

DSGE Models in Central Banks: Progress and Prospects¹

Christophe Cahn², Patrick Fève³ &
Julien Matheron⁴

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ABSTRACT

This paper traces how dynamic stochastic general equilibrium (DSGE) models became a central tool for quantitative policy analysis in Central Banks. Their appeal grew out of the shortcomings of large-scale macroeconomic models, the Lucas and Sims critiques, and the gradual shift from real-business-cycle theory to the New Keynesian framework. The paper reviews the medium-scale DSGE model that became standard in policy institutions, as well as extensions dealing with unemployment, open-economy transmission, financial frictions, and fiscal policy. It also discusses the practical machinery (solution, estimation, forecasting, and counterfactual analysis) through which these models are brought to the data and used in policy work. The final part turns to heterogeneous-agent New Keynesian models (HANK), where incomplete markets and distributional heterogeneity reshape the transmission of monetary and fiscal policy. The central claim is that DSGE models remain valuable less as definitive descriptions of the economy than as a disciplined way to connect theory, data, and policy experiments, while identifying where richer mechanisms are needed.

Keywords: DSGE Models; Central Banks; New Neoclassical Synthesis Models; HANK; Monetary Policy; Policy Analysis

JEL classification: E32, E52, E58, C11, D14, D31.

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² Banque de France, christophe.cahn@banque-france.fr.

³ Toulouse School of Economics (UT-Capitole), patrick.feve@tse-fr.eu.

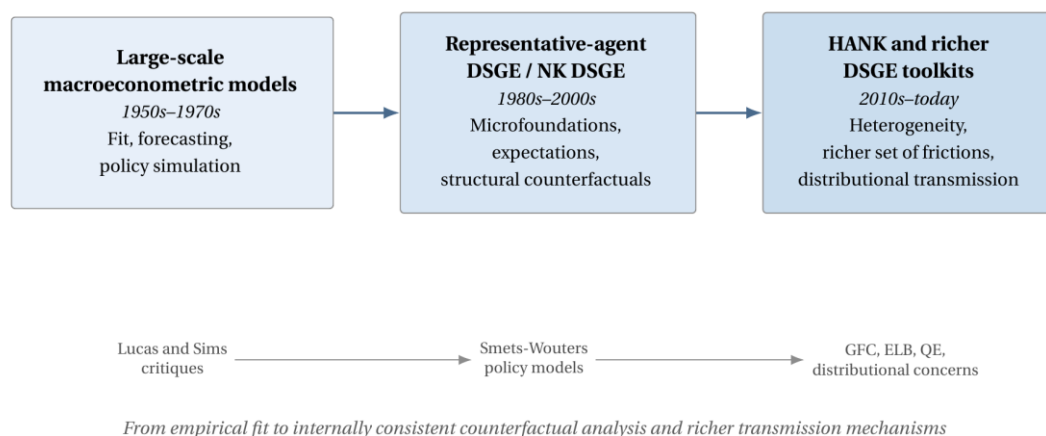
⁴ Banque de France, julien.matheron@banque-france.fr.

NON-TECHNICAL SUMMARY

Central banks need models not only to forecast the economy, but also to assess how economic outcomes may differ across alternative policy and economic scenarios. This requires counterfactual analysis: understanding how the economy might evolve under a different path for interest rates, a change in fiscal policy, or an intervention in financial markets. This article explains why Dynamic Stochastic General Equilibrium (DSGE) models have become an important tool for conducting such analyses. By describing how households, firms, financial markets, and policymakers interact, these models provide a coherent framework for understanding how economic shocks and policy decisions affect the economy.

DSGE models emerged partly in response to the limitations of the large macroeconomic models used in the 1960s and 1970s. Those models could reproduce historical relationships reasonably well, but these relationships could change when policy itself changed. Modern DSGE models instead make explicit how households and firms respond to their economic environment and to policy. This makes them particularly useful for policy experiments in which past experience alone may provide limited guidance. The timeline below illustrates how the framework subsequently evolved as new economic and policy challenges emerged.

Over time, the framework has evolved with the questions faced by central banks. Models have been extended to incorporate, among others, unemployment, international linkages, financial markets, fiscal policy, and unconventional monetary policies. The global financial crisis, for example, highlighted the importance of banks, credit conditions and financial balance sheets, leading these mechanisms to play a much larger role in subsequent models.



More recently, heterogeneous-agent models have addressed another important limitation of traditional DSGE models: households are not all affected by economic policies in the same way. Borrowers and savers, wealthy and liquidity-constrained households, or workers with different income risks can respond very differently to changes in interest rates, taxes or transfers. Heterogeneous-agent New Keynesian (HANK) models incorporate these differences and therefore allow policymakers to study not only the aggregate effects of a policy, but also how those effects depend on who gains income, who loses it, and who adjusts spending the most.

The main lesson is therefore not that one generation of models should simply replace another. DSGE models remain valuable because they provide a common language for organizing economic arguments and checking that policy scenarios are internally consistent. But their conclusions inevitably depend on the assumptions, data and mechanisms built into them. In practice, central banks therefore benefit from using a portfolio of models: relatively simple and fast models for routine analysis, richer models when financial or distributional mechanisms are central, and other empirical tools and institutional judgement alongside them.

Les modèles DSGE au sein des banques centrales : avancées et perspectives

RÉSUMÉ

Cet article retrace la manière dont les modèles d'équilibre général dynamique stochastique (DSGE, *Dynamic Stochastic General Equilibrium*) sont devenus un outil central de l'analyse quantitative des politiques économiques au sein des banques centrales. Leur essor répond aux limites des grands modèles macroéconométriques, aux critiques formulées par Lucas et Sims, ainsi qu'au passage progressif de la théorie des cycles économiques réels (*Real Business Cycle Theory*) au cadre néokeynésien. Le papier présente le modèle DSGE de taille moyenne qui s'est imposé comme une référence dans les institutions de politique économique, ainsi que certaines de ses extensions, portant notamment sur le chômage, la transmission internationale dans les économies ouvertes, les frictions financières et la politique budgétaire. Il examine également les outils pratiques (résolution, estimation, prévision et analyse contrefactuelle) qui permettent de confronter ces modèles aux données et de les utiliser pour l'analyse des politiques économiques. La dernière partie est consacrée aux modèles néokeynésiens à agents hétérogènes (*HANK, Heterogeneous Agent New Keynesian*), dans lesquels l'incomplétude des marchés et l'hétérogénéité des agents modifient les mécanismes de transmission des politiques monétaire et budgétaire. L'idée centrale est que les modèles DSGE conservent leur utilité non pas tant comme descriptions définitives du fonctionnement de l'économie que comme cadres rigoureux permettant d'articuler théorie, données et expériences de politique économique, tout en mettant en évidence les domaines dans lesquels des mécanismes plus riches et plus réalistes sont nécessaires.

Mots-clés : modèles DSGE ; banques centrales ; modèles de la nouvelle synthèse néoclassique ; modèles HANK ; politique monétaire ; analyse des politiques économiques.

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1 Introduction

O. Blanchard (2009) characterizes macroeconomics as having moved, since the fragmentation of the field in the 1970s, toward a broadly shared view of macroeconomic fluctuations and methodology. The emergence of DSGE models in policy institutions can be understood as part of this broader convergence around models that combined explicit economic structure, empirical discipline, and a framework for policy experiments. Tovar (2008) emphasizes that, by the late 2000s, Central Banks in both advanced and emerging economies had become increasingly interested in these models for policy analysis and forecasting. Their appeal was not that they replaced judgment or reduced-form evidence, but that they offered a coherent way to organize policy discussions, identify the sources of fluctuations, and evaluate counterfactual analyses. This last role is especially important for systematic policy changes, such as shifts in monetary-policy regimes, where randomized experiments are unavailable and purely historical or reduced-form comparisons leave open which relationships should be treated as policy-invariant (Christiano, Eichenbaum & Trabandt, 2018). Dotsey (2013) makes the same point from the perspective of monetary-policy practice: DSGE models are useful because they place households, firms, fiscal authorities, and Central Banks in a single general-equilibrium environment, where prices, wages, interest rates, and expectations jointly determine the aggregate equilibrium. This makes their forecasts and policy experiments interpretable in terms of economic mechanisms rather than only statistical correlations.

The transparency of DSGE models is part of their value for policy institutions. Christiano et al. (2018) argue that DSGE models are useful precisely because their assumptions, missing forces, and empirical tensions are explicit. This facilitates scientific criticism: one can ask which friction is missing, which mechanism is too powerful, or which moment the model fails to match. DSGE models are therefore best seen as structured inputs into policy judgment, not as substitutes for it.

Moreover, there is a more basic reason for using the DSGE apparatus. Galí (2017) argues that, given the nature of macroeconomic fluctuations, it is natural for frontier macroeconomic models to be dynamic, stochastic, and general equilibrium: dynamic because central macroeconomic objects such as interest rates, investment, public debt, and expectations are intrinsically intertemporal; stochastic because observed fluctuations contain an unforecastable component; and general equilibrium because aggregate outcomes reflect the simultaneous interaction of households, firms, financial intermediaries, and government across several markets.

As DSGE models became standard in policy institutions, they were also presented as evidence of progress in macroeconomic modelling. Sergi (2017) argues that central-bank presentations of DSGE models often describe them as the outcome of two cumulative forces: a theoretical consensus around microfoundations, rational expectations, and nominal rigidities, and a technical improvement in computation and econometric estimation.¹ This is a useful starting point, but the history did not follow a purely Schumpeterian process in which each new class of models replaced its predecessors. What changed over time was the benchmark for a credible policy model: empirical fit was no longer sufficient without structural interpret-

¹See also Avouyi-Dovi, Fève and Matheron (2007) for a similar analysis.

ation; structural interpretation then had to support internally consistent counterfactuals; and recent advances have placed more weight on distributional transmission and policy incidence. This broad reading is close to Galí (2017)’s assessment. The DSGE methodology can cover early Real Business Cycle (RBC) models, medium-scale New Keynesian (NK) policy models, and newer frameworks with financial frictions, learning, or heterogeneity. At the same time, many applied models still inherit restrictive assumptions, notably the infinitely lived representative household and the stationarity and linearity imposed in standard solution and estimation methods. Those restrictions matter for Central Banks because they limit the analysis of distributional transmission, persistently low natural rates, asset-price bubbles, financial-crisis dynamics, and non-linear adjustment after large shocks. The chapter therefore reads the DSGE tradition less as a single model class than as a sequence of responses to successive empirical and institutional problems: policy-invariance after the Lucas critique, inflation stabilization after the rational-expectations revolution, financial transmission after the global financial crisis, and distributional transmission in the recent heterogeneous-agent New Keynesian (HANK) literature. This chapter is narrower than Rojas Bernal and Markevych (2026), who study changing standards for cycle measurement and empirical credibility, and Baksa (2026), who studies forecasting systems in policy institutions. It focuses on DSGE models as tools for structural counterfactual analysis, typically as used in central banks.

1.1 From Old-Fashioned Econometric Models to Microfounded DSGE Frameworks

This section traces the intellectual path that led from the large macroeconometric systems of the postwar period to the DSGE framework used in modern policy analysis. It first recalls the empirical strengths and theoretical weaknesses of large-scale Keynesian models, then reviews the celebrated Sims and Lucas critiques that exposed their identification and policy evaluation problems. It then turns to RBC models as the first operational microfounded benchmark, before explaining how NK DSGE models combined that discipline with nominal rigidities and a renewed role for stabilization policy.

1.1.1 The Era of Large-Scale Macroeconometric Models

Before the rational expectations revolution, macroeconomic policy analysis was dominated by large-scale macroeconometric models developed during the postwar period. These models, typified by the Federal Reserve Board-Massachusetts Institute of Technology-University of Pennsylvania (FRB-MIT-Penn, or FMP) model in the United States (Ando, Modigliani & Rasche, 1972; Fair, 1984) and similar collections of equations in Europe, sought to capture the aggregate relationships among consumption, investment, output, and prices through empirically estimated behavioral equations. Their structure combined Economics of the Synthesis principles with statistical estimation techniques. Policymakers used them to simulate counterfactual scenarios and assess the effects of fiscal and monetary interventions under different assumptions.² At this first stage, model building was driven less by a search for deep structural invariance than by the practical need to assemble large data systems that could support regular forecasting and policy simulation.

