Instead, staff provide subjective probability distributions around the baseline, which are structured and reported in the QRA. The main modelling input to the risk analysis is therefore organised through sensitivity analysis or scenarios. Event-based risk analysis consists of elaborating fully-fledged scenario analysis of selected macroeconomic contingencies. These contingencies are qualified using an analytically tractable structural narrative that makes it possible to configure a clear simulation roadmap. The scenario is performed through one or a range of models, exploiting cross-functional expertise for calibration design in particular.

Scope for improvement

A range of empirical models are available or could be developed to provide forecast uncertainty and balance of risk. Statistical risk metrics can be derived from the predictive densities of the suite of dedicated macroeconometric models.

Projection models could be extended to generate density forecasts or uncertainty bands around the projection baseline. Main projection models can be expected to provide uncertainty ranges around their point forecast and possibly fully-fledged conditional or unconditional predictive densities. Box 12 illustrates this using the density forecast from ECB-BASE, describing the associated bootstrapping strategy.

Partially as a result of the failure to adequately evaluate risks before the global financial crisis, increased attention has been paid in recent years to models that can provide a better quantification of the uncertainty surrounding economic forecasts. Traditional forecasting models like VAR can provide a full predictive density, but this is generally a by-product; their main concern is usually the point forecast. Models such as quantile regressions are developed and estimated specifically to assess risks and uncertainty, as their focus of interest is not the mean or median, but other quantiles of the distribution. Many central banks in the Eurosystem have developed this kind of model or are currently working on them. For example, Chavleishvili and Manganelli (2020) show how to estimate and forecast multivariate quantiles within a recursive structural system, estimating a model with real and financial variables that displays different dynamic properties across quantiles. This is relevant both in a forecasting framework and for stress testing exercises, where the goal is to forecast the tail behaviour of the economy when hit by large financial and real shocks.

Working with probability densities instead of point forecasts makes many types of analysis more complicated, and the literature has recently worked on tackling these issues. For example, forecasts can be combined, both by making several models work together to produce a single density forecast, and by mixing distributional information from survey-based risk metrics into model forecasts. All of this requires more sophisticated methods than when working with point forecasts only. Ganics and Odendahl (2019) use both entropic tilting and soft conditioning to input the distributional information from the ECB's Survey of Professional Forecasters into a BVAR model and show how this improves both the point and density forecasts from the model. Box 13 also illustrates methods to obtain risk measures from multivariate density forecasts: following Odendahl (2020), it proposes estimating joint density forecasts on the basis of univariate density forecasts available from surveys and copula functions.

Overall, developing, selecting and validating a set of time-series models delivering full predictive densities appears warranted. Model combination techniques that make it possible to construct a consistent statistical distribution around the baseline and other synthetic risk indicators are also worth exploring. An example of this sort of use of combination techniques is illustrated in Box 14.

Where there are large shocks, Knightian uncertainty or a multi-modal risk profile, scenario analysis could become the main avenue for risk analysis. The pandemic scenarios introduced since the June 2020 BMPE are good examples of this when the use of statistical risk metrics is technically challenging due to unprecedented shocks. Box 15 provides an illustration, focusing on the pandemic scenarios produced by the Deutsche Bundesbank for the June 2020 BMPE.

5.4 Model-based monetary policy evaluation

Current practice

Model-based monetary policy evaluation can vary across different policy processes, simulation designs and types of model. Macroeconomic models are used to assess the impact of monetary policy decisions in various contexts. The set of models and type of model-based analysis used for economic projections or stance and impact assessment are not necessarily always the same. As baseline projections are conditional on financial assumptions, the impact of measures on inflation and output in Eurosystem countries relies on the sensitivity to these assumptions of the country models used by NCBs and the ECB for BMPE and MPE exercises respectively. By contrast, in the context of the monetary analysis the impact of monetary policy decisions is regularly assessed using an alternative suite of models that are not necessarily run under the same procedures as in the projection process. The differences are further compounded by the fact that the large semi-structural models mostly used for projection purposes tend to show substantially lower effects of monetary policy measures than structural models.

In the context of monetary analysis, the impact of monetary policy decisions is quantified through a suite of models: a set of satellite models from the Eurosystem, a BVAR model (Rostagno et al., 2019), NAWM II and ECB-BASE. These types of quantification may nevertheless treat the assessments from the projection models used by the NCBs and other assessments homogenously. The model-based input is also used to calibrate monetary policy, mainly based on the average elasticities of the suite of models. While in principle the heterogeneity in the model simulations underscores the high uncertainty of this calibration procedure, the difference between the elasticities chosen to calibrate the program and the one used for projections creates a specific need for harmonisation.

The largest difference between assessments from the suite of models deployed in the context of monetary analysis and those from projection models seems to come from the different conceptual design between DSGE models and semi-structural models. The upper range of assessments in the suite of models mainly come from DSGE models while the lower range of assessments is generally given by semi-structural projection models. These two types of models come from two different modelling traditions. Recent developments have brought both families of models closer together, notably through alternative expectations formation processes (with more forward-looking semi-structural models and a learning mechanism in DSGE models), and wider incorporation of financial frictions. Nonetheless, one should not aim to excessively harmonise the properties of alternative model classes, and differences are expected to remain across modelling approaches. Consequently, ensuring an appropriate degree of robustness in model-based input to the policy process and avoiding segmentation of model types into specific uses seems warranted.

As illustrated in Box 16, in the case of France the impact of forward guidance policies as seen through the lens of several DSGE models can differ significantly compared to using a semi-structural model (FR-BDF). These differences are sensitive to several modelling features that deserve specific attention. On the DSGE side, estimating key parameters like the intertemporal elasticity of substitution (instead of calibrating it) and allowing a finite planning horizon strongly reduce the impact of this policy and its convexity with respect to length. The importance of estimating intertemporal elasticity (and relaxing the log-utility assumption) concerns not just the stylised models considered in Box 16, but also some of the large estimated DSGE models used in the policy process.[36]

On the semi-structural side, some models used for projections do not make the role of expectations explicit or lack the relevant financial frictions, which makes it difficult to use them to analyse monetary policy transmission. Some projection models follow the FRB/US approach and get closer to DSGE models by making the role of expectations explicit, but allow deviation from model-consistent expectations by using VAR-based or hybrid expectations too. Other projection models, like BIQM at Banca d'Italia, incorporate a role for expectations by including statistical indicators of inflation expectations from surveys or market sources in some equations. Even with such set-ups, sensitivity to standard and non-standard monetary policy may be underestimated in some of these models because it is possible not all relevant propagation mechanisms are properly accounted for.

The exchange rate also matters for improving the consistency of the assessments produced. While all projection models at NCBs are (small) open-economy models and take the macroeconomic impact of policies related to the exchange rate into account, some in the suite of models are closed-economy type and hence take the impact of standard and non-standard policies into account through interest rates and credit volumes only, not through this external channel.

Divergences between assessments could in some cases also come from discrepancies related to the impact of policies on financial assumptions more than the sensitivity of output and inflation to these assumptions. Assessments based on projection models always follow an indirect approach, where macroeconomic assessments are conditioned on a common assessment of the impact of policies on financial assumptions.[37] However, many DSGE models follow a direct approach, where the impact of balance sheet purchases on long-term yields and macroeconomic variables, for example, are assessed jointly by the model itself. Hence one way to avoid this source of inconsistency could be to make the indirect approach the standard.

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36 For example, in NAWM II this specific parameter is calibrated to one to ensure a balanced growth path, around which the model is log-linearised. Although it does not fully constrain the sensitivity of consumption to the real rate, which also depends on the degree of habit, such a constraint could bias this sensitivity upward. As shown by An and Schorfheide (2007) and Chen, Curdia and Ferrero (2012), relating the utility of households to their consumption relative to the technology level can ensure a balanced growth path without relying on this parameter constraint. A balanced growth path can also be secured with lower intertemporal elasticity by relaxing the assumption of additive separability between consumption and labour, as done for example in Smets and Wouters (2007).

37 The impact of asset purchases on term premia and exchange rates are based on Eser et al. (2019) and Dedola et al. (2020) respectively.

A further way to analyse these model differences would be to rely on ex post historical decompositions. For example, models that show a larger sensitivity of inflation to non-standard monetary policy measures since 2014 should explain the shortfall in inflation during this period by a larger impact from negative shocks or extra negative shocks compared to other models. An overall assessment of the underlying monetary and non-monetary shocks in each model would help in understanding their economic narratives and checking how plausible these are.

Scope for improvement

The influence of models in monetary policy preparation could be strengthened by more consistent deployment and articulation across the various policy processes. Higher consistency across models would not mean they all converge on a single assessment of the impact of monetary policy. Heterogeneity is also the result of high uncertainty around assessments and should be used to inform policymakers. Indeed, the monetary policy preparation process requires robust model-based analysis. This robustness should be achieved across model types and layers of structural uncertainty (e.g. regarding unobservable factors like the output gap, the natural rate of interest, the shadow interest rate capturing the monetary policy stance, etc.).

Improvements in the use of macroeconomic models for monetary policy evaluation largely hinge on adapting the projection and policy analysis models in line with the recommendations put forward in Section 3.

The academic literature has relatively clear prescriptions in this respect. The approaches that have been put forward in the DSGE literature to address the forward guidance puzzle fall broadly into three categories, depending on which area of the model is affected by the relaxation: (i) introducing stronger discounting of the future than in the standard model; (ii) introducing a consumption wealth effect from government bonds; and (iii) relaxing the assumptions of full credibility and rational expectations. With respect to semi-structural models, Kiley and Roberts (2017) show that FRB/US does not feature the strong power of forward guidance obtained with a standard DSGE model (from Lindé, Smets and Wouters, 2016). The role of quantitative easing has also been embedded in the FRB/US framework for example in Bernanke (2020), where, combined with forward guidance, it is possible to offset the zero lower bound when the neutral nominal interest rate is in the range of 2 to 3 percent.

Progress made within the Eurosystem and other policy institution also provides relevant guidance on the adaptations needed to the main models. With respect to the role of expectations in DSGE models, there have been advances along two dimensions. First, it has been shown how the effect of forward guidance in the Eurosystem models can become more realistic (less powerful) when the inattentiveness of a substantial share of households is taken into account. This inattentiveness approach would be better suited to large-scale DSGE models than the other approaches proposed in the academic literature, and helps align the results from DSGE models with more empirical estimates. The Eurosystem has also made an effort to modify different models used in the different institutions to relax the assumption of full-information rational expectations. As there is not yet a consensus in the literature on how agents form their expectations, it is important to evaluate model-based prescriptions under different assumptions about the expectations formation process. Changing these implies different impacts in the transmission of monetary policy, letting policymakers evaluate different alternatives under a robust approach that makes it possible to understand a variety of outcomes.

With respect to the explicit role of expectations in semi-structural models, the FRB/US approach has been followed in ECB-BASE and FR-BDF. This means that those models can be run both under VAR-based as well as model-consistent expectations, or a combination of both (whereby some agents in the model would form VAR-based expectations whereas others would have model-consistent expectations). Concerning the role of financial frictions in semi-structural models, ECB-BASE includes them in a reduced-form way by relating several risk premia to the expected output gap, used as a proxy for the probability of default. This shows that allowing for such frictions at the euro area level creates strong amplification, particularly on the real side. As shown in Figure D.5 of Angelini et al. (2020), after a 100 bps increase in the monetary policy rate the peak response of GDP is far smaller when financial propagation is shut down (-0.2 instead of -0.5). On the nominal side, the amplification stemming from the financial side is less impressive (-0.3 in this exercise, instead of -0.35 in the baseline set-up).

Leveraging further developments to the main macroeconomic models, one important direction for improvement would be to aim at ensuring more consistency between impact studies of monetary policy decisions and projection revisions. Analysing and validating heterogeneity in the transmission of monetary policy across different model classes is warranted. The main objective would be to narrow down model heterogeneity to its relevant and empirically supported dimensions. Several operational steps might be considered:

- First, launch a review of the suite of models used in the impact studies in the monetary analysis to: (i) ensure they are immune to the forward guidance puzzle by taking into account, for example, households' short-sightedness or inattentiveness (the type of extension implemented in models in the FORE report); (ii) review the calibration or estimation strategy for key parameters for the monetary policy transmission mechanism, to reinforce their empirical support; (iii) check these all take the exchange rate channel into account; and (iv) confirm they are consistent with the impact of policies on the financial assumptions in the projections.
- Second, encourage a review and benchmarking of the main projection models to evaluate the needs for enhancing: (i) the specification of the monetary policy transmission mechanism and the role of financial frictions; (ii) the simulation procedures for monetary policy interventions; and (iii) the articulation with dedicated satellite models.

- Third, provide an analysis of remaining differences within the suite of models (including projection models) with respect to assessments of monetary policy transmission. This would require identifying the key channels that play a quantitative role in discrepancies between these assessments and trying to understand the sources of these (e.g. whether they are related to estimation methodology or theoretical specification). The benefits of this analysis would be to provide policymakers with an improved understanding of the sources of model-based uncertainty.

5.5 Enhanced medium-term reference scenarios

Current practice

In the Eurosystem, a medium-term reference scenario (MTRS) is a scenario for economic activity and inflation that extends the BMPE baseline five years into the future. The MTRS is created for the euro area economy only, and country-specific projections are not available. The main tool for building the scenario is NAWM II. The MTRS is conditioned on potential output growth estimates by NCB experts. Additional conditioning assumptions over the extended projection horizon include changes in government consumption and the euro area's external environment, the latter normally based on IMF projections. Box 17 summarises the analytical design of the MTRS and clarifies the assumptions and conditioning factors. Overall, the MTRS is used to illustrate how shocks that hit the euro area economy in the short run unwind in the medium run. The speed at which the output gap closes and inflation returns to its target level is shown. The MTRS largely reflects the mean-reversion properties of the model used to build it. Consequently, updates to the MTRS rarely result in new messages. Given this, one could consider improving it and developing an enhanced medium-term reference scenario with the aim of improving its impact and relevance in the policy process.

Medium- and long-term macroeconomic projections and scenarios are in limited supply. The OECD (2018) and European Commission (2012) occasionally publish very long-term projections for GDP growth. These projections focus on the supply side of the economy, normally using a production-function approach. The projections are based on trends in, for example, demographics, technology and capital. Claire et al. (2020) built climate change scenarios to project GDP growth 50 to 100 years out. In this case, only the supply side of the economy is modelled, and the demand side and nominal side are missing. These examples indicate that building a model-based medium-term scenario that goes beyond the supply side can be a very ambitious task.

Scope for improvement

To achieve more prominence in the policy process, the MTRS could be enhanced towards a fully-fledged model-based medium-term extension of the euro area baseline, leveraging Eurosystem expertise across selected dimensions.

Including policy areas other than monetary policy in the modelling framework could be an important step towards making the MTRS more relevant and possibly generating new policy insights. In the current framework, pressing policy issues such as labour market policies, goods markets reforms, fiscal policy, stability of government debt, macroprudential policy, heterogeneity, distributional aspects of policies and policies related to climate change are dealt with only implicitly or not at all.

In addition, the MTRS should ideally be better related to the assessment of long-run trends, more specifically the supply-side determinants of product and labour markets. The associated macroeconomic propagation channels may have to be added, especially when considered relevant for the policy conduct.

Experimenting with different mechanisms for expectations formation might also be of interest. In fact, any of the analytical gaps identified in Section 4 could be addressed in an MTRS.

Medium-term reference scenarios are currently developed for the euro area as a whole. Switching to a BMPE-style bottom-up approach appears infeasible and is not recommended. NCB resources are limited. Also, the BMPE timetable is already tight and offers little room for iterations of medium-term scenarios. Nonetheless, NCB involvement could be stepped up by including additional country-specific elements in the medium-term scenarios that go beyond potential output. The scenarios could stimulate sharing information on country-specific long-term real anchors to be included in the MTRS for the euro area. Exchange of information on long-term anchors may also encourage NCBs to study the long-term convergence properties of the main projection models.

Moving from a single reference medium-term scenario to a set of medium-term scenarios could also be considered. An important feature of the current MTRS is that it is fully model-based and the output of a single model only. Given the current frequency of the exercise (every three months), changing this practice is not appealing and therefore not recommended. However, addressing all analytical gaps or including all policy areas in one modelling framework is practically impossible. This argues in favour of addressing one or two issues at a time using an extended core model (e.g. NAWM II) with a limited number of additional features. A drawback of this approach is that singling out a specific medium-term scenario as the reference, i.e. a scenario with clear properties that one can always refer to, may not be fully relevant because the outcome of this scenario will differ depending on the version of the model used to construct it. Instead, one could aim to build a portfolio of medium-term baseline extensions from different euro area-wide models (ECB-BASE, for example) that tackle different policy issues, underlining the point that projections are inherently uncertain, and medium-term scenarios even more so.

Alternatively, or as a complement, a specific medium-term extension of the baseline could be accompanied by a regular sensitivity analysis exploring several dimensions:

- the long-term real anchors of the projections;
- the expectations formation process;
- monetary policy conduct, considering endogenous policy scenarios: Box 17 explores the analytical roadmap for producing a model-based sensitivity analysis of monetary policy conduct and provides some illustrative simulations using NAWM II;
- fiscal and financial policies, considering alternative fiscal rules and supervisory and macroprudential intervention.

5.6 Articulating country-specific and euro area-wide model-based analysis

The focus of this section is on the main projection models, primarily those dealing with the larger countries, which technically cannot be represented as a small open economy within a monetary union.

Current practice

A major challenge for model-based analysis in the Eurosystem is the combination of (or sometimes the trade-off between) a more country-specific perspective and the focus on the euro area aggregate. The aggregate is of course much more important for monetary policy decision-making than the individual country perspective. Nevertheless, country-specific characteristics must also be taken into account. For this reason, model-based analysis should not neglect heterogeneities among countries.

One of the reasons for breaking down modelling efforts and approaches to the national level is related to the sovereignty of the individual member states over their economic policy. This is particularly evident in exceptional times like the current situation, where an important role is attributed to economic policy measures in individual countries. These are much more targeted and very heterogeneous in nature, scope and effect due to the different structures and levels of vulnerability of the individual countries. Very specific and detailed information must be available; experts from national institutions and central banks are more likely to have access to this than the ECB. Therefore, models with a national focus are mainly deployed in the NCBs, while the ECB naturally puts much more emphasis on the aggregate.

However, the type of model used in the analysis, more country-specific or more aggregate-based, depends on the issue to be analysed.

The articulation of country-specific models with euro area-wide models is particularly challenging for the BMPE. For baseline projection activities, NCBs produce forecasts using their own models for the individual member countries, while the trade consistency exercise (TCE) offers a timely update of the individual projections associated with intra-euro area trade.[38] The ECB then computes the euro area aggregates from the national projections and, as a cross check, uses its own models for the euro area and the largest member states. Apart from the efficiency of the whole process and the effectiveness of stepwise iterations to mimic the multi-country macroeconomic propagation mechanism within the euro area, the challenge is to maintain the consistency of the common economic narrative. Not only can the individual models differ in structure, the focus on national economies can also lead to different implications for the aggregate level than those originally laid out in the common narrative for the euro area.

