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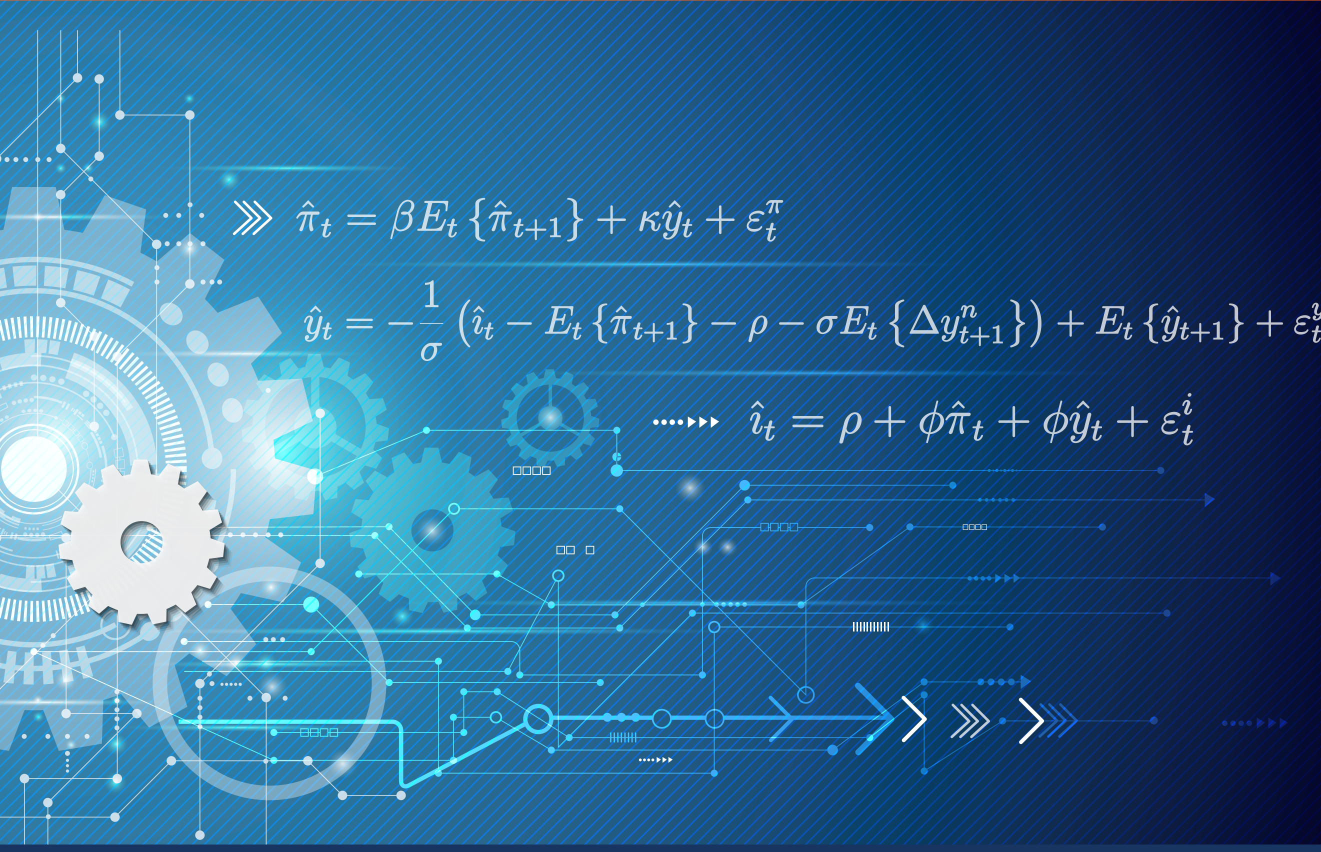
DSGE Models in the Conduct of Policy: Use as intended

Edited by Refet S. Gürkaynak and Cédric Tille



A VoxEU.org Book

CEPR Press

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Foreword

There has been continuing disagreement over the use of Dynamic Stochastic General Equilibrium (DSGE) models within economic research. Many central banks have been using them in policy analysis since the turn of the century. However, they have come under heavy criticism due to their complex nature and reliance on disputable assumptions.