²The institutional afterlife of this model-building ambition, from early forecasting systems to modern model suites, is discussed in Baksa (2026).

The strength of these models lay in their empirical orientation and their capacity to fit observed data. However, their theoretical foundations were weak: they typically lacked explicit optimization behavior, consistent expectations, or general equilibrium discipline. Moreover, behavioral equations were estimated under the assumption that structural parameters were policy-invariant, an assumption later shown to be untenable. Despite these shortcomings, such models guided policy decisions throughout the 1960s and 1970s and formed the backbone of forecasting exercises in many Central Banks (See Fair, 1984).

In retrospect, what aged well was the ambition to build policy models that could be used routinely for forecasting, scenario analysis, and institutional communication. What aged less well was the reliance on reduced-form behavioral equations whose coefficients could not easily be interpreted as stable objects under changes in policy regimes. This tension was already visible in earlier debates over statistical macroeconomics. Keynes's criticism of Tinbergen's business-cycle regressions, including his famous reference to econometric "black magic," was not a rejection of quantitative economics as such. It was a warning that statistical fit could be misleading when the economic relations being estimated were insufficiently identified, unstable across historical regimes, or weakly connected to a theory of behavior (Keynes, 1940, p. 156).

1.1.2 The Sims Critique: Identification and Dynamic Specification

A first wave of criticism emerged from Sims (1980), who argued that traditional macroeconometric models suffered from ad hoc identification restrictions and failed to respect the statistical properties of dynamic systems. Sims proposed the use of Vector Autoregressions (VARs)³ as an alternative, atheoretical framework for capturing dynamic correlations among macroeconomic variables. VARs treated all variables as endogenous and allowed data, rather than prior structural assumptions, to determine the dynamic relationships. For Central Banks, the VAR approach provided a transparent empirical benchmark for impulse response analysis and forecast evaluation. However, it lacked the structural interpretation necessary for policy design. As Sims (1982) later emphasized, VARs could describe but not explain macroeconomic fluctuations. This limitation became more evident once the Lucas critique highlighted the conceptual fragility of policy simulations based on reduced-form relationships.

1.1.3 The Lucas Critique and the Microfoundations Revolution

In his seminal paper, Lucas (1976) argued that the parameters of 1970's macroeconometric models were not structural (i.e, invariant to policy) but instead functions of the policy regime. When policymakers changed their behavior, agents expectations would adjust, rendering previous empirical relationships invalid. Lucas formalized this argument in a simple expectations-augmented Phillips Curve framework, showing that policy evaluation based on historical regressions could lead to systematically misleading conclusions. The implication was radical: to evaluate policy systematically, economists needed models built on microeconomic foundations (i.e., models where behavior derived from the optimization of rational agents subject

³Rojas Bernal and Markevych (2026) provide the fuller business-cycle narrative behind this shift, from large structural systems to VARs, structural VARs (SVARs), Bayesian VARs (BVARs), and later DSGE and HANK frameworks; for broader background on time-series methods, see Fuleky (2026).

to constraints), and where expectations were consistent with the models structure (rational expectations). This critique fundamentally reshaped macroeconomics (Lucas & Sargent, 1979), giving rise to the micro-foundations revolution that culminated in the DSGE paradigm. The DSGE response to Lucas was therefore powerful, but only partial. By deriving behavioral equations from preferences, technologies, constraints, and policy rules, DSGE models make explicit which objects are meant to be policy-invariant. This does not prove, however, that the parameters labelled as structural are genuinely deep—that is, rooted in the underlying microeconomic structure. Habits, price-indexation coefficients, adjustment costs, policy rule coefficients, or shock processes may summarize institutional arrangements, expectations formation, or approximation choices that themselves change across regimes. The Lucas critique is thus displaced rather than eliminated: it becomes the question of whether the model's supposedly structural parameters are identified, stable, and invariant over the counterfactuals for which the model is used. The historical break was therefore methodological as much as theoretical: policy models now had to explain why their behavioral equations would remain valid under the very policy experiments they were used to study.

1.1.4 Real Business Cycle (RBC) Models: A Benchmark of the New Paradigm

The first operational realization of the new paradigm was the Real Business Cycle (RBC) model developed by Kydland and Prescott (1982) and Long and Plosser (1983). Building on Lucas and Rapping (1969), the RBC methodology suggested that economic fluctuations could be explained by real shocks (especially technology shocks) propagated through intertemporal substitution in consumption and labor. Agents were rational, markets cleared continuously, and prices were fully flexible.

A simplified RBC setup can be summarized as follows. A representative household chooses consumption, labor, and next period's capital (savings) so as to maximize expected, discounted utility over time, balancing both the intratemporal arbitrage between consumption and leisure and the intertemporal arbitrage between consumption and saving. Output is produced by combining capital and labor through a neoclassical production function hit by a stochastic productivity shock. In this environment, the discount factor governs intertemporal trade-offs, labor-supply curvature pins down the Frisch elasticity, and the production technology determines capital's income share. Under perfect competition, wages and rental rates equal marginal products, and aggregate fluctuations emerge from the economy's optimal response to productivity shocks.

In contrast to previous models, RBC frameworks are internally consistent and forward-looking. One may argue that they are in essence more immune to the Lucas critique. Moreover, they offer an elegant narrative: fluctuations arise as optimal responses to real shocks under rational expectations. However, they fail to explain persistent deviations of output and employment from potential, nor (obviously) the observed sluggish dynamics of inflation and output. The empirical shortcomings of RBC models (highlighted by Cogley & Nason, 1995) motivated the incorporation of real frictions and nominal rigidities that would restore a role for stabilization policy.

Historically, RBC models did not settle the debate, but they showed that fully specified intertemporal equilibrium models could be computed, calibrated, and taken to data. Their flexible-price view of business

cycles has aged less well for policy analysis, but their discipline on expectations, technology, and intertemporal choices became part of the DSGE toolkit. The next historical step was to preserve this discipline while restoring the nominal frictions needed to make monetary stabilization meaningful.

1.1.5 From Real to NK DSGE Models

The transition from RBC to NK models represented a reconciliation between microfoundations and Keynesian stabilization policy. While retaining the optimizing behavior and general equilibrium consistency of RBC models, NK frameworks introduced nominal rigidities (sticky prices and/or wages) that generated short-run non-neutralities of monetary policy.

The Rotemberg and Woodford (1997) model provided the canonical NK setup with monopolistic competition and Calvo-style price rigidity.⁴ The representative firm faces a downward-sloping demand curve, sets prices subject either to adjustment costs or to staggered repricing opportunities, and produces output with a technology in which labor is the only input, subject to exogenous productivity shocks.⁵

The model highlights two core equations. On the pricing side, current inflation depends on expected future inflation, on real marginal-cost pressure captured by the output gap, and on exogenous cost-push disturbances. On the demand side, the output gap is forward-looking and decreases when the ex ante real policy rate rises relative to the natural real rate. In this representation, the key objects are the output gap, the nominal policy rate, the natural real interest rate, and markup or cost-push shocks. Together with a monetary-policy rule, typically of Taylor type, these relationships form the standard three-equation NK core used in modern monetary policy analysis.

1.1.6 Operational DSGE Models in Central Banks

The integration of DSGE modeling into central-bank practice occurred through the work of Smets and Wouters (2003, 2007). Building on Christiano, Eichenbaum and Evans (2005), their medium-scale DSGE model combined the theoretical structure of NK models with a rich set of frictions. Using Bayesian estimation techniques, they demonstrated that the model could fit postwar U.S. data as well as unrestricted VARs while preserving structural interpretability. The Smets-Wouters (SW) model's empirical success marked a turning point. It bridged the gap between theoretical rigor and empirical relevance, showing that DSGE models could serve both as structural laboratories for policy analysis and as quantitative tools for forecasting and scenario simulation. Central Banks rapidly adopted variants of this framework, including the New Area-Wide Model (NAWM) at the European Central Bank (ECB) (Christoffel, Coenen & Warne, 2008), the Federal Reserve's SIGMA open-economy model (Erceg, Guerrieri & Gust, 2006), and the Terms-of-Trade Economic Model (ToTEM) at the Bank of Canada (Murchison & Rennison, 2006), among others.

⁴Price rigidities can also be modeled through quadratic price-adjustment costs in the spirit of Rotemberg (1982), or through nominal contracts as in Fisher (1977) and Taylor (1980).

⁵Important precursors include Hairault and Portier (1993), Yun (1996), and Kim (2000), which already embed nominal rigidities in dynamic general-equilibrium environments with capital accumulation, but do not yet model monetary policy through the now-standard explicit Taylor-type interest-rate rule.

By the mid-2000s, a broad consensus emerged around the NK DSGE framework as the ‘core model’ of modern macroeconomics and monetary policy (see Woodford, 2003; Galí, 2008). The resulting ‘New Neoclassical Synthesis’ (Goodfriend & King, 1997) unified the microfoundations of RBC models with the nominal and real rigidities of Keynesian analysis. Central Banks employed these models to study the transmission of monetary shocks, to estimate potential output, and to evaluate alternative policy rules. This was the moment at which DSGE models became operational central-bank tools rather than mainly academic laboratories, largely thanks to Michel Juillard and Dynare (Cherrier, Saïdi & Sergi, 2026). The features that aged well were the combination of nominal rigidities, policy rules, Bayesian estimation, and shock decomposition; the features that aged less well were the representative household, the limited role of financial balance sheets, and the near-exclusive focus on small fluctuations around a stable, deterministic steady state.

Yet this consensus was soon challenged by new developments, calling for an improved model design. The Great Recession did not end the use of DSGE models in policy institutions. It made clear, however, that the standard toolkit was missing mechanisms that had become central for policy analysis. In particular, the global financial crisis of 2008 revealed the inadequacy of models with frictionless financial markets to capture financial instability and the widening of interest rate spreads. These shortcomings motivated extensions incorporating financial frictions (e.g., Carlstrom & Fuerst, 1997; Bernanke, Gertler & Gilchrist, 1999; Christiano, Motto & Rostagno, 2014) and the rise of Heterogeneous-Agent New Keynesian (HANK) models, which reintroduced distributional mechanisms into the DSGE framework.

1.2 Chapter Scope and Organization

This chapter studies how DSGE models became a central framework for economic policy analysis in Central Banks and other institutions, and how their role has changed as the field moved from representative-agent NK models to heterogeneous-agent environments. The focus is deliberately practical: the chapter emphasizes the mechanisms, empirical implementation, and policy exercises that make DSGE models useful for organizing data, interpreting shocks, and evaluating counterfactual policy scenarios.

The chapter is organized as follows. Section 2 presents the canonical medium-scale NK DSGE framework used in Central Banks, together with selected extensions, particularly relevant for Central Banks, that add unemployment, open-economy, financial frictions, and fiscal policy to the core framework. It also reviews the solution and estimation methods that turn these models into quantitative tools. Section 3 explains how estimated DSGE models are used for dynamic analysis, forecasting, counterfactual experiments, and policy applications such as disinflation, unconventional monetary policy, and natural-rate measurement. Section 4 turns to HANK models, showing how incomplete markets and household heterogeneity modify transmission mechanisms, revive the Keynesian-cross logic in a structural setting, and broaden the set of policy questions that DSGE models can address. Section 5 concludes.

2 The Canonical NK DSGE Model for Central Banks

This section provides the backbone used in the remainder of the chapter. It first presents the medium-scale NK benchmark in the SW tradition, then reviews extensions that became central for policy institutions (labor-market slack, open-economy transmission, financial frictions, and fiscal interactions). It then turns to the operational implementation of these models: solution methods, from log-linear to nonlinear approaches, and estimation strategies, from limited-information methods to likelihood-based Bayesian procedures.

2.1 Medium-Scale DSGE Models

While the canonical three-equation model is analytically tractable, it abstracts from many empirically relevant frictions. Building on Christiano et al. (2005), Smets and Wouters (2003, 2007) introduce a richer environment designed to reconcile structural discipline with the persistence and comovement observed in postwar macro data. This medium-scale agenda was further developed by Justiniano, Primiceri and Tambalotti (2010, 2013), which provide complementary quantitative evidence on shock transmission and policy trade-offs in estimated NK frameworks.