One illustration of such dissonance between top-down and bottom-up modelling of the euro area is the issue of the long-term nominal anchors of the projection models. The main challenge arises from the fact that the country-specific models differ in terms of their medium-to-long-term inflation rates, which in the models used for the BMPE are generally based on country-specific long-term averages. As these have declined in some countries since the financial crisis and not increased accordingly in others (such as Germany), there may be a deviation from the aggregate inflation target. As a result, a persistent inflation gap may arise even when the output gap is closed. This could be interpreted as indicating a need for monetary policy action, even though the output gap is closed and the euro area economy is actually in equilibrium.

Scope for improvements

The goal of this section is not to assess the BMPE process itself, but discusses complementary approaches which might help deal with the challenge described in a more model-based environment while keeping the projection process as it is. For this purpose, three options are discussed.

The first option, perhaps the most sophisticated but also the most technically and institutionally challenging, would be to develop a multi-country model of the euro area consistent with the main country-specific projection models. The ECB has developed ECB-MC, which exactly serves the purpose of taking the multi-country dimension, i.e. heterogeneity and interdependency among countries, into account in the forecasting procedure. ECB-BASE, a model for the euro area aggregate, is also available; this features the same model structure and characteristics, and can provide a reliable consistency check. For individual NCBs this option would probably not be very relevant and come at a very high cost. Establishing and maintaining such a comprehensive set of models is very resource-

[38] For more details on the TCE see Hubrich and Karlsson (2010).

intensive.[39] A first step could be to have all country-specific models from NCBs integrated into a unified modelling framework for the euro area, but the computational tractability and other hurdles for such an endeavour would be unmanageable.

The second option involves articulating a satellite multi-country model with the main country-specific projection model. The satellite multi-country model would be used as a cross-check by means of counterfactual simulations or shock decompositions and would enhance the narrative from the main projection model. In addition to the respective country bloc, the model should ideally contain (at least) a second bloc representing the rest of the euro area to allow for mutual interaction between the two blocs within the common model framework. While the majority of main forecasting models are semi-structural, DSGE models are often used for policy simulations around the baseline, and they can also provide additional information (e.g. in terms of shock decomposition) for constructing and interpreting the baseline. Some NCBs operate with similar tools to combine their individual country and the rest of the euro area perspective. The Deutsche Bundesbank has recently used its three-region DSGE model for internal purposes and on a preliminary basis to interpret the projection baseline through the lens of a cross-check macroeconomic model. The same applies for Banco de España with the interactions between its main projection model for the Spanish economy, MTBE, and the multi-county DSGE model JoSE. This option would allow more flexibility for NCBs and also support the idea of having greater model diversity in the portfolio.

Articulation between a satellite multi-country DSGE model and the main country-specific model would still pose significant operational challenges. Several aspects have to be kept in mind. First, DSGE models are mainly used to analyse deviations from the steady state, which depend on deep parameters that are sometimes not estimated but calibrated. This characteristic can be crucial for the projection. Second, to maintain a common narrative it may not be sufficient just to have a rest-of-the-euro area block in the model, because there is no guarantee that the rest-of-the-euro area blocks individually specified by each NCB will yield the same (or at least a similar) outcome as the corresponding aggregates in the country forecasts. Third, the lessons and dynamics learned from the cross-check model would have to be implemented in the forecasting model. This might need to be done using additional judgement, given that the forecasting and cross-check models can exhibit different features, implying differences in the transmission of shocks. This is exemplified by different levels of aggregation in the models. While the cross-check model might only display aggregate investment, for instance, the forecasting model differentiates between its components. Hence, when adjusting the aggregate investment path, specific reflection on the allocation between constituents is needed.

The third option would consist of extending the country-specific projection models towards a multi-country model of the euro area. The basic idea would be to have a unitary but sufficiently flexible model extension to the NCB-specific main forecasting models such that each individual country model could be augmented with

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39 The Deutsche Bundesbank used to maintain a large multi-country model (see Deutsche Bundesbank, 2000), but discontinued it when the harmonised projection exercises in the Eurosystem started in 2004.

a corresponding rest-of-the-euro area block that would in operation and outcomes represent the main features of an aggregate of the respective NCBs national models. Some degree of harmonisation could be obtained through a common theoretical specification of this block, adapting its estimation to the rest-of-the euro area dataset associated with each jurisdiction-specific model. Flexibility might also be relevant in the way the additional block is connected to the core national model. The natural candidates are the trade equations, which would need to allow for differentiation between intra- and extra-euro area trade. One could also consider additional transmission channels via financial market linkages, for instance.

However, constructing such a uniform model block requires broad agreement about its structure and an appropriate way to estimate or derive the model elasticities. One could think of using the BMEs as common ground to start with, since they provide helpful information about the quantitative dynamics behind each individual country model applied in the projections, given shocks in a largely harmonised set-up. For instance, depending on the country composition, a weighted average of the relevant BMEs could yield an estimate of the most important model coefficients. Given that BMEs represent linear approximations of the country-specific models used in the projection process, this could also help improve consistency between individual forecasts by NCBs. Building a coherent model extension would require collaboration between the ECB and NCBs and could promote a more model-based way of establishing a common economic narrative in the projection exercise while maintaining the flexibility of individual country-specific modelling approaches.

The Banque de France has recently developed an extension of this sort to its semi-structural model (FR-BDF), representing a valuable example of how to augment the main projection models with a bloc that reflects the rest of the euro area (see Box 19). Having such a tool available may allow NCBs to anticipate euro area feedback effects at an earlier stage in the iterative projection process. It may also promote a focus on the euro area narrative and more targeted and efficient implementation of corresponding action points agreed in the Working Group on Forecasting. The tool could also incorporate an endogenous monetary policy and be used for applications beyond pure forecasting. It would therefore help align projection models with the tools typically used for stance evaluation. The former could then also be applied more extensively to assess monetary policy effects, facilitating the quantification of their contribution to the projection baseline. Finally, the country-specific forecasting models would still be under the full control of each NCB. This notwithstanding, the feasibility and practical issues of this model-based approach would need to be further investigated, looking at both development and possible application in the projection process.

Box 8
A structural analysis of euro area macroeconomic dynamics through the lens of NAWM II

One of the most widespread uses of DSGE models is structural analysis of observed data by shock decomposition. Compared to semi-structural or purely empirical models, they identify deviations from model expected values as structural shocks,[40] taking full advantage of the general equilibrium perspective. This use of DSGE models extends to the forecasting framework by treating the full sample, including the forecast period, as observed data, i.e. it is an ex post approach once the forecast has been made.[41] This makes it possible to build narratives based on the forecast and identify inconsistencies in its construction, making use of the general equilibrium features of the model.

Filtering out the contribution of structural shocks to macroeconomic observables is a typical use of estimated DSGE models

In this box we present the NAWM II shock decomposition of the Eurosystem December 2020 projection exercise.[42] NAWM II is the main area-wide DSGE model at the ECB, and it extends the Smets and Wouters framework by including external and banking sectors (see Coenen et al., 2018). The model features 24 orthogonal shocks, which makes analysis of the raw results from the model very challenging for the average reader. Shocks are therefore grouped into categories with a more immediate interpretation, as follows: (i) “interest rate shocks”, comprising shocks which mainly explain the short-term interest rate (monetary policy shock), the long-term interest rate (shock to banks’ survival rate) and the lending rate (shock to retail banks’ markdown); (ii) “foreign and trade”, covering shocks to foreign demand, foreign prices, US three-month and ten-year interest rates, competitor export prices, oil prices, import demand, export preferences, mark-up shocks to export and import prices and a foreign risk-premium shock; (iii) “domestic demand”, including domestic risk premium shocks and shocks to government spending; (iv) “domestic supply”, comprising supply shocks, namely transitory and permanent technology shocks, and wage and price mark-ups; and (v) “other”, includes measurement errors and residuals from bridge equations.

Real growth dynamics

Focusing on the results of the decomposition, the GDP profile in 2020 has been marked by the impact of the pandemic, declining in the first and second quarters of 2020 but rebounding in the third (see Chart A). The model interprets the weakening in real economic activity as being mainly driven by adverse domestic supply-side and demand-side effects. The domestic demand-side shocks mainly reflect a fall in domestic consumption following the introduction of confinement measures across the euro area to tackle the spread of the virus, implying “forced saving”. A steep fall in foreign demand owing to the global dimension of the crisis contributed to the contraction in euro area output. GDP recovered in the third quarter of 2020, mainly driven by domestic demand-side factors as consumption rose and, to a lesser extent, by a positive impact from the external sector. Over the rest of the projection horizon supply-side factors remain contractionary, but only slightly.

Inflation

Domestic and foreign demand-side effects and, to a lesser extent, pressures from shocks to interest rates, which drove GDP growth down in 2020, were the main factors behind the fall in euro area HICP inflation in the first half of 2020 (see Chart A). This reflects the fact that firms tend to lower

40 Given this approach, there are infinite combinations of shocks that would explain the observed data; the combination that is chosen is the one that maximises the likelihood of the data given the model.

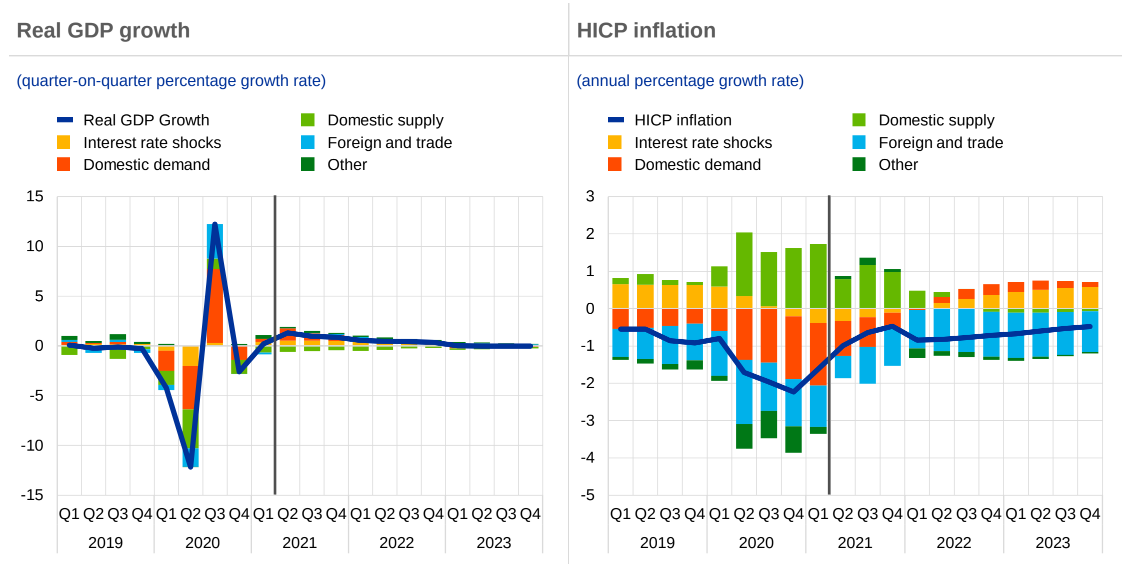
41 Given the use of the Kalman smoother in the computation of the shocks, forecast data may affect the shocks in non-forecast periods.

42 See December 2020 BMPE report.

prices in response to lower demand. Supply-side effects, however, prevented inflation from falling even further. On the supply side, the drivers of the fall in GDP growth were a combination of adverse effects on factor productivity and direct pricing decisions by firms. Shocks related to the former have, however, relatively minor consequences for inflation dynamics. Through the lens of the model, firms tried to stabilise profits by leaving prices largely unchanged, facing extra non-labour-related costs to adapt to the new requirements of doing business during a pandemic, while weaker demand would have indicated an even stronger fall in inflation. On balance, these domestic supply-side factors largely offset the downward pressure from weaker domestic demand and mitigated the pass-through from the real side to the nominal side of the economy. Inflation is expected to return to its pre-crisis level in the course of 2021, with a diminishing negative contribution from demand shocks. In 2022 and 2023 the model sees a very muted contribution from the supply side, while demand factors are estimated to contribute positively to inflation throughout the period.

Chart A

Structural shock decomposition of the December 2020 BMPE baseline for growth and inflation



Source: NAWM II.

Box 9

Euro area inflation projections through the lens of models

Inflation projections are a key input for monetary policy decision-making, given that price stability is typically either a main objective, as for the Eurosystem, or at least a prominent one, as in the case of the Federal Reserve System. In the Eurosystem, projections of inflation and other macroeconomic variables for the euro area and its individual constituent countries play a highly relevant role in monetary policy decision-making, as a tool for bringing together information on current and expected economic developments. BMPE projections are presented to the Governing Council as an input to its monetary policy deliberations; it then uses its own overall assessment of the inflation situation and outlook, as well as of the risks to medium-term price stability. These projections of inflation and other macroeconomic variables, conditional on a set of assumptions, combine the use of models and other tools with the knowledge and judgement of economic experts.[43] Euro area figures are obtained by aggregating all individual euro area country projections. These take into account a rich set of national data sources and incorporate the details of individual countries' institutional frameworks.

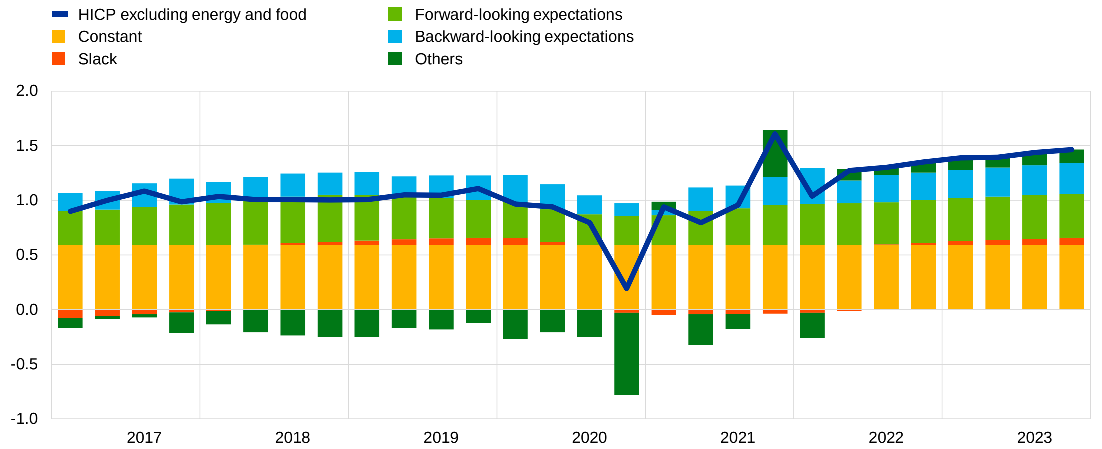
The fact that a bottom-up approach is used makes it particularly important to cross-check results for the euro area as a whole. At Banco the España, two such tools are used: a thick-modelling Phillips curve approach (Álvarez and Correa, 2020) and the DSGE JoSE (joint Spain-euro area) model.

Under the thick-modelling approach, following Granger and Jeon (2004), we consider New Keynesian hybrid Phillips curves using a wide variety of inflation expectations and slack variables. Specifically, we consider inflation expectations measures for consumers, firms, financial markets and experts and, as measures of slack, the output gap, GDP growth, the unemployment rate and the unemployment gap. Interestingly, consumer inflation expectations and the output gap/unemployment gap are found to have particularly high explanatory power.[44] The model can be used to determine whether there are risks on the upside or downside to baseline projections. Considering the December 2020 BMPE projections, this thick-modelling approach would suggest that inflation could be slightly lower than considered in the baseline BMPE projections.

Chart A

Phillips curves cross-check of inflation and outlook for the euro area

(year-on-year growth and contributions)



Sources: Eurostat, ECB, European Commission, Consensus Economics, Banco de España.
Notes: Average of nine Phillips curve models of seasonally-adjusted HICP excluding energy and food, using alternative measures of inflation expectations (consumer, producer, financial markets and trend inflation), the structure of expectations formation (backward, forward or hybrid) and slack (the output gap or unemployment gap).

Over the last year, JoSE has been used to assess whether the economic shock associated with the COVID-19 pandemic was mostly a demand shock or a supply shock, using the Kalman filter to decompose the trend in GDP and inflation as a sum of contributions from the different structural shocks included in the model. This was a particularly relevant question in the first stages of the pandemic, as it was not clear at that time whether the fall in output would be explained mostly by supply factors associated with lockdowns and mandatory curfews, which would have an inflationary effect, or by demand factors related to the fall in income and higher precautionary savings, which

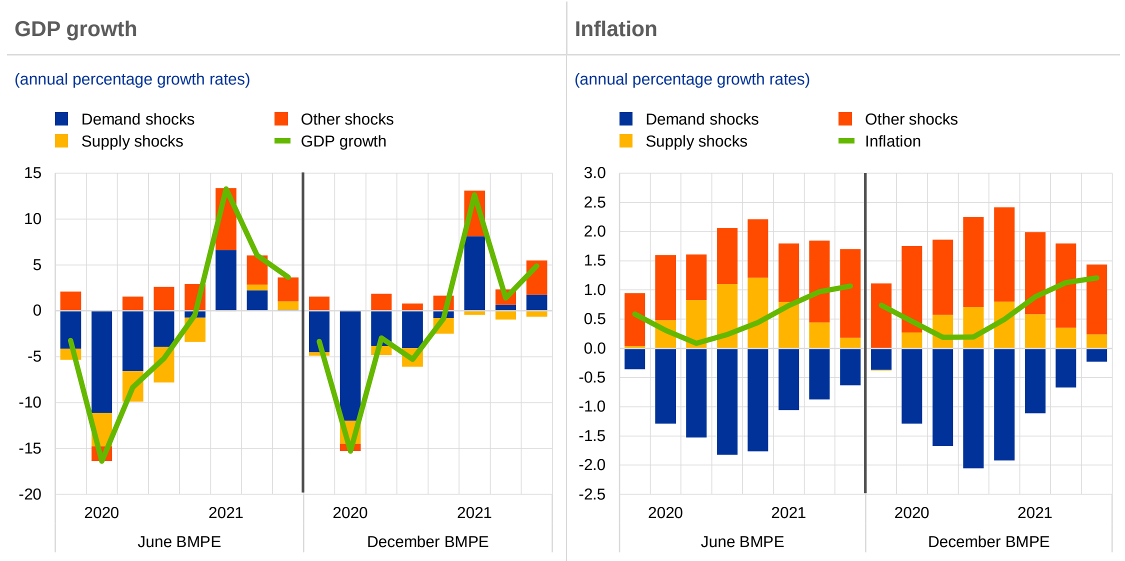
[43] See Álvarez and Sanchez (2019) for the tools used at Banco de España.

[44] The meta-analysis shows that the best performing inflation expectation measure is the qualitative response on inflation over the next 12 months in the consumer-based survey by the European Commission.

would have a deflationary effect. As the answer provided by the model when it is used to filter the data depends on past, present and future developments in all variables, the exercise uses both observed data and projections available at the time. The results can therefore be seen, in part, as an evaluation of the different elements implicit in the projections, as seen through the lens of the model. With the June 2020 Eurosystem macroeconomic projections, the model interpreted the fall in euro area GDP in 2020 as being explained by a mix of different shocks, with a slightly larger role for demand shocks, but a sizeable inflationary contribution from negative supply shocks. With more recent data and revisions in the forecast, taking the December 2020 Eurosystem macroeconomic projections the model identifies a much higher role for demand shocks associated with a fall in inflation.