The limitations of DSGE models are well recognised, and this eBook seeks to address concerns by focussing on richer versions with better established hypotheses and focus. It reviews the use of DSGE models in policy institutions; lessons learned; and the ways forward. The eBook covers a range of topics to ensure an all-round evaluation of DSGE model implementation. It explores their use in monetary policy; historic and current cases; challenges and opportunities; counterfactual analysis; and their future in economics.

CEPR is grateful to Professors Refet Gürkaynak and Cédric Tille for their joint editorship of this eBook. Our thanks also go to Sophie Roughton and Simran Bola for their excellent and swift handling of its production. CEPR, which takes no institutional positions on economic policy matters, is delighted to provide a platform for an exchange of views on this important topic.

Tessa Ogden
Chief Executive Officer, CEPR
April 2017

Introduction: Are DSGE models useful for policymakers?

Refet S. Gürkaynak and Cédric Tille
Bilkent University and CEPR; Graduate Institute, Geneva and CEPR

Dynamic Stochastic General Equilibrium (DSGE) models have been the workhorse framework of macroeconomic analysis since the 1990's. In addition to their presence in academic research, these models have increasingly been used in policy institutions, especially in central banks.

DSGE models' use in policy analysis is the last step in a long tradition of relying on formal models. Macroeconomic policy analysis using formal models began in earnest in the 1960s, with the large-scale Keynesian settings which were built on behavioural equations. These were easy to tweak as functional forms and variables to be included could be chosen at will by the researcher. Importantly, expectations were treated as, essentially, independent variables. Then came the Lucas critique in the 1970s, which argued that agents who understand the world do not make inefficient forecasts, that their expectations are rational, and that their behaviour changes in response to shifts in policies. In terms of modelling, this required expectations to be endogenous and model consistent. While this was a major challenge for the extant macroeconomic models, microeconomic theory was unscathed.

DSGE models result from the understanding that policy analysis can only be satisfactorily carried out when the optimising behaviour of agents at the microeconomic level is well understood. In contrast to old-style, Keynesian macroeconometric models that relied on ad-hoc behavioural relationships, DSGE models rest on microfoundations. The first set of models to have microfounded, optimising behaviour, rational expectations and a general equilibrium framework were the non-monetary real business cycle (RBC) models, focused on the impact of technology shocks. While these early DSGE models showed that business cycle research is possible without being subject to the Lucas critique, they did not leave much scope for monetary policy analysis.

DSGE models have since been extended to encompass a role for economic policy. They include various inefficiencies and frictions, almost always including price stickiness, allowing for nontrivial policy analysis with an emphasis on monetary policy. In different guises and with different bells and whistles, these New Keynesian models are the current state of the art in monetary policy research.

One could get the impression that DSGE models are the latest vintage in a progression of models, each better than the one before, and that the DSGE approach is better than all the previous ones. Much like car vintages, older vintage models still have their fans and, indeed, may even be better in some or all dimensions, despite the technical improvements seen in more recent models.

In reality, the DSGE framework is not seen as *the* right one by policymakers. Instead, central banks continue to use large scale macroeconometric models in the older Keynesian tradition, as well as other statistical methods, such as structural VARs for policy analysis and forecasting, in addition to DSGE models. The DSGE framework is in fact not unanimously positively received. In recent years, several economists have offered deeply critical assessments of these models (see for instance Blanchard (in this eBook), Blanchard 2016, Korinek 2015, Romer 2016), in particular arguing that the profession has become too fascinated with technical sophistication at the expense of being able to offer relevant insights on real-world issues.

This eBook approaches the issue from the point of view of DSGE use in the work of policy institutions. Do these criticisms imply that DSGE models are a tool whose benefits do not justify the substantial costs? If DSGE models have their place, what can (and cannot) we reasonably expect of them? What are the lessons from their use in recent years in guiding policy? And where should we go next?

Our review relies on contributions from nine sets of authors and is presented around three sections. The first considers how DSGE models fit in the broader toolbox of policymakers, in a section that contains the assessments of policymakers. We then delve into the lessons learned from the building and use of these models, with contributions from some of the foremost practitioners of the art. The final section assesses the way forward, with two essays by two of the founding fathers of DSGE models.

In *DSGE Models: A Cup Half Full*, John C. Williams stresses that DSGE models are only one of several inputs in the policy process. The reliance on several types of models allows for a robustness check of the key macroeconomic features. While there is a large body of work, developing and strengthening DSGE models, some major areas need additional efforts. These include the workings of the labour market, the inclusion of long cycles to better capture persistent changes, and a richer view of financial markets and their imperfections.