Households On the demand side, *habit persistence* in consumption increases the intertemporal complementarity in consumption decisions, thus generating extra persistence, which helps generate hump-shaped responses of consumption to monetary and demand shocks. Investment is governed by *dynamic adjustment costs*, so households optimally smooth investment over time because changing the growth rate of investment is costly; this friction reproduces the gradual response of investment observed in the data (Christiano et al., 2005).⁶ The model also allows for *variable capital utilization*, which gives agents an intensive margin of capital services in the short run and improves the joint fit of output, labor, and inflation dynamics by dampening the response of real marginal costs to macroeconomic shocks.

Firms and Labor Market As in the canonical NK model, production is undertaken by monopolistic firms. They combine capital and labor through a neoclassical production function and possibly face fixed production costs. Price setting is subject to nominal rigidity. A key medium-scale contribution is the introduction of *sticky wages*. Nominal wage rigidities play a crucial role in improving the model's empirical fit. In addition, both price and wage rigidities are combined with *partial indexation* to past inflation. Relative to a purely forward-looking NK block, this delivers more realistic inertia in price and wage inflation and helps match the delayed, persistent pass-through of shocks. Wage stickiness is especially important for labor-market dynamics: it slows real wage adjustment and improves the empirical behavior of hours worked and marginal costs.

⁶At first glance, it may seem odd that physical capital is accumulated at the household level rather than at the firm level. In the context of the NK model, this assumption helps circumvent an important difficulty. As firms are heterogeneous in terms of their ability to reset prices, one expects also heterogeneous accumulation decisions if capital were decided at the firm level. For further details, see Sveen and Weinke (2005), Woodford (2005), Matheron (2006), Eichenbaum and Fisher (2007), and Altig, Christiano, Eichenbaum and Lindé (2011).

Monetary Policy The Central Bank follows an interest-rate rule à la Taylor (1993), reacting to inflation and real activity. The rule also features *interest-rate smoothing*, in the spirit of Clarida, Galí and Gertler (2000). Smoothing is not merely a statistical add-on: it captures observed policy gradualism and is crucial for matching the persistence of short rates and the transmission of policy shocks.

Shock Structure and Empirical Role Smets and Wouters (2007) combine four standard real shocks (technology, risk-premium, investment-specific, government spending) with three nominal disturbances (price-markup, wage-markup, and monetary policy shocks). This richer shock structure is essential for historical decompositions and policy counterfactuals in Central Banks, because it separates demand, supply, and cost-push sources of fluctuations within a single coherent model.

In practice, the model is estimated in a Bayesian state-space framework, as discussed in Section 2.4.3. Its success comes from this combination: enough frictions to fit the data, but still sufficiently structured to support welfare analysis, forecasting, and policy simulation. As such, this class of DSGE models imposes economic structure on the data and helps clarify the transmission mechanisms through which policy affects output, inflation, and other macroeconomic aggregates.

2.2 Extensions Relevant for Central Banks

The SW framework gave Central Banks a workable core model for monetary-policy analysis, but its benchmark version was too narrow for many of the questions that later became central. It had no explicit unemployment rate, treated the economy largely as closed, left financial intermediation in the background, and gave fiscal policy only a limited role. Much of the subsequent DSGE literature can be read as an attempt to keep the discipline of the medium-scale model while opening it to these margins. The coverage below is deliberately selective. It focuses on extensions that became especially useful in Central Bank environments because they could be embedded in estimated DSGE models and linked to recurrent policy questions, rather than surveying the full literature on each margin.

2.2.1 Unemployment

Galí, Smets and Wouters (2012) start from a simple gap in standard New Keynesian DSGE models, including Smets and Wouters (2007): the models track the output gap and total hours, but they do not distinguish employment from hours per worker and therefore have no unemployment rate. The dramatic deterioration of the labor market during the Great Recession made that omission increasingly untenable. Central Banks needed an estimated model in which unemployment could move together with output, inflation, wages, and policy rates. The extension also speaks directly to Chari, Kehoe and McGrattan (2009), who argued that estimated NK models were still weak policy tools, notably because their shock structure did not cleanly distinguish wage cost-push (wage-markup) disturbances from labor-supply shocks.

Their model enriches the SW framework by introducing, along the lines of Galí (2011), a heterogeneous labor supply with an endogenous participation rate, so that unemployment arises as the gap between the

labor supply desired at the prevailing wage and actual employment. This formulation preserves the log-linear tractability of the model and allows Bayesian estimation on U.S. data, while adding observed unemployment to the vector of variables used to identify the structural shocks. The model can thus decompose unemployment fluctuations into contributions from demand, technology, monetary-policy and, above all, labor-supply (or *wage-markup*) shocks.

This is not the only way to introduce unemployment into DSGE models, and for some questions it is not the most natural one. Search-and-matching extensions model unemployment as the outcome of vacancy posting, matching frictions, job creation, and wage bargaining, building on the Mortensen-Pissarides tradition (Mortensen & Pissarides, 1994). They are therefore better suited when the policy question concerns labor-market tightness, hiring costs, job destruction, or the Beveridge-curve dimension of unemployment. Examples include estimated monetary DSGE models with unemployment and wage bargaining (Gertler, Sala & Trigari, 2008) and NK models in which labor-market frictions shape the inflation-unemployment trade-off (O. Blanchard & Galí, 2010). For Central Bank applications, the choice between the Galí-style unemployment block and search-and-matching frictions is thus pragmatic: the former preserves medium-scale tractability and direct observability, while the latter gives a more structural account of labor-market flows and matching inefficiency.

Two results emerge. First, adding unemployment as an observable sharpens the identification of *wage-markup* shocks, reducing their estimated volatility and clarifying their role in wage and price inflation. Second, labor-supply and demand shocks account for most medium-run unemployment fluctuations, whereas monetary-policy and technology shocks play only a minor role. In particular, the sharp rise in unemployment during the Great Recession is attributed primarily to demand shocks.

2.2.2 Open-Economy NK DSGE Models

Modern Central Banks operate in open economies, where exchange rates and external shocks matter. Open-economy NK models accordingly augment the canonical closed-economy block with foreign demand, trade linkages, and exchange-rate pass-through. A typical open-economy Phillips curve states that domestic inflation depends on expected future inflation, domestic slack, imported inflation, and a cost-push shock, with the imported-inflation term scaled by the degree of exchange-rate pass-through to import prices. Extensions of the SW framework have followed three broad routes, depending on the Central Bank's institutional setting.

A first strand treats the domestic economy as a small open economy taking world prices and interest rates as given. Building on Galí and Monacelli (2005), Adolfson, Laséen, Lindé and Villani (2007) estimate an SW-style model with incomplete exchange-rate pass-through for Sweden (the backbone of the Riksbank's RAMSES model), while Lubik and Schorfheide (2007) use a similar setup to ask whether Central Banks in small open economies respond to exchange-rate movements beyond their indirect effect on inflation and activity.

A second strand abandons the small-open-economy approximation in favor of two-country structures in which both blocks are fully specified and linked through trade and financial flows: Rabanal and Tuesta

(2010), for instance, estimate such a model on euro area and U.S. data to account jointly for the real exchange rate and the international business cycle.

A third strand, of particular relevance for the Eurosystem, considers monetary unions in which member countries share a common currency and policy rate but differ in their cyclical positions. For example, the Euro Area and Global Economy (EAGLE) model of Gomes, Jacquinot and Pisani (2012) was developed within the Eurosystem to analyze macroeconomic interdependence across euro-area countries and the rest of the world under a single monetary policy. Similarly, the International Monetary Fund (IMF) developed the Global Integrated Monetary and Fiscal Model (Kumhof, Laxton, Muir & Mursula, 2010), a multi-region DSGE designed for the joint analysis of monetary and fiscal policy and cross-border spillovers.

2.2.3 Financial Frictions

In the baseline NK DSGE, financial markets are frictionless: firms borrow at the risk-free rate, and balance sheets play no allocative role. This assumption is convenient but counterfactual, as it rules out any transmission channel through credit spreads, leverage or financial intermediaries net worth, and thus leaves the model silent on the episodes in which these variables are most informative. Introducing financial frictions restores a role for the financial sector in shock propagation and complicates the implementation of monetary policy by giving the Central Bank a second set of margins (spreads, leverage, risk premia) to monitor alongside inflation and the output gap.

The seminal contributions are Carlstrom and Fuerst (1997) and Bernanke et al. (1999). Both embed a costly-state-verification problem à la Townsend into an otherwise standard business-cycle model: entrepreneurs finance capital purchases with a mix of internal net worth and external debt, and the cost of external finance rises with leverage. The resulting *financial accelerator* amplifies and propagates shocks, because a fall in asset prices erodes net worth, raises the external-finance premium, and further depresses investment. For monetary policy, this mechanism implies that interest-rate changes transmit not only through the intertemporal consumption margin, but also through balance sheets and credit spreads, so that identical policy rates can have very different effects depending on the state of borrower net worth.

Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) shift the friction from non-financial borrowers to financial intermediaries themselves. Banks face a moral-hazard constraint that ties their lending capacity to their own net worth, so that shocks to bank equity disrupt credit supply. This reformulation proved central to interpreting the 2007-2009 crisis: the collapse was not driven by a standard productivity or monetary shock, but by an impairment of intermediary balance sheets that widened spreads, tightened credit, and contracted activity even as policy rates were cut to zero. It also provides a natural laboratory for unconventional policies: once private intermediation is constrained, central-bank asset purchases and direct credit provision substitute for impaired intermediaries and relax the constraint, which rationalizes large-scale asset purchases and, more tentatively, the analysis of unconventional instruments more broadly.

2.2.4 Fiscal Policy

Fiscal policy enters NK DSGE models through the aggregate resource constraint, which states that output is allocated to private consumption, private investment, and government consumption, and through a government budget identity linking debt, taxes, and spending.

The financial crisis put fiscal policy on the forefront (e.g., American Recovery and Reinvestment Act in the United States, Sarkozy's stimulus package in France).⁷ Cogan, Cwik, Taylor and Wieland (2010) use the SW model to evaluate the 2009 U.S. stimulus and find government-spending multipliers well below unity—an order of magnitude smaller than the 'old Keynesian' numbers that informed the debate at the time. The mechanism is the standard NK one: forward-looking households anticipate future taxes and higher real rates, crowding out private consumption and investment. The exercise also exposes a more structural limitation: SW was estimated with only a residual treatment of the government sector (no distortionary taxes, no debt feedback, and a nearly unit-root spending process) so that the model is silent on precisely the transmission channels (anticipations of future taxes, debt dynamics, regime shifts) that drive fiscal multipliers, and its quantitative answers on stimulus are fragile for that reason.

Three subsequent contributions take this critique seriously. First, Leeper, Traum and Walker (2017) develop a medium-scale DSGE model with a fully specified fiscal block (distortionary labor, capital and consumption taxes, transfers, and a debt-stabilizing rule) and show that the reported dispersion of multiplier estimates collapses once one controls for the fiscal-monetary interactions, the financing assumption and the inclusion of non-Ricardian households.

Second, the influence of monetary policy on fiscal policy is particularly prominent at the zero lower bound. As shown by Christiano, Eichenbaum and Rebelo (2011), when the policy rate is stuck at zero, a positive government-spending shock no longer triggers an offsetting rise in the real interest rate, so that multipliers become substantially larger than in normal times. This result reconciles the small NK multipliers of Cogan et al. (2010) with the much larger numbers invoked to justify stimulus during the 2008-2009 episode.

Third, Fève, Matheron and Sahuc (2013) make a complementary but more technical point: estimated government-spending multipliers obtained from DSGEs are biased when the econometrician treats the exogenous spending process as a first-order autoregressive process (AR(1)) while in fact it responds systematically to economic activity (automatic stabilizer). Ignoring these features delivers multipliers that are artificially low and unstable across samples.

Overall, once taxes are distortionary rather than lump-sum, they modify households' and firms' optimality conditions (intertemporal consumption, labor supply and investment margins) as in Leeper, Plante and Traum (2010), so that the fiscal instruments used to finance spending shape the propagation of fiscal shocks themselves. This literature uses estimated DSGE models to quantify fiscal multipliers and the interaction of tax and spending rules with the monetary regime.

⁷See Coenen et al. (2012).

2.3 Solving DSGE Models: Linear and Nonlinear Methods

DSGE models, whether canonical or medium-scale, involve dynamic stochastic systems derived from households' and firms' first-order conditions, together with feasibility constraints and market-clearing requirements. In general, these systems do not have an analytical solution, due to their nonlinearity, forward-looking structure, and size. Consequently, approximate solution methods are employed to obtain the equilibrium dynamics necessary for quantitative analysis.

2.3.1 Log-Linearization

Following King, Plosser and Rebelo (1988) the standard workhorse method in the DSGE literature is log-linearization around a deterministic steady state. They showed that the full equilibrium dynamics of a neo-classical business-cycle model could be characterized by a small linear system in percentage deviations from the balanced growth path, lending itself to transparent analytical and numerical manipulation (see Campbell, 1994). Using the stability conditions identified by O. J. Blanchard and Kahn (1980), one can also assess whether the dynamics are determinate. Practical recipes such as Uhlig (1999), Sims (2002), and Klein (2000) turned log-linearization into the routine first step of virtually every applied DSGE exercise, from textbook NK models to the medium-scale systems estimated at Central Banks.

In practice, each endogenous state variable is rewritten as a deviation from its steady-state level, typically in log-deviation form, which at first order is equivalent to a percentage gap relative to steady state. This change of variables converts the original nonlinear equilibrium conditions into a linear expectational system in which current states, expected future states, and exogenous shocks are linked by coefficient matrices evaluated at the deterministic steady state. In that representation, the state vector collects the model's endogenous variables and the shock vector collects the exogenous disturbances. Because this is a first-order approximation, it is accurate for small fluctuations around steady state and is especially convenient for computing impulse response functions. For policy analysis, however, this convenience comes with a caveat. By evaluating all propagation margins at the steady state, log-linearization can suppress economically relevant state dependence. Lindé and Trabandt (2018) show this in a NK fiscal-multiplier environment in which the nonlinear model and the linearized model deliver sharply different answers at the zero lower bound. A key mechanism is that nonlinear price dispersion and strategic complementarities can change the effective slope of the Phillips curve over the cycle, whereas a first-order approximation treats that slope as locally fixed. For Central Banks, this matters because the policy prescription may depend precisely on whether inflation becomes more or less responsive to slack in stressed states.

2.3.2 Higher-Order and Nonlinear Solutions

Log-linearization is convenient but comes also with certainty-equivalence. This method preserves first-order dynamics and therefore misses any effect of risk on decisions and can become grossly inaccurate when shocks push the economy far from its deterministic steady state. A parallel literature, synthesized

early on in Judd (1998), has developed higher-order and global solution methods to address these limitations.

Within this literature two families dominate. *Perturbation methods* extend the Taylor expansion beyond the first order. Early higher-order perturbation algorithms were developed by Collard and Juillard (2001a, 2001b), who showed that a second- or third-order Taylor expansion of the policy function around the deterministic steady state could be implemented systematically in forward-looking models and assessed its accuracy on asset-pricing applications. Schmitt-Grohé and Uribe (2004) then popularized a compact matrix formulation of the second-order perturbation, which preserves the tractability of log-linearization while restoring the risk-adjustment terms (precautionary savings, risk premia) that are absent under certainty equivalence, and opened the way to third-order methods routinely used to study stochastic volatility and rare-disaster dynamics (Fernández-Villaverde, Guerrón-Quintana & Rubio-Ramírez, 2015). *Projection methods* instead approximate the policy functions directly on a grid of state variables, via Chebyshev polynomials, splines or finite elements; they preserve full nonlinearity and handle occasionally binding constraints, at a much higher computational cost. Aruoba, Fernández-Villaverde and Rubio-Ramírez (2006) provide a systematic comparison of the two families and show that perturbation is usually sufficient for smooth medium-scale DSGEs, while projection becomes indispensable when nonlinearities are economically first-order. These methods are computationally more intensive but increasingly feasible with advances in numerical algorithms and computing power (Judd, 1998). A complementary branch, the parameterized expectations approach, replaces the unknown conditional expectations by flexible parametric functions fitted on simulated data (Den Haan & Marcet, 1990; Marcet & Lorenzoni, 1999).

2.4 Estimation Techniques

Once specified, DSGE models can be estimated to match observed macroeconomic data. Various estimation techniques are used in practice.

2.4.1 Generalized Method of Moments (GMM)

Introduced by Hansen (1982), GMM estimates the structural parameter vector by exploiting model-implied orthogonality conditions (typically Euler equations, first-order conditions, or other equilibrium restrictions).⁸ In practice, one chooses parameters so that the empirical counterparts of those conditions are as close to zero as possible, using a quadratic criterion that weights each sample moment according to a positive-definite weighting matrix. Asymptotic efficiency is attained when that weighting matrix converges to the inverse of the long-run covariance matrix of the moments (Hansen & Singleton, 1982; Hansen, 1982). Two-step, iterated, and continuously updated variants (Hansen, Heaton & Yaron, 1996) are common, and finite-sample improvements have been extensively documented (Newey & West, 1987; Stock, Wright & Yogo, 2002).

⁸See Mátyás (1999) for a comprehensive treatment of GMM estimation.

In the early DSGE and RBC literature, GMM (and its limited-information cousins) was the workhorse for estimating preference and technology parameters from Euler equations (Hansen & Singleton, 1982; Christiano & Eichenbaum, 1992; Burnside, Eichenbaum & Rebelo, 1993; Fève & Langot, 1994), because it requires neither a full likelihood nor a complete solution of the model. Its use has waned in modern medium- and large-scale NK DSGE estimation, largely supplanted by Bayesian likelihood methods, due to weak-identification problems (Stock et al., 2002), sensitivity to the choice of instruments and weighting matrix, and the difficulty of imposing all cross-equation restrictions of a fully specified general-equilibrium model. It nonetheless remains a useful benchmark and a natural tool for single-equation estimation, as in the influential GMM estimates of forward-looking Taylor rules and New Keynesian Phillips curves (Clarida et al., 2000; Galí & Gertler, 1999).

A closely related extension of GMM is *Minimum Distance Estimation* (MDE), often called impulse-response matching when the targets are dynamic responses to identified shocks. Rather than matching unconditional moments, parameters are chosen to minimize a weighted distance between empirical targets (typically impulse responses estimated from a structural vector autoregression (SVAR)) and the corresponding model-implied objects. As in GMM, estimation is based on a quadratic loss in the gap between data moments and model moments, with the weighting matrix governing efficiency and robustness trade-offs. This approach was popularized by Rotemberg and Woodford (1997) and Christiano et al. (2005) to discipline medium-scale NK models against monetary-policy shock responses, and is a natural bridge between SVAR-based identification and structural estimation (Hall, Inoue, Nason & Rossi, 2012). Like GMM it is robust to misspecification of features outside the targeted moments, but inherits sensitivity to the choice of weighting matrix and to weak-identification problems (Canova & Sala, 2009).

2.4.2 Identification of Structural Parameters

These difficulties point to a more general requirement: estimated DSGE parameters are useful for policy analysis only insofar as they are identified by the empirical objects used in estimation. In this context, identification is not simply a property of a single econometric technique. It depends on the whole mapping from deep parameters to the model solution, from the solution to the moments, likelihood, or impulse responses targeted by the econometrician, and finally from those population objects to their sample counterparts. Canova and Sala (2009) show that this mapping can be ill behaved even in otherwise standard DSGE models. Different parameter vectors may generate nearly indistinguishable impulse responses (observational equivalence). Moreover, some parameters may affect only dimensions of the model that are not disciplined by the selected data (partial identification). In addition, the criterion may be so flat in some directions that posterior or sampling uncertainty understates the true fragility of structural inference.

Fernández-Villaverde and Rubio-Ramírez (2008) raise a related concern from a different angle: even parameters given a deep structural interpretation in the model may display substantial time variation in estimated medium-scale DSGE models. Their evidence on drifting monetary policy and nominal-rigidity parameters suggests that empirical “deepness” should not be assumed from microfoundations alone. It

must be assessed against the stability of the estimated mapping over the policy regimes and inflation environments covered by the sample.

The practical implication is that the credibility of an estimated DSGE model does not come only from fitting a set of aggregate series or from obtaining tight posterior intervals. It also requires checking which parameters are actually informed by the observables, which restrictions separate economically distinct mechanisms, and whether the policy counterfactuals of interest are robust to weakly identified dimensions of the parameter space. The monetary-policy example in Carrillo, Fève and Matheron (2007) illustrates this point. A DSGE model can be used to discriminate between interest-rate smoothing and persistent monetary-policy shocks only when the estimation targets contain enough information on the joint dynamics of output, inflation, and the nominal interest rate. If the econometrician focuses too narrowly on the policy rate alone, the two interpretations become difficult to separate, although they carry different structural and policy implications.

2.4.3 Maximum Likelihood and Bayesian Estimation

Likelihood-based methods exploit the fact that linearized DSGE models with Gaussian shocks yield a state-space representation, allowing for exact evaluation of the likelihood through the Kalman filter.⁹ Pioneering full-information maximum-likelihood (ML) estimations of an equilibrium business-cycle model are due to Christiano (1988) and Altuğ (1989). Closely related contributions include the ML estimation of stochastic growth models by McGrattan (1994) and Leeper and Sims (1994), and the maximum-likelihood study of nominal rigidities and monetary shocks by Kim (2000) and Ireland (2004). These early efforts also exposed the well-known pathologies of frequentist DSGE estimation (flat or multimodal likelihoods, parameters reaching the boundaries of the parametric space, and stochastic singularity when the number of shocks is smaller than the number of observables).

Bayesian techniques address many of these difficulties by combining the state-space likelihood with prior distributions on structural parameters through Bayes' rule: posterior beliefs are proportional to the product of the likelihood and the prior. Posterior simulation typically relies on Random-Walk Metropolis-Hastings or, more recently, Sequential Monte Carlo (Herbst & Schorfheide, 2014). The Bayesian DSGE program was launched by DeJong, Ingram and Whiteman (2000) and Schorfheide (2000), extended to medium-scale NK models by Smets and Wouters (2003, 2007), and is surveyed in Fernández-Villaverde (2010) and the canonical handbook treatment of An and Schorfheide (2007); see also Herbst and Schorfheide (2015) for a textbook synthesis. Bayesian methods now dominate empirical DSGE work because they discipline weak likelihoods through priors, accommodate large parameter spaces, deliver coherent probabilistic statements about shocks and policy counterfactuals, and integrate naturally with model comparison via marginal likelihoods.

⁹For a complementary historical account of how nominal rigidities, state-space likelihoods, Bayesian methods, and medium-scale DSGE policy use came together, see Section 21.7 of Rojas Bernal and Markevych (2026).

2.4.4 Simulation-Based Methods

When the model lacks a closed-form likelihood (because the solution is nonlinear, the state space is high-dimensional, or some shocks are non-Gaussian) estimation often relies on simulation. The general principle is to replace intractable population objects (moments, likelihoods, score functions) by Monte Carlo averages computed from artificial data simulated at candidate parameter values (Gouriéroux & Monfort, 1996; Duffie & Singleton, 1993).

The earliest such strategy is the *Simulated Method of Moments* (SMM), introduced by McFadden (1989) and Pakes and Pollard (1989) and brought to time-series macroeconomics by Lee and Ingram (1991): the parameter vector is chosen so that a vector of empirical moments is matched, in a quadratic norm, by its simulated counterpart averaged over many artificial paths, with an efficiency loss that shrinks as the number of simulations increases. SMM remains the workhorse for complicated equilibrium models, notably heterogeneous-agent models, where the cross-sectional distribution makes likelihood evaluation prohibitive (Kaplan, Moll & Violante, 2018; Auclert, 2019).

A generalization is *indirect inference*, developed by Gouriéroux, Monfort and Renault (1993) and Smith (1993): the parameters of a tractable auxiliary model (typically a VAR or a reduced-form regression) are estimated on real and on simulated data, and structural parameters are chosen to minimize the distance between the two pseudo-true binding-function estimates. The approach is especially attractive when the auxiliary model summarizes salient dynamic features the structural model is required to reproduce. (See Gouriéroux et al., 1993, Smith, 1993, and Gallant & Tauchen, 1996 for theoretical expositions, and Dupaigne, Fève & Matheron, 2007 for a quantitative illustration in a DSGE setting).