Chart B

Decomposition of euro area GDP growth and inflation according to the JoSE model



Source: Jose model.

Box 10

The macroeconomic impact of the COVID-19 pandemic on the Italian economy: an estimate of the main channels of transmission using the Banca d'Italia semi-structural model

The Banca d'Italia quarterly econometric model (BIQM) is a large-scale semi-structural macroeconometric model primarily employed to produce projections for the Italian economy.[45] It is also used to construct counterfactual scenarios, in particular for evaluating the economic impact of crisis events by artificially replacing the actual developments with alternative hypothetical assumptions (equivalent to a "no-crisis" scenario).[46]

This box provides a preliminary estimate of the main transmission channels of the COVID-19 pandemic on the Italian economy using BIQM. The counterfactual scenario is represented by the macroeconomic forecasts published in January 2020, just before the start of the crisis. These are

45 See Bulligan et al. (2017) for a detailed description of the structure and the main properties of BIQM.

46 Caivano, Rodano and Siviero (2011) provide a counterfactual analysis on the impact of the global financial crisis, while Busetti and Cova (2013) examine the sovereign debt crisis.

contrasted with the actual developments during the crisis and the GDP forecasts for 2020-21 that were published in July 2020, which are broadly consistent with the more recent projections of the main forecasters; an update of these estimates is currently under preparation.[47]

The main channels considered in this analysis are: (a) the direct impact of containment measures; (b) the decline in international trade and foreign demand; (c) the fall in international tourism flows; (d) the impact of uncertainty and confidence on firms' propensity to invest; and (e) the fiscal policy response. The rich analytical nature of semi-structural models such as BIQM makes it possible to isolate individual contributions from the different channels mentioned through careful "exogenisation" of the various crisis factors involved. This provides a useful decomposition that largely avoids double-counting of effects. However, these crisis factors cannot strictly speaking be interpreted as structural shocks, since they are all interrelated.[48]

Table A shows the contribution from each channel of the crisis and the mitigating impact of the fiscal response, quantified using simulations in BIQM. The direct impact of containment measures accounts for about one-half of the recession experienced in 2020, but it also provides a large contribution to the rebound in 2021. The large fall in foreign demand (estimated at the time at around 13% in 2020) and the interruption of international tourism together subtracted about 5% from GDP in 2020. The recession was further amplified by the large fall in confidence and the increased uncertainty that constrained firms' investment demand and household spending decisions. The fiscal support measures enacted by the Government in the first half of 2020 (amounting to about 4.5% of GDP) had a mitigating impact on economic activity of about 2 percentage points.[49] Some measures, such as the debt moratorium and public guarantees on new loans to firms, had little direct impact on GDP but were essential to prevent severe financial consequences which would have significantly amplified the magnitude of the crisis.

The biggest challenge was to produce an estimate of the effect of the containment measures: these can be seen as a very large but temporary supply shock that cannot easily be nested within a macroeconomic model. In Italy, the strictest measures, i.e. a generalised lockdown, were in place for a total of 11 weeks. The direct effects are calculated based on the observation that between 9 and 27 March and between 4 and 17 May the restrictions affected activities accounting for just over 15% of total value added, and that between 28 March and 3 May the business activities subject to lockdown were responsible for just under 30% of value added. It is also estimated that the persistence of the barriers to production into the second half of May and June involved less than 5% of value added. In annual terms, the direct effect of business suspensions amounts to a reduction in value added of about 5 percentage points in 2020. These shocks were introduced in the model in a largely judgemental way, mainly by adding factors affecting the equations covering household consumption and employment. The flexibility of a semi-structural model makes it possible to impose these additional factors on top of the other transmission channels, for which the historically estimated relationships between macroeconomic variables continue to hold.

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47 The estimates reported here are based on the box "The macroeconomic impact of the COVID-19 pandemic on the Italian economy: an estimate of the main channels of transmission" published in the Bank of Italy Economic Bulletin, 3, 2020. An update of these estimates and additional details are contained in Bulligan, Caivano and Rodano (2021, forthcoming).

48 For instance, uncertainty would have likely risen to a lesser extent without the concurrent deterioration in foreign demand; similarly, the fall in international tourism depends at least partially on containment measures such as mobility restrictions and quarantine obligations.

49 These estimates do not include the impact of the additional measures included in the budget law of 2021 and in the Economic and Financial Document published in April 2021.

Table A

Transmission channels of the COVID-19 shock to the Italian economy (percentage changes)

	GDP	
	2020	2021
x. "No crisis" scenario (1)	0.5	0.9
a. Containment measures	-5.0	3.5
b. World trade	-2.3	-0.6
c. Net international tourism flows	-2.5	-0.9
d. Confidence and uncertainty	-2.2	1.1
e. Fiscal policy	2.1	0.3
f. Other factors (2)	-0.1	0.4
Pandemic scenario (x+a+b+c+d+e+3)	-9.5	4.8

Notes: (1) Forecasts published in Banca d'Italia Economic Bulletin No 1 - 2020. (2) This is a residual item, mainly encompassing effects attributable to revisions of data and changes in technical assumptions. (3) Actual developments and annual projections published in Banca d'Italia Economic Bulletin No 3 - 2020.

Box 11
Forecasting with ECB-BASE

This box describes how the ECB-BASE model is used to produce forecasts during the forecasting rounds at the ECB: for details see Angelini et al. (2019). We explain the three main modes in which the model is applied – examining the impact of assumptions, the projection update and a pure model-based forecast.

ECB-BASE

ECB-BASE is a large semi-structural model of the euro area that can be used to conduct policy scenarios and produce forecasts. In a general form, we can describe every semi-structural model as:

$$Y_t = f\left(A(L)Y_t, X_{t_0:t}, R_{t_0:t}\right)$$

where $A(L)Y_t$ is the lag-polynomial of the endogenous variables and exact form of polynomial and function f depends on the model specification, $X_{t_0:t}$ are the exogenous variables that enter the model and $R_{t_0:t}$ are the residuals of specific equations.

The model depends on three components. First, the current realisation of endogenous variables is dependent on historical realisations; this is referred to as "the effect of history". Second, the exogenous variables, referred to as assumptions; these are all the variables treated from the model perspective over the projection horizon. The framework of the forecasting process at the ECB is such that the set of exogenous variables is relatively large, and many are forecast with satellite tools in different divisions that do not use the main model. For example, forecasts for fiscal variables are provided by the Fiscal Policies Division. The forecasts for some variables are obtained from market expectations, including the short-term interest rate. Third, we need to determine the value of the residuals over the projection horizon; this could be loosely interpreted as a type of judgemental intervention within the model confines. The different ways of forecasting explained below are designed to understand the contributions made by history, assumptions and judgement to the final forecast.

Modes of forecasting

As at other central banks, the forecasting process at the ECB is characterised by the use of judgement and continuity of quarterly forecasts. We will not dwell here on why this is so. Our focus is on discussing the implications for the forecasting process and the different modes in which the model is used.

Continuity of forecasting naturally leads to the question of the effect of information received since the previous forecast. This comes in two forms. First, new statistical data is released, providing additional historic observations. Second, new information implies different forecasts for exogenous variables over the projection horizon. For example, developments in the futures market imply different forecasts for oil prices, and changes in the yield curve imply a different expected path for the short-term interest rate.

The first statistic produced using ECB-BASE is called the impact of assumptions. This uncovers the effect of new assumptions made. We construct it by using the history and judgement from the previous round of forecasting, but changing the assumptions implied by the new information. In equation form:

$$E_t Y_{t:T} = f\left(E_{t-1} A(L) Y_t, E_t X_{t_0:T}, E_{t-1} R_{t_0:T}\right)$$

where $E_t Y_{t:T}$ is the impact of assumptions forecast for the period from t until period T. History, $E_{t-1} A(L) Y_t$, enters with expectations at date t-1, as we use the history from the previous forecasting round. The same is true for judgement too, as we use the judgement from the previous forecasting round, $E_{t-1} R_{t_0:T}$. The only component we change from the previous round's final forecast are the assumptions, $E_{t-1} X_{t_0:T} \rightarrow E_t X_{t_0:T}$.

Chart A shows a concrete example. The dashed blue line marks the final September 2020 MPE forecast and the solid blue line the final December 2020 BMPE forecast. The projection update based only on the new information for assumptions is shown in light green dots. The natural comparison when performing a projection update based only on assumptions is with the forecast from the previous round. In this example we compare it to the September 2020 MPE forecast to gauge the effects of the new assumptions. The change in assumptions from September to December had a positive effect on GDP in 2021, while in later years the new information implied lower GDP growth compared to the forecast in September 2020. On the other hand, the new set of assumptions implied slightly faster growth in prices. We also want to understand how different subsets of assumptions affect the forecast, and therefore we split them up into different categories: for example, fiscal, financial, external, commodity prices, etc.

The second mode of forecasting is called the projection update. This aims to leave judgement unchanged from the previous forecasting round. In equation form:

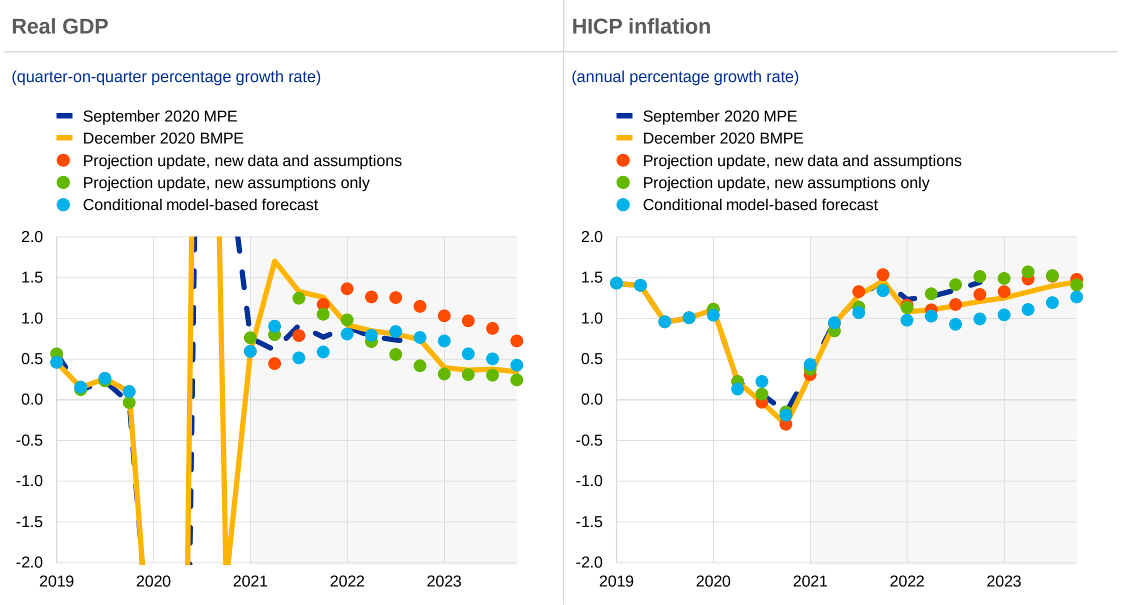
$$E_t Y_{t:T} = f\left(E_t A(L) Y_t, E_t X_{t_0:T}, E_{t-1} R_{t_0:T}\right)$$

where now both history and assumptions are updated, while we still keep the judgement (residuals) from the previous exercise, $E_{t-1} R_{t_0:T}$. Using residuals from the previous exercise serves two reasons. First, comparing these forecasts to ones where only assumptions have been updated shows the effect of the new history on the forecast.[50] Second, judgement sometimes also serves to correct for missing elements, misspecifications and irregular re-estimations in the model.

In Chart A the projection update is shown in red squares. Comparing the projection update to the final December 2020 BMPE forecast, we see that inflation is in line with the final projections, while the update implies lower growth in 2021 and higher growth in later periods. The difference can be explained by the change in the judgement of ECB forecasters due to incoming information not captured in the model. This related to the re-introduction of lockdowns in November 2020, pushing GDP growth down, and the expected reversal of those measures in 2021, pushing it up again. As this description makes clear, the projection update is a useful device for understanding how both the new history and any change in judgement have affected the new forecast.

Chart A

Different modes of forecasting – euro area (December 2020 BMPE)



Source: ECB-BASE.
Notes: Final September 2020 MPE and final December 2020 BMPE forecasts for GDP and HICP inflation, with the three different forecasts produced using the ECB-BASE model.

The third mode of forecasting is the statistical model-based forecast proper. Since we condition this on exogenous assumptions, we call it the conditional model-based forecast. In equation form:

$$E_t Y_{t:T} = f\left(E_t A(L) Y_t, E_t X_{t_0:T}, E_t R_{t_0:T}\right)$$

The main difference compared to the projection update is that we also update the residuals. This update applies an integrated model that uses historical patterns in residuals to set future values:

$$E_t R_{t+1:T} \; = \; g(E_t R_{t_0:t})$$

[50] In most cases the history contains not only data published by statistical offices, which are published with a considerable lag, but also nowcasts from short-term satellite forecasting tools.

A model-based forecast incorporates no external judgement. Its role is to evaluate the effect the judgement of the forecasters has had on the final forecast. In Chart A this is shown in green diamonds. We can see the model would not predict a strong reversal in GDP growth in 2021, but steadier growth over the whole forecasting horizon. This is not surprising, given the specific nature of the COVID-19 pandemic and related lockdowns, which could generate jumpy behaviour in GDP growth. These features are clearly not captured by the model mechanisms, and therefore specific judgement may be warranted.

Box 12

Density forecasting with ECB-BASE

This box describes how the ECB-BASE model is used to produce density forecasts during the forecasting rounds at the ECB.[51] We show how we technically obtain density forecasts, explain the underlying assumptions and provide an example of density forecasting from the December 2020 BMPE round. We also discuss the difference between conditional and unconditional density forecasts performed with ECB-BASE and consider possible improvements in future.

Density forecasting with ECB-BASE

In the ECB-BASE model, density forecasts are computed using a bootstrap method introduced by Efron (1979).[52] In general, density forecasts can be constructed by exploring the uncertainty around the parameters of the model and the stochastic residuals. With ECB-BASE we explore the uncertainty about the stochastic residuals of the model, while parameter uncertainty is ignored by assuming the model represents the true data generating process (DGP).[53]

More specifically, we re-sample the residuals from historical values and suppose that the actual value of an endogenous variable from the model is equal to the value predicted by the model plus an error. The distribution of the errors is not known, and no hypothesis is made about their distribution; their empirical distribution is approximated by means of the bootstrap method. As the model has many equations, to do the re-sampling the bootstrap selects the residuals of each equation for one period to capture cross-correlation in the residuals. Once an observation has been selected, it is replaced in the sample. This process is repeated many times until the distribution of the endogenous variables is obtained.

The BMPE 2020 as an example

The density forecasts in ECB-BASE can be computed in different ways. Our standard approach is to compute the median forecast from the model and then use re-sampling techniques to produce the distribution around this. However, in practice we also use a second method, in which we

51 See Angelini et al. (2019).

52 The original application was designed to capture the uncertainty in parameters. Bootstrapping was used to generate artificial data samples and, with re-estimation on those samples, the distribution of the parameters too.

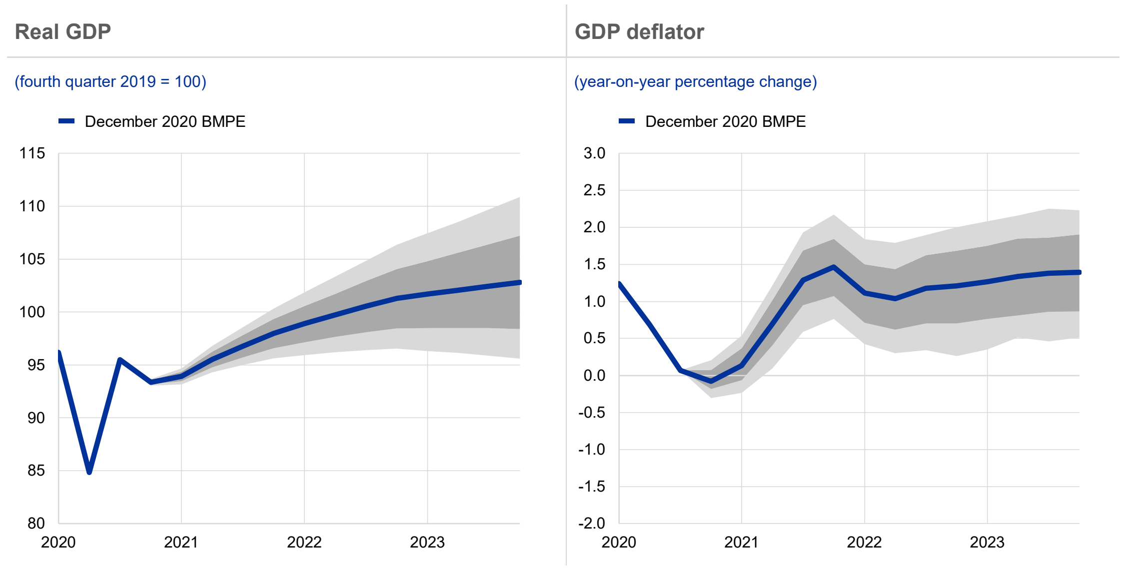
53 In principle the uncertainty in parameters can also be considered, and this will be done in future. However, given the multiple estimation methods used to estimate the model, including calibrations, the implied distribution may not be close to true statistical uncertainty. Additionally Chatfield (2000) explains that parameter uncertainty seems to contribute only marginally to total forecast uncertainty: “Overall, the effect of parameter uncertainty seems likely to be of a smaller order of magnitude in general than that due to other sources, notably the effects of model uncertainty and the effects of errors and outliers [...].”

assume that the median of the forecast is the actual forecast produced by the ECB. In this case we centre the mean of the re-sampled residuals in such a way that they are consistent with the actual forecast. In both cases a chosen number of draws are computed. For each simulation the residuals of one period are selected randomly. With each draw of residuals we solve the model, giving us a distribution of the endogenous variables.

The example in Chart A below shows the density forecast produced by ECB-BASE centred around the December 2020 BMPE forecast:

Chart A

Density forecasting– euro area (December 2020 BMPE)



Source: ECB-BASE.
Notes: Chart A shows the real GDP and the GDP deflator density forecast produced by ECB-BASE centred around the final December 2020 BMPE. The light grey area represents the 68% confidence interval, while dark grey shows the 95% confidence interval. The density forecast is computed using a bootstrap method that re-samples the in-sample residuals of the model. The forecast value of an endogenous variable is calculated by adding the re-sample residual to the value forecast by the model and the distribution is obtained by repeating the process 500 times.

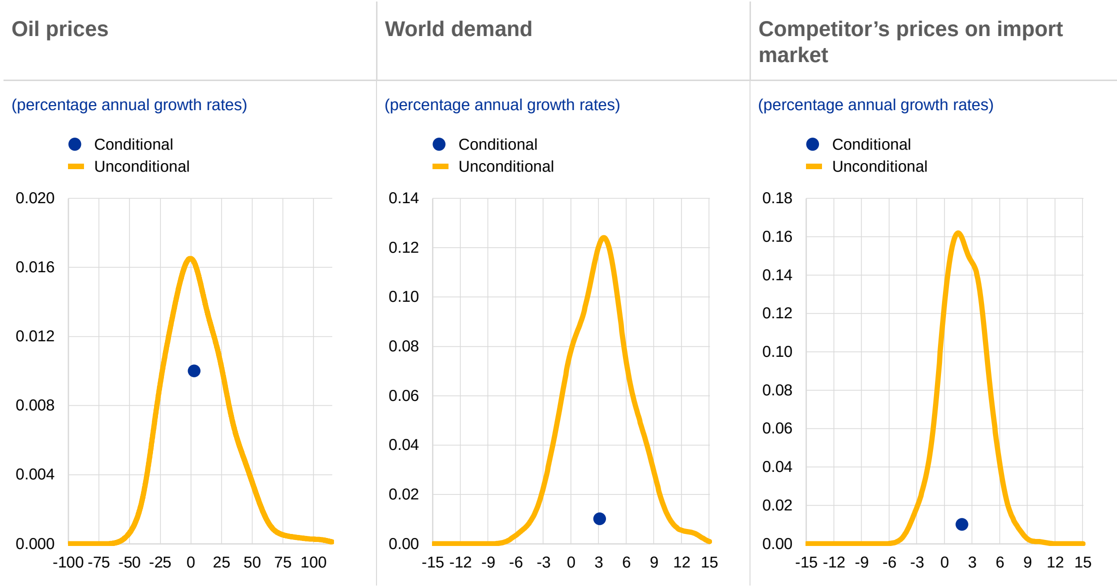
The differences between conditional and unconditional forecasts

During the projection rounds, the forecasts produced by ECB-BASE are conditional. Several variables are projected by specialised teams and the model retrieves their predicted values to make the forecast. This is the case for financial, external and fiscal variables for example. The model treats these conditioning variables as exogenous and some uncertainty is therefore not captured. They can be predicted by the model, however, and, in the case of density forecasts, their residuals considered. Hence, it is interesting to compare the distribution of the density forecasts in these two cases: when conditioning variables are treated as exogenous, and when they are treated as endogenous and the uncertainty in the conditioning variables considered.

As an example, Chart B shows the distribution of the selected set of foreign variables when we use the endogenous model to calculate their dynamics and retrieve the implied densities. As we can see, the distributions are wide – for example, even a 50% increase or decrease in the oil price has a considerable weight in the distribution. The large dispersion of foreign variables is due to their large movements historically. It may therefore be important to take the uncertainty in the conditioning set of variables into consideration as well.

Chart B

Differences in density forecast distributions – foreign variables, euro area (December 2020 BMPE)

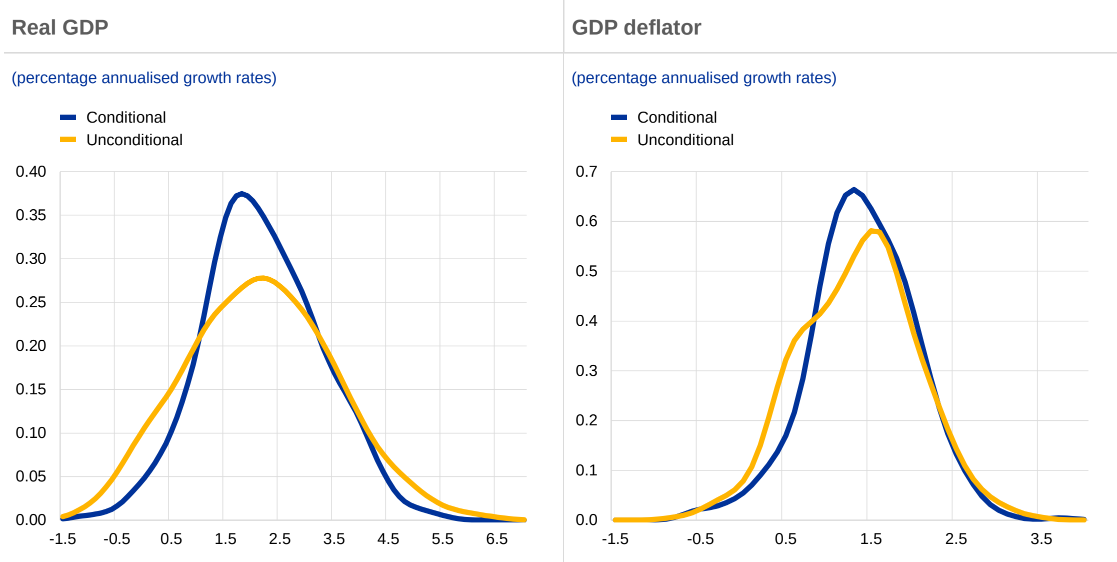


Source: ECB-BASE.
Notes: Chart B shows the density forecast distribution of oil prices, world demand and competitors' prices on the import market produced by ECB-BASE and centred around the actual forecast. The density forecast is computed using a bootstrap method that re-samples the in-sample residuals of the model. The forecast value of an endogenous variable is calculated by adding the re-sample residual to the value forecast by the model and the distribution is obtained by repeating the process 500 times. The ECB-BASE forecast is conditional and uses values produced by ECB staff for the fiscal, foreign, UIP, transfers, exchange rate, house prices, financial and policy rule blocks.

Chart C shows the density forecast distribution for real GDP and the GDP deflator in the two cases. To compare density predictions only, the distributions are centred around the final December 2020 BMPE. The charts highlight that when uncertainty about the conditioning variables is considered, the uncertainty in GDP and inflation is larger too, due to endogenous transmission from foreign to domestic developments. The distributions of the unconditional forecasts are larger, less concentrated and give higher probabilities to extreme values.

Chart C

Differences in density forecast distributions – GDP and consumer deflator, euro area (December 2020 BMPE)



Source: ECB-BASE.
Notes: Chart C shows the density forecast distribution of real GDP and the GDP deflator produced by ECB-BASE and centred around the actual forecast. The density forecast is computed using a bootstrap method that re-samples the in-sample residuals of the model. The forecast value of an endogenous variable is calculated by adding the re-sample residual to the value forecast by the model and the distribution is obtained by repeating the process 500 times. The ECB-BASE forecast is conditional and uses values produced by ECB staff for the fiscal, foreign, UIP, transfers, exchange rate, house prices, financial and policy rule blocks.

Box 13
Survey-based multivariate risk indicators

Probabilistic forecasts are becoming increasingly available, since they provide information about the uncertainty surrounding point projections. Ideally, policymakers would like to have multivariate density forecasts, i.e. information on the joint distribution of possible future outcomes of macroeconomic variables. This would allow them to obtain risk measures related to joint movements in several variables. For instance, they might be interested in the probability of a recession, jointly taking into account trends in GDP and unemployment, or wish to focus on tail risk events such as low inflation in a contractionary economy.

Unfortunately, existing macroeconomic surveys such as the ECB Survey of Professional Forecasters only report univariate (marginal) distributions for variables such as inflation, GDP and the unemployment rate. In novel work, Odendahl (2020) proposes estimating joint density forecasts on the basis of univariate density forecasts from survey data and copula functions. This makes it possible to obtain, for example, an indicator of the risk of an economic downturn. The underlying idea is that any joint distribution function can be decomposed into its marginals and a copula function, and vice versa (Sklar, 1959). In his approach, the joint density is characterised by the univariate densities (available from the survey), the copula function and the estimated distributional dependence of the variables. More technically, the forecaster needs to: (i) obtain the realised probability integral transform based on historic realisations and past univariate survey forecasts; (ii) choose a copula family; and (iii) choose a model for the dynamics of the dependence parameter. Both the choice of the copula family and the model for the dynamics of the dependence parameter matter for the forecasting performance and the joint density.

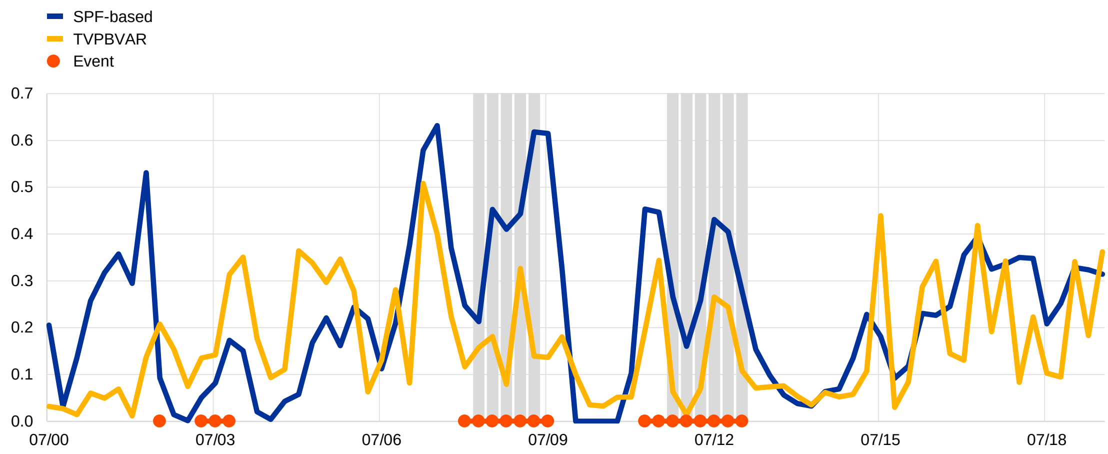
In the estimation of the survey-based multivariate density forecasts, Odendahl (2020) focuses on the fixed-horizon, one-year-ahead forecasts, with a sample ranging from the first quarter of 1999 to the first quarter of 2019. To convert the panellists' histogram forecasts to a smooth density, skew t-distributions are fitted using the probability distribution of Jones and Faddy (2003) (the use of estimated skew t univariate density forecasts in combination with a normal copula does not imply a multivariate normal distribution). The dynamic copula model of Hafner and Manner (2012) makes it possible to take into account the time-varying nature of the correlations between key macroeconomic variables, in particular for the period after the Great Recession.

Chart A

Multivariate risk indicators

Joint probability of lower GDP growth and higher unemployment rate

(probability on one-year-ahead outcomes)



Source: Odendahl (2020).
Notes: SPF-based = probability based on data from the Survey of Professional Forecasters. TVPBVAR = probability based on a Bayesian VAR model with stochastic volatility that allows for time-varying parameters. Event = actual outcome of the downturn event.

One of Odendahl's applications is the development of an indicator of the risk of an economic downturn; more specifically, the probability that real GDP growth is going to be lower than the previous quarter and that the unemployment rate is going to be higher. The indicator is therefore computed based on the joint change in real GDP growth and the unemployment rate. Chart A displays the one-year-ahead economic downturn probabilities. The black line is the economic downturn probability (left-hand scale), calculated using the joint density forecasts estimated based on data from the Survey of Professional Forecasters (SPF). As a comparison, the blue line plots the economic downturn probability computed using the joint density forecast from a Bayesian VAR (BVAR) model with stochastic volatility that allows for time-varying parameters (Del Negro and Primiceri, 2015). The red dots display the actual outcomes of the downturn event.

The survey-based indicator provides a feasible alternative real-time assessment of the downturn risk. The methodology proposed can also be used to look at a specific tail-risk event of particular interest, such as the probability of negative output growth accompanied by low inflation; in such cases the survey-based indicator again offers an alternative to benchmark econometric models.

In general, joint predictive distributions have received little attention in the forecasting literature despite the popularity of multivariate models such as BVARs and factor models. This is true for both forecast evaluations of the entire joint predictive density and the construction of potential indicators.

Box 14

Risk analysis with a suite of models: model combination strategies

Optimally combining forecasts from multiple models to robustly predict future paths of macroeconomic variables is a methodology that has been advocated for some time in the economic literature (for a comprehensive review, see Bassetti et al., 2020). However, it is hard to find an individual model that can be considered the “best performing” in all possible forecasting dimensions, i.e. for any variable, at any forecast horizon, at any point in history and for any loss function metric (be it in terms of point or density forecast). Hence it is natural to consider combinations as a way of averaging multiple measurements of the same outcome. These measurements may be the result of known econometric models, or they may come from a mixture of unobserved data, models, forward-looking information and judgement calls, such as the figures published in survey forecasts or the projections of the (Broad) Macroeconomic Projection Exercise (B)MPE, conducted by the Eurosystem.

Following this idea, the Forecasting and Policy Modelling Division at the ECB uses a suite of econometric models. The objective is to provide probabilistic (density) forecasts for euro area real GDP and HICP inflation for one- and the two-year-ahead horizons based on the time-series properties of these and other indicators. It can be employed for several applications. The forecasts can be used to cross-check official projections and assess the associated risks (for the latter, well calibrated probabilistic forecasts are key). The models can be also used to evaluate scenarios by means of conditional forecasting. Finally, the suite can be used as a benchmark when evaluating the usefulness of alternative models (in terms of forecast accuracy).

Following Bańbura et al. (2021), we include several types of Bayesian vector autoregression model (BVAR) in the toolbox; these have become a standard method for forecasting and scenario analysis in the central banking community. We choose several specifications, which differ in modelling choices such as data set size and composition, data transformation, degree of time variation, prior specification and inclusion of off-model information.[54] We then hedge against model uncertainty by combining these model forecasts by means of linear optimal pooling, where each model contributes to the combination with a time-varying weight driven by the model's performance in terms of predictive density (see Geweke and Amisano, 2011) using the log scoring criterion:

$$\sum_{t=T_1}^{T_2} \log\left(p(y_{t+h}; y_t, \dots, y_1, M)\right),$$

where $p(y_{t+h}; y_t, \dots, y_1, M)$ is the predictive density from model M for y_{t+h} given the data $y_1, \dots, y_t$. The individual predictive densities are obtained by simulating the parameters from the posterior distribution and deriving the “future” shocks. The optimal weights are found by solving the following constrained maximisation problem:

[54] For a detailed description of all the models included, see Bańbura et al. (2021).

$$w^*_{t+h|t} = \text{argmax} \sum_{t=T_1}^{T_2} \log\left[\sum_{i=1}^{I} w_{t+h|t,i}\, p(y_{t+h}; y_t, \dots, y_1, M_i)\right]$$

where I is the number of models and $w_{t+h|t,i}$ is the time-varying weight for model M_i. The weights are constrained to be non-negative and sum to one:

$$w^*_{t+h|t,i} \geq 0 \sum_{i=1}^{I} w^*_{t+h|t,i} = 1$$

The optimal weights are the outcome of a real-time exercise for the euro area over the sample 2000-2019, where we also evaluate the performance of individual models and their combinations at one- and two-year-ahead horizons in terms of both point and density forecast accuracy. We find optimal weights for each variable based on univariate predictive likelihood, and across both variables based on bivariate predictive likelihood.

The combined density is a mixture of the individual densities, weighted over time by the optimal weights. The combination improves on individual models in terms of predictive performance (relative accuracy), but does not always achieve good calibration (absolute accuracy) for both variables and horizons. Calibration is often overlooked in forecast evaluations, even though it is a key aspect when accurate measures of uncertainty around the point forecasts are needed. A well-calibrated density forecasts means that the probability of the realised value being higher or lower than the forecast value is the same on average over time. This is independent of whether we consider high or low outcomes for the variable we are forecasting.

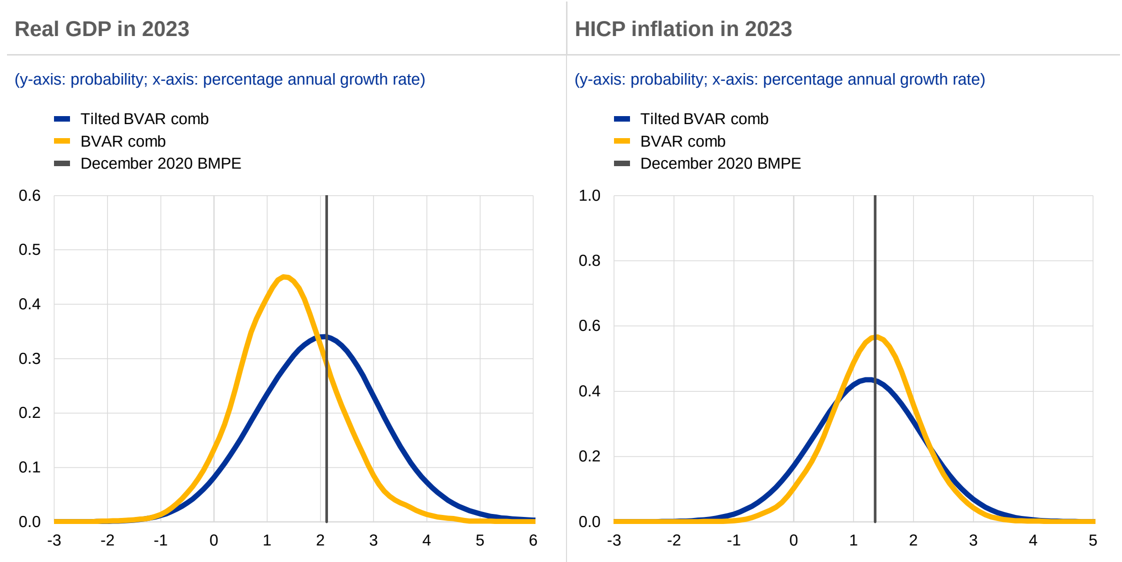
Finally, as also shown in Bańbura et al. (2021), we can apply entropic tilting[55] to further improve on forecast accuracy by using an additional source of off-model information, namely the BMPE, while at the same time being able to cross-check the risks associated with the official projections. We incorporate this information in a unique forecast density. This allows us to reap the benefit of both the more subjective (B)MPE forecasts, which contain forward-looking information, and the more academic and model-based BVAR forecasts, which are mostly based on backward-looking information.

As shown in Chart A, tilting the model combination to the first moment of the (B)MPE provides us with a tool for better assessing the risks surrounding the baseline produced by the Eurosystem. The probability of GDP in 2023 being above the December BMPE projection is only about 20% according to the BVAR combination, while after tilting to the BMPE forecast this increases to 44%. Meanwhile, the probability of HICP in 2023 being above the December BMPE figure is only about 50% according to the BVAR combination, while after tilting to the BMPE value it falls to 45%.

[55] For a detailed description of entropic tilting see Robertson et al. (2005).

Chart A

Statistical risk metrics: model combination predictive densities



Source: Projections database for the December 2020 BMPE real GDP and HICP inflation values.
Notes: ECB calculations based on an optimal pooling combination of BVAR models ("BVAR comb") as described in Bańbura et al. (2021), and the same density combination tilted to the median of the December 2020 BMPE ("Tilted BVAR comb") using entropic tilting methods where the distributions are re-weighted so their median coincides with the December 2020 BMPE.

Box 15
Bundesbank pandemic scenarios in the June 2020 BMPE

To illustrate the high uncertainty surrounding the economic outlook due to the pandemic, the Working Group on Forecasting (WGF) agreed to complement the baseline scenario in the June 2020 Broad Macroeconomic Projection Exercise (BMPE) with two alternative scenarios. This box briefly summarises the procedure conducted by the Deutsche Bundesbank to produce these scenarios.[56]

As a result of the abrupt occurrence of the pandemic, typical short-run indicators and conventional short-term forecasting models were not able to adequately reflect and quantify the economic effects.[57] The empirical regularities captured by the estimated behavioural equations in standard macroeconometric models were also called into question. A less conventional methodology was therefore used to develop the macroeconomic forecast.