The chapter by Katrin Assenmacher, *Bridging the gap between structural VAR and DSGE models*, contrasts the models with the more data-oriented VAR approach. It stresses that the two approaches are not as far apart as one may think, with, for instance, SVAR frameworks being used to infer the parameters of DSGE models, and the DSGE models providing the necessary restrictions needed for the identification of shocks in a SVAR.

Stefan Gerlach's contribution, *DSGE models in monetary policy committees*, points out that policymakers are far from relying only on such models. This limited reliance results from several aspects. The performance of DSGE models during the crisis has been quite disappointing, which highlighted that their deep structural features turned out not to be so deep. In addition, DSGE models rely on too limited a set of indicators and economic mechanisms, and can thus miss relevant transmission channels. The complex nature of the models also limits their usefulness as communication devices.

Turning to the experience from DSGE use in central banks, Del Negro and Giannoni, in *Using Dynamic Stochastic General Equilibrium Models at the New York Fed*, review the experience across various uses. While DSGE are not the best forecasting tools, their performance remains strong enough. DSGE models proved useful in accounting for the historical experience, and allow for the computations of estimates of relevant but unobservable variables, such as the natural rate of interest. They also provide a framework for the conduct of "what if" analyses, including providing a sense of the probability of various outcomes. Despite improvements, no model will ever be "the" true model, and thus contrasting the messages across a range of different setups offers the best way to assess the robustness of conclusions.

In *Empirical DSGE Models: from the Great Moderation, to the Great Recession and beyond*, Justiniano, Primiceri, and Tambalotti review the performance of empirical analyses that rely on DSGE models. There has been substantial progress made on methods, with the use of Bayesian procedures as well as multi-indicators approaches. The models have proved useful in informing researchers on the sources of business cycles. Nonetheless the crisis has sharply highlighted the limitations of the models, and substantial improvements are being developed to better capture financial frictions, enrich the set of tools of policymakers, and develop settings with heterogeneous agents.

In addition to their use in understanding monetary policy, DSGE settings shed light on the interactions across various policies. In *Policy Packages: Challenge and Opportunity for DSGE Research,* Fabio Ghironi points out that frameworks built on optimising behaviour are particularly useful in assessing reforms that span several areas of policy. For instance, structural reforms affect the incentives of agents at the micro level, and thus one should assess them using a setting that captures this. These settings also allow the researcher to assess how reforms can be best accompanied by other policies, such as monetary policy.

One of the main appeals of DSGE models is their ability to conduct scenario analysis. In *DSGE models and counterfactual analysis,* Coenen, Motto, Rostagno, Schmidt and Smets stress this aspect. The models fit the data reasonably well and their explicit modelling of expectations limits their vulnerability to the Lucas critique. The authors illustrate the point through several examples, namely the de-anchoring of inflation expectations, an assessment of the drivers of movements in financial markets, and the identification of the shocks behind growth and inflation developments.

The eBook concludes with two contributions on the next steps. In *Some Scattered Thoughts on DSGE Models* Gali points out that DSGE models are still lacking in several dimensions. Promising avenues for research include a move away from the standard infinite horizon and representative agent assumptions. DSGE models are also built on the constraining assumption that the economic variables are stationary, and are thus ill-equipped in their current form to handle long lasting shifts.

Blanchard's contribution, *Do DSGE Models Have a Future?*, points out that DSGE models rely on constraining assumptions, and that the reliance on *a-priori* methods (calibration and Bayesian methods) for estimation is questionable.

Their normative dimension is also questionable, and often the complexity of the models hinders their use as communication devices. While these limits do not call for abandoning DSGE settings, this line of research must be broadened if it is to go beyond the restrictive assumptions on which it relies.

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Refet S. Gürkaynak is professor and department chair at Bilkent University Department of Economics and research fellow at CEPR, CESIfo and CFS. Formerly he was at the Monetary Affairs Divison of the Federal Reserve Board. He is a frequent consultant to central banks and the recipient of several grants and awards, including an ERC Consolidator Grant. Gürkaynak's research is broadly on central banking, with emphasis on the intersection of asset prices and monetary policy.