For nonlinear, non-Gaussian state-space DSGE models, the likelihood itself can be approximated by sequential Monte Carlo (the particle filter) and embedded in a Bayesian Markov chain Monte Carlo (MCMC) sampler (Fernández-Villaverde & Rubio-Ramírez, 2007; Andrieu, Doucet & Holenstein, 2010). This pseudo-marginal approach has opened the door to estimation of models with stochastic volatility, Epstein-Zin preferences, and occasionally binding constraints (Fernández-Villaverde & Guerrón-Quintana, 2021).

3 Quantitative Experiments in DSGE Models

This section moves from model construction to actual model use. It describes how Central Banks turn estimated DSGE structures into quantitative policy evidence: tracing shock transmission, decomposing historical fluctuations, building forecasts and scenarios, and evaluating policy counterfactuals under alternative objectives and constraints. This shift from model-building to model-use marks an important stage in the historical evolution of DSGE modelling in central banks: by the 2000s, the central question was no longer only whether such models could be solved and estimated, but whether they could organize recurrent policy work inside institutions.

This also changes how one should interpret empirical fit. A DSGE model that tracks the joint dynamics of output, inflation, and interest rates well is not automatically a reliable guide for policy. The fit may

come from additional shocks, measurement errors, or frictions that improve the unconditional likelihood without identifying the mechanisms that matter for a particular counterfactual. Kocherlakota (2007) makes this point sharply: a model can fit the observed data, even perfectly in a stylized example, and still deliver poor conditional forecasts if the parameters that govern the policy experiment are not identified. His later contribution on practical policy evaluation pushes the argument further (Kocherlakota, 2019). Modern macroeconomic models are naturally suited to comparing well-specified policy regimes, but many actual policy decisions are local, sequential, and made within an existing regime. For such decisions, the relevant standard is not simply global fit, but whether the model isolates the marginal channel through which the contemplated intervention affects outcomes.

This critique should not be read as a rejection of empirical discipline. Rather, it clarifies what kind of discipline is needed. Chari et al. (2009) argue that NK DSGE models were, at that stage, not yet useful for policy analysis because their quantitative policy prescriptions depended on reduced-form wedges and shocks whose economic interpretation was fragile. The broader lesson is that fit is a necessary but incomplete criterion. A policy model must also explain which restrictions generate the fit, whether those restrictions survive alternative observables and episodes, and whether the welfare-relevant margins are disciplined by data rather than by convenient auxiliary shocks. For Central Banks, this implies treating fit as an entry condition for model use, not as a sufficient validation of policy counterfactuals.

3.1 Dynamic Analyses

Canonical and medium-scale NK DSGE models provide a unified laboratory for Central Banks: once log-linearized and cast in state-space form, they deliver a coherent mapping from structural shocks to observed macroeconomic outcomes, and from policy rules to counterfactual paths. This makes DSGEs useful not only for interpretation (*which shocks drive fluctuations?*) but also for decision support (*which policy response stabilizes inflation and activity at lowest welfare cost?*).

This section is organized as follows. We first study dynamic propagation through impulse responses and forecast-error variance decomposition, turn to historical decomposition, then to model-based forecasting, and finally to policy simulations under alternative objectives and institutional mandates.¹⁰

3.1.1 Impulse Response Functions (IRFs) and Shock Decomposition

After log-linearization and solution of the rational-expectations system, the DSGE model can be written as a linear state-space system in which latent states evolve from their own lags and current structural shocks, while observables are linear combinations of those states around their steady-state levels. In this representation, one block of matrices governs state transition, one maps shocks into states, and one maps states into observables such as output growth, inflation, and policy rates, among many others.

¹⁰For broader background on time-series methods, see Fuleky (2026); for a complementary discussion of business-cycle models, see Rojas Bernal and Markevych (2026). These dynamic exercises also connect to the Forecasting and Policy Analysis System (FPAS) perspective discussed in Baksa (2026): in policy institutions, forecasts, scenarios, decompositions, and judgmental adjustments are typically organized as parts of a recurrent decision process rather than as isolated model outputs.

For an innovation in a given structural shock, the impulse response of any observable is obtained by propagating that shock through the transition and measurement mappings of the state-space system. IRFs summarize transmission channels over time (impact, peak, persistence, and overshooting), which is central to policy discussions in Central Banks. For example, consider an energy-price cost-push shock and take consumer price index (CPI) inflation as the target variable. The IRF profile indicates whether inflation reacts sharply on impact, when the maximum effect is reached, and how quickly it decays. These moments are directly relevant for policy calibration: a short-lived spike may call for partial accommodation, while a persistent response typically requires a stronger and more sustained monetary tightening to re-anchor inflation expectations.

The same state-space objects deliver forecast-error variance decompositions (FEVD): at any horizon, the contribution of each shock is the variance share obtained by comparing the cumulative forecast-error variance generated by that shock with the cumulative variance generated by all shocks jointly. Hence, IRFs describe *how* a given shock propagates, while FEVD quantifies *how much* each shock drives the business cycle.

3.1.2 Historical Shock Decomposition

Historical decomposition allocates realized fluctuations to sequences of identified structural shocks. Using smoothed shocks from the Kalman filter/smoothers, one computes shock-specific latent state trajectories and their associated contributions to observables, then adds those contributions across shocks to recover total deviations from steady state. This is fundamentally similar to the FEVD exercise, except that one can now zoom in a particular historical episode. This decomposition is routinely used to distinguish, for each episode, the roles of demand, supply, monetary, fiscal, and financial shocks, and to connect model-based narratives to policy decisions.

3.1.3 Forecasting

In central-bank practice, forecasting with DSGE models starts from the estimated posterior distribution of parameters and latent states. As Del Negro and Schorfheide (2013) explain, given the state-space law of motion, one projects latent states forward horizon by horizon and maps them into observables to obtain model-consistent projections for output, inflation, and policy rates at multiple horizons. Because parameters are uncertain, forecasting is typically conducted in density form: predictive distributions integrate forecast paths implied by each parameter draw over the posterior distribution of parameters, conditional on the information available at the forecast date.

Del Negro and Schorfheide (2004) show that forecast performance can be improved by embedding DSGE restrictions into a VAR prior (the DSGE-VAR), which allows controlled misspecification while preserving structural discipline. This approach is particularly useful when pure DSGE restrictions are too tight for short-run forecasting but a fully unrestricted VAR sacrifices policy interpretability.

Del Negro and Schorfheide (2013) provide a comprehensive assessment of DSGE-based forecasting in real time. Medium-scale DSGEs can deliver forecast accuracy comparable to benchmark time-series models for key macro variables, but their forecasting performance improves when the measurement system is fed with information that sits outside the core model, such as survey nowcasts, expected policy-rate paths, and long-run inflation expectations. This is also how they are usually used inside Central Banks. They rarely replace the rest of the forecasting apparatus; rather, they discipline part of it by forcing projections, economic narratives, and policy counterfactuals to be mutually consistent.

3.1.4 Policy Design

DSGE policy simulations are typically organized as a constrained optimal control problem in which the Central Bank minimizes a welfare-based loss subject to the model's equilibrium conditions. A standard approximation is an intertemporal quadratic loss that penalizes inflation fluctuations, activity-gap fluctuations, and, when desired, excessive changes in the policy rate to capture implementation frictions and gradualism. The linear-quadratic approach of Benigno and Woodford (2004) and the welfare foundations in Benigno and Woodford (2005) provide the analytical link between micro-founded utility and tractable policy objectives used in central-bank applications.

This framework naturally distinguishes *commitment* (Ramsey policy) from *discretion* (re-optimization each period). Under commitment, history dependence improves stabilization by shaping private-sector expectations, while discretion generally implies stabilization bias. Giannoni and Woodford (2005) show how optimal policy can be represented through implementable targeting criteria, clarifying the operational content of model-consistent optimal rules for Central Banks.

For practical policy design, Central Banks also compare alternative simple mandates. Debortoli, Kim, Lindé and Nunes (2019) show that a parsimonious loss function with a non-negligible (sometimes large) weight on real activity can approximate welfare well, supporting the quantitative relevance of the Federal Reserve System's dual mandate. In simulation exercises, these alternative objectives are mapped into counterfactual interest-rate paths and welfare outcomes after demand, supply, financial, or cost-push disturbances.

3.2 Applications for Central Banks

This section illustrates how Central Banks use estimated DSGE frameworks in concrete policy work. It first examines disinflation episodes to quantify short-run real costs and longer-run gains, then turns to unconventional monetary-policy tools when the policy rate is constrained, and finally discusses how structural models are used to infer latent policy benchmarks such as the natural real rate of interest.

3.2.1 Disinflation

Disinflation experiments are a natural laboratory for DSGE models in Central Banks: they combine a sharp, identifiable change in the monetary-policy regime with persistent output and labor-market adjustments,

and they require the model to speak about the *cost* of reducing inflation (the sacrifice ratio) and/or the *welfare* gains from lower steady-state inflation. Two contributions are particularly representative of the way medium-scale NK-DSGE models have been used to address these questions: Fève, Mathéron and Sahuc (2010) on the euro-area disinflation of the 1980s-90s, and Ascari and Ropele (2012) on the normative trade-off between the short-run costs and the long-run benefits of disinflation.

Fève et al. (2010) quantify the macroeconomic effects of the disinflation engineered by European Central Banks in the run-up to the euro. Their identification strategy illustrates methodological tools discussed earlier in this chapter. The authors first estimate a structural VAR on euro-area data¹¹ and identify a *disinflation shock* as a permanent downward shift in the central-bank inflation target, using long-run restrictions. The identified shock generates a persistent fall in inflation, a temporary but persistent decline in output, a gradual and permanent adjustment of the nominal rate. These are IRFs that the structural model is required to reproduce. The latter is a medium-scale NK-DSGE model (sticky prices and wages, partial indexation, habits, investment adjustment costs, Taylor-type rule, and noisy signals on the inflation target as a proxy for imperfect credibility), which they estimate by *matching* its model-implied impulse responses to those of the identified VAR, in the limited-information tradition of Rotemberg and Woodford (1997) and Christiano et al. (2005). The estimated model is finally put to work in two families of *counterfactual* experiments. First, they shut down a candidate propagation mechanism (e.g., nominal or real rigidities, monetary-policy gradualism) and re-estimate the remaining parameters to re-minimize the IRF-matching loss. Second, they impose the same perturbation while keeping all other parameters at benchmark values. Comparing IRFs, fit deterioration and sacrifice ratios across these two exercises identifies which mechanisms are essential and which can be offset by parameter re-adjustments. Their main finding is that a sizable fraction of the 1980s-90s decline in euro-area inflation is traceable to a credible reduction of the target, at a moderate but non-negligible sacrifice in activity.

Ascari and Ropele (2012) study the same class of experiment from a normative angle. Using a medium-scale NK model with trend inflation and price and wage indexation, they compute both the sacrifice ratio associated with a permanent reduction of the inflation target and the welfare gain from operating at a lower steady-state inflation rate. They show that the short-run output losses can be quantitatively large, but are outweighed (under plausible calibrations) by the welfare benefits of reduced price dispersion, lower nominal-wage distortions and less indexation-induced inertia, yielding a favorable *welfare-gain ratio*.

The two papers are complementary: Fève et al. (2010) is positive and data-driven (VAR identification, impulse-response matching, counterfactual history) while Ascari and Ropele (2012) is normative and quantitative-theoretic.

These contributions illustrate the modeling and estimation methodologies described earlier. The underlying structure is the medium-scale NK-DSGE of Christiano et al. (2005) and Smets and Wouters (2003, 2007) (Section 2), with its combination of nominal rigidities, real frictions and an interest-rate rule with smoothing. The VAR-to-DSGE impulse-response matching step of Fève et al. (2010) connects directly to the

¹¹The sample starts in the 1980s and covers the countries that later joined the euro area. As such, the analysis proceeds as if a fictitious Central Bank had implemented the disinflation policy.

identification literature reviewed in the GMM section, and the counterfactual exercise relies on the shock-decomposition tools introduced in the sections on IRFs, FEVD and historical decomposition; the welfare reading of Ascari and Ropele (2012) maps into the loss functions of Benigno and Woodford (2004, 2005) used in the section on policy design.