The first step was to assess the expected evolution of the pandemic and the containment measures required to control it. This built on the idea that, after a relatively strict lockdown, measures could be gradually loosened in line with the learning effects associated with the containment policy, medical research and corporate and household behaviour, until a medical solution, e.g. a vaccination, was available and a normalisation period set in. The approach was translated into a path of stylised

56 The outlook for the German economy was published in Deutsche Bundesbank (2020).

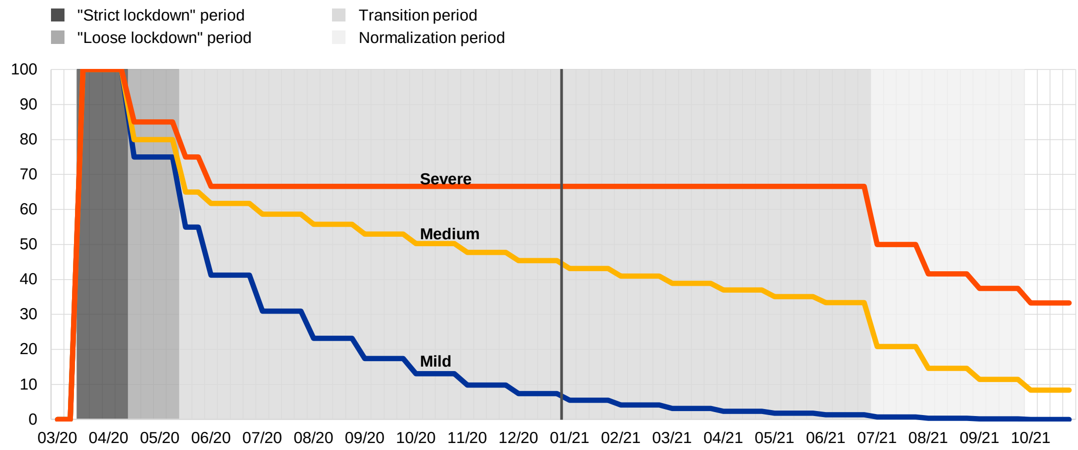
57 As a partial remedy, Eraslan and Götz (2021) developed a weekly activity index (WAI). This is designed to measure real economic activity in Germany in a timely manner in the spirit of the index published by the Federal Reserve Bank of New York. See also www.bundesbank.de/wai.

economic output losses due to the domestic containment measures.[58] The associated degree of economic damage caused by the successful containment of the virus until a medical solution was available therefore became the key parameter of the exercise and provided an illustrative framework for the projections. To capture the speed of pandemic developments, the alternative time profiles for economic losses were specified at the relatively high frequency of twelve equidistant intervals per quarter.

Chart A

Output loss due to domestic containment measures

(percentage of the damage during initial strict lockdown period)



Source: Deutsche Bundesbank.

In the course of the June 2020 BMPE, the WGF established a common narrative individually specified for the baseline and the mild and severe scenarios. For each of the scenarios, it was assumed that a medical solution would become available by mid-2021. The above schema of expected output losses was then used to distinguish between the three scenarios, as these were supposed to be characterised by different levels of learning effects (see Chart A on the left).

Building on the narratives underlying the pandemic, the second step was to identify and calibrate several broadly orthogonal shocks to aggregate demand for the three alternative scenarios and feed these shocks into the macroeconometric model.[59] The resulting estimates provided three different paths for the overall macroeconomic effects caused by the pandemic, which could be translated into three alternative scenarios using the baseline projection from the December 2019 BMPE as a reference path representing a scenario excluding the pandemic.

[58] The losses over time were specified as a percentage of the initial output loss during the strict lockdown period. This initial lockdown loss was also subject to high uncertainty, as several alternative unconventional approaches for quantification implied a high range of estimates. However, this range narrowed down as more economic data for the strict lockdown period became available.

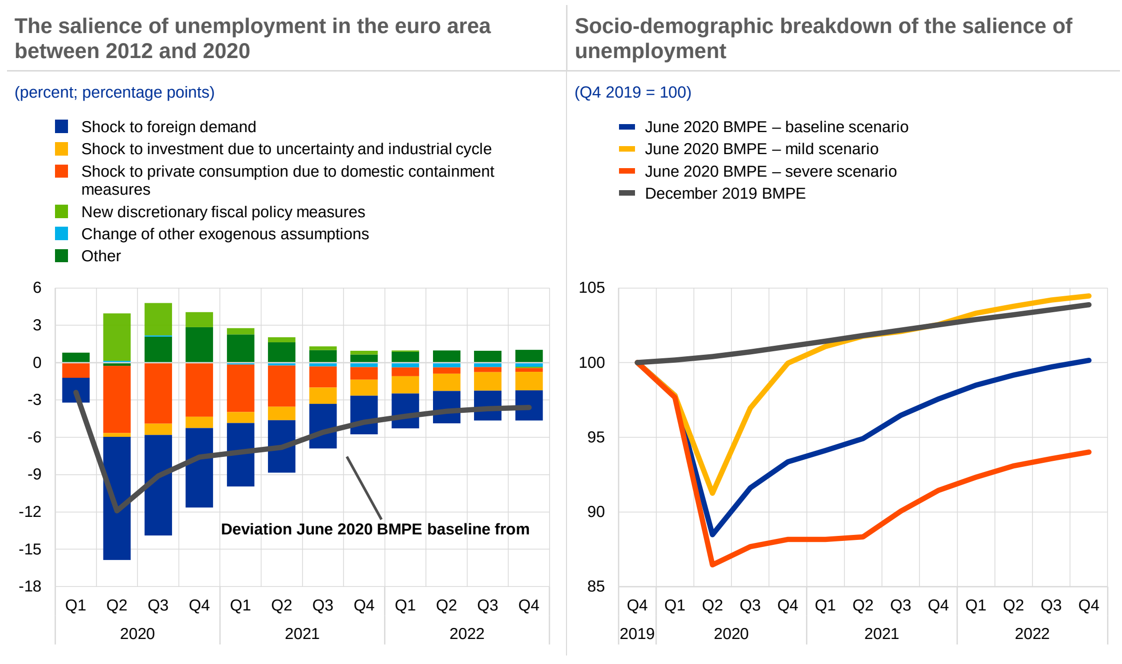
[59] This demand-side approach was developed and applied in full awareness of the fact that supply-side disturbances also played a key role in the pandemic. These were addressed by additional quantitative approaches applied to cross-check the simulation results. The demand-side approach was favoured mainly because of practical issues, including the ability to apply the established modelling and simulation framework and the clear way of taking external assumptions into account, as well as the relatively precise specification of the domestic shock on private consumption (against the background of the overall level of uncertainty) and the ability to include macroeconomic feedback effects over the full projection horizon. However, the strong dependence on the highly uncertain projection for the international environment and the question of the underlying orthogonality assumption regarding the calibrated shocks are at least two caveats that should be mentioned.

Given that the domestic containment measures were mainly targeted at specific service sectors that were more or less shut down, the stylised high-frequency time paths of expected domestic output losses could be used to assess the losses in the various consumption categories. This was done to calibrate the first shock, i.e. an aggregate shock on private consumption expenditure directly related to domestic lockdown measures.

The second shock aimed at capturing uncertainty effects on business investment to account for potential wait-and-see behaviour by firms and assess the impact beyond the endogenous response of investment to lower external and domestic demand. For that purpose, a satellite VAR model was deployed which extended the investment equation of the macroeconometric model and additionally incorporated an uncertainty measure to quantify the shock on business investment.[60] Uncertainty was assumed to follow the dynamics of the general domestic output loss schema indicated above.

Chart B

Real GDP projection revisions (left panel) and scenarios for real GDP (right panel)



Source: Deutsche Bundesbank.

The third, and quantitatively most important, shock was the decline in German export markets stemming from reduced demand among trading partners as a result of the pandemic. The size of the shock was derived from the revisions to foreign demand assumptions since the December 2019 BMPE. The implications of changes in other exogenous assumptions were similarly taken into account in the simulation exercise as well.

Finally, and in addition to the combination of these shocks, the construction of the macroeconomic outlook integrated the estimated effects of the fiscal policy measures undertaken to provide support to firms and households during the crisis. The assessment of these effects was again based on simulations with the macroeconometric model. The procedure was run for each of the three

60 The VAR also included another variable, i.e. firms' production plans from a large-scale industry survey, accounting for further cyclical effects which are not captured in the standard projection model equation. This allowed for a more timely response to news in the projection process.

scenarios, differentiating the magnitude and persistence of the respective shocks. As these were determined by differing assumptions regarding expected falls in private consumption due to domestic containment measures, foreign demand and the technical variables, the imputed fiscal impact was incorporated in a way that the fiscal measures included in the projection baseline would be exhausted to a greater or lesser extent depending on the respective scenario.[61] The final outcome of the projection exercise is presented in Charts B and C.

Box 16

A comparison of responses to forward guidance policies: FR-BDF versus DSGE models

This box explains the discrepancies in the assessment of forward guidance policies between FR-BDF (a semi-structural model that follows the FRB/US approach) and a variety of DSGE models (from a simple textbook version to those that are designed to cope with the forward guidance puzzle).

Baseline DSGE models generically predict a very strong reaction in output and inflation to forward guidance policies. In addition, they predict that the more distant the date when an interest rate cut is promised, the larger the immediate increase in GDP and inflation. If anything, one would expect promises of future interest rate cuts to be less powerful than current ones. This peculiar prediction from DSGE models has come to be known as the “forward guidance puzzle”, a term coined by Del Negro et al. (2012).

The dots labelled Non-discounted Galí in Chart A illustrate the forward guidance puzzle encountered in baseline DSGE models. They represent the peak effect on output and inflation of decreasing the (annualised) interest rate by 25bp for one to eight quarters, in a simple textbook DSGE model based on Galí. This model consists of the dynamic IS curve, the New Keynesian Phillips curve and an inertial Taylor rule for monetary policy. As can be seen on the graph, the effect on GDP and inflation is a convex function of the duration of forward guidance: the impact of one more quarter of lower rates increases with the horizon.

Overall, the puzzling prediction of standard DSGE models come from the fact that agents are assumed to be very forward-looking. Households' consumption depends heavily on future interest rates, and firms' pricing decisions depend heavily on future inflation. Solutions to the forward guidance puzzle in DSGE models all consist in ways to make agents less dependent on future economic conditions than simple models suggest.

In this box, we consider five such DSGE models designed to provide a solution to the forward guidance puzzle.

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61 This approach is a schematic procedure, rather than one that accounts for differentiated estimates of a discretionary fiscal response to the respective developments of the epidemic and the economy. Nonetheless, it allows a scenario-dependent reaction of the automatic stabilisers, as these are captured by the model framework.

- A DSGE model denoted “discounted Galí”, which assumes that households do not react as much to interest rate cuts far in the future (because they discount future consumption), as a short-cut to modelling imperfect expectations or credit markets.[62]

- The DSGE model of Grosse-Steffen Matheron, or GSM. This is an extension of the Smets and Wouters (2007) model, featuring an overlapping generation structure which reduces the length of agents' planning horizons. It also contains a frictional banking sector.

- The Grosse-Steffen Matheron model featuring in addition imperfect credibility of forward guidance announcements, or GSM-ic. Specifically, the model assumes that the private sector believes the central bank's promises only with a probability of 85%. Similar DSGE models are extensively used in policy analysis, for instance in the MPC Forecast Task Force.

- Two versions of a DSGE model where agents have finite planning horizons. The first is a fully calibrated stylised version of Woodford (2018), denoted FPH, with an average planning horizon, h, of 4 quarters and an intertemporal elasticity of substitution, σ, of 1. The second model, FPH-est, is in the spirit of Galí, Smets and Wouters (2011), (GSW), with an estimated h of 0.9 quarters and estimated σ of 0.14.[63]

Each DSGE model is subjected to the same forward guidance shocks as the non-discounted Galí model. Once the short-term nominal interest rate peg is over, the nominal interest rate is assumed to follow the Taylor rule embedded in each of the models.

Chart A shows the reaction of GDP and inflation in these models and FR-BDF in response to the same forward guidance experiments as for the baseline DSGE model.[64] The scale of responses is very wide, and for better presentation we split the models into two groups: (1) those with the forward guidance puzzle and a big response to the shock; and (2) those with no puzzle and a much smaller response.

Comparing all models, two results stand out. First, for a standard monetary policy shock that lasts only one quarter and contains no forward guidance, the peak output response is weaker in FR-BDF than in almost all the DSGE models considered except the estimated GSW-based FPH model. The same remark applies for inflation, however here even the stylised calibrated Woodford-based FPH model delivers weaker results than FR-BDF.

Second, FR-BDF does not suffer from the forward guidance puzzle, and non-baseline DSGE models provide either a partial or full solution to the puzzle. In FR-BDF, the peak impacts on GDP and inflation are almost perfectly linear in the duration of the forward guidance announcement. Among DSGE models, all variants of the baseline DSGE model attenuate the response to forward guidance announcements, although some only partially solve the puzzle. The GSM-ic model and FPH models offer the most satisfying solutions. In GSM-ic, the peak impacts on GDP and inflation are linear in the duration of the forward guidance announcement. In FPH models, the impacts are

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62 McKay et al. (2017) argue that this could arise if some households are credit-constrained. Subsequent literature has shown that credit constraints do not necessarily lead to this type of discounting, nor necessarily solve the forward guidance puzzle by themselves: credit-constrained households also respond more to increases in their income, which can actually strengthen the forward guidance puzzle.

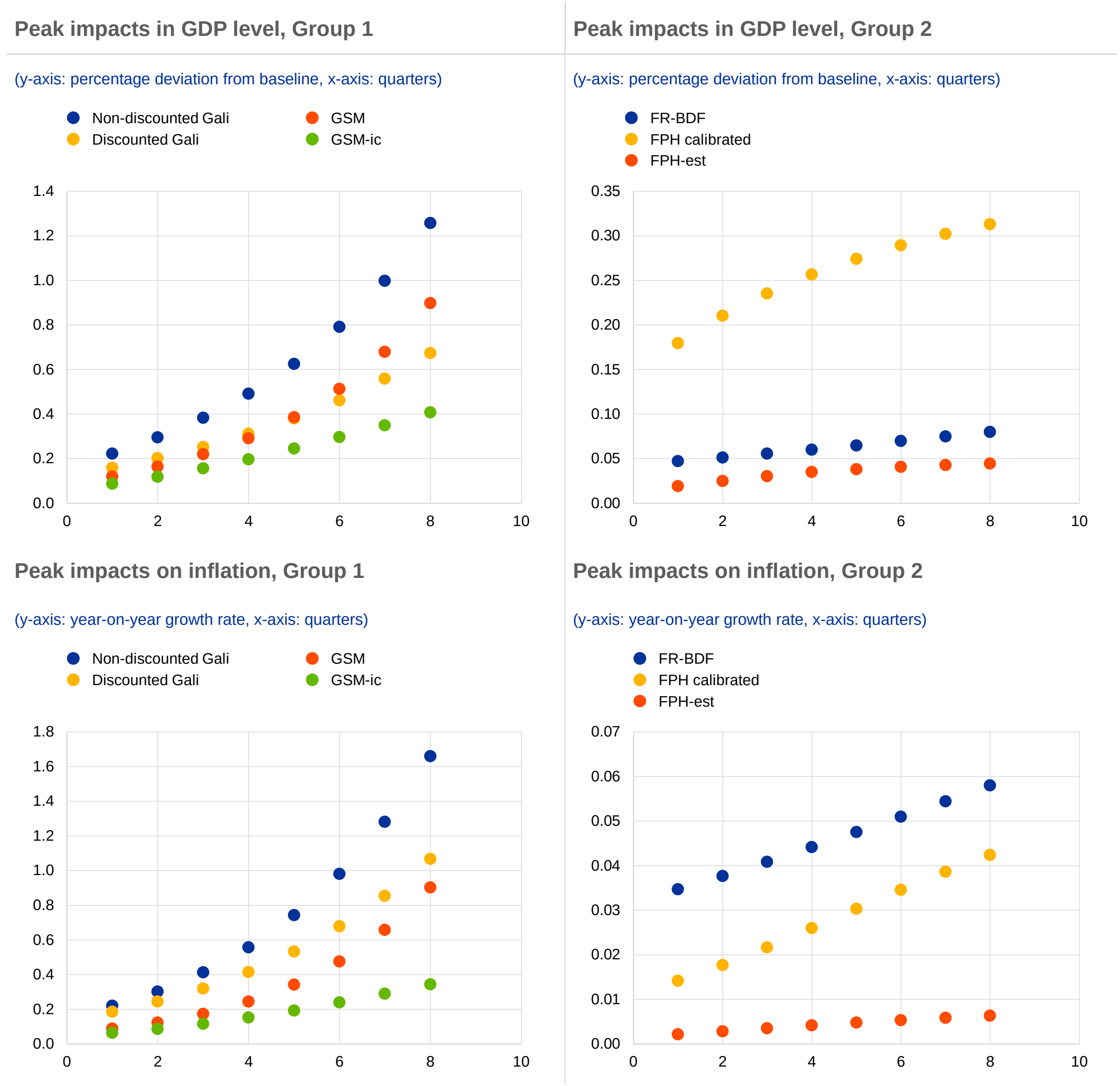
63 The model is estimated using euro area data over the period from the first quarter of 1995 to the fourth quarter of 2014.

64 Please note that the dots for FR-BDF correspond to the following experiment: after a peg of 1 to 8 quarters, the interest rate is assumed to return to steady state following its historical persistence; expectations are set to model-consistent mode, i.e. agents' forecasts coincide with that of the model; euro area variables are exogenised.

even concave over the horizon of the announcement: the effect of forward guidance fades with the horizon.

Chart A

Responses in GDP and inflation to forward guidance policies



Source: FR-BDF and Banque de France DSGE models.

To conclude, generally DSGE models tend to predict a higher reaction in output and inflation than found in FR-BDF, even when they solve the forward guidance puzzle. However, within each category of models, results can be sensitive to specific details relating to their specification and parametrisation. In particular, in FR-BDF, agents are implicitly characterised by a very high degree of risk aversion. In most of the DSGEs shown here this elasticity is calibrated to values close to 1, corresponding to the lower bound of available empirical estimates. In the case of the estimated GSW-based FPH model (FPH-est), the elasticity of output to the real interest rate has a similar magnitude as in FR-BDF. The peak effects of output and inflation in the FPH-est model are even smaller than those of FR-BDF.

Box 17
Medium-term reference scenarios using NAWM II

Current practice

Medium-term reference scenarios (MTRSs) have been conducted on a regular basis for the quarterly staff projection exercises at the Eurosystem since the December 2010 BMPE. These scenarios extend the baseline projections beyond the BMPE horizon by five years. Generally, such an extension can be obtained by combining two types of input. The first involves expert judgements and opinions, while the second is mechanical and based on a model. The purpose of this box is primarily to discuss how the MTRS is currently obtained, relying on both these types of input and building on the interpretation of the projection baseline through the lens of a model. We also propose some ideas on how the scenario can be further developed.

Methodology

The methodology for the MTRS is based on a DSGE model, the NAWM II, which is the most recent version of the ECB's workhorse DSGE model for the euro area. It should be kept in mind, however, that the methodology is not model-dependent and other models, such as ECB-BASE, could be used for the same purpose. Moreover, while the discussion is based on a linear model, it also applies to non-linear models, such as when the effective lower bound on nominal interest rates is imposed.