Cédric Tille is a Professor of Economics at the Graduate Institute for International and Development Studies. Prior to joining the Institute, he worked in the International Research Function of the Federal Reserve Bank of New York. His research focuses on the impact of financial globalization on international economic linkages, covering theoretical and empirical contributions. Recent works analyzes the Swiss foreign investment positions, the determinants of currency use in international trade, and the drivers of banks' activities in different currencies.

Section I

How do DSGE models fit in the toolbox?

1 DSGE models: A cup half full

John C. Williams
Federal Reserve Bank of San Francisco[1]

Macroeconomic models are an essential part of a monetary policymaker's toolkit. Although simple theoretical models provide valuable insights into economic mechanisms and partial-equilibrium models are useful for forecasting and analysis, macroeconomic models provide a general equilibrium perspective that is critical for economic forecasting, assessing alternative scenarios and macroeconomic risks, and analysing monetary policy strategy. Over the past decade or so, a new generation of dynamic stochastic general equilibrium (DSGE) models have been developed and are now in everyday use at many central banks, including the Federal Reserve. In theory, DSGE models feature more explicit micro foundations, impose cross-equation restrictions that relate macroeconomic responses to shocks, and provide a closer connection between academic research and central bank practice. In this chapter, I will offer my personal assessment of the usefulness of DSGE models currently in use at the Federal Reserve and identify three key issues that the next generation of DSGE models will need to address to be more relevant for policymakers. My comments reflect my own views and not necessarily those of anyone else in the Federal Reserve System.

DSGE: one of many inputs to policy

DSGE models have supplemented, and in some cases, replaced, standard macroeconometric models at many central banks. At the Federal Reserve, a number of DSGE models currently coexist alongside more traditional structural models like FRB/US and FRB/Global (Brayton *et al*. 1997).

1 The views presented are the view of the author and do not necessarily reflect the views of the Federal Reserve Bank of San Francisco or the Federal Reserve System.

The staff of the Board of Governors has developed two working DSGE models, the EDO model of the US economy and the SIGMA multi-country model. In addition, several research departments at Federal Reserve Banks have developed DSGE models that are used for forecasting and analysis. DSGE model-based forecasts and other analyses are regularly shared among economists and policymakers across the Federal Reserve System.

The addition of DSGE models to the suite of models my colleagues and I regularly consult at the Fed is a positive development. My research on robust monetary policy strategy emphasises that we shouldn't place too much confidence in any one model (Levin *et al*. 1999, Levin and Williams 2003). From a robustness perspective, the more models, the better! This is equally true for forecasting, alternative simulations, and policy strategy analysis. This is particularly salient for models that are designed to be consistent with key features of the macroeconomic data, which is the case for the set of DSGE models in use at the Fed. For these reasons, I find DSGE (alongside other macroeconomic) models useful to help identify which results are robust across models and cases where different models yield different conclusions and why.

Despite these benefits, the practical value of DSGE models in addressing critical policy issues of the past decade has been limited by key modelling assumptions at the foundation of many DSGE models used at the Fed. Specifically, in recent years three key issues for monetary policymaking at the Federal Reserve have been the extent of slack in the labour market, the productivity slowdown, and the natural (or equilibrium) rate of interest. In theory, the claimed micro-foundations underlying DSGE models should make them well suited for analysing these issues. In practice, microeconomic theory is primarily used to pin down certain parameters and cross-equation restrictions in the dynamic responses to shocks, leaving the models silent on these key policy issues.

The labour market

This shortfall is illustrated by the treatment of the labour market in many DSGE models (Levin *et al*. 2006). Although there have been numerous advances in the modelling of the labour market in DSGE models over the past decade, the models in use at the Fed typically treat it in a cursory manner or abstract from it entirely.

The cyclical state of the economy is summarised by the output gap. In debates about the structural versus cyclical nature of fluctuations in the labour market that have been the subject of so much attention and research at the Fed in recent years – related to the unemployment rate, labour force participation, job vacancies, and part-time employment – these DSGE models are silent. Given that one-half of the Fed's mandate concerns employment, the next generation of DSGE models needs to have a greater focus on modelling the labour market and the degree of slack.