3.2.2 Analyzing Unconventional Monetary Policies and Quantitative Easing (QE)

Once the policy rate reached its effective lower bound (ELB) in the aftermath of the Great Recession and, later, during the euro-area sovereign-debt crisis, Central Banks turned to balance-sheet instruments, notably large-scale asset purchases (LSAPs) on the Federal Reserve side, long-term refinancing operations (LTROs) and asset purchase programs on the ECB side. Assessing these tools requires DSGE frameworks that go beyond the standard short-rate transmission channel and explicitly model the frictions through which balance-sheet policies can affect aggregate outcomes. Two contributions are emblematic of this literature: Chen, Cúrdia and Ferrero (2012) on the U.S. LSAPs and Cahn, Matheron and Sahuc (2017) on the ECB's LTROs.

Chen et al. (2012) study the macroeconomic effects of the Federal Reserve's second LSAP program (QE2, where QE stands for quantitative easing) using a medium-scale NK-DSGE model augmented with *segmented asset markets* in the tradition of Andrés, López-Salido and Nelson and of the preferred-habitat view. In their setup, a fraction of households can trade only long-term bonds while another fraction is restricted to short-term instruments; imperfect arbitrage between the two maturity segments generates a non-trivial term premium that the Central Bank can influence by purchasing long-duration securities. A LSAP shock is operationalized as an exogenous reduction in the supply of long-term bonds held by the public, which compresses the term premium, lowers long rates and stimulates investment, consumption and inflation. The model is estimated on U.S. data by Bayesian methods and used to generate counterfactual paths: the authors find that QE2-type purchases have quantitatively meaningful but moderate macroeconomic effects, concentrated on activity via the term-premium channel and conditional on the policy being perceived as persistent and on short rates remaining at the ELB.

Cahn et al. (2017) address the symmetric question on the euro-area side by assessing the macroeconomic contribution of the one-year LTROs conducted by the ECB throughout 2009. Their framework is a medium-scale NK-DSGE model with a *banking sector* in the spirit of Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In this setup, banks finance loans to non-financial firms with deposits and central-bank liquidity, are subject to endogenous leverage constraints driven by agency frictions, and transmit funding-cost shocks to the credit supply faced by the real economy. LTROs enter the model as a direct easing of banks' funding costs for a specified maturity, relaxing their balance-sheet constraint and lowering lending spreads. The distinctive methodological contribution, which the authors emphasize, lies in the econometric treatment of this unconventional instrument. Standard Bayesian estimation on a long sample would blur the LTRO effect into generic bank-funding shocks and miss the fact that the LTROs *were announced and anticipated*. More fundamentally, temporary activation of 6- and 12-month facilities implies that the model's state-space representation changes over time. In practice, each ECB announcement updates beliefs about

facility maturity, allotment mode (fixed-rate full allotment, FRFA henceforth), and the expected unwind of liquidity operations. The authors therefore reconstruct the full announcement timeline and solve the model by backward induction under each announced policy path, which delivers time-varying transition matrices. Estimation then proceeds in a Bayesian framework using a time-varying state-space system, the Kalman filter, and Metropolis-Hastings simulation. Their counterfactual exercise shuts down nonstandard 6- and 12-month LTROs (and the associated FRFA regime) over 2008-09. Absent these measures, they estimate that average 2009 output, consumption, investment and the gross domestic product (GDP) deflator would have been lower by about 2.5%, 0.5%, 9.7% and 0.5%, respectively, while credit spreads would have been roughly 400 basis points higher, consistent with LTROs having prevented a severe credit crunch.

Taken together, the two papers illustrate how the medium-scale NK-DSGE apparatus introduced in Section 2 can be extended to analyze balance-sheet policies.

3.2.3 Estimating the Natural Rate of Interest

The natural (or efficient) rate of interest, defined as the real rate that would prevail in an economy without nominal rigidities and inefficient cost-push disturbances, has become a central input of monetary-policy analysis in advanced economies, especially since the post-financial crisis decline in equilibrium real rates has made the effective lower bound a recurring constraint. While semi-structural filters in the tradition of Laubach and Williams (2003) remain a workhorse at policy institutions, DSGE-based approaches provide a model-consistent alternative in which the natural rate is derived jointly with the other structural objects of the model and decomposed into its underlying shocks. Three contributions illustrate how medium-scale NK-DSGE models have been used to measure the natural real rate and to discuss its operational usefulness for policy: Cúrdia, Ferrero, Ng and Tambalotti (2015), Barsky, Justiniano and Melosi (2014) and Del Negro, Giannone, Giannoni and Tambalotti (2017). This nicely illustrates how DSGE models help identify non-observable latent variables crucial for monetary policy analysis.

Cúrdia et al. (2015) ask whether U.S. monetary policy has tracked the *efficient* real rate, defined as the real interest rate that would prevail in the model's counterfactual flexible-price, markup-shock-free allocation. Using a medium-scale NK-DSGE model estimated on U.S. data by Bayesian methods in the SW tradition, they recover the history of the efficient rate via the Kalman smoother applied to the estimated state-space system, and compare it to the path of the observed federal funds rate adjusted for inflation. Two results matter for Central Banks. First, over most of the Great Moderation, the actual real rate followed the efficient rate reasonably well, suggesting that U.S. monetary policy was broadly consistent with the model's welfare-relevant benchmark. Second, in the aftermath of the Great Recession, the efficient rate fell sharply into negative territory while the observed real rate was pinned down by the effective lower bound (ELB), producing a large and persistent gap that rationalizes the recourse to unconventional instruments discussed in the previous section.

Barsky et al. (2014) deliver a cautionary companion message using essentially the same toolbox. They extract the natural rate from the SW model estimated on U.S. data and emphasize two features that condition its usefulness for policy. The natural rate is *highly volatile* at business-cycle frequencies and sensitive to

the identification of structural shocks, in particular to the treatment of investment-specific technology and markup disturbances. Their conclusion is not that the natural-rate concept is meaningless, but that mechanical tracking of a single point estimate of the natural rate would be a poor guide for the policy rate, and that the operational value of the natural-rate estimate lies rather in its decomposition into economically interpretable shocks.

Del Negro et al. (2017) take a longer-run perspective and ask *why* the natural rate has trended down in advanced economies. They augment a DSGE model with an explicit *safety and liquidity premium* on U.S. Treasuries, using long time series on convenience yields (spreads between Treasuries and less-liquid, less-safe instruments) as additional observables. In their decomposition, the secular decline of the natural real rate reflects a combination of slower productivity growth, demographic shifts lowering the natural rate of growth, and a sustained increase in the convenience yield attached to safe and liquid assets (the latter captured as a shift in the preference for safe assets rather than as a pure equilibrium real-rate phenomenon). For Central Banks, the policy implication is that the low-natural-rate environment is unlikely to reverse quickly, so ELB episodes are likely to remain frequent, reinforcing the relevance of the unconventional instruments analyzed in Section 3.2.2.

4 HANK Models: A Structural Revisit of the Keynesian Cross

This section presents the heterogeneous-agent extension of the New Keynesian framework and explains why it may at some point become central for monetary and fiscal policy analysis.¹² Once households differ in liquidity, income risk, and marginal propensities to consume (MPCs), aggregate stabilization and distributional incidence become part of the same mechanism. The distributional dimension is therefore not only a transmission channel: it can also be an object of interest in its own right, for instance when policy evaluation concerns the allocation of consumption, wealth, labor income, or welfare gains and losses across households. The section starts from the benchmark HANK structure, then turns to solution and estimation methods, before using policy experiments to show how redistribution, cash-flow exposure, and market incompleteness reshape the transmission of conventional and unconventional policies.

Seen from this historical perspective, HANK models do not abandon the DSGE program. They preserve its general-equilibrium and policy-counterfactual discipline, but redirect it toward questions that earlier representative-agent models were poorly equipped to answer: who is the most impacted by shocks, whose consumption responds, how redistribution shapes aggregate demand, and how policies affect inequality and welfare across the household distribution. They are therefore best understood as the latest stage in a cumulative sequence: each generation of models retained part of the previous discipline while adding the mechanisms made salient by new empirical and policy problems.

¹²For a complementary analysis of heterogeneous-agent models as part of the post-representative-agent turn in business-cycle research, including their links to measurement, identification, micro data, and production-network approaches, see Rojas Bernal and Markevych (2026).

4.1 The Benchmark HANK Model

This section sets out the baseline HANK architecture used in the rest of the chapter. It first introduces the household and labor-market building blocks that generate heterogeneous MPCs and nominal transmission, then explains how aggregation through the cross-sectional distribution changes equilibrium dynamics, and finally links the full model to the intertemporal Keynesian-cross representation used for policy analysis.

4.1.1 Micro Foundations and Nominal Transmission

Building on Aiyagari (1994), Huggett (1993), and Krusell and Smith (1998), Heterogeneous-Agent New Keynesian (HANK) models relax the representative-household assumption by introducing incomplete markets and idiosyncratic labor-income risk into a standard NK environment with nominal rigidities. This matters quantitatively because households differ in wealth and exposure to income fluctuations, so they also differ in marginal propensities to consume; many are liquidity-constrained and react strongly to current disposable income. As a result, monetary and fiscal policies transmit not only through intertemporal substitution, but also through redistribution across households, in line with micro evidence documenting substantial consumption responses to income and transfers (Jappelli & Pistaferri, 2010; Parker, Souleles, Johnson & McClelland, 2013)¹³ and with the mechanisms emphasized by Kaplan et al. (2018) and Auclert (2019).

A useful intermediate benchmark is the two-agent New Keynesian (TANK) model. TANK models split households into a Ricardian group that smooths consumption intertemporally and a hand-to-mouth group that consumes current income (see, e.g., Galí, López-Salido & Vallés, 2007; Bilbiie, 2008). This parsimonious structure is transparent and often sufficient when the main goal is to introduce a high-MPC household share into an otherwise standard policy model. HANK models go further by replacing the two household types with an endogenous distribution of assets, income risk, and occasionally binding constraints. This matters when the distribution itself shapes aggregate dynamics or when policy incidence across the wealth and income distribution is part of the question. HANK is therefore richer, but not automatically preferable in every application: TANK may be the better tool when data, computation, or the policy question do not justify modelling the full distribution.

On the household side, the economy contains a continuum of ex-ante identical agents who become ex post heterogeneous due to idiosyncratic efficiency shocks. Households choose consumption and saving subject to an intertemporal budget identity and a borrowing limit, so self-insurance is partial and the distribution of assets and income becomes a core state variable. This is the key source of heterogeneous MPCs that amplifies the income channel of aggregate demand.

On the labor side, wages are set by unions for differentiated labor types under monopolistic competition. A standard aggregator maps those labor types into total labor services and implies type-specific labor demand that declines with relative wages. Nominal wage stickiness, introduced via staggered re-optimization or adjustment costs (often with partial indexation), then generates realistic wage and inflation inertia. Taken together, these ingredients allow HANK models to preserve structural discipline while rein-

¹³Boehm, Fize and Jaravel (2025) provide a critical reassessment of this literature and report substantially smaller MPCs.

stating distributional channels that are first-order for policy analysis, thus complementing the approach promoted by Smets and Wouters (2003, 2007).

4.1.2 Aggregation and Distributional Effects

Because the population is a continuum, aggregation is expressed using the cross-sectional distribution of households over individual states, typically assets and idiosyncratic labor efficiency. Aggregate variables are therefore population-weighted integrals over that distribution. Likewise, any object entering equilibrium (income, marginal utility, MPC, labor earnings) is a distribution-weighted integral, not an average over a finite number of ‘types.’ The law of motion for the distribution is induced by optimal household decisions and the Markov transition for idiosyncratic risk.

This distributional state is quantitatively central in HANK models. Changes in prices, wages, taxes, or interest rates reallocate income and wealth across households with heterogeneous MPCs. Aggregate demand then moves through both intertemporal substitution and redistribution channels. Relative to representative-agent NK models, this mechanism typically generates stronger and more persistent responses of output and consumption to monetary and fiscal disturbances.

4.1.3 Linking HANK to the Keynesian Cross

The usefulness of HANK models becomes clearest when we return to one of the most elementary objects of textbook macroeconomics, the Keynesian cross (Bilbiie, 2020). In its static form, the Keynesian cross states that equilibrium output is the fixed point of a feedback loop in which aggregate demand depends on current income through a marginal propensity to consume out of disposable income, with investment and public spending treated as autonomous components. When the marginal propensity to consume is strictly between zero and one, the familiar Keynesian multiplier is equal to one divided by one minus that propensity, measuring how an autonomous demand impulse is amplified by induced consumption. Representative-agent NK-DSGE models, by contrast, anchor short-run consumption on the Euler equation, so current income drops out of the consumption function and the Keynesian-cross feedback disappears from the aggregate demand block. Monetary and fiscal transmission operate essentially through intertemporal substitution and through wealth effects on the permanent income of a single representative household. HANK models reinstate the Keynesian-cross feedback within a fully specified intertemporal equilibrium framework. The key reason is the distribution of marginal propensities to consume induced by incomplete markets and borrowing constraints. A non-negligible mass of households is liquidity-constrained or near-constrained, and for those households current disposable income matters far more than the real interest rate. Aggregating the household problem over the cross-sectional distribution of household states then yields an aggregate consumption function in which current and recent disposable income enter with quantitatively large weights, and the *income-driven* component of aggregate demand becomes first-order, alongside the standard intertemporal-substitution component.

A useful way to make the link explicit is the *intertemporal Keynesian cross* of Auclert, Rognlie and Straub (2024), which extends the New Keynesian-cross logic of Bilbiie (2020). They show that, around a steady-state equilibrium, aggregate consumption in HANK economies admits a linear decomposition into two components: one driven by the path of aggregate disposable income, and one driven by the path of real interest rates. The associated intertemporal response matrices map an income or interest-rate impulse at one date into consumption responses at all future dates. In the representative-agent setup, the income-response matrix is close to the permanent-income benchmark and the income channel is largely muted. In empirically plausible HANK calibrations, the same matrix assigns large weight to contemporaneous income (households spend a substantial share of transfers on impact) and retains a slowly decaying influence of recent income on current consumption. The resulting dynamic fixed-point condition for output is the intertemporal counterpart of the static Keynesian cross, with the additional discipline that these response objects are derived from a fully specified household problem with idiosyncratic risk and constraints rather than postulated.

This decomposition also organizes the transmission of monetary policy shocks in HANK along the lines emphasized by Kaplan et al. (2018) and Auclert (2019). A change in the policy rate has a *direct* effect through intertemporal substitution by unconstrained households, captured by the interest-rate response matrix, and an *indirect*, general-equilibrium effect that operates by moving aggregate labor income, which then feeds back into consumption through the income-response matrix. In quantitatively realistic HANK calibrations, the indirect channel typically dominates, in line with the Keynesian-cross intuition: the bulk of the consumption response to a monetary shock comes from changes in disposable income of high-MPC households, not from their willingness to substitute consumption over time. Symmetric logic applies to fiscal disturbances: a transfer to constrained households is amplified by the income-response matrix in a way that the representative-agent benchmark mechanically misses.

This empirical discipline should nevertheless be used with caution. The MPCs estimated from tax rebates or transfer experiments are not model-free primitives. They depend on the timing of treatment, the consumption categories observed, the horizon over which spending is measured, and the implementation of the transfer itself. The influential estimates of Parker et al. (2013) made high short-run consumption responses a natural calibration target for HANK models. But Borusyak, Jaravel and Spiess (2024), revisiting related event-studies, find substantially smaller notional MPCs out of U.S. tax rebates, concentrated in the first month. Conversely, Boehm et al. (2025) show in a randomized French experiment that average MPCs are sensitive to the transfer design: cash-like transfers generate smaller responses than transfers with expiry or negative-interest features, and the response is difficult to reconcile with a purely frictionless notion of fungible income. For HANK-based policy analysis, the implication is that matching a single average MPC can be misleading.

For Central Banks, this rehabilitation of the Keynesian cross has two operational implications that motivate much of what follows. First, the size and shape of the income-response matrix (hence the strength of HANK transmission) depend on objects that can be disciplined by household-level micro data: the distribution of liquid wealth, intertemporal MPCs, and the response of consumption to transitory income shocks

(Jappelli & Pistaferri, 2010; Parker et al., 2013; Borusyak et al., 2024; Boehm et al., 2025). Second, policy counterfactuals built on a representative-agent NK structure may significantly understate the short-run response of aggregate demand to redistributive policies and to monetary shocks that move labor income. The next sections turn to the numerical resolution and estimation of HANK models, and then to the policy experiments in which the intertemporal-Keynesian-cross logic translates into quantitative policy advice.

4.2 Resolution and Estimation

This section explains how HANK models are made operational for policy analysis. It contrasts recursive state-space methods with sequence-space approaches, then discusses how each strategy maps into estimation, historical decomposition, and forecasting workflows, highlighting the trade-off between computational speed, numerical accuracy, and empirical discipline.

4.2.1 Recursive Approaches

Solving and estimating a HANK model is, in essence, the problem of propagating a high-dimensional cross-sectional distribution forward in time jointly with aggregate quantities and prices, under rational expectations about aggregate shocks. Any practical algorithm must therefore take a stand on two dimensions: (i) how to represent the distribution numerically, and (ii) how to treat the dependence of individual decisions on the aggregate state. The class of *recursive approaches* tackles both within a standard state-space representation in which that distribution (or a finite-dimensional approximation of it) enters the vector of states, and in which aggregate dynamics are obtained either by simulation or by perturbation around a stationary equilibrium.

The historical benchmark is the simulation-based algorithm of Krusell and Smith (1998). They approximate the aggregate law of motion of the distribution by a small number of its moments (typically the mean of wealth) and postulate a forecasting rule in which households condition their decision rules on these moments rather than on the full distribution. A fixed point is found by iterating between (a) solving the household problem given a conjectured law of motion for the moments, and (b) simulating the economy to update that law of motion. The key conceptual result, *approximate aggregation*, is that the first moment is typically sufficient for accurate forecasting because concavity of the household policy functions dampens the contribution of higher-order moments. The method is robust and handles nonlinear aggregate dynamics, but it is computationally expensive, relies on simulation, and does not deliver a state-space representation amenable to Kalman filtering or Bayesian estimation. For central-bank applications, where IRFs, historical decomposition and likelihood-based estimation are routine, this is a serious limitation.

The modern recursive workhorse is the projection-plus-perturbation algorithm of Reiter (2009), which combines the two techniques along orthogonal dimensions. The idiosyncratic household problem is solved *globally* by projection. Policy functions over individual asset and efficiency states are computed at the stationary equilibrium, keeping all the nonlinearities induced by borrowing constraints, occasionally binding limits and non-Gaussian income processes. Aggregate dynamics, by contrast, are handled by *first-order*

perturbation around the stationary equilibrium. The law of motion for the cross-sectional distribution is discretized on a finite grid, stacked with the aggregate endogenous variables and prices into a large but *linear* state-space system, and standard DSGE solution methods deliver the policy rules as a function of the discretized distribution and the aggregate shocks. This separation preserves the micro nonlinearities that matter for MPC heterogeneity while delivering a linear state-space representation that is fully compatible with the Kalman filter, impulse-response decompositions and Bayesian estimation. The main practical cost is the size of the state vector, since the discretized distribution may contain several thousand grid points.

A series of subsequent contributions has pushed the Reiter algorithm to empirically relevant scale. Winberry (2018) proposes a parametric approximation of the distribution (typically low-order polynomial families in the wealth distribution dimension) that reduces the size of the discretized state while preserving accuracy, and packages the method in a toolkit that integrates Dynare-style linearization and Bayesian estimation. Ahn, Kaplan, Moll, Winberry and Wolf (2018) develop a continuous-time counterpart in which the Kolmogorov forward equation for the cross-sectional distribution plays the role of the law of motion and in which a low-rank approximation of the Jacobian dramatically compresses the state vector without loss of IRF accuracy. Bayer and Luetticke (2020) develop a complementary discrete-time implementation that uses a Discrete Cosine Transform and a copula-based separation of marginal distributions from their dependence structure to reduce dimensionality, with estimated HANK applications on euro-area and U.S. data.

In particular, Bayer, Born and Luetticke (2024), building on the dimensionality-reduction strategy of Bayer and Luetticke (2020), estimate a medium-scale HANK model with sticky prices and wages, investment adjustment costs, a government sector and an endogenous distribution of wealth on U.S. data, using Bayesian-likelihood methods. The resulting model delivers the full SW suite (IRFs, historical decompositions, forecast error variance decomposition) augmented with a decomposition of inequality dynamics, and fits the data comparably to the representative-agent benchmark while assigning meaningfully different roles to demand, supply and monetary disturbances. The exercise demonstrates two points that matter for policy. First, HANK models can be estimated on macroeconomic observables with Bayesian techniques close to those already in use in Central Banks. Second, the resulting posterior distributions over structural shocks and transmission mechanisms differ from those of the representative-agent benchmark in ways that are quantitatively relevant.

Taken together, these recursive algorithms deliver three outputs that matter for Central Banks. First, they provide IRFs and historical decompositions of aggregate variables that are directly comparable to those produced by representative-agent NK-DSGE models, and can therefore be plugged into existing policy-round pipelines. Second, they deliver linearized state-space representations of HANK economies that support Bayesian estimation on standard macroeconomic observables, so that posterior inference on structural parameters remains feasible even in models with several thousand latent states. Third, they preserve enough of the micro heterogeneity (MPC distributions, occasionally binding constraints, non-Gaussian income risk) to be disciplined jointly by macroeconomic and household-level data. The main remaining limitation of this family of methods is that it is anchored on a first-order approximation of the aggregate

dynamics, which can be restrictive when the objects of interest are highly nonlinear (large shocks, state dependence, occasionally binding aggregate constraints such as the ELB).

4.2.2 Sequence-Space Jacobians and Higher-Order Methods

The recursive methods of the previous section solve HANK models in *state space*. The cross-sectional distribution is a state, and policy functions are indexed by it. An alternative, mathematically equivalent at first order but operationally much more efficient, consists of working directly in *sequence space*, that is, in the space of time paths of aggregate variables. This is the core insight of Auclert, Bardóczy, Rognlie and Straub (2021), whose sequence-space Jacobian (SSJ) approach has become a prominent computational tool for HANK estimation.

The starting point is the observation that, under a first-order perturbation around a stationary equilibrium, any HANK model reduces to a fixed-point equation on the path of aggregate quantities and prices. The household block, the firm block, the monetary and fiscal rules each map aggregate sequences into other aggregate sequences, and aggregate equilibrium is a set of paths such that the composed mapping is consistent. The key numerical object is the *sequence-space Jacobian* of each block. It consists of a matrix whose entry for each pair of dates gives the response of an aggregate output variable at one horizon to a shock to an aggregate input at another horizon. The Jacobians of the household block are nothing other than the intertemporal MPC matrices that appear in the intertemporal Keynesian cross, so the SSJ apparatus makes the decomposition introduced in Section 4.1.3 directly operational. Crucially, each block's Jacobian can be computed *independently* by a one-shot differentiation of the stationary equilibrium. The accuracy depends on the fineness of the grids and on the truncation horizon for aggregate paths. IRFs for a medium-scale HANK are obtained in seconds. The authors also show how to use these IRFs to efficiently compute the likelihood function associated with the model, thus rendering Bayesian estimation feasible.

Both the SSJ and the Reiter families, however, rely on a *first-order* approximation of aggregate dynamics. This is innocuous for small shocks and smooth responses, but it is restrictive when the questions of interest involve genuine nonlinearities: precautionary savings that respond to aggregate-risk premia, state-dependent IRFs, occasionally binding aggregate constraints such as the ELB, and the feedback of time-varying aggregate uncertainty on the distribution itself. A second methodological strand therefore develops *higher-order* and fully nonlinear HANK solvers. Fernández-Villaverde, Hurtado and Nuño (2023) compute a continuous-time HANK with financial frictions using a global nonlinear scheme that solves the household Hamilton-Jacobi-Bellman (HJB) equation and the Kolmogorov forward equation for the distribution simultaneously with the aggregate equilibrium conditions, delivering nonlinear IRFs and state-dependent transmission. Bhandari, Bourany, Evans and Golosov (2023) develop a higher-order perturbation of incomplete-markets economies that preserves the distributional state and supports welfare-based policy analysis with precautionary effects. From the estimation side, higher orders are essential when one wants to let the data speak on *macroeconomic risk*. Stochastic volatility of aggregate shocks, risk premia, rare disasters, and the feedback from uncertainty to the wealth distribution enter aggregate dynamics only at second order

or above, so quantifying their contribution to central-bank-relevant objects such as the natural rate or the equilibrium risk premium requires solving and estimating HANK models at higher order.

4.2.3 Key Takeaways for Central Banks

For Central Banks, the operational takeaway from this methodological literature is threefold. First, speed: SSJ-based estimation of HANK on standard macro observables is now feasible within the computational budget of a quarterly policy round, removing a long-standing barrier to the use of heterogeneous-agent models in policy analysis. Second, micro-macro consistency: the same linearized SSJ pipeline supports joint identification on macro time series and on micro moments (intertemporal MPCs, wealth distribution, consumption responses to transfers), so that the discipline emphasized in Section 4.1.3 translates into estimation practice. Third, nonlinearity when it matters: higher-order and global solvers extend the toolkit to questions (macro risk, uncertainty shocks, occasionally binding constraints) for which the first-order approximation is insufficient, and they do so within the same structural modeling framework rather than by stepping outside the HANK paradigm.

4.3 Policy Experiments in HANK Models

HANK models are especially useful when policy works through households that are not all exposed in the same way. A cut in the policy rate affects borrowers, savers, workers, and asset holders differently. A transfer has a different aggregate effect depending on whether it reaches households with high or low MPCs. Likewise, the impact of QE or forward guidance depends on who holds the relevant assets and how expectations feed into current cash flows. The section uses these examples to discuss conventional monetary policy, fiscal multipliers, and unconventional instruments.

4.3.1 Monetary Policy

In HANK models, the effects of a policy-rate change are decomposed into two channels. The first is the standard intertemporal-substitution channel, which mostly affects unconstrained households with positive liquid wealth. The second is an income-and-cash-flow channel, operating through labor income, debt-service positions, and portfolio exposures. Quantitatively, the second channel is often dominant, because the households with the highest MPCs are also those whose spending reacts most to changes in disposable income. This is the core reason why representative-agent NK models tend to understate short-run consumption and output effects of monetary disturbances (Kaplan et al., 2018; Auclert, 2019; Auclert et al., 2024).

4.3.2 Fiscal Policy

Fiscal experiments are where distributional structure matters most and HANK models allow macroeconomic researchers to study policies that were previously beyond their reach. Transfers targeted to liquidity-constrained households generate stronger aggregate-demand responses than uniform transfers, because

they are directed toward agents with high MPCs. Government spending effects are also state dependent. When labor income risk is elevated and balance sheets are weak, the induced rise in household income can produce larger consumption spillovers than in representative-agent environments. Accordingly, HANK-based fiscal multipliers are typically more sensitive to program design, cyclical conditions, and financing assumptions than their representative-agent counterparts (Kaplan et al., 2018; Auclert, 2019).

Ferriere and Navarro (2025) provide a particularly direct quantification of this point. In a HANK model with heterogeneity in both MPCs and labor responses, they show that the distribution of tax financing is a first-order determinant of spending multipliers. Multipliers are substantially larger when the fiscal burden is shifted toward higher-income households, who are less responsive at the margin. Using long U.S. historical data, they also document that spending shocks were often accompanied by increases in tax progressivity, and they estimate progressivity-dependent multipliers that align with the model. For policy analysis, their result implies that ‘the multiplier’ is not a structural constant of spending alone. It is jointly determined by the composition of spending and by the cross-sectional tax adjustment used to finance it.

4.3.3 Unconventional Policy and Quantitative Easing (QE)

Two recent contributions sharpen the unconventional-policy message in heterogeneous-agent environments. Cui and Sterk (2021) study large-scale asset purchases in a HANK model with liquid and partially liquid wealth and sticky prices. Their key mechanism is a liquidity-composition effect: QE shifts household portfolios toward more liquid claims, and because the MPC out of liquid wealth is much higher than the MPC out of illiquid wealth, aggregate demand and inflation respond materially. In their estimated U.S. model, this channel implies that QE significantly cushioned the Great Recession, while also generating potentially adverse distributional side effects relative to conventional rate policy.

Hagedorn, Luo, Manovskii and Mitman (2019) focus on forward guidance in an incomplete-markets liquidity-trap setting and obtain the opposite quantitative conclusion. Under empirically plausible rigidities and a realistic horizon for policy commitments, the macro effects of forward guidance are small. Their framework resolves the ‘forward-guidance puzzle’¹⁴ of representative-agent NK models by showing that the required general-equilibrium redistribution and real-rate movements are too muted to generate large current output and employment effects.¹⁵

¹⁴The forward-guidance puzzle is the tendency of standard representative-agent New Keynesian models to predict implausibly large current effects of announcements about future policy-rate paths. The mechanism comes from the forward-looking Euler equation and Phillips curve: distant expected real-rate changes affect current demand and inflation too strongly, and the effect may grow with the announcement horizon. See Del Negro, Giannoni and Patterson (2023); for related interest-rate-peg pathologies and reversal effects, see Carlstrom, Fuerst and Paustian (2015).

¹⁵The idea that incomplete markets and household heterogeneity could attenuate the forward-guidance puzzle goes back at least to McKay, Nakamura and Steinsson (2016). Werning (2015) challenged the generality of that conclusion, showing that incomplete markets need not weaken forward guidance and may leave its power close to, or even above, the representative-agent benchmark. Subsequent work clarified that the answer depends crucially on the distributional consequences of the policy experiment, in particular on the cyclicity of idiosyncratic income risk: procyclical risk tends to dampen New Keynesian paradoxes, whereas countercyclical risk can amplify them (Acharya & Dogra, 2020; Hagedorn et al., 2019).

4.4 Implications for Central Banks

Three implications are especially relevant for Central Banks. First, optimal stabilization in heterogeneous-agent environments must take distribution aspects into consideration. Acharya, Challe and Dogra (2023) show that optimal monetary policy in HANK differs from the representative-agent benchmark because policy trades off price stability, activity stabilization, and consumption-inequality dynamics. Similarly, Challe (2020) shows that uninsured unemployment risk can call for systematically more accommodative policy than in complete-markets benchmarks. On the fiscal side, Le Grand and Ragot (2025) emphasize that optimal debt and tax adjustment in heterogeneous-agent economies depends on how financing instruments map into constrained households' behavior.

Second, the monetary-fiscal mix cannot be assessed independently of distributional incidence. In representative-agent models, the standard classification of regimes relies on policy-rule coefficients and debt stabilization behavior (active/passive monetary and fiscal policy in the sense of Leeper (1991)). In HANK, this is no longer sufficient: monetary and fiscal shocks propagate through heterogeneous cash-flow and income exposures, and the aggregate response depends on who receives income gains and who bears tax adjustments (Kaplan et al., 2018; Auclert, 2019). In the intertemporal-Keynesian-cross framework, this dependence is explicit because output and inflation dynamics are pinned down jointly by policy rules and by distribution-dependent income-response objects (Auclert et al., 2024). The empirical importance of financing incidence is further documented by Ferriere and Navarro (2025), who show that spending multipliers vary strongly with tax progressivity. For policy institutions, the practical implication is that 'fiscal dominance' versus 'monetary dominance' must be assessed as a joint, estimated property of policy behavior and household distribution, rather than as a purely representative-agent taxonomy.

Third, determinacy and numerical solvability are now central operational constraints. For incomplete-markets models, Hagedorn (2023) provides a local determinacy criterion based on dimensionality reduction. The underlying winding-number logic traces back to Onatski (2006) in linear rational-expectations systems. Building on sequence-space methods, Auclert, Majic, Rognlie and Straub (2026) show how determinacy tests and large-scale model solution can be handled jointly in very high dimensions, a key practical step for central banks and other policy institutions running multi-block HANK systems.

4.5 Limitations and Future Directions

Despite major methodological progress, several constraints still limit the routine use of HANK models in policy institutions, especially Central Banks.

- *Computation and scalability.* Even with SSJ and related dimensionality-reduction techniques, high-dimensional state spaces, rich shock structures, and nonlinear policy constraints remain computationally intensive in real-time policy environments.

- *Identification and data requirements.* Estimation requires joint discipline from macro time series and household-level moments (wealth distribution, MPCs, cash-flow exposure), and measurement choices can materially affect posterior transmission mechanisms.
- *Nonlinear risk and regime dependence.* Questions involving uncertainty shocks, occasionally binding constraints, and large policy interventions often require higher-order or global solution methods that are not yet as operationally standardized as linear pipelines.
- *Adding firm heterogeneity.* A key frontier is to complement household heterogeneity with heterogeneous firms and financial constraints, so that investment transmission and firm-level cash-flow channels are treated symmetrically with household consumption channels (Winberry, Auclert, Rognlie & Straub, 2025).
- *Broader policy architecture.* Integrating open-economy blocks, financial intermediation, and fiscal institutions in a single estimated framework remains an ongoing task for most Central Banks.

The medium-run research agenda is therefore not to replace current DSGE toolkits overnight, but to build hybrid policy platforms in which HANK blocks can be activated when distributional incidence is first-order while retaining the speed and transparency required for routine forecasting and policy rounds.

5 Conclusion

DSGE models became central to modern policy analysis because they offer a structured way to connect shocks, expectations, frictions, and policies within a single equilibrium framework. Their value lies in their ability to impose economic discipline on the data, to make counterfactual exercises internally consistent, and to translate policy questions into explicit transmission mechanisms. The move from large macroeconomic systems to microfounded DSGE models, and then to estimated medium-scale New Keynesian models, gave Central Banks a shared language for discussing economic policies. This shared language is valuable precisely because policy decisions are counterfactual decisions: they require a disciplined account of what would happen under alternative interest-rate paths, fiscal measures, balance-sheet policies, or regulatory regimes. In that role, DSGE models provide a useful starting point for policymaking and a particularly useful device for ruling out internally inconsistent or quantitatively implausible policy narratives. They are not, however, mature enough to replace policy judgment. Their recommendations remain conditional on modelling choices, identification assumptions, data limitations, and institutional information that often lies outside the formal model. Read together with the companion chapters, this points to a common lesson. Rojas Bernal and Markevych (2026) emphasize that progress in business-cycle analysis has come from clarifying measurement, identification, and counterfactual discipline rather than from finding a final model of the business cycle. Baksa (2026) show how policy institutions turn that lesson into practice: DSGE models become one component of a broader suite that also includes statistical forecasting tools, semi-structural models, scenario analysis, and policy judgment.

The chapter has also emphasized that this language is still evolving. Representative-agent models remain useful because they are tractable, transparent, and operational in routine policy environments, but they miss distributional channels that are often first-order for monetary, fiscal, and balance-sheet policies. HANK models address this limitation by linking aggregate dynamics to household balance sheets, income risk, liquidity, and marginal propensities to consume. They therefore refine the interpretation of policy multipliers, forward guidance, QE, and the monetary-fiscal mix. The practical lesson is not that HANK should simply replace existing DSGE toolkits, but that policy institutions need a portfolio of models: fast representative-agent platforms for routine analysis, richer heterogeneous-agent blocks when incidence and redistribution are central, and disciplined empirical procedures to decide which mechanisms matter in a given episode.

In that respect, contemporary criticism of DSGE models belongs to a longer history rather than to a wholly new controversy. The concern that formal models may acquire more authority than their identifying assumptions warrant runs from Keynes's critique of early econometric business-cycle models to later debates over VARs, rational expectations, and DSGE policy counterfactuals. The relevant lesson is therefore not to abandon formal modelling, but to make explicit which restrictions are technical devices, which are behavioral assumptions, and which empirical claims are robust enough to guide policy.

All in all, the DSGE framework aged well as a language for disciplined counterfactual policy analysis and as a guardrail against weak policy reasoning, but particular modelling shortcuts aged unevenly as the policy questions moved from inflation stabilization to financial instability, the effective lower bound, and distributional transmission. Put differently, the framework aged well as a way of disciplining policy arguments, but not all of its early shortcuts aged equally well. The most useful historical reading is therefore not a verdict for or against DSGE models, but a distinction between the enduring modelling discipline and the specifications that had to be revised as policy problems changed.

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