NAWM II can be expressed as a state-space model where the observed variables are linked to the steady state, a subset of the model or state variables, and measurement errors. The state variables are determined by the cross-equation restrictions that the solution of the model imposes, where the solution is expressed as a VAR system whose innovations are given by the structural shocks of the model. The former equations are the measurement equations, while the latter give the state equations. Jointly, they are known as a state-space form of the model.

To produce an extended baseline with NAWM II, it is important to recognise that the observed variables for any time period T+h (where T is the last period of the projection sample and h>0) can be decomposed into four terms:

- the steady state of the model;
- the (unobserved) state variables at period T;
- the structural shocks between period T+1 and T+h;
- the measurement errors at period T+h.

The approach we consider is essentially a generalisation of conditional forecasts, where judgement can enter at several levels.

The steady state of NAWM II is known, while it is natural to let all measurement errors be zero for the extended baseline. The state variables at the end of the projection sample can, for example, be estimated via the Kalman smoother by treating the projections as data. In addition, it is possible to estimate these variables taking additional assumptions until the end of the projection horizon into account using a constrained Kalman smoother.[65]

Concerning the structural shocks, two groups are considered. For the first group, values are selected such that certain conditioning assumptions for the extended baseline are satisfied. Building on input from the IMF's World Economic Outlook and market-based estimates for oil prices and US long- and short-term interest rates, conditioning is on assumptions for the euro area's external environment.[66]

The remaining structural shocks are assigned values that can be related to their weighted average estimated values over the projection sample. The constrained Kalman smoother estimates of the shocks using additional assumptions may be used as an alternative to the unconstrained smooth estimates. Both sets of shock values incorporate judgement taken from the projection sample. The shock values over the extended baseline may also be multiplied by a decay parameter between zero and one, with the exponent equal to the time period when the shock is assumed to be realised relative to the end of the projection sample. Similarly, the weighted average value of a shock may be directly affected by adding a value to it (the default is zero). This means that judgement can be shock dependent and gradually phased out over the extended baseline.

Once the input values have been determined, the model is used to trace the implications over the extended baseline sample for the observed variables. For the additional assumptions for the constrained Kalman smoother, ECB calculations on the contribution of the ECB's asset purchases programmes (APP and PEPP) to the term premium on long-term government bonds is utilised.[67]

The MTRS extends the projection baseline up to five years. The MTRS is conditioned on the potential output projections for the extended horizon.[68] In addition, the scenario is based on the prescriptions of a standard Taylor-type monetary policy rule, according to which the short-term nominal interest rate adjusts endogenously, while also accounting for the APP and PEPP. The reinvestment policy for maturing securities is also accounted for through the related downward impact on the term premium in long-term nominal interest rates. With these aspects in mind, the MTRS focuses on the consequences for economic activity and inflation over the extended horizon.

Possible enhancements to the MTRS

The approach when compiling the MTRS in the (B)MPEs tries to mimic what is done for the regular horizon regarding the compilation of assumptions and then follow a mechanical approach for the

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65 Prior to the introduction of NAWM II, staff views on potential output growth or the output gap over the projection were conditioned on for the constrained Kalman smoother. Since the output gap is one of the observed variables in NAWM II, this is no longer necessary.

66 The extended baseline of the MTRS is currently not conditioned on an assumption for government consumption, as was previously the case. In the case of NAWM II, this is the only fiscal variable which directly affects the model.

67 Technically, this is implemented through a delta approach where the model-based concept of the ex ante excess return on long-term government bonds is first estimated without the contribution of the APP and PEPP, and the ECB calculations are then added to this estimate.

68 The potential output projections are the NCB/ECB staff estimates over the (B)MPE horizon, and a quarterly interpolation of the annual NCB estimates over the extended horizon. Additional conditioning assumptions over the extended projection horizon concern the performance of the euro area's external environment, based on the IMF World Economic Outlook. Oil prices are extrapolated from the (B)MPE baseline technical assumptions, and US long- and short-term interest rates follow the usual market-based assumptions. The nominal effective exchange rate is determined endogenously within the model based on a no-arbitrage condition, with expected exchange rate revaluations needing to equal expected discounted excess returns of domestic over foreign long-term government bonds.

rest of the process. This yields a simple scenario trying to be as neutral as possible, but also limits its economic content.

There may be different ways of enriching the scenario, at the cost of increasing complexity:

(a) Use a richer international environment scenario: this is a combination of steady-state values for international macro variables and the futures market for commodity prices and financial variables. However, these variables may be inconsistent, and the scenario might not be realistic in view of recent trends such as deglobalisation and potential structural changes to US monetary policy, e.g. an end to non-standard policies.

(b) Use a richer supply-side content: currently the scenario incorporates an aggregation of potential output estimates from the NCBs as the main statistic summarising the average view on the supply side, but there are many uncertainties and nuances surrounding the supply side that can have different impacts, for instance climate change, increasing digitalisation and policies to address these issues.

(c) Use a richer fiscal scenario: NAWM II is not particularly suited to a rich fiscal scenario, but with the build-up of fiscal imbalances during the pandemic and the introduction of important new policies like the Next Generation EU, there is a pressing need to add a fiscal aspect.

(d) Provide additional information on the uncertainty surrounding the scenario.

(e) Combine the MTRS with counterfactual scenarios over the projection horizon.

Box 18
Model-based sensitivity analysis of monetary policy conduct in the (B)MPE

This box discusses why structural macroeconomic models are desirable for evaluating alternative monetary policy scenarios, and shows how to do so using structural models. For central banks, including the ECB, it is of the utmost importance to understand and quantify the impact of different monetary policy options, especially over their policy projection horizons. This analysis has become more critical recently, as the portfolio of monetary policy instruments has been expanded because short-term nominal interest rates are constrained by the effective lower bound (ELB).

Monetary policy instruments and the monetary policy stance

Before considering different monetary policy options, central banks need to understand the macroeconomic impact of their current monetary policy stance. Obtaining a sound estimate of that stance is challenging. A proper assessment relies on timely information, informed judgement and a well-constructed economic analysis which can separate economic shocks from purely monetary policy factors, but also considers the synergies between them. Monetary policy factors include the value of current monetary instruments, their transmission lags and their impact on expectations and future economic developments. Analysis of the current stance is generally subject to a considerable amount of uncertainty. In periods when the economic situation is changing rapidly, with heightened volatility and possibly structural breaks, such as during the COVID-19 pandemic, models based on past empirical regularities can become less accurate. A robust determination of the monetary policy stance requires a comprehensive and broad suite of analyses that makes effective use of the economic, financial and monetary information available, as well as experienced judgement that can help understand the common outcomes across the different analyses and where they diverge.

In terms of the monetary policy instruments to be examined, until the financial crisis of 2008 central banks used mostly short-term nominal interest rates to implement their desired monetary policy stance. However, once those nominal rates reached their ELB, the use of unconventional instruments became common. In the case of the ECB, inflation has remained subdued since mid-2014, posing additional challenges to monetary policy strategy. The ECB has therefore expanded its portfolio of monetary policy measures to achieve its price stability mandate. Policies that have become relevant include forward guidance (FG) with strengthened policy communication, asset purchases (APP), long-term refinancing operations (TLTROs) and more recently, due to COVID-19, the pandemic emergency purchase programme (PEPP). Due to the exceptional nature of these instruments, it was unclear how to evaluate their transmission channels and their impact on the economy. Two problems emerged: first, evaluating the monetary policy stance was more challenging and complex than before; second, there was substantial uncertainty in the estimated impact of the different policies. Macroeconomic models for policy evaluation and forecasting had to be swiftly adapted to overcome these challenges.

So how can the monetary policy stance be evaluated in macroeconomic models? Regardless of the instrument, monetary policy can be implemented in macroeconomic models using a reaction function or specific policy interventions. The interaction between research and policy has resulted in a consensus to adopt monetary policy rules. Rules allow better understanding and communication of monetary policy and can support policy discipline. Taylor rules, for example, help to distinguish between the systematic part of interest rate policy and deviation from this rule, which can be interpreted as policy interventions. They also provide firm anchoring for households' and firms' expectations on the conduct of policy. While Taylor rules, which react to current inflation and real activity, have proven their usefulness in normal times, periods of low inflation and low interest rates have called for modifications to the standard rule. Average inflation targeting, as proposed by the Federal Reserve System, provides a framework for allowing temporary overshoots of inflation without a prompt increase in interest rates. An even stronger effect can be attained with price targeting rules, which imply that periods of low inflation need to be compensated by periods of higher inflation to bring the price level back to its target.

These concepts provide a well understood framework for standard interest rate policies, but they need to be extended to cover non-standard policy too. Forward guidance can be understood as an explicit (and anticipated) deviation from the policy rule. Like Odysseus, policymakers tie their hands not to raise interest rates for a certain time, even if the policy rule indicates the need to do so. Successful FG reduces interest rate expectations and stimulates the economy. It can be perceived, however, as disclosing negative future events and can affect expectations in a negative way. These considerations increase the requirements on the expectations formation process in the models. Micro-founded DSGE models in which agents are assumed to have rational expectations lend themselves to evaluating these policies. Sometimes, though, they predict implausibly high responses, as discussed in the forward guidance puzzle literature.

Asset purchases as an instrument of monetary policy have been incorporated in macroeconomic models either as specific policy interventions, or as an additional policy rule. The models can be extended to feature different transmission channels for them or rely on an indirect approach. In the indirect approach, satellite models are used to evaluate the impact of asset purchases on risk or term premia. General macroeconomic models can then be conditioned on the path for the premia to evaluate the final impact of the purchase programme. This implies that asset purchases can be used as an instrument to manage the long end of the yield curve, so the central bank could decide either on a path of asset purchases for the future (the direct approach), or a path that would implement desired changes in long term rates (the indirect approach).

Finally, in contrast to rules on interest rate setting, asset purchasing rules have received less attention in the literature. Coenen et al. (2020) propose linking asset purchases to the gap between actual interest rates and the interest rate unconstrained by a lower bound, and find that the rule has stabilising properties, especially in the presence of the ELB.

Model requirements and selection for sensitivity analysis

Various types of models have been used to understand the monetary policy stance and the transmission of different monetary policy instruments and measures. In normal times before the financial crisis, time-series, semi-structural and structural models all focused on estimating the transmission of standard short-term nominal interest rate shocks, uncoupling them from other macroeconomic shocks (such as changes in demand and supply). Advances in econometric methods allowed those models to deliver accurate and consistent estimates of the impact of monetary policy. The transmission channel was relatively clear: changes in the short-term nominal interest rate and expectations about future rates influenced the yield curve, and were transmitted to the real economy by affecting lending rates, mortgages rates and yields on corporate bonds.

Once central banks adopted a broader set of monetary policy instruments after the short-term nominal rate reached its ELB, models for evaluating the monetary policy stance had to be adapted, and the transmission mechanisms were not so well understood. The ELB introduces non-linearity in the transmission of monetary policy, so structural models have been updated to account for the possibility that the interest rate can occasionally be constrained. More recent econometric advances also allow for the estimation and filtering of DSGE models subject to this constraint. Structural and semi-structural models have also been augmented to include rich financial sectors, giving a better understanding of the different transmission channels of monetary policy and providing a careful understanding of the financial crisis. Asset purchase programmes and central bank balance sheets have been diligently modelled too, to understand and account for the macroeconomic impact of this new policy instrument. More recent modelling advances include how to evaluate and possibly estimate the impact of forward guidance announcements in structural models, including cases with deviations from rational expectations. Semi-structural models tend to either feature no expectational channels or deviate from the rational expectations approach. They lend themselves to providing an answer to questions where rational expectations seem too restrictive an assumption. Reduced-form models have also provided insights into estimating the impact of different policies and the monetary policy stance. Initially, lack of data posed estimation problems, but more recently time-series models have been used to estimate the impact of asset purchases and forward guidance, and non-linearities have also been incorporated to account for the ELB. Those advances in reduced-form, structural and semi-structural models have make it possible to better characterise the monetary policy stance in recent periods.

Nonetheless, on top of evaluating the current monetary policy stance, central banks also need to evaluate alternative monetary policy scenarios, especially if the monetary policy stance becomes too tight or loose after an unexpected economic shock. While time-series models can deliver historical estimates of the stance, structural and semi-structural models are by their nature best suited to performing counterfactual analysis based on changing the reaction function of the central bank, looking for an optimised design of monetary policy and understanding the relationship between the monetary policy stance and fiscal and/or macroprudential policy. These exercises are significantly harder, if not impossible, to explore in reduced-form models. For example, evaluating a forward guidance programme requires a proper understanding of how expectations are formed and possibly exploring the outcomes under different possibilities. Without a structural model, this analysis may not be feasible.

More specifically for the ECB, it is important to understand a) the current monetary policy stance around each (B)MPE, and b) the different monetary policy options to be implemented around those projections with their estimated impact, and the optimal design to achieve price stability in the medium term. The next section explores these issues using a fully-fledged DSGE model.

Scenario design and simulation protocol

How can macroeconomic models be used to evaluate different monetary policy scenarios? In normal times, with sufficient distance from the interest rate to the ELB, linear models are often seen as providing an adequate description of the economic environment and simulations can be conducted around the steady state or the forecast baseline. Counterfactual scenarios can be constructed assuming alternative specifications of the policy rules, or assuming a different path for underlying economic shocks to evaluate different monetary policy options. This provides point estimates of the impact of the options. But models can also be used to generate stochastic distributions of different variables of interest such as real GDP and inflation under different monetary policy options. This last exercise helps to better understand the stabilisation properties of different monetary policy strategies. Of course, in these counterfactual scenarios it is critical to account for non-linearities such as the ELB. As soon as non-linearities occur, the underlying baseline becomes key and stochastic simulations around the actual data and forecast baseline make it possible to address uncertainties and risks. The next sections show different scenarios constructed using the extended New Area-Wide Model (NAWM II) for the euro area.

An illustrative model-based sensitivity analysis with NAWM II

NAWM II is an estimated small open-economy DSGE model with a rich financial sector that also incorporates asset purchases by the central bank. The model is routinely used at the ECB to interpret different baseline projections and explore alternative model-based monetary policy scenarios in a consistent way. In the latter case, the starting point is generally the respective (B)MPE. Using the model, it is possible to recover the structural shocks that drive the projection, and thereby separate demand, supply or foreign shocks out from the impact of monetary policy. In the simplest case the model is linear, and the shocks can be recovered using a standard Kalman filter. The impact of forward guidance can also be recovered by introducing anticipated monetary policy shocks and using forward interest rates to identify these. This initial step provides an estimate of the monetary policy stance embedded in each projection.

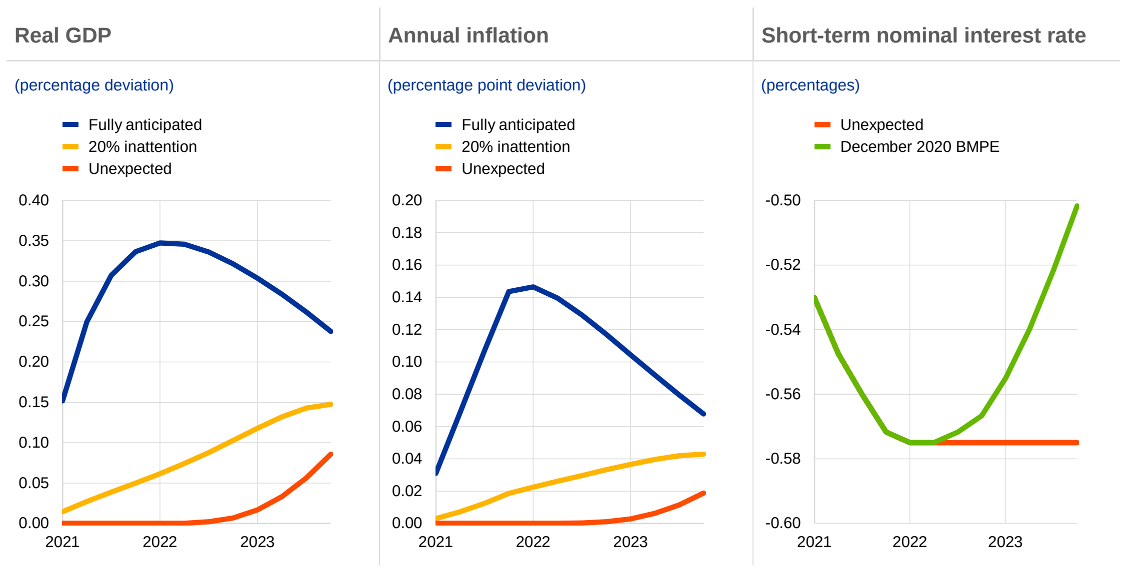
Alternative monetary policy conduct around the (B)MPE baseline

The model is then used to explore the impact of different policies around the (B)MPE. The following simulations show how the model is used to analyse alternative interest rate paths, the transmission of asset purchase programmes and the impact of alternative strategies.

Chart A shows the estimated impact of a lower-for-longer policy around the December 2020 BMPE. The simulation assumes that once the short-term nominal interest rate reaches its minimum value over the projection, it stays there until the fourth quarter of 2023. Compared to the baseline projection, the policy entails a relatively small monetary policy accommodation. If the policy is announced in the first quarter of 2020 and agents fully understand and internalise it, this is tantamount to a fully credible forward guidance announcement (the blue lines). In this case, the peak impact on real GDP would be 0.35% over the baseline, and 0.15 percentage points on annual HICP inflation. However, it is well known that unless modified, DSGE models can be subject to the forward guidance puzzle. Moreover, empirical evidence points to the fact that agents might not be fully attentive to monetary policy announcements.[69] Thus, the new policy is also simulated assuming that 20% of agents might not be attentive to the announcement (the red lines). In this case, the impact on both real GDP and HICP inflation is significantly smaller, as expected. Finally, it is also assumed that, rather than announcing the path, the central bank implements the new policy via unexpected monetary policy shocks (the green lines). In the latter case, real GDP and inflation only react at the end of the projection horizon once the interest rate path starts to deviate from the baseline. The response in macroeconomic variables in this case is the smallest. Given that the level of attention and understanding of economic agents may be difficult to estimate and may change over time, the chart shows how to provide a robust assessment of forward guidance announcements, yielding both a lower and an upper bound on the impact of the policy.

Chart A

Lower-for-longer policy around the December 2020 BMPE



Source: NAWM II.
Notes: The chart shows model-based simulations using the NAWM II model around the projection baseline of the December 2020 BMPE. The simulation assumes that the short-term nominal interest rate remains fixed once it reaches its minimum. Real GDP is shown as percentage deviations from the December 2020 BMPE. Annual inflation refers to the percentage point deviation from the BMPE. The short-term nominal interest rate is shown as a percentage.

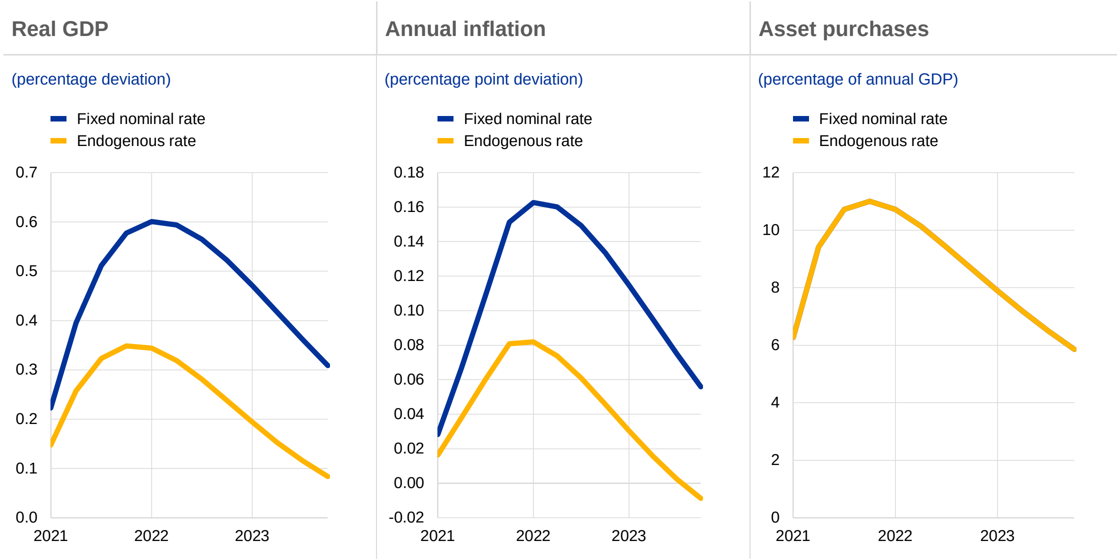
NAWM II also makes it possible to estimate the impact of asset purchases, possibly in combination with other monetary policy instruments. Chart B shows the impact of an asset purchase shock with a peak impact of around 11% of annual GDP. First, it is assumed that the nominal interest rate will react endogenously to the shock (the red lines). Since both real GDP and inflation increase, the

[69] For a summary of the evidence see, for example, the FORE taskforce report.

nominal interest rate will be higher than the baseline values and mitigate the macroeconomic impact of the announcement. In this case, real GDP will have a peak impact of 0.35% and inflation 0.08 percentage points in terms of deviations from the baseline values. However, if the central bank decides to coordinate the asset purchases programme with the interest rate, so the latter remains at its baseline values (the blue lines), the impact is more expansionary, thanks to the additional monetary policy accommodation. As in the previous case, the interest rate path may be anticipated or not – in the chart it is assumed that 80% of agents do so, as in Chart A.

Chart B

Asset purchases around the December 2020 BMPE



Source: NAWM II.
Notes: The chart shows model-based simulations using the NAWM II model around the projection baseline of the December 2020 BMPE. The simulation assumes that there is an asset purchases shock and that the short-term nominal interest rate is either kept at the December 2020 BMPE baseline or increased in reaction to real GDP and inflation. Real GDP is shown as percentage deviations from the December 2020 BMPE. Annual inflation refers to the percentage point deviation from the BMPE. The short-term nominal interest rate is shown as a percentage.

The previous chart showed the impact of asset purchases using a direct approach; that is, the central bank decides on the quantity of assets. Given that one of the main transmission channels of asset purchase programmes is the reduction in long-term yields, it would also be possible to run a simulation using an indirect approach in which the central bank decides on a path for the long-term interest rate and the model then delivers the (endogenously determined) amount of asset purchases that will determine that path. This would also allow the central bank to target both legs of the yield curve (short- and long-term) simultaneously.

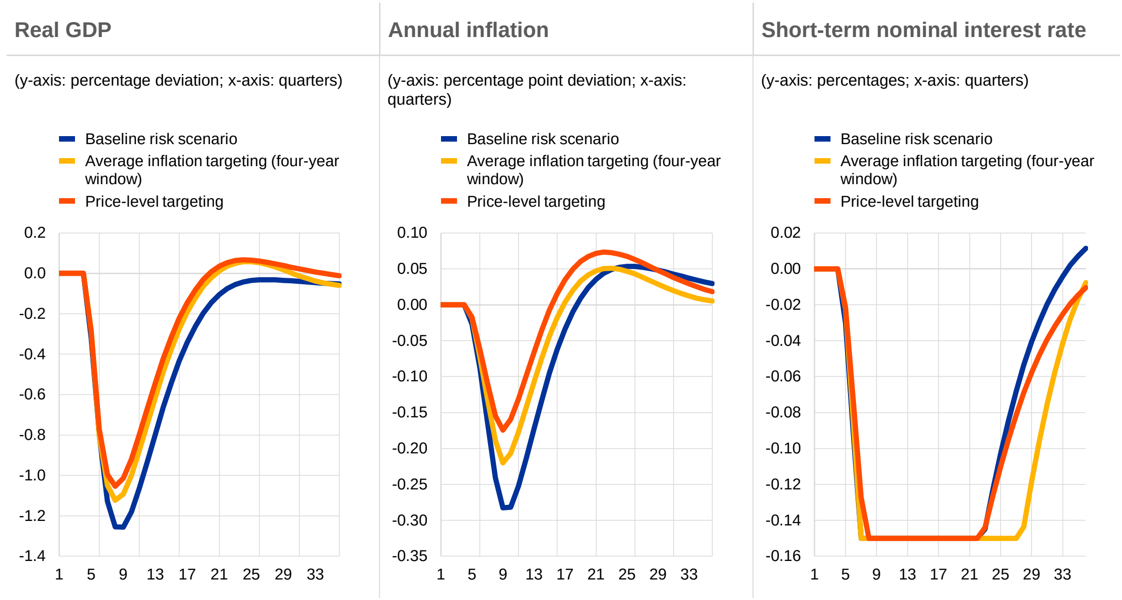
To conclude, structural models are best suited for exploring alternative monetary policy scenarios that would be difficult to investigate with time-series models. Using structural models, it is possible to explore the sensitivity of different strategies to how agents' expectations will react. While not discussed in this box, it is also possible to explore the response under different assumptions about key structural parameters such as the slope of the Phillips curve, or parameters that govern transmission from the financial sector to the real. It should be emphasised that, for robustness, the impact of different policies should be analysed as ranges – that is, considering the lower and upper bounds of the response of the private sector to account for different behavioural characteristics.

Alternative monetary policy conduct around a risk event

The previous simulations showed scenarios in which the central bank decided on specific interventions beyond what the monetary policy rule might dictate. However, structural models such as NAWM II also make it possible to explore the stabilisation properties of different monetary policy rules. This is especially important when there is limited monetary policy space, as the interest rate gets closer to the ELB. In fact, some policy rules may provide better macroeconomic outcomes after an adverse shock that brings the short-term nominal interest rate to the ELB.

Chart C

Make-up strategies in a recession scenario



Source: NAWM II.
Notes: The chart shows model-based simulations using the NAWM II model in a recession scenario under different monetary policy strategies. It is assumed that there is a sequence of contractionary demand shocks. Real GDP is shown as percentage deviations from the baseline. Annual inflation refers to the percentage point deviation from the baseline. The short-term nominal interest rate is shown as a percentage.

Chart C provides an example of how make-up strategies such as average inflation targeting (AIT) and price level targeting (PLT) can mitigate the contraction in output and inflation in a recession scenario where the interest rate is close to the ELB. The starting point for introducing AIT or PLT into a structural model is the baseline short-term nominal interest rate rule. In the case of NAWM II, the rule can be written as

$$r_t = \max\left(\phi_R r_{t-1} + (1-\phi_R)(\phi_\Pi \pi_t + \phi_Y y_t) + \phi_{\Delta\Pi}(\pi_t - \pi_{t-1}) + \phi_{\Delta Y}(y_t - y_{t-1}), \bar{r}\right)$$

where r_t is the (quarterly) short-term nominal interest rate, π_t is quarterly consumer price inflation and y_t is the logarithmic deviation of output from its trend output level (the output gap in the model). In the case of AIT, the rule is augmented so the central bank also reacts to the four-year average of past inflation, so it becomes

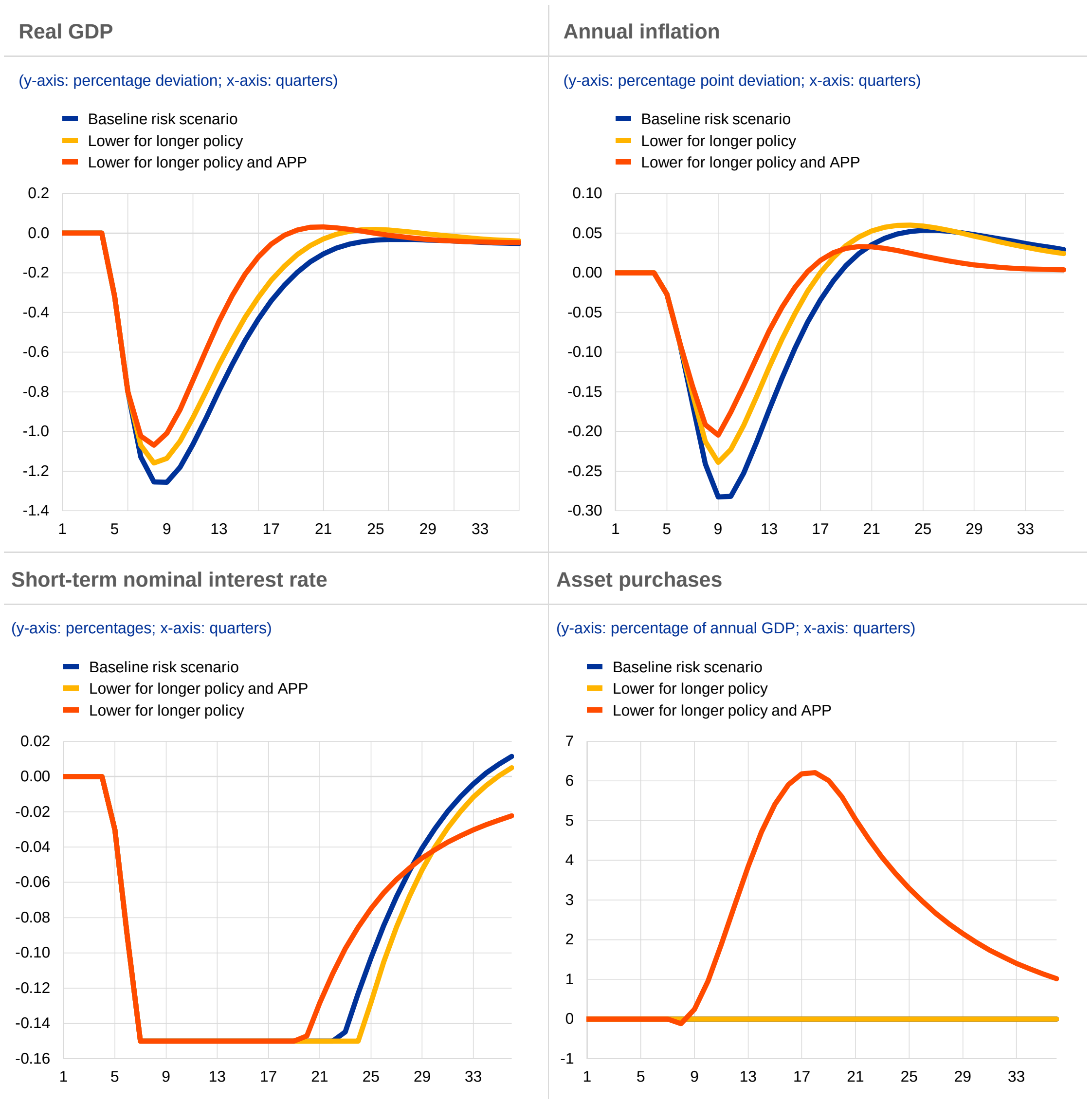
$$r_t = \max\left(\phi_R r_{t-1} + (1-\phi_R)(\phi_\Pi \pi_t + \phi_Y y_t) + \phi_{\Delta\Pi}(\pi_t - \pi_{t-1}) + \phi_{\Delta Y}(y_t - y_{t-1}) + \frac{\phi_A \sum_{j=1}^{16} \pi_{t-j+1}}{16}, \bar{r}\right)$$

In periods when inflation has been low in the past, especially during ELB periods in which the interest rate is constrained and inflation cannot be stabilised, the policy rule would therefore call for an additional layer of accommodation. With PLT, the central bank instead targets a price level gap (p_t), i.e. the logarithmic difference between the price level and the price level target of the central bank. The policy rule becomes

$$r_t = \max\left(\phi_R r_{t-1} + (1-\phi_R)(\phi_\Pi \pi_t + \phi_Y y_t) + \phi_{\Delta\Pi}(\pi_t - \pi_{t-1}) + \phi_{\Delta Y}(y_t - y_{t-1}) + \phi_P p_t, \bar{r}\right)$$

Chart D

Unconventional strategies in a recession scenario



Source: NAWM II.
Notes: The chart shows model-based simulations using the NAWM II model in a recession scenario under different monetary policy strategies. It is assumed that there is a sequence of contractionary demand shocks. Real GDP is shown as percentage deviations from the baseline. Annual inflation refers to the percentage point deviation from the baseline. The short-term nominal interest rate is shown as a percentage.

In the simulation, there is a sequence of adverse demand shocks which mimic a recession. Moreover, it is assumed that there is limited monetary policy space (15 basis points), which implies a substantial drop in real GDP and annual inflation as the central bank cannot cut the interest rate any further. In the baseline case (the blue lines), the recession implies a drop in real GDP of 1.25% below the baseline values, while inflation is 0.3 percentage points lower. However, if the central bank were to target a medium-term inflation average or price level, the responses in GDP and inflation would be more muted. Under make-up strategies, the central bank will tolerate higher inflation in future to make up for the short-term losses due to the recession. Higher expected future inflation lowers real interest rates and thereby stimulates household spending and firms' investment. Likewise, firms respond to the increase in expected future inflation by curbing the reduction in current goods prices. Overall, both AIT and PLT can provide some stabilisation after recessionary shocks.

Finally, Chart D provides an example of how state-dependent lower-for-longer policies and asset purchases can mitigate the contraction in output and inflation in the previous recession scenario where interest rates are ex ante close to the ELB. In this simulation, the amount of forward guidance and asset purchases is determined endogenously using a policy rule that reacts to shortfalls in the desired nominal interest rate once it becomes constrained by the ELB. To be more concrete, the standard monetary policy rule in the NAWM II model is first augmented following a Reifschneider-Williams rule. We define

$$Z_t = \alpha_Z Z_{t-1} + r_{t-1} - r_{t-1}^s$$

as a variable that keeps track of the cumulative differences between the actual interest rate (subject to the ELB), and a shadow rate r_t^s, which is the interest rate that would prevail at each period if the ELB was not in place. Then the interest rate rule is modified so the central bank takes into account the cumulative shortfalls:

$$r_t = \max\left(\phi_R r_{t-1} + (1-\phi_R)(\phi_\Pi \pi_t + \phi_Y y_t) + \phi_{\Delta\Pi}(\pi_t - \pi_{t-1}) + \phi_{\Delta Y}(y_t - y_{t-1}) - \phi_Z Z_t, \bar{r}\right)$$

The rule implies a lower-for-longer policy. Once the nominal interest rate is constrained by the ELB, the variable Z_t keeps accumulating and will still be different from zero after the shadow interest rate has started to rise, keeping the actual rate below the shadow rate during some periods, and providing additional monetary policy accommodation. This is expected by agents in the model, who anticipate lower real interest rates in future, and hence consumption and investment do not drop as much after the recessionary shocks, also implying a smaller shortfall in inflation. The cumulative shortfalls in the interest rate can also be introduced in an asset purchases rule. Thus, asset purchases react endogenously following a simple rule as follows:

$$b_t = \beta Z_t$$

Both rules can mitigate the negative impact of the recession, as seen in the chart, including in combination. In the case of a lower-for-longer policy only, the interest rate stays at the ELB for additional quarters compared to the baseline risk scenario, and there is a peak impact on GDP of 0.2% and of 5 basis points in annual inflation. Once the APP is introduced, there is an additional positive impact on real GDP and annual inflation, which also allows the interest rate to start rising earlier.

Box 19

Combining country models with a model of the rest of the euro area: an example for France

The Banque de France has recently developed a medium-scale macroeconomic model for the rest of the euro area (REA): STREAM (the semi-structural rest of euro area model).[70] Connected to the large-scale semi-structural macroeconomic model for France (FR-BDF) (Lemoine et al., 2019), STREAM allows us to build a two-country semi-structural macroeconomic model for the euro area with an exogenous rest of the world. Complementary to basic model elasticities (BMEs), STREAM allows us to study various shocks, including asymmetric shocks under different types of expectations, with an endogenous response in monetary policy.

Building an REA model: a brief description of STREAM

STREAM follows a similar approach to FR-BDF (Gaulier, Robert and Turunen, 2021). It is a semi-structural model inspired by the FRB/US approach: it uses the polynominal adjustment costs framework and includes explicit expectations that can be either VAR-based, model-consistent or hybrid. We estimate this model equation by equation under VAR-based expectations, using the structural VAR as in FR-BDF (E-SAT), but extended with REA variables. We have made several simplifications in STREAM compared with FR-BDF. First, on the supply side, potential output is exogenous and a New Keynesian price Phillips curve based on the unemployment gap determines inflation (the GDP price deflator). We do not explicitly model the labour market or the price-wage loop: an Okun's law relates unemployment and output gaps. Second, on the demand side, we simply relate the nominal income of households to nominal GDP with a reduced-form error-correction equation. Then we relate household consumption to permanent income and the interest rate, with a role for current demand in the short run. The main drivers of total investment are demand and the expected real cost of capital, based on the sovereign long-term bond rate. As in FR-BDF, the government uses a fiscal rule on social transfers to stabilise its budget deficit/GDP ratio toward a level consistent with a target for the debt/GDP ratio. To capture trade spillovers between France and the REA, the trade block is less simplified. We model both consolidated and internal EA exports and imports (volumes and deflators). Consolidated exports and imports depend on foreign and internal demand and relative price, through error-correction models. We relate internal imports (volumes and deflators) to REA demand and prices; we assume internal exports equal internal imports. Finally, the euro effective exchange rate and the euro/dollar exchange rate equations (real uncovered interest rate parity conditions) are common to both models and the REA term structure is similar to that of France, applied to a weighted average of the sovereign bond rates in the four biggest REA countries. We have checked that the BMEs of STREAM are generally quite close to those implied by the BMEs of the NCBs of the Eurosystem for the REA.

Applications of two-country EA models and complementarity with BMEs

When connected to FR-BDF, STREAM makes it possible to study various shocks, including asymmetric shocks at the EA level, under different types of expectations and endogenous monetary policy responses. First, we are able to simulate EA-wide shocks with an endogenous reaction in monetary policy transmitted to the long-term interest rate and nominal effective exchange rate. As a result, we can consider different types of monetary policy rules (inflation, price level or average

[70] STREAM has been developed by the authors of this box with Guillaume Gaulier, Pierre-Antoine Robert and Harri Turunen and is currently a work in progress; detailed specifications will be published in a working paper soon.

inflation targeting rules) and their respective stabilisation properties in response to shocks. Second, the ability to switch from VAR-based to model-consistent or hybrid expectations is a strength of our model, in particular with respect to questions related to monetary-fiscal interactions and alternative monetary rules (a topic we studied in the expert group on inflation expectations (2021). It becomes particularly useful when analysing unconventional measures such as the asset purchase programme and the pandemic emergency purchase programme. Third, having a two-country model allows us to simulate both symmetric and asymmetric shocks and evaluate spillover effects from trade and monetary policy responses.