Including longer cycles

A second and related shortcoming of the current set of DSGE models is their exclusive focus on shorter-term, or business-cycle frequency, responses to transitory shocks. Many of the most important issues facing central banks today are related to medium- or long-run developments to both the "supply" and "demand" sides of the economy, including the labour market, productivity, and other structural changes. Because the current crop of DSGE models assumes that all shocks are transitory and that the economy eventually returns to a fixed steady state, these models are not designed to analyse longer-term shifts in demographics, productivity, preferences, or other structural shifts. Instead, through the lens of these models, such developments manifest themselves as positively correlated sequences of shocks. For example, a trend slowdown in the rate of productivity growth would appear as a long sequence of negative shocks to productivity, and a permanent shift in household preferences towards greater risk aversion would appear as a sequence of shocks to risk preferences.

This confusion between transitory and longer-term changes in the economy is not without consequences. For example, the macroeconomic response to a transitory slowdown in productivity growth can be very different from the response to a long-lasting one, due to the very different wealth effects implied in the two cases (Edge *et al*. 2007). The restriction that treats all shocks as transitory in nature may significantly bias the predictions of these models when substantial structural changes occur, such as those that currently appear to be affecting many advanced economies, including demographic swings, a productivity slowdown, and shifts in risk aversion (Holston *et al.* 2016).

The assumption that all shocks are transitory has also had a particularly strong effect on the predictions of DSGE models for the natural rate of interest, that is, the real short-term interest rate that would prevail absent nominal frictions. In DSGE models, the long-run natural rate of interest is assumed to be a constant, and the natural rate fluctuates around this value in response to temporary shocks. In contrast, other models that allow for low-frequency time variation in the natural rate of interest display a marked persistent decline in the natural rate over the past decade (Laubach and Williams 2003, Lubik and Matthes 2015, Holston *et al.* 2016). In DSGE models, this period of a persistently low natural rate of interest is "explained" by a long sequence of unanticipated negative shocks to the economy (Cúrdia 2015). According to the logic of these models, once this unusual set of shocks wears off, everything will return to normal. That is, the "new normal" is always the same as the "old normal". This contrasts with the predictions of models that allow for structural shifts, which suggest the future may be very different from the past.

This brings me to the second area where the next generation of DSGE models needs to evolve: the inclusion of medium- and longer-term shocks and dynamics. This is already done in a coherent way in the Federal Reserve Board's FRB/US model, where the supply-side block is modelled and estimated using the Kalman filter (Fleischman and Roberts 2011). DSGE models can similarly be augmented to incorporate and estimate longer-term trends in the labour market, productivity, and other structural factors. By extension, these models will also be able to speak to the issue of longer-term movements in the natural rate of interest. This will provide a richer description of the various factors influencing the macroeconomic landscape and help make these models more useful to policymakers.

Financial markets

Finally, the first generation of DSGE models incorporated a very restrictive set of assumptions about financial markets and asset prices. A great deal of research has gone into relaxing these assumptions to provide models that can confront the data and issues on policymakers' minds.

Given the importance of unconventional monetary policy actions and their transmission to financial market conditions, DSGE models used at central banks need to be developed further to incorporate a richer and more realistic description of the financial system and account for the ways in which unconventional policies are transmitted. Such improvements will help these models be effectively integrated into policy discussions.

Next steps

The origin of current, policy relevant DSGE models was the splicing of the DNA from micro-founded real business cycle models with theories of nominal frictions. The goal was to create a new generation macroeconomic synthesis that combines factors that influence aggregate supply and demand in a coherent framework. Much of the development of these models, both in the academic literature and at central banks, focused on matching key aspects of the data in terms of the responses to shocks and forecasting. This progress has made such models useful to policymakers like myself for certain purposes. However, DSGE models will need to evolve further – including incorporating a more thorough representation of the labour market; adding medium-term shocks and dynamics related to demographics, productivity, and other structural shifts; and including a richer description of the financial system and unconventional monetary policies – in order to become more useful for addressing the key issues before policymakers today and the future.

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About the author

John C. Williams took office as President and Chief Executive Officer of the Federal Reserve Bank of San Francisco on March 1, 2011. In this role, he serves on the Federal Open Market Committee, bringing the Fed's Twelfth District's perspective to monetary policy discussions in Washington. Dr. Williams was previously the Executive Vice President and Director of Research for the San Francisco bank, which he joined in 2002.

He began his career in 1994 as an Economist at the Board of Governors of the Federal Reserve System, following the completion of his Ph.D. in Economics at Stanford University. Dr. Williams' research focuses on topics including: