External Monetary Policy Review of the Czech National Bank: A Review of the Analytical Framework used for Policy Analysis and Forecasting for Monetary Policy Making

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Preface

In January 2024, the Governor and Board of the Czech National Bank requested that we should prepare an independent review of the analytical framework used for policy analysis and forecasting for monetary policy making at the Czech National Bank, covering the set of core and satellite models as an integrated framework. They also encouraged observations on parts of the framework, and the way it is transformed to monetary policy recommendations and decisions. This Review evaluates in detail the capabilities of the New Keynesian DSGE-type core model and satellite models, considers the current forecasting process and the underlying assumptions and expert judgments, and assesses how the models' findings and forecasts are communicated to the Board for monetary policy decision-making.

We spent three days at the CNB in May for intensive meetings with the monetary policy group (MPG) and the macroprudential policy group, and individual meetings with all members of the Board and their advisers. Further issues were discussed in online meetings and via email correspondence. We were provided with detailed documentation, not all in the public domain. We were met with unfailing courtesy and willingness to cooperate. We were impressed by the sophistication and technical competence of the staff, and the modern technical infrastructure of IT systems, data management and software at the CNB.[1] The CNB has become a leader in the regular application of macroprudential tools to manage the credit cycle, as documented in the CNB's Financial Stability Reports.

Executive Summary

The ensuing set of recommendations is summarised below, and with greater detail in the Review, *and using the same heading numbers.*

1. The motivation for the external reviews.

Four reasons appear to have motivated the external reviews. There has never been an external review, and it was timely. The inflation surge in 2022-3 and the 12-month ahead mis-forecast in October 2021, one of the largest in Europe, signalled a need to re-examine the models generating the forecast. A third reason concerned the model-derived trajectory in the second half of 2022, which effectively implied raising the repo rate to 11%, which the Board rejected. The fourth reason was unhappiness by most of the new Board after February 2023, with aspects of the decision-making process involving the model and model-generated forecasts. This concerned the usefulness of the models; "group think" and focusing on a narrow category of model; a lack of transparency about the models, assumptions and "expert judgments"; and limited flexibility for discussion and simulation of a range of scenarios.

2.1 Limited documentation on the models

The CNB (2024) paper, provided for the outside reviewers (Board members had not seen this paper), is the first attempt to document in one place the modelling and forecasting process. This includes now-casting, near-term forecasting and medium-term forecasting using more eclectic but often sophisticated, data-intensive statistical methods. Prior to this, there were large gaps in the description of the core (g3 or g3+) model. The g3 model was documented in Andrle at al. (2009); developments in the revised g3+ model were summarised in the Inflation Report of 2019(3), and further explained in Brázdik et al. (2020). The core model excludes many variables needed for a holistic understanding of the economy and policy debate. Hence satellite models were developed since 2009 (e.g. for house price forecasting), but were never been fully documented in one place, and their role in adjusting model forecasts via expert judgment was often obscure.

CNB (2024) still does not fully describe the entire framework and its assumptions, and lacks detail. The bases for expert judgments is mostly not given, nor is there systematic documentation of parameter settings and their evolution. An explanation of the dynamics of consumption and investment is absent

[1] By contrast, the latter was an area found deficient by the Bernanke review of forecasting at the Bank of England.

in Andrle at al. (2009). Brázdik et al. (2020) provided hints about consumption dynamics, but not on investment dynamics. These omissions continue in CNB (2024).

None of these papers is explicit about the channels of monetary transmission (the logic of the model suggests these are via intertemporal substitution for households and the exchange rate). The 2021 Autumn Monetary Policy Report, Box 4, explains the transmission mechanism to inflation as seen by the CNB, with credit and asset price channels for households and firms. These are missing in the g3+ model, creating a logical disjunction between the story told in Box 4 and the output of the model. It is unsurprising that most Board members did not fully understand the model or its implications for monetary transmission.

2.2 Assumptions underlying the g3 and the g3+ models

Assumptions underlying the g3 model are laid out in Section 2.2. Household behaviour assumes a utility-maximising representative household with an infinite horizon, and expectations that are consistent with the g3 model. Households face no liquidity or credit constraints, own the firms and make both consumption and investment decisions. Price setting by firms assumes that the frequency of price changes is independent of the state of the economy. The central bank follows a Taylor rule, focused on expected inflation over the next four quarters. There is no stabilising role for fiscal policy. Three significant model developments in the revised g3+ model from 2019 were assigning 30% of households to be non-Ricardian, endogenising a foreign sector based on the Euro area, and restricting forward-looking behaviour to the next three years. Problems with the assumptions, including those about expectations, the lack of a financial sector, the lack of credit constraints and of balance sheet effects, are discussed in Section 4.

R1. To improve transparency and understanding of the current Forecasting and Policy Analysis System (FPAS), we recommend publication of the May 2024 documentation prepared for the external reviewers but adding a clear explanation of the monetary transmission mechanism implied by the g3+ model. The documentation should include more details on satellite models and the extent to which expert judgements are based on these satellite models and on other information sources.

3. Interaction of the "Forecasting and Policy Analysis System" (FPAS) and Board meetings

The Monetary Department produces four macroeconomic projections accompanied by four updates, resulting in eight reports annually. The forecasting process includes consistency checks using inputs from expert judgments and Board members' views. In many respects, the FPAS is a smoothly-functioning and highly professional machine. However, the lack of fit between its underlying assumptions and the Board's understandings of the real world Czech economy and channels of monetary transmission, has probably handicapped the Board's engagement with the FPAS.

In principle, the FPAS and the core model are flexible and capable of producing a variety of sensitivity and policy scenarios. The Board has scope for intervening twice during the preparation of forecasts, before policy meetings. However, with multiple other responsibilities and limited time, Board members often cannot be present at preparatory meetings. A subtext may be that as most members find that the core model and expert judgements opaque, it could be unrewarding to attend. Also, complex simulations involve preparing a full parallel forecast, so that on-the-spot feedback with Board members is limited.

On the Friday prior to the policy meeting of the full Board, the forecasts and draft report are circulated. At the briefing, early in the next week, discussion is very limited: there are no changes to forecasts or recommendations via Board interventions. CNB (2024) documents all simulations of alternative scenarios and simpler sensitivity analyses presented at these meetings. Since the pandemic and the Russian invasion of Ukraine, more consideration has been given to alternative scenarios, sometimes up to two per meeting. However, some Board members felt that a wider range of scenarios and a fuller discussion were lacking.

4.1 The reputational decline of NK-DSGE models for policy modelling

Failure to anticipate the global financial crisis (GFC) of 2008 is linked to New Keynesian thinking, exemplified in the fashionable DSGE models of the time, such as the CNB's core model. These models trivialize the role of uncertainty and heterogeneity, miss key lags in relationships, ignore important feedback loops (seen in the GFC), while co-ordination failures in labour and financial markets are absent. Credit constraints and trading costs faced by households, and household balance sheets play no role in influencing consumption. Credit flows and asset prices, implicated in the financial crisis, are absent from the system dynamics and the long-run. The role of current and near-term income for consumption is ignored, radically affecting monetary policy conclusions. Advances in economic theory and accumulating macro- and especially micro-evidence have undermined key elements of these models. Theoretical developments contributing to the shift in understanding are described in Section 4.1.

At most central banks, more flexible semi-structural econometric policy models, that give greater scope to learn from data, are now preferred to the New Keynesian-DSGE models - no longer seen as the fashionable, at-the-theory-frontier basis for designing a policy model.

4.2 Specific examples of problems with the g3 and g3+ NK-DSGE models

The stylised assumptions to 'micro-found' the g3 and g3+ models, outlined in Section 2.2, do not appeal to most Board members. There is no financial sector, no housing market and no financial assets (except a 'bond'). There is only one domestic interest rate, when the yield curve should be an important focus for policy. The assumption that households, rather than firms, make investment decisions, is hard to swallow, especially when such a large fraction of large companies are foreign-owned, with access to foreign finance. The treatment of government seems rudimentary when fiscal policy rules could potentially be pro-cyclical or anti-cyclical. There are major problems with the simplistic assumptions on wage and price changes, contradicting survey evidence. The service sector is typically more labour intensive than the goods sector, something not captured in the models, and differences in price formation are unlikely merely to concern the frequency of price changes.

Section 4.2 gives an example showing how the g3+ model provides a highly implausible explanation for how inflation affects consumption and therefore aggregate demand, which may help explain why the model-implied interest rate policy response in the second half of 2022 was so large.

4.3 Weaknesses of the core model in communicating with the Board and informing monetary and macro-prudential policies

Board members, in forming their opinions about the economy, generally track GDP components and associated price movements, and sectoral sub-divisions such as services and industry. Consumption and investment are in the g3+ model, but the underlying equations are unlisted and not easily interpretable. Also included in the Board's thinking are credit developments, asset price trends, other aspects of financial sector activity, and labour market developments. These features and sectoral sub-divisions are currently handled only through (poorly documented) satellite equations, which are driven by the macro-variables generated by the g3+ model but without any feedback to the macro variables. These features impede effective communication with the Board.

Central bank policy models should serve a dual function - both for monetary and macroprudential policy. Many mechanisms by which interest rates transmit in the economy are similar to those by which loan standards (i.e. non-price credit conditions), are transmitted. Policy models incorporating both the interest rate channel and the inter-related loan standards channel are helpful in coordinating the two policies. These analyses could not be done using the g3 and g3+ models.

R2. As understandings among central banks of monetary policy transmission have shifted away from those implied by New Keynesian DSGE models, we recommend that the CNB follow widespread central bank practice in developing a more flexible semi-structural econometric model (SEM). Equations for the main components of aggregate demand should incorporate dynamic adjustment around long-run specifications

which incorporate qualitative insights from contemporary theory and micro evidence. Wage and price equations need to be more eclectic, drawing on a broader range of theory and institutional information than the current Calvo pricing assumption in the g3+ model. Such a model should improve communication with Board members and ease the tasks of simulating alternative scenarios.

5.1 Feasible alternatives: a macro-data approach: semi-structural econometric policy models

Most central banks now have semi-structural econometric policy models (SEMs). A more flexible SEM, absorbing some existing satellite models, will improve forecasting performance, facilitate generating alternative scenarios, and integrate the Board more closely with the modelling and forecasting process. However, a critique of central bank SEMs, focused on the European central banks and the ECB, suggests none is fully satisfactory (Muellbauer, 2022). There is no single off-the-shelf model that could be adapted to the special features of the Czech economy. Section 5.1 outlines six areas of weakness in central banks SEMs that should be properly addressed when developing a SEM.

One weakness concerns modelling the household sector, so crucial in Czechia, where final consumption expenditure comprises two thirds of GDP. Most SEMs retain an inadequate specification of the consumption function, omitting interactions of housing with the economy, with poor linkages between the economy and the financial system. Shifting loan standards and household balance sheets are absent, or balance sheet effects are restricted to a single net worth effect. The relatively short effective sample of data for Czechia limits how much of an SEM can be purely evidence based, and modelling is complicated by potential structural breaks associated with major crises. Some parameters need to be calibrated to avoid over-fitting in short samples.

R3. Central to an SEM would be consumption and investment equations paying proper attention to balance sheet effects (hence endogenising balance sheets) and credit channels of monetary transmission. It would be important to avoid specification errors common in the current generation of central bank SEMs, by introducing strong linkages between the banking system and the real economy.

5.2 Feasible alternatives: an approach based on micro- and macro-data: agent-based models

There have been major strides in the ABM approach. ABMs use micro survey data and macro data from national accounts, sector accounts, input–output tables, government statistics, and census and business demography data and a granular treatment of the banking sector and its loan book. Adaptive learning and simple heuristics for household and firm decisions are part of the micro-foundation. The integration of ABMs into the analytical frameworks of central banks is well suited to addressing structural changes like the pandemic, digital currencies and climate change. The Bank of Canada has incorporated an ABM into its policy modelling platform to allow examination of macroeconomic dynamics under significant uncertainty. The detailed structure allows for a breakdown into sector-level forecasts and medium-run macroeconomic effects. Forecasting performance compares well with DSGEs and VARs.

Wiese et al. (2024) calibrates models for 38 OECD economies, including Czechia, offering a useful base for building an ABM model. The CNB has access to far more granular data, for example, from banking supervision and the loan survey, and recent research by the macroprudential division should enable significant improvements to the specification of household budget constraints and behavioural rules for the housing and credit markets. The external sector in g3+ could inform the necessary extension to endogenise the exchange rate and links with the 'Rest of the World'. The resulting ABM would serve as a vehicle for integrating macroprudential and monetary policy issues in the same model.

R4. With increased access to granular micro-databases, the ambition to model aggregate behaviour 'from the ground up' has led to major developments in agent-based modelling (ABM). Such models, have been developed for countries such as Austria, Hungary and Poland, and in one version, for 38 OECD countries, including Czechia. At the Bank of Canada, an agent-based model is now part of the modelling framework for monetary policy, and research on ABMs is ongoing at around 24 central banks. While the time needed to develop such an ABM for Czechia is longer than for the new SEM, running it alongside would illuminate

the transmission channels. It would improve the effectiveness of both monetary and macroprudential policy, and, in particular, help evaluate their distributional consequences.

6. Practical issues for organising these model developments

During the transition to a new SEM, it is important that the CNB's current forecasting framework is maintained. Once a team has been assembled, developing a SEM, with back-testing and running alongside and comparing with g3+, could take 24 months. Current now-casting and short-term forecasting functions will remain. Expert judgements will continue, but not to the degree that had been necessary to make the g3+ model forecasts plausible. The required skill set of the new team is likely to be similar to that of the current MPG, though with greater focus on applied time-series econometric skills. Of the pre-existing set of satellite models, some will be modified and absorbed into the SEM, some will complement the SEM, and some will be discarded. A somewhat longer horizon will be needed to develop an ABM to run alongside and cross-check with the SEM and the satellite models.

Practical issues to ensure a smooth transition include organising and motivating staff, ensuring that the appropriate skills are available, and adjusting personnel policies to facilitate hiring from an international pool. For both the SEM and ABM, it is important that career ladders are designed to reward productive and innovative staff engaging in these developments of the policy modelling frameworks.

R5. Developing a new SEM should draw on existing satellite models both from the macroprudential division and the current monetary policy group, and aim to develop the model on a time scale of 18-24 months. In terms of organisation and personnel, it requires a dedicated team of perhaps six persons which could draw on volunteers from all parts of the Bank, but under the supervision of a senior staff member outside the current MPG to encourage fresh thinking (or possibly a Board member).

R6. The new model should be run alongside the g3+ model, and be evaluated for about 18 months. A smooth transition should then be possible, assuming a satisfactory performance. The g3+ model should be retained for some time, but resources should not be used for its further development.

R7. Consideration of, and publication of, a range of alternative scenarios, developed relatively early in the forecasting process, is important for robust policy-making and for communicating to the public the uncertainties faced by policy-makers. This also helps the public understand how the CNB sees monetary transmission. We recommend enhancement of what is already being done in this respect, which should become easier with the implementation of R2, R3 and R5.

R8. Some adjustment of personnel policies may be required to assist in the realisation of the detailed recommendations in this Review. Researchers with doctoral qualifications may be tempted to work mainly on research that could lead to academic publications in top journals. Career ladders need to be adjusted to reward quality research that enhances the policy-relevant modelling and forecasting capacity of the Bank.

7. Further scope for broadening the research agenda and enhancing research quality

Evidence-based research on expectations requires survey data. New surveys are needed with wider coverage, e.g. of expectations of house price appreciation, for horizons up to and beyond 12 months ahead. These should aim to improve survey participation rates and may require collaboration with outside researchers and agencies. Empirical research on productivity trends, down to granular firm-level data, and R&D, and FDI, would help explain supply-side developments. Labour market puzzles should be investigated with institutionally informed empirical research on labour force participation, labour mobility across occupations, and migration across locations (including cross-border).

R9. Concerns were raised by several of the research staff that there is not enough support for the international visibility of research and for the ability of the Czech National Bank to hire internationally to expand the talent pool and retain high-quality staff. This recommendation calls for greater support for all kinds of research data, software, conferences, visitor-ships, bringing in foreign researchers and foreign speakers. One easily addressed problem is that contracts are always in Czech, making it difficult to attract non-Czech speaking employees.

R10. Expectations play a very important part in economic thinking, for example expectations of inflation and of income growth. It is important to ground these expectations on empirical evidence. Existing surveys are not always of high enough quality and often lack adequate coverage of variables, for example, of asset prices, and of relevant time horizons. Extending coverage and data quality in cooperation with outside agencies would be an appropriate use of resources.

R11. Current research is focused mainly on relatively short-term cyclical properties of the economy to the neglect of evidence-based research on longer-run trends on the supply side. Such research should include analysing productivity growth trends down to the sectoral, regional and even firm levels; and analysing the development of labour supply, and of labour and housing market mismatch, including the impact on labour mobility.

The Review.

1. The motivation for the external reviews.

From the interviews with the Board members, advisors and different groups within the CNB, there appeared to be four main reasons motivating the external reviews of the analytical framework used for policy analysis and forecasting for monetary policy making, and the role of the model in decision-making processes.

The first reason was that there has never been an external review, it was timely, and the CNB should in future commission regular external reviews. The second reason arises from the aftermath of the inflation surge in 2022-3, which appears to have triggered reviews at other central banks, such as the Bank of England.[2] Board members were concerned about inflation forecast failures by the Monetary Policy Group (MPG) generating the forecasts for the Board meetings, in the period of high inflation following the COVID pandemic and the onset of the Russian invasion of Ukraine. The region as a whole had a large inflation spike, and many central banks had forecast failures at this time. Inflation peaked in October 2022 in Czechia, at 18.3% for the 12-month CPI inflation rate. However, Board members considered that the 12-month ahead mis-forecast of around 15%, made in October 2021, and one of the largest in Europe, signalled a need to re-examine the models generating the forecast.

The third reason concerned the model-derived trajectory in the second half of 2022, which effectively implied raising the repo rate to 11%, which the Board rejected. Rates remained at 7% until December 2023, the level to which they had been raised in June 2022.[3] The proposed rate hike proved unnecessary, as by February 2024, the 12-month CPI inflation rate had fallen to 2.0%.

The new Governor was appointed to a six-year term from July 2022. In February 2023, there were significant composition changes in the Board. The fourth reason was unhappiness by the majority of members of the new Board with aspects of the monetary policy decision-making process that involved the model and model-generated forecasts. This included doubts about the usefulness of the core and satellite models underlying the forecasts; concern was expressed about the possibility of "group think"

[2] As our commissioning letter put it: "The motivation for such reviews is to draw valuable lessons for the future from the recent high-inflation episode, aiming to prevent its recurrence. The central banks search for answers to some key questions. What has been omitted from our analyses? Can we improve our analytical and modelling approaches, processes and tools?"

[3] The Board wisely changed the inflation forecast horizon in August 2022 from a 12-18 month horizon to 18-24 months, giving more time for tighter policy to operate, and hence a less sharp tightening.

and focusing on a narrow category of model. There was concern about a lack of transparency about the nature of the models, the assumptions for exogenous variables underlying the forecasts in different decision-making periods, and modifications to the forecasts made by "expert judgment". Some Board members, advisors and members of the staff viewed the models and model forecast to some extent as a black box. The concerns also encompassed a lack of flexibility in being able to discuss and simulate a range of scenarios, including in a sectoral context, for the decision-making process.

2. What is in the public domain about the core model, satellite models and the basis for assumptions about exogenous variables.

2.1 Limited documentation on the models.

The new g3 model was first documented in a CNB working paper in September 2009 by Andrle at al. (2009). The model was trialled from January 2007, running alongside the previous Quarterly Projection Model (QPM), which was based on 'gap' principles. The new model was brought into use as the core forecasting tool in July 2008. The g3 model was a New Keynesian DSGE model for a small open economy with rational (i.e. model-consistent) expectations, sticky wages and prices and an inflation-targeting central bank. Its adoption reflected intellectual fashions reigning in academia and at leading central banks before the global financial crisis. For example, Pagan (2003) argued that these models were at the frontier of what he saw as the inevitable trade-off between theory consistency and ability to fit the data. His paper was influential in persuading the Bank of England to abandon its semi-structural econometric model in favour of its first DSGE-based model BEQM in 2004, then superceded by a simpler DSGE model, COMPASS in 2011, see Hendry and Muellbauer (2018). The Czech economy only started functioning as a market economy in the mid-1990s (joining the EU in 2004), and the banking sector only began normal functioning in the early 2000s. Therefore the limited time series of relevant data has forced modellers toward calibration, rather than estimation, of model parameters. Since calibration or Bayesian estimation, with strongly applied priors, is standard in NK-DSGE models, this could have been another factor in the choice of model type.

As the 2009 paper argued, model development is never stationary. One obvious defect of the 2009 version, discussed further in Section 4, was the assumption that all households are fully informed intertemporal optimisers. Gali et al (2007) had already introduced a hybrid DSGE model where a fraction of households (often referred to as non-Ricardian) just spend current income (though there are no micro-foundations for such an ad hoc assumption). This feature is one of the three significant model developments in the revised g3+ model, first summarised in the Inflation Report of 2019(3) and more fully explained in another working paper, Brázdik et al. (2020).

It is worth noting that development of ancillary (or termed satellite) models to the g and g3+ models has been significant since 2009. These ancillary models are sometimes a basis for 'expert judgments'. As the core (g or g+) model does not include all the variables needed for a holistic understanding of the economy and for policy debate, to quote CNB (2024): "we employ satellite models that base their outputs on a set of variables from the core model to ensure consistency. A typical example is the forecasting of credit and monetary aggregates, which relies on a satellite model and utilizes inputs from the core macroeconomic forecast. There are a number of such satellite models, for example, a model tool for NAIRU and output gap estimation, the decomposition tool for inflation components, a house price forecasting (and valuation estimation) model, a fiscal forecast model, or balance of payments

models. Some of these satellite tools also serve for consistency checks and/or detailed scenario analyses."

The CNB (2024) paper, required for the outside reviewers in May, seems to have been the first attempt to document in one place the process of modelling and forecasting at the CNB. This includes the g3+ model, now-casting, near-term forecasting and medium-term forecasting. It is important to point out that near-term forecasting (NTF) and now-casting has been used throughout with much more eclectic but often sophisticated, data intensive statistical methods.[4] Several members of the Board claimed they had never seen a complete listing of the model as in this document.

Nevertheless, the 2024 document does not provide a fully comprehensive description of the entire framework and its assumptions. A table with a full list of satellite models would be a desirable addition to a future version of CNB (2024). The documentation lacks detail: it should explain, for example, for which variables, the near-term forecasting models are used beyond one quarter ahead. And evidently, since there is no concept of search and match unemployment in the core model, and credit plays no role in that model, a good deal of expert judgment needs to be regularly applied to adjust forecasts from g3+. However, it is obscure how ancillary information, for example on the labour market (see CNB (2024), section 3.2), or from the bank lending survey (see section 6), is used to form such 'expert judgments'.

In general, expert judgment has been heavily used to modify model-derived forecasts. In CNB (2024), Table 2.1 shows the degree to which the root mean square error (RMSE) of forecasts of four variables at 1 and 4-quarter horizons has been reduced by the application of expert judgment for the period 2010Q1 to 2019Q4. For year-on-year inflation, there is 66% reduction at t+1 and 18% at t+4; for the quarterly GDP growth rate the reductions are 41% at t+1 and 28% for t+4; and for 3 month PRIBOR (closely related to the policy rate), the reductions are 73% for t+1 and 71% for t+4. In sum, a dramatic difference is made to the quality of the forecasts by the application of expert judgments, though the bases for such judgments are mostly not spelled out.

Another aspect of lack of transparency to the Board and outside observers is lack of systematic documentation of the parameter settings and how these have evolved over time, if they have. For example, it is unclear to what degree parameters were frequently adjusted to produce more plausible model forecasts.

Below we discuss the assumptions underlying the g3 and g3+ models as presented in the above working papers. Members of the Board and outside observers have found gaps in the explanations of the core model. For example, the Euler equations for consumption and investment are not explicitly mentioned in the 2009 paper, though are important for the dynamics of consumption and investment within the model, see below. The 2020 paper on the g3+ model does state the consumption Euler equation, but does not state the equation for investment, or the respective linearisations around the steady state growth path used in the actual computations. This leaves readers with little appreciation of how investment is determined within the model. This omission is still present in the overview paper, CNB (2024). Indeed, its discussion of domestic demand leaves out investment altogether.

[4] However, we wonder whether advantage has been taken of methodological innovations for now-casting as exemplified in research by Castle et al. (2015) and Druba et al. (2017). For near- or medium-term forecasting, an endemic problem is structural change involving a mean shift in the variable being forecast. Martinez et al. (2017) and Castle et al. (2024) propose practical methods for robustifying such forecasts.

Finally, we turn to transparency about the monetary transmission mechanism in the documentation of the core (g3 or g3+) model. It is striking that none of the three papers (2009, 2020 or 2024) is explicit about the key channels of monetary transmission. The only comment in CNB (2024), is on p.19, referring to the impulse response functions (IRF) for a domestic monetary policy shock. This shows an immediate drop in consumption in Q1, followed by a slight recovery by Q3, drops in exports as well as imports (Figure 2.E6) and an *increase* in real investment, after a tiny fall in Q1. The story behind these IRFs is unexplained, though intertemporal substitution is mentioned for the consumption IRF. The 2020 paper on g3+ does not provide IRFs for investment, exports and imports; and the 2009 paper provides no IRFs at all. It is therefore unsurprising that the Board is baffled by the model.

The 'elephant in the room' is: how does monetary transmission on aggregate demand and inflation operate in the economy of the model? The logic of the model suggests intertemporal substitution for households and the exchange rate as the key channels. A verbal and diagrammatic exposition of the transmission mechanism to inflation as seen by the CNB, one assumes by the MPG as well as by the Board, was given in Box 4 of the 2021 Autumn *Monetary Policy Report*. Interestingly, this exposition contradicts the logic about monetary transmission embedded in the g3+ model. Most importantly, the transmission mechanism in the exposition includes a credit channel and an asset price channel both for households and firms, which are missing in the g3+ model. Therefore, one may well ask: why work with a core model that excludes these fundamental channels? Another example of a contradiction is that the drop in corporate investment seen in Box 4 does not match the IRF in Figure 2.E6. There is a logical disjunction between the story told I Box 4 and the output of the model.

Up until 2024 - the 2024 paper for external reviewers was not previously seen by Board members - the core (g3 or g3+) model was imprecisely described, with large gaps in description, across two working papers and the occasional box in Monetary Policy Reviews. Moreover, the satellite models have never been fully documented in one place, and their roles in adjusting model forecasts via expert judgment has often been obscure. It is unsurprising that most Board members did not fully understand the model or its connection to the monetary transmission process as they perceived it.

We recommend greater transparency of documentation, and at the very least, our **Recommendation R1**.

2.2 Assumptions underlying the g3 and the g3+ models.

In order to claim tractable micro-foundations for the g3 model, several assumptions are made. There is a representative, utility-maximising household with an infinite horizon, which makes *both* consumption and investment decisions. Each household owns a nominal home currency bond. Their income consists of after-tax wage income (and an insurance transfer[5]), lump-sum government transfers, interest income on the bond, rental income on the capital stock and dividend income from firms. The monopolistic firms operate in various sectors of the economy: intermediate, export, import, consumption, investment and public good-producing sectors. Capital accumulation is subject to quadratic adjustment costs, which helps to explain persistence in the investment data. Analogously, to generate persistence in the consumption data, the utility function assumes 'external habits'. This means that utility depends on aggregate consumption in the previous period, as well as on individual consumption in the current period, and this generates a dependence between aggregate consumption at times t and t-1. Wages are

[5] A mathematical device required by the model to handle household uncertainty about income.

set according to Calvo contracts, which means that the probability of a worker obtaining a wage increase is constant over time – independent of economic conditions. When linearised around the steady state, these assumptions give rise to a hybrid New Keynesian Phillips Curve, in which aggregate wage inflation depend on last period's wage inflation and the expected wage inflation in the next period. Pricing in other sectors also follows the Calvo principle, plus a mark-up, so that the probability of any price change is also state-independent. All price equations also incorporate cost-push shocks.

On the supply side, in the domestic intermediate goods sector, firms face a Cobb-Douglas production function with labour and capital inputs. The industry output is one of the inputs to the consumption, government and export-producing sectors. However, intermediate goods are also imported. The remaining sectors are primarily aggregators and distributors, as none of them uses labour or capital. Their value-added comes from monopolistic profits only. Final consumption goods are produced from the domestically-produced and imported intermediate goods with a constant elasticity of substitution between them. It is acknowledged that some consumer prices are regulated but this is regarded as temporary phenomenon. There is no difference between regulated and unregulated consumer goods prices, except for temporary regulated price shocks. In the long-run, all goods become unregulated market goods. For investment goods, the assumption is that they are produced only from imported intermediate goods. For public goods, the assumption is that they are produced only from domestic intermediate goods.

To endogenise the exchange rate, an international bond is introduced and the uncovered interest parity condition is applied to the exchange rate. Artificial assumptions are made about forex dealers to keep the model tractable.[6]

The export sector combines domestic and intermediate inputs in a CES production function, with similar Calvo pricing, and in addition assuming that exporters' prices are sticky in foreign currency. Export production grows with world trade and depends on the price of exports relative to the world price level, where 'world' is proxied by the imports of the EA14.[7] However, expert judgement can add special factors to permit deviations from this assumption.[8]

There are six sector-specific stochastic processes for productivity and stochastic processes for mark-ups, preferences and other sources of shocks. These processes have implications for trends in relative prices as well as for a potential balanced growth path of GDP and its components. However, since trade tends to grow faster than GDP because increased of trade-openness, an 'openness technology' (an extra trend) is introduced to account for the rising nominal share of trade in GDP. There are also stochastic processes for measurement errors. These are features of both the g3 and g3+ models, and documented in the 2009 and 2020 working papers.

A Taylor Rule assumption is followed where the central bank follows a lagged adjustment rule for interest rates, with adjustment around the expected inflation over the next four quarters minus the target inflation rate.

[6] For example, forex dealers would be in the banking and corporate sectors, but as there is no banking sector in this model, the forex profits have to be taxed away by the government.
[7] The EA14 are the 14 members of the Euro area.
[8] For example, an expert judgment might concern the role of China, which is not part of the E14.

The fiscal authority collects direct and indirect taxes and fees, gives out lump-sum transfers and consumes public goods with no utility value to households. It can accumulate public debt. Alternative assumptions about the fiscal rule can be made, for example that public transfers are adjusted in line with revenue receipts. There is no stabilising role for fiscal policy.

The model set-up is consistent with the national expenditure (GDP=C+I+G+X-M) and stock-flow accounts defining the current account and the evolution of foreign debt. The model uses 19 macroeconomic time series: national accounts data for volumes and deflators, the CPI, an index of regulated prices, the wage rate and employment, the domestic nominal interest rate, the exchange rate and world variables on demand, inflation and interest rates.

Kalman and other filters are applied to smooth the many stochastic trends in the model to make them suitable for modelling and forecasting. Optimising behaviour by households generates intertemporal efficiency conditions – Euler equations, which, after linearising around the balanced growth path, imply dynamic paths for consumption and investment. The assumption of model-consistent expectations, combined with stochastic trends, and the requirement to solve the whole system simultaneously, implies a complex iterative process to generate expectations of future paths for all the endogenous variables in the system. Surprisingly, these Euler equations for consumption and investment are not explicitly mentioned in the 2009 paper, but presumably must be quite important for the dynamics of consumption and investment within the model if these are truly consistent with the claimed micro-foundations in optimising behaviour. The 2020 paper on the g3+ model gives the consumption Euler equation but not the equation for investment, and this is still absent in CNB (2024).[9]

The revised g3+ model from 2019 introduced three significant model developments. As mentioned in Section 3.1, a hybrid DSGE model was adopted where a fraction of households (often referred to as non-Ricardian) just spend current income (though there are no micro-foundations for such an ad hoc assumption). It is now assumed that 30% of households are non-Ricardian. The second development is an endogenisation and development of the foreign sector in the form of a model for the Euro area. And the third is a major revision of the infinite horizon rational expectations assumption, attributed to the agents in the model, to a limited horizon. The next 1.5 years receive a full weight, and weights then diminish to the end of the horizon, three years ahead. This means that information relevant for forecasting more than three years ahead is disregarded. The first and third of these revisions amount to an admission of fundamental problems with DSGE models of the kind exemplified in the g3 model.

Problems with the above assumptions, including those about expectations, the lack of a financial sector, the lack of credit constraints and of balance sheet effects, are discussed in Section 4.

3. Interaction between the "Forecasting and Policy Analysis System" (FPAS) and Board meetings.

The Monetary Department produces four macroeconomic projections per year accompanied by four updates, resulting in a total of eight reports annually. As noted above, the forecasting system comprises the g3+ core model, now or near-term forecasting, a range of ancillary models for variables not in the core model, and 'expert judgments', used to amend model forecasts. As the CNB's survey of 22 central

[9] In response to a request for clarification, we received confirmation that the Euler equation for investment, derived from the household budget constraints, is indeed in the g3+ equation system.

banks in Benecká et al. (2024) points out, the basic structure of these systems, long promoted by the IMF, is very similar across many central banks. However, there are major differences in the core model, usually a SEM or a DSGE model or both, in the more developed economies. There are also differences in the degrees to which expert judgment is used to modify forecasts, in the degree of involvement of the ultimate decision makers in the forecast, and in transparency about details of the forecasting process.

The forecasting process is clearly explained in CNB (2024), Section 2.5. The process starts with assumptions about exogenous foreign and domestic fiscal variables and some administered prices. Together with now-cast and short-term forecast information, mainly on the current state of the endogenous variables, and expert judgments, these are fed into the g3+ model for an initial consistency check, which settles on the initial conditions for running the model. The model is then used to generate out-of-sample forecasts of the main macroeconomic variables. A further consistency check is carried out with inputs from expert judgments, and views from Board members.

There are also annual assessments of forecast performance. This is not a straightforward, given data revisions and revised assumptions to include the expert judgments made at the time of the forecasts.

In principle, the FPAS and the core model are flexible and capable of producing a variety of sensitivity and policy scenarios. These could be relatively simple policy simulations such as "what if the CNB keeps rates unchanged for next few quarters", to a more complex ones such as introducing temporarily elevated inflation expectations. The more complex simulations involve preparing a full parallel forecast, with all the satellite computations, which takes time. Regarding alternative scenarios, the Board meets the MPG twice during the preparation of forecast. The meetings are usually take place 3 weeks and 2 weeks before the policy meetings. The Board has scope for intervening in the process during the two meetings and may add or modify alternative scenarios or simulations. Though the forecast is primarily a staff forecast, Board interventions sometimes affect the forecast. However, Board members have multiple other responsibilities within the CNB and limited time, and often cannot be present at the preparatory meetings. A subtext may be that since most of the Board members find that the core model and expert judgements too complex or opaque to fully understand, they felt that it would be unrewarding to attend the preparatory meetings. Also, given the complexity of the core model, simulations take some time to run, so that on-the-spot feedback with Board members is limited.

On the Friday before the main policy meeting of the full Board, usually on Thursday, the forecasts and draft report are circulated and are presented at a three-hour briefing for the Board on Tuesday or Wednesday. However, as the briefing also considers financial stability and financial market operations, there is limited scope for discussion. These meetings are briefings, and no changes to forecasts or recommendations are discussed. There are no Board interventions. The forecast is primarily a staff forecast and the Board does not try to intervene once it has received the final forecast on the previous Friday.

The record in CNB (2024) of the discussion of scenarios at Board meetings since 2008 (see their sub-section 2.5.7), gives the full documentation of all simulations of alternative scenarios and simpler sensitivity analyses presented at these meetings, see their Appendix 2G. Around 40 percent of simulations and sensitivity analyses were not published; and in less turbulent years, only simpler sensitivity checks were carried out. Since the pandemic and the Russian invasion of Ukraine, more consideration has been given to alternative scenarios, sometimes up to two per meeting.[10] However, some Board members felt that a wider range of scenarios and a fuller discussion were lacking.

[10] Of the eight meetings of the Board, only four are followed by publication of the MPR. Internal, unpublished scenarios were also prepared for the some of the four intervening meetings.

After the 2022-3 inflation surge, following discussions with the Board, the Monetary Department developed the 'Scoreboard of Inflationary and Monetary Policy Risks', drawing on a range of eclectic forecasting approaches, including quantile regressions. Where the channels of inflation are complex and non-linear, this visual scoreboard is a way of drawing attention to such risks and introducing them as a potential additional argument in the monetary policy decision-making process

In many respects, the FPAS is a smoothly-functioning and highly professional machine. However, as discussed further in the next section, the lack of fit between its underlying assumptions and the Board's understandings of the real world Czech economy and of the channels of monetary transmission, has probably handicapped the Board's engagement with the FPAS. It may have resulted in sometimes too little discussion of alternative scenarios. What lies behind the expert judgments used to modify and supplement forecasts involving the core model is often unclear to the Board.

4. Critique of the core model.

4.1 The reputational decline of NK-DSGE models for policy modelling.

"Why did no one see it coming?" was the question the UK's Queen Elizabeth famously posed to economists in November 2008, six weeks into the biggest financial crisis in history. Part of the answer lay in New Keynesian thinking, exemplified in the fashionable DSGE models of the time (such as the g3 and later g3+ models), that ignored interactions of the economy with the financial sector. In these models, domestic monetary transmission works mainly through the real interest rate and the inter-temporal substitution channel, where a higher real interest rate reduces current consumption by raising planned future consumption. Credit constraints faced by households, and household balance sheets play no role whatsoever in influencing consumption. Credit flows and asset prices (e.g. prices of equities and real estate), which in reality were heavily involved in the financial crisis, are effectively 'memo items' in these models, merely proxying expectations of future growth, but they are absent from the system dynamics and absent from the long-run.

Along with advances in economic theory – see below, accumulating evidence, both macro- and especially micro-evidence, has undermined key elements of the New Keynesian 'Science of Monetary Policy', as proposed by Clarida, Gali and Gertler (1999). For a critique, see the 2018 special issues of the *Journal of Economic Perspectives* and the *Oxford Review of Economic Policy*. In the latter, Hendry and Muellbauer (2018) argue that representative agent NK-DSGE models (e.g. g3 and the Bank of England's COMPASS) were insufficiently 'stochastic' – as they trivialize the role of uncertainty and heterogeneity, insufficiently 'dynamic' – because they miss key lags in relationships, insufficiently 'general equilibrium' – as important feed-back loops are ignored (seen for example in the global financial crisis), and insufficiently 'Keynesian' – as co-ordination failures in labour and financial markets are completely absent.

Three major theoretical developments have contributed to these shifts in understanding. Buffer-stock saving theory (Deaton, 1991; Carroll, 1992), heavily-cited, explained early on how rational behaviour under income uncertainty and liquidity constraints contradicted the simple textbook permanent income model of consumption which ignored such constraints. It is therefore surprising that the NK-DSGE view of household behaviour, which rests on the simple textbook view, was so widely adopted, when

buffer stock theory radically undermined it. The next development was an early extension of the buffer-stock model to introduce an *illiquid* asset (with a higher return but subject to trading costs), alongside a liquid asset, Otsuka (2004). There are no illiquid assets or trading costs in NK-DSGE models. Trading costs are also a key feature in Kaplan and Violante (2014) and Kaplan et al. (2014) who present theory and evidence on 'hand-to-mouth' consumption, corresponding to short-horizon behaviour by asset-rich consumers who face trading costs in the illiquid asset and a credit constraint.

The third development was to integrate this household behaviour into a general equilibrium model with an otherwise conventional New Keynesian production and pricing side of the economy, see Kaplan et al. (2018) on their 'heterogeneous agent New Keynesian' (HANK) model. In a different paper, Kaplan and Violante (2018) provide a non-technical overview of HANK, showing that monetary policy conclusions are radically transformed compared to the standard representative agent rational expectations life-cycle/permanent income version of the New Keynesian model. The key reason is that in HANK, current and near-term income matter strongly for consumption, and therefore interest rate changes, which affect incomes through the whole economy, then feed through to consumption. This channel is missing in NK-DSGE models. This version of HANK, however, does not incorporate endogenous asset prices (e.g. of equities and real estate), through which, in reality, monetary policy also operates.

Another problem with the current version of HANK is that optimising models with credit and liquidity constraints in a rational expectations setting have yet to be developed as feasible tools for monetary policy modelling. In part, this is because of the great complexity of micro-optimising behaviour when agents face corners and other non-linearities in their intertemporal budget constraints. The makes it hard to develop common model-consistent expectations for macro variables. It also stretches credibility that individuals can solve not only their own complex optimising problems, but those of the other agents in the economy in order to be able to solve for the system dynamics.

The final problem with HANK lies in the pricing assumptions which assume that the frequency of price changes is independent of the state of the economy.

Blanchard (2018) has proposed that, by contrast with the DSGE model approach: "Partial equilibrium modelling and estimation are essential to understanding the particular mechanisms of relevance to macroeconomics". At most central banks, the more flexible semi-structural econometric policy models, that give scope to learn from data, are now preferred to the New Keynesian-DSGE models. Pagan himself, who helped to persuade the Bank of England to switch away from their SEM to the DSGE approach, more recently advised the Australian Reserve Bank to upgrade and add to models in their suite of models to a semi-structural econometric model[11] satisfying the national income and expenditure and stock-flow accounts. The Bank of England is in the process of developing a semi-structural model in 2024.[12] To put it another way, among central bank practitioners, the NK-DSGE approach is no longer seen as the fashionable, at-the-theory-frontier basis for designing a policy model.

4.2 Specific examples of problems with the g3 and g3+ NK-DSGE models.

[11] See Cusbert and Kendall (2018) and Ballantyne et al. (2020).
[12] The small team working on this project are using the ECB-BASE model as a starting point according to information provided at a meeting with the chief economist and staff members in June 2024.

The stylised assumptions to 'micro-found' the g3 model, effectively the same as g3+, except for the latter's addition of non-Ricardian households and the endogenization of the external sector, were outlined in Section 3.2. They are unlikely to appeal to Board members, especially those with a real economy background, whether from business or the public sector. There is no financial sector, no housing market and no financial assets (except a 'bond'). There is only one domestic interest rate, when the yield curve should be an important focus for policy. The assumption that households, rather than firms, make investment decisions, is hard to swallow, especially when such a large fraction of large companies are foreign-owned, with access to foreign finance. The treatment of government seems rudimentary when fiscal policy rules could potentially be pro-cyclical or anti-cyclical.

As noted in Section 2.1, the omission of the credit and asset price channels of monetary transmission directly contradicts the CNB view of how monetary transmission operates (as summarised in Monetary Policy Report 2021 (3), Box 4).

On the basic issue of how inflation affects consumption and therefore aggregate demand, the g3 model provides a highly implausible explanation, which becomes only slightly less implausible with the addition of non-Ricardian households in g3+. Consider a positive shock for both price inflation and inflation expectations with an unchanged nominal interest rate. In the g3 model, with a lower *real* interest rate, consumption should jump because of intertemporal substitution. With higher aggregate demand, inflationary pressure then increases, suggesting a sharp increase in the policy rate. However, real world transmission is likely to be quite different. With the inflation shock, liquid assets are worth less in real terms and the prices of illiquid assets probably decline with the expected increase in interest rates, adding to a negative real balance sheet effect. With nominal inertia in wages, real incomes this quarter decline, as will the short-term expectations of real incomes, until wages can be expected to catch up. In the real world, households are far more sensitive to the near-term outlook than implied by the g3 model. While for a few households, intertemporal substitution could be a factor in their decisions, real aggregate consumption would almost certainly decline. With softer aggregate demand, a far less aggressive monetary response to the inflation shock is suggested than that implied by the g3 model (and somewhat less aggressive than implied by g3+). It is plausible that this is part of the reason for why the model-implied interest rate policy response in the second half of 2022 was so large.

There are major problems also with the state-independent nature of the Calvo assumptions on wage and price changes, contradicting survey evidence, see Bradzik et al. (2024). The service sector is typically much more labour intensive than the goods sector, something not captured in the g3 and g3+ models, and differences in price formation are unlikely merely to concern the frequency of price changes.[13]

4.3 Weaknesses of the core model in communicating with the Board and informing monetary and macro-prudential policies.

A policy model should serve as a key communication instrument between researchers and forecasters and the Board. Our interviews suggested that Board members in forming their opinions about the economy generally tracked the components of GDP (consumption, investment, government, exports and imports) and the associated price movements, and sometimes sectoral sub-divisions such as services and industry. These features are in the g3+ model, with the exception of the sectoral sub-divisions

[13] For example, after suffering profit loss from larger than expected claims, insurance companies tend to raise prices to restore margins. The stochastic processes for mark-ups in g3 and g3+ exclude this.

handled through satellite models. Board members also included in their thinking credit developments, asset price trends, other aspects of financial sector activity, and labour market developments, omitted in the core model. These features are currently handled through satellite equations, but which are driven by the macro-variables generated by the g3+ model, though without any feedback to these macro variables. The lack of feedback is quite implausible.

Consumption and investment are in the g3+ model, but the underlying equations are not easily interpretable. Explicit equations explaining the developments of consumption and investment would help communication and interactions between the modellers and Board members - but are not provided by the g3+ model. By contrast, SEMs have the flexibility to easily run alternative simulations of the system incorporating changes to assumptions, so that alternative scenarios can easily be explored. For example, a Board member could take a different view about some critical parameter in an equation. This would address another key difficulty raised about the current monetary policy process: the lack of opportunity to consider a wider range of scenarios. Apparently, the complexity of the work and the time consumed in running simulations is a reason why more scenarios are not regularly explored using the g3+ model.

Central bank policy models should serve a dual function - both for monetary and macroprudential policy. Many mechanisms by which interest rates transmit in the economy are similar to those by which loan standards (i.e. non-price credit conditions), are transmitted, as explained in detail in Muellbauer (2022). Loan standards play a crucial role in the credit cycle - but also in changing risks for the stability of the financial system and households. Excessively lax loan standards for a period can lead to credit booms resulting in over-indebtedness and over-valuation of asset prices, especially house prices and other real estate prices. When negative shocks arrive, asset prices fall, and households and firms have increasing debt-servicing problems. Then bad loans mount, and a credit crunch typically follows as lenders tighten loan standards, exacerbating the downturn of economic activity. Even without a full-blown banking crisis, macroprudential policy should mitigate the severity of such a credit cycle, see Muellbauer (2024).

Central bank policy models incorporating both the interest rate channel and the inter-related loan standards channel are helpful in coordinating the two policies. See Frait, Malovana, and Tomsik (2015) and Malovana and Frait (2017), for a discussion of such coordination in the Czech context. For example, tighter macroprudential policies have macro-consequences; monetary policy settings need to take account of this, and, where necessary, used in a complementary direction to strengthen the effectiveness of macroprudential policy. Top-down risk scenarios, used for stress-testing financial institutions and for calibrating macroprudential settings in a forward-looking manner, could be improved by being able to simulate different macroeconomics scenarios for the economy, and the associated evolution of asset prices and debt levels. These analyses could not be done using the g3+ model.

The above considerations lead to **Recommendation R2**, to follow widespread central bank practice in developing a more flexible semi-structural econometric model (SEM).

5. Feasible alternatives.

We examine feasible modelling alternatives in the form of SEMs based on macro-data and agent-based models based also on granular data, with macro- and micro-economic implications.

5.1 A macro-data approach: semi-structural econometric policy models.

Most central banks now have semi-structural econometric policy models (SEMs), as discussed in Section 4.1. We recommend that Czechia develops a semi-structural model, absorbing some of the existing satellite models, to improve forecasting performance and the policy usefulness of the model and communication about the model with the Board.

However, none of the SEMs in the public domain is fully satisfactory. A comparative, critical exemplification of central bank SEMs, focused on the European central banks and the ECB, is given in Muellbauer (2022). There is no single off-the-shelf model that could be adapted to the special features of the Czech economy. In what follows, some of the areas of weakness in central banks SEMs are explained, and we propose that these should be properly addressed when developing a Czech SEM.

In Czechia, final consumption expenditure is around two thirds of GDP, so that the household sector of a potential SEM will play a crucial role. However, most SEMs used for policy retain an inadequate specification of the consumption function, omit major interactions of housing with the economy, and have poor linkages between the economy and the financial system, for example through omitting shifting loan standards and balance sheets.

The first defect is that some models have no explicit role for expectations, but instead adopt the opposite extreme of the infinite horizon, model-consistent expectation approach of DSGE model. Two influential models that do have an important role for expectations in their consumption equations, especially for future income expectations, are the Fed's FRB-US and the ECB's ECB-BASE models. These models accept an argument, made in Muellbauer and Lattimore (1985), to reject text-book theory that implies a low discount rate based on real interest rates should be used to discount future incomes. Instead, because of income uncertainty, FRB-US and ECB-BASE both assume that households discount future income with (the quarterly equivalent of) an annual discount rate of 25%. Neither model, however, has a fully satisfactory treatment of how large, unanticipated structural breaks, such as caused by the global financial crisis, affect these household expectations. In principle, such crises are preceded by over-optimism, followed by a learning process as households adapt to new realities, and this can be modelled.

A second defect is that many SEMs (including FRB-US and ECB-BASE), restrict balance sheet effects on consumption to a single net worth effect, where net worth is the sum of liquid and illiquid financial assets and housing wealth owned by households, minus their mortgage and non-mortgage debt. This restriction is highly problematic for multiple reasons. It is quite obvious that pension wealth or housing wealth is not as liquid as a bank deposit or cash, and will therefore imply different marginal propensities to consume. Moreover, housing is both an asset and a consumption good; variations in house prices, therefore, have very different effects (positive) on owner-occupiers and (negative) on renters. The implication of this is first, that consumption equations in SEMs should allow marginal propensities to consume to differ by asset type, and second, the negative effect of worsening housing affordability on consumption by renters and aspirant home-buyers also needs to be controlled for. Applications and evidence for various countries can be found in Chauvin and Muellbauer (2018), DeBonis et al. (2023) and Aron and Muellbauer (2024).

Once household balances are included in a SEM, by disaggregating household balance sheets into liquid assets, mortgage and non-mortgage debt, illiquid financial assets and housing wealth, these elements need to be endogenised in a household sector model. Housing wealth depends on the accumulation of

residential investment and also on house prices. Chauvin and Muellbauer (2018) present a model for France that meets the above objections to conventional models of the household and housing sector. This is extended for residential investment in Muellbauer (2022).

A third defect is that virtually all extant SEMs used for policy neglect how varying loan standards or varying non-price credit conditions affect consumer expenditure. Jorda et al. (2016) track the vast secular expansion of collateralised lending to households by the financial sector in market economies, in the post-war period. However, rather than a common size of debt expansion, there are large country differences in the ratios of household debt to GDP and in the time profiles of these ratios. In Europe, Czechia, Austria, Italy and Greece are at the low end of the spectrum, while Switzerland, Norway, the Netherlands, Sweden, Denmark, and the UK are at the upper end. These differences can largely be explained by the different tax treatment of mortgage debt, and by differences in financial regulation, housing institutions and tenure structure by country.

The mortgage market in Czechia only began in the early 2000s, with a high rate of owner-occupation and zero mortgage debt inherited from the previous socialist planned economy. The growth in mortgage debt is related to the arrival of new generations of young families and their financing needs. It is probable that initially cautious loan standards for mortgages eased over time, and will have varied with variations in the asset base of banks and in macroprudential controls, especially of borrower-based measures (BBMs). The regulation of unsecured debt has also evolved, see Minder (2024) as reported in the Financial Times. Hence, potentially, shifts in loan standards for both mortgage and non-mortgage borrowing could have implications for consumer spending.

Practical modelling of the credit channel for monetary transmission in France, and for macroprudential policy, is illustrated in Chauvin and Muellbauer (2018). Changes in credit conditions, with different measures of these for housing and non-housing loans, affect consumption, and enter equations for housing and non-housing loans, and house prices. These measures play a major role in driving non-performing loan (NPL) ratios for the banking system. For example, a long period of loose loan standards, followed by negative shocks such as higher interest rates, higher unemployment, lower income growth and falling house price to income ratios, will increase the NPL ratio. A credit crunch typically follows, exacerbating the downturn. Moreover, the empirical evidence for France suggests that a higher NPL ratio drives up the spread between the lending rate on housing loans and the cost of bank funds, and also affects residential investment (after controlling for house prices, income and interest rates). These findings all capture important linkages between the financial sector and the real economy.

A fourth defect found in most SEMs, is the treatment of the direct transmission of interest rates to consumption.[14] These SEMs exclude the possibility that nominal interest rates matter in the short-run, as well as real interest rates. Where there are loans with floating interest rates or loans with fixed interest rates but which include some relatively short-term fixes, a cash-flow effect for borrowers arises when the nominal effective interest rate (i.e. which includes the repayment element in debt contracts) changes. The relevance of this timing for debt-refinancing, as fixes reach their end, has been recognised at the CNB following rises in interest rates in 2022-23. This should be incorporated in an estimated consumption function, using information on the proportion of mortgages approaching the end of their

[14] This excludes, therefore, the indirect transmission through income, income expectations and balance sheets.

fixed period. Note that the sign of the long-run real interest rate effect on consumption is not necessarily negative.[15]

Some SEMs include a single model for aggregate investment, but a few disaggregate and specify a separate model for residential investment. The search for a model for *aggregate* investment may be futile since the components of investment behave very differently. The well-specified and easily interpretable model for residential investment in Chauvin and Muellbauer (2018) hints that part of the solution to the notoriously difficult task of finding good empirical models for investment lies in disaggregation, by sector or type of firm (i.e. SMEs vs larger firms if such data exist), or by type of asset. Hubbard (2000) provides a useful summary of debates about how monetary policy transmission is affected by credit market imperfections, with a role for balance sheet effects. However, the empirical literature predominantly uses panel data and there are challenges translating the insights into useful models that can be estimated on aggregate time-series data. Inventory investment also has to be treated separately, see Kahn and Bils (2000), including for insights into business cycle dynamics.

Finally, regarding models for wage and price formation, crucial for good econometric policy models, recent literature draws on a broader range of theory and institutional information than the g3+ assumption of Calvo pricing. The examples include Bernanke and Blanchard (2023), originally developed for the US, applications to other economies in Bernanke and Blanchard (2024), to the euro area by Arce et al. (2023), and, most interesting for a small open economy with a floating exchange rate, a UK application by Haskel et al. (2023). There are also several applications to individual euro area economies, with differing labour market and wage bargaining frameworks.

As noted above, the relatively short effective sample of data for Czechia means that there is a limit to how much of an SEM can be purely evidence based. Moreover, modelling is complicated by potential structural breaks associated with major crises such as the GFC, the euro sovereign debt crisis, the pandemic and the Russian invasion of Ukraine. Clearly, some parameters need to be calibrated to avoid over-fitting in short samples. Not all of the modelling choices made in Chauvin and Muellbauer (2018) are likely to be ideal for Czechia. A separate annex provided with this Review makes some suggestions for the practical implementation of this style of modelling for the household sector in an SEM for Czechia.

This leads to **Recommendation R3.**

5.2 An approach based on micro- and macro-data: agent-based models.

In recent years, major strides have been made in the development of the ABM approach. This alternative approach takes full account of granular micro data and proposes heuristic decision rules for all the agents in the economy. ABMs are now high on the research agenda of a substantial number of central banks, as documented by Borsos et al. (2024). These authors argue that the integration of ABMs into the analytical frameworks of central banks is particularly suited to dealing with structural changes such as those caused by the COVID-19 pandemic, digital currencies and climate change. At the Bank of

[15] Intertemporal substitution is an argument for finding a negative long-run real interest rate effect in the consumption function. However, as explained in Aron et al. (2012) and Beaudry (2024), the structure of household balance sheets and the strength of income growth expectations as well as the degree of intertemporal substitution in preferences affect the size and even the sign of the long-run real interest rate effect.

Canada, such an ABM, entitled CANVAS, see Hommes et al. (2022) has been officially incorporated in the Bank's policy modelling platform. This platform also includes a semi-structural model, LENS, and a DSGE model, ToTEM. Inflation expectations in the ABM are based on adaptive learning with endogenous switching between adaptive learning and extrapolative expectations, see Hommes et al. for further discussion.

CANVAS follows the application of ABMs to specifically macroeconomic forecasting for a small open economy in the study on Austrian data by Poledna et al. (2023). While the treatment of housing is over-simplified[16], both these ABMs use micro and macro data from national accounts, sector accounts, input–output tables, government statistics, and census and business demography data and includes a granular treatment of the banking sector and its loan book. The models incorporate adaptive learning and heuristics, to equip the model to examine macroeconomic dynamics under significant uncertainty, marking a sharp contrast with model-consistent (or 'rational') expectations in DSGE models.

The detailed structure of the Austrian ABM and of CANVAS allows for a breakdown into sector-level forecasts as well as medium-run macroeconomic effects of lockdown measures taken in Austria and Canada to combat the COVID-19 pandemic. Potential applications of the model include stress-testing and predicting the effects of monetary or fiscal macroeconomic policies. Comparisons with DSGEs and VARs of 12 quarters ahead forecasting performance for the main macro aggregates for Austria and Canada, show good performance of the respective ABMs. Like Poledna et al. (2023), the simplified treatment of households and the housing sector in CANVAS misses some elements of the monetary transmission mechanism. Despite this simplified treatment, an application of CANVAS to modelling the post-pandemic inflation surge, by Grazzini et al. (2023), shows considerable forecasting improvements over the vintage forecasts in monetary policy reports from the Bank of Canada.

Articulating linkages between housing markets and credit supply has been an important feature in developing policy-relevant ABMs. The pioneering application is a study of the housing bubble in metropolitan Washington D.C. using household and loan-level data, see Geanakoplos et al. (2012) and Axtell et al. (2014). A later application using UK granular housing and mortgage data was by Baptista et al. (2016), and slightly extended in Carro et al. (2023). Important features of the above studies are the treatments of transitions between owner-occupation and renting, and of drivers of default. These features emphasise model suitability for macroprudential as well as monetary policy. Mero et al. (2023), significantly extend these prior studies. They apply the ABM approach to Hungarian micro-data, with fixed and floating rate loan markets, and importantly, also endogenise the construction sector. The most comprehensive model to date, with a highly articulated coverage of housing and credit markets, finance-real economy connections, and endogenising the major macroeconomic feedbacks (including construction), is by Kazsowska-Moja et al. (2024), calibrated with granular data for Poland.

A significant, recent advance on Poledna et al. (2023) and Hommes et al. (2022), is the ABM in Wiese et al. (2024). The housing market is articulated into owners, renters and landlords, and linked with credit, provision by banks, and there is a more flexible treatment of business investment, resulting in richer macro dynamics. The paper adopts an 18-sector industrial classification. It draws on Compustat micro data for firms and banks, household finance surveys (such as the HFCS), and macroeconomic data, including from balance sheets. Moreover, it calibrates models for 38 OECD economies, *including Czechia*. For forecast performance on macro-data, it compares well against standard benchmarks, and

[16] It assumes that all households invest in housing, ignoring distinctions between owners, free-market and social renters.

against Poledna et al. (2023). This version of the ABM has a highly simplified treatment of the 'Rest of the World', a fixed exchange rate, and does not distinguish between short and long interest rates, but it nevertheless offers a remarkably useful base for building an ABM model for Czechia.

The CNB has access to a great deal more granular data than used by Wiese et al. (2024), for example, from banking supervision and from the loan survey (heavily used for macroprudential policy). The research of the last decade by the macroprudential division should enable significant improvements to the specification of household budget constraints and of behavioural rules relevant for the housing and credit markets. The articulation of the external sector in g3+ could inform the necessary extension of the Wiese et al. model to endogenise the exchange rate and links with the 'Rest of the World'. Building on existing research, the resulting ABM could, in due course, serve as an ideal vehicle for integrating macroprudential issues with monetary policy issues in the same model.

This leads to **Recommendation R4.**

6. Practical issues for organising these model developments.

We have recommended transitioning over a period of around 24 months from the current g3+ model to a new semi-structural econometric model (SEM). A somewhat longer horizon will be needed to develop an agent-based model (ABM) to run alongside the SEM.

It is important that the CNB's relatively smoothly running current forecasting framework is maintained while transitioning to the new framework. Once a team has been assembled, developing a new SEM, together with back-testing and running alongside and comparing with g3+, is likely to take around 24 months. The now-casting and short-term forecasting functions will remain. Expert judgements will still be needed, but not to the degree necessary to make the g3+ model forecasts plausible. The required skill set of the new team is likely to be not so different from the skill set of the current MPG, though with more of a focus on applied time-series econometric skills. Of the pre-existing set of satellite models, some will be modified and absorbed into the SEM, some will complement the SEM, and some will be discarded. It is difficult to be precise about this as little is in the public domain about this set of models (see Section 2.1).

The more flexible SEM will make it easier to generate alternative scenarios, important for robust policy making and for integrating the Board more closely with the modelling and forecasting process.

This leads to **Recommendations R5, R6 and R7**.

The development of an ABM to run alongside and cross-check with the SEM and the retained, complementary satellite models is likely to require the hiring of some new staff with programming and IT skills. The remarkable progress in realism and practical applicability of ABMs has relied heavily on international collaboration. Implementation of a Czech ABM useful for policy modelling will undoubtedly entail more international collaboration than currently prevails at the CNB, and openness to hiring staff from international talent pools, including on short-term contracts.

This is one reason for **Recommendation R9**.

The intellectual foundation on microeconomics for the ABM has parallels with that of the g3 and g3+ models. The differences are that the ABM is founded on micro-data and evidence, with behavioural assumptions based on simpler heuristics, rather than on assumptions about optimising behaviour tuned

to finding tractable equation specifications applicable to aggregate data. Together with similarities in calibrating the microstructure of behaviour and running simulations, the likelihood that ABMs will increasingly be seen as the 'wave of the future', make it plausible that some staff will be keen to invest in developing their human capital in this direction. Significantly, the Bank of Canada, which played a leading role in the adoption of DSGE approaches for policy modelling, has recently endorsed the ABM approach for monetary policy modelling. Moreover, expertise developed in recent years in the macroprudential group, and the micro-data collected, will fit nicely into developing a local adaptation of the ABM framework toward dual use, both for macroprudential and monetary policy making.

Practical issues to ensure a smooth transition from the old to the new modelling framework include organising and motivating staff, ensuring that the appropriate skills are available, and adjusting personnel policies to facilitate hiring from an international pool. For both SEM and ABM, it is important that career ladders are designed to reward productive and innovative staff engaging in these developments of the policy modelling frameworks.

This is expressed in **Recommendation R8.**

7. Further scope for broadening the research agenda and enhancing research quality.

It is widely accepted that progress in the physical sciences and medicine is evidence-based. For several decades, much of macroeconomics appeared to be insulated from the empirical evidence, or evidence was heavily filtered to fit with pre-conceived ideas. This is apparent from what was published in the top journals. Since the GFC, the top journals have become more open to publishing evidence-based research that contradicted these pre-conceived ideas (especially if based on granular data). This has shifted views about how, for example, the channels of monetary transmission operate. As faith in the assumptions of 'rational expectations' has declined, greater attention has shifted to survey data on expectations. Manski (2018) and Shleifer (2019) track these developments and provide evidence on the usefulness of such data.

The CNB should make greater use of existing survey data on expectations, both for domestic sectors and for key trading partners, where surveys meet good quality standards. A good example is the recent paper by Bradzik et al. (2024), analysing data for Czechia from the European Commission on 12-month ahead inflation expectations of households and firms. The findings highlight the adaptive formation of inflation expectations from survey data in the short term, with a more pronounced inflation pass-through during high-inflation periods. New surveys are needed with wider coverage, for example of expectations of house price appreciation, and setting appropriate horizons beyond 12 months ahead. These should aim to improve survey participation rates and in many cases will require collaboration with outside researchers and agencies.[17]

This leads to **Recommendation R10**.

DSGE models, along with their RBC antecedents, emphasise the supply side of the economy, but specify a collection of fairly arbitrary stochastic trends to capture aspects of shifting technologies (and institutions) in policy models, which are not sufficiently based on economic data and actual institutions.

[17] A commendable effort in local collaboration is this project: https://science.fsv.cuni.cz/en/project/survey-of-short-term-and-long-term-inflation-expectations-of-czech-households/

Empirical research on productivity trends, even down to granular firm-level data, and R&D, and FDI, is needed to inform an understanding about supply-side developments important for inflation, as well as growth. In our visit to the CNB, various puzzles about the Czech labour market were repeatedly raised in meetings, and the issues appeared to be imperfectly understood. As wage formation and developments in productivity and competitiveness have such macroeconomic significance, empirical and institutionally informed research on the labour market on issues such as labour force participation, labour mobility across occupations, and migration across locations (including cross-border), should be enhanced. One question concerns the longer-term impact of the pandemic on the labour force. Another concerns potential interactions between housing and labour markets, and the impact on labour mobility (on mobility see Causa and Pochelmann (2020)). Another is whether the mortgage lock-in effect that comes from fixed rate mortgages, that was found relevant in the US (Fonseca and Liu, 2023), is also relevant in Czechia.

This leads to **Recommendation R11.**

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