Our approach of connecting a country model to an endogenous REA model complements rather than replaces the BME software maintained by the ECB. BME software is the best tool for computing the revisions to a country forecast implied by an isolated revision of an assumption. Another advantage, particularly valuable for small central banks, is that it does not require the substantial resources needed to develop and maintain the extension presented in this box. On the other hand, our two-country approach makes it possible to build richer counterfactual scenarios thanks to the endogeneity of monetary policy and the ability to switch the type of expectations. This could potentially provide additional information for constructing the baseline scenario at the early stage of the forecast, before iterations with the ECB and other NCBs.

6 Assessment of cooperation across the Eurosystem

This section reviews information sharing and cooperation for model developments across the Eurosystem. It proposes alternative sourcing and organisational strategies to close the knowledge and analytical gaps identified. After reviewing the main points of modelling information and knowledge sharing within the ESCB, the section puts forward recommendations on the scope for improvements, benefitting from the experience of recent projects like the projection platform at the ECB, the ESCB/IO and the Schuman Programme.

6.1 Information sharing and modelling infrastructure

Modelling information and knowledge are primarily shared in the ESCB within the Working Group on Econometric Modelling (WGEM) and the Working Group on Forecasting (WGF), whose supporting roles for the Monetary Policy Committee (MPC) are broadly complementary. The WGEM has the mandate to assist the MPC in fulfilling its tasks to (i) promote improvements in the macroeconometric modelling toolkit to meet the needs of the Eurosystem, and (ii) assess analytical and technical issues of interest to the MPC. The mandate of the WGF is to assist the MPC in (i) preparing the economic projections and scenario analyses for the euro area and the euro area countries, and (ii) developing the corresponding procedures, indicators and tools, including evaluating Eurosystem projections. Most of the short-to-medium term activities of the two working groups revolve around the macroeconomic projections, in terms of number crunching and refining the modelling tools needed. The projections are produced using a number of data, models and tools that provide a framework for organising the forecast and important insights, which are fed into discussions with policymaking bodies.

The current organisational framework for sharing information, data and knowledge is based on an infrastructure that works smoothly and efficiently at local level but can still be improved at the overall level. Over the years, the breadth, complexity and sophistication of this process have increased across the board and the solutions in terms of data and model repositories have been coordinated across the ESCB by the WGEM and the WGF to preserve this local efficiency. The result is that many current databases, models and tools are not connected to each other. Independently driven modelling projects have been successful, but not necessarily coordinated. Sometimes both working groups have been able to produce relevant contributions to macroeconometric modelling tools as a result of cooperation between modellers across the ESCB. Notable examples are the EAGLE model, a joint project between the ECB and NCBs that over the years has provided a common platform and facilitated discussion on the use of multi-country DSGE models for policy analysis, and the UCM tool, a joint project to estimate potential output and output gaps in a unified framework across the NCBs in the Eurosystem. The rationale for developing these tools on different data and modelling platforms is based several factors, including legacy reasons. However, there is considerable scope to efficiently exploit synergies when it comes to sharing knowledge, information and models.

To take the projection process alone, the consequences of a "scattered" framework are numerous and, in an evolving digital world, increasingly visible. The use of different software and repositories means that data often has to be transferred from one repository to another for further processing, hindering the end-to-end integrity of the data. Databases are also updated at different times and delays can occur in uploads, sometimes as a consequence of institutional differences between countries. The projections process still suffers from its dependence on bottlenecks in data ingestion and validation (for instance, providing retrieved data from NCBs is a semi-manual process where data is uploaded in DARWIN and then needs to be transferred to local platforms such as FAME). Another consequence of scattered use of databases and tools is extensive use of licenced data and software. The ECB and NCBs run local procurement agreements with data and software providers, most of which are licence-based and can be expensive.[71]

The environment in which our organisations operate is changing at very high speed. Cloud technologies, artificial intelligence and robotics are increasingly being used to reduce costs and improve quality, and digital technologies have become the new norm in the financial world. Against the backdrop of rapidly changing demands, roles and governance, the quality of the operational processes and the skill sets they require have also evolved.

The recommended solution requires us to start designing our organisations for adaptability. One possible way forward is to foster a shift from a functional view to an end-to-end process perspective, delivering complete solutions. End-to-end solutions can eliminate many middle layers or steps and improve the performance and efficiency of a business.

Coordination between ESCB members reflects the internal organisational legacy, but there is scope for improvement. Teamwork and transparent information sharing across borders can be promoted by leveraging common technological innovations and redefining the key processes needed to manage interactions and information flow. One prime example is the ECB's new projection platform, which could serve as a starting point for closer interaction between the ECB and NCBs at the interface of business and IT (see Box 20). The platform architecture and its purpose of providing a data science solution for internal ECB projections processes has similarities to other IT projects within the ESCB such as CASPER and BITBUCKET. A common platform could be used not only for a more efficient projection process but also to effectively share modelling knowledge and practical ways to apply it. The creation of sharing platforms would bring at least three benefits to all NCBs:

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71 One example of an easily accessible data provider is DBnomics, which centralises many data providers and provides data through an easily accessible application programming interface.

- A sustainable, fully supported and long-term user solution would enable projection exercises to run smoothly.
- A central ESCB infrastructure would support efficient use of a wide range of tools by providing a single store for models and make it easy to transfer data and knowledge from one bank to another.
- The data and model repository would improve institutional knowledge and allow the ESCB to develop shared models for common use.
- Feasibility issues should not be underestimated. NCBs may have different preferences for specific platforms for organisational reasons. A common, efficient projection platform would only be feasible if NCBs were in full agreement over its suitability.

What starts as a single process could become the standard for cooperation between central banks. The WGEM and WGF could include promoting, developing and managing projection and modelling platforms in their medium-term work programmes, with NCBs contributing on a voluntary basis, to launch a sustainable innovation process for projections and the associated modelling. The WGEM could be developed towards becoming a model innovation hub, and its activities managed by creating platforms for ideas generation, knowledge sharing and networking.

6.2 Organisational strategies

Creating and making effective use of platforms for knowledge sharing requires central banks to become more interconnected, innovative and flexible. The ESCB starts from a smooth-running basis of two decades of cooperation. It only needs the support and adoption of a few technological advances to crystallise into a truly agile and collaborative system of organisations within an open platform.

The WGEM can play a pivotal role in the modelling agenda, and this agenda has to be able to go beyond model building. The WGEM has always shared practical experience with methodologies, techniques and general developments in econometric modelling and the use of models in policy analysis between ESCB central banks. Its successive chairpersons have maintained a constructive atmosphere over the years, promoting cordial discussions among members, generating constructive suggestions and exchanging information. The WGEM has also made relevant contributions to macroeconometric modelling tools as a result of the cooperation between modellers across the Eurosystem. The intention is to maintain this well-established forum for fostering model development and sharing information with the help of new technologies and formats. Specific recommendations to foster the WGEM agenda can be grouped as follows:

- Enhance the modelling hub function of the WGEM by creating IT platforms for sharing data, models and knowledge, generating ideas and networking.

- Foster connections with similar groups of other central banks around the world, financial institutions, data providers and universities. This can be achieved by boosting the existing ESCB/IO programme and promoting the formation of modelling groups outside the ESCB (similar to the existing Global Group on Semi-structural Models).
- Develop new shared models based on existing success stories like the EAGLE project), embrace new technologies and promote new opportunities. This could be achieved within the framework of the existing Schuman programme.
- Build capabilities and skills in shared technical training sessions offered to and by ESCB staff on modelling-related topics.

Box 20
Model sharing and PERFORM

The ECB **p**rojections **e**nabler plat**form** (PERFORM) will be a user-centric, unified platform that covers the projection process end-to-end. It will provide business practices and technology to produce forecasts and ad hoc model-based analyses using common data access.

What is PERFORM?

PERFORM will provide a unified user experience for ECB economists and modellers, allowing them to share data collected from various sources, use common functions to validate and process data and run models to produce forecasts, visualise data and prepare reports. The projection process will be coordinated collaboratively in an access-controlled environment for decision-making and will ensure traceability and reproducibility.

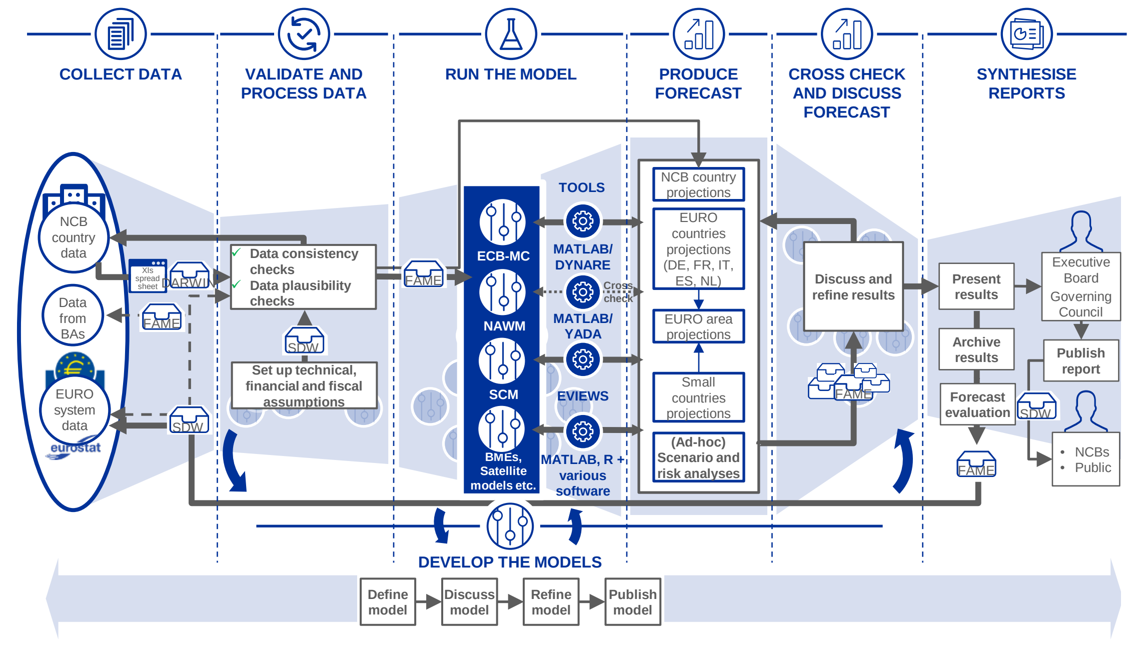
The new platform will provide a single store for models and orchestrate the wide range of models and interactions within the forecasting process. The key guiding principle for its design is to provide more transparent and efficient support for the projection process, with the aim of maximising the amount of time available to analyse and discuss forecasting results. The target solution builds on the data, models and tools currently used in the forecasting process, and will allow flexible and modular extensions in future. PERFORM is intended to be a sustainable, long-term, steady-state solution that will be used to meet ECB/Eurosystem forecasting and reporting needs to the high standards required by modern central banking. It will provide a straightforward workflow for combining models, tools, and processes with data to produce projections and scenario and simulation analyses, adjusting the projections to incorporate judgement, and visualising and reporting the results in several different ways. The data and model repository will preserve institutional knowledge, allow continuous model development, and maximise synergies across business areas and with the ESCB. PERFORM is a joint project of Directorate General Economics and Directorate General Information Systems, facilitated in cooperation with Directorates General Monetary Policy, International and European Relations, Statistics and Research.

Deep dive: the as-is projections process

The as-is projections process illustrated in Chart A serves as the groundwork for developing PERFORM. The current approach for producing forecasts can be summarised as follows. First, models are developed, and data collected from different internal and external sources; the data is validated and checked for consistency and plausibility. Various softwares, models and tools are then run against the data. Each forecast requires a specific model to be run on specific software and toolboxes. These are run in parallel and several times during a projection exercise, applying multiple tools and processes such as data aggregations, trade consistency exercises, satellite models, quantitative risk analysis, etc. The forecasts are then produced based on the outputs of the tools (tables and charts). Ad hoc scenario and risk analyses are performed, in addition to the projections for the regular forecast exercises (MPE and BMPE). Finally, cross-checks and discussions of the forecast results take place, using other models or running different scenarios and adding judgement to produce the final output. This is then synthesised in reports to the MPC, the Executive Board and the Governing Council for policy decision-making.

Chart A

High-level ECB projections process (as-is)



Source: ECB.

Benefits of PERFORM and changes required

The user-friendly graphical user interface is a key element of PERFORM. This will enable users to access different models, adjust parameters, update validation rules, and select internal and external data to run against the model. It has been built around the data, models and tools currently used in the forecasting process, but will allow flexible extension in future so new models can be added if needed without extensive functionality updates.

One of the main benefits of PERFORM and changes it requires from the current way of working relates to the code lifecycle. All model developers will use Bitbucket and GIT repositories. This will ensure a single code repository, automatic model versioning, collaborative working, code sharing and code reusability. The PERFORM data store eliminates most redundant data transfer and conversion operations. The code repository supports model development and data validation and transformation procedures, providing a modern distributed version control system (GIT) and an automation tool (Jenkins). All model code executed by PERFORM will be deployed in a standardised way (e.g. Jenkins) and maintained in a model repository (e.g. GIT). No custom code will be accepted. Jenkins is responsible for packaging the source code of the models stored on GIT and deploying it to the target engines. It is configured with the necessary plug-ins to support the various technologies of the engines. Jenkins will also be able to perform additional checks on the model (e.g. I/O definition, description), to ensure compliance with development standards and store/update model information in PERFORM. GIT is used as the versioning repository and is directly accessible by model developers. Business users of PERFORM will have read-only access to source code files via the GIT web interface. The GIT version structure will be considered an audit trail for model development and version releases.

The process will follow a specific workflow. The workflow engine is crucial to optimising the projection process and reducing the amount of work: it establishes clear dependencies and deadlines between business areas. This will enable users to share data collected from different sources using functions to validate and process data. They will be able to run models to produce forecasts, visualise data and prepare reports in an access-controlled environment with traceability and reproducibility: for example, there will be functions to run different versions of the models supported against different versions of the data, access to the history of model runs and forecast results with metadata providing traceability to the version of data used. Access to data history management with metadata providing traceability to the data submitter, validation checks and the processing applied to the data will also be available. Transparent workflow mechanisms will provide an approval process for models and forecast results. The interface will also enable model developers to upload new models and new versions of existing models.

Box 21

Towards a borderless organisation

The main general strategy that the Eurosystem should pursue is a vision of becoming borderless organisations. This means allowing the boundaries of our institutions to become progressively less precise, opening up to third parties, and building sustainable networks. Realising this vision starts with opening up among the members of the system and then building a more extended network of experts. It may also include joint projects and cooperation with (i) educational institutions and universities, as a way of establishing common specialised knowledge, (ii) other central banks beyond the Eurosystem, to preserve worldwide central banking knowledge, and (iii) fintechs, regulators and industry leaders, to promote an environment for accelerating innovation. The idea is not just to organise conferences and talks as a way of reaching out to scholars and students and allowing central bankers to come together, but also to help central banks position themselves as attractive and innovative employers.

It would be a good idea for the central banks of the Eurosystem to blur their boundaries and embrace a vision of greater openness. There are at least two main reasons to move towards a vision of borderless organisations, and various cooperation models can be considered.

First, there are economic aspects. The central banks of the Eurosystem should not only consider building up know-how and skills internally but also think about leveraging external resources. Investing in more sophisticated models and tools and automating common processes requires specialised skills – and these are scarce. Sharing resources is a natural way to alleviate the skill scarcity while making it possible to preserve a common technical pipeline and knowledge across borders. The Working Group on Econometric Modelling has been using this strategy and the example should be continued. The ESCB/IO contracts have also served this purpose, but in a unilateral way and often only as a privileged entry point for becoming a permanent member of staff at the ECB. The Schuman programme should have the ambition to become an institutionalised open innovation initiative by becoming less bureaucratic and more visible.

Second, engaging with people outside the bank helps ward off tunnel vision and can produce clear efficiency gains. The Eurosystem can purposefully build up a network of experts to leverage third-party knowledge, expertise, experience, capabilities and tools in order to extend our own abilities and gain on-demand access to specialised know-how that our central banks cannot always have in house. This can be done in various ways, e.g.: (i) preparing shared procurement contracts to access the same experts, databases, software, etc.; (ii) teaming up with universities and technical labs to expand the technical expertise of our working groups, including across disciplines; and (iii) enhancing the ESCB/IO programme and opening it up to other world leaders in central banking, financial institutions and regulators through bilateral agreements.

7 Conclusion

This paper provided an assessment of the macroeconomic models regularly used for forecasting and policy analysis in the Eurosystem. These include semi-structural, structural and time-series models covering specific jurisdictions and the euro area within a closed economy, small open economy, multi-country or global setting. Models are used as analytical frameworks for building baseline projections and for supporting the preparation of monetary policy decisions. The paper delivered four main contributions.

First, it surveyed the macroeconomic modelling portfolios currently used or under development within the Eurosystem. The overall suite-of-models approach, which have led a wide array of models, seems adequate and flexible. The projection models (mostly semi-structural) have proved relatively resilient over the last decade, and the structural models used for scenario and policy analysis constitute an important complement to semi-structural models.

Second, the paper explored the analytical gaps in the Eurosystem models and investigated the scope for further enhancement of the main projection and policy models, and the creation of new models. The paper identified the following most relevant areas for enhancement of main projection models: (i) the specification of the expectations formation process and its empirical validation, (ii) the accounting for the relevant transmission channels of non-standard monetary policy measures, (iii) the accounting for exogenous long-term trends in growth, (iv) the adaptation of climate-change related features at the business cycle frequency, and (v) the treatment of large shocks and nonlinearities in the estimation of the models.

As concerns the specific areas for development of the main structural models, these include (i) the complementarities across monetary policy instruments, the microfoundations of the side effects across different non-standard measures and the empirical validation of their transmission channels, (ii) the usage of advanced computational methods to account for non-linearities and multiple equilibria, and (iii) the incorporation of a relevant role for long-term trends. Development of new models should focus on (i) including household heterogeneity and its implications for monetary policy transmission, (ii) accounting for the relevant dimensions of non-linearities in the transmission of monetary policy, and (iii) emphasizing the specification of the energy sector in order to micro-found climate change-related externalities and the role of climate change mitigation policies in the global setting.

Third, the paper reviewed current practices in model-based analysis for monetary policy preparation and forecasting and provided recommendations and suggestions. Avenues for improvement relate to the improvement of the structural underpinning of projection models, the increasing transparency in the use of models, a more systematic use of model-based risk metrics for the projection baseline and the extension of some country-specific models to the rest of the euro area.

Finally, the paper reviewed existing cooperation modalities on model development and proposes alternative sourcing and organisational strategies to remedy any knowledge or analytical gaps identified. Careful consideration should be given to enhancing organisational and collaborative strategies for macroeconomic modelling; the creation of a shared modelling infrastructure could foster knowledge transfer, facilitate information flows and increase the transparency and technical accountability of model-based analysis. The build-up of a voluntary Eurosystem model repository and the development of new models by pooling resources and skills across the Eurosystem and beyond through the standard institutional fora would also be beneficial.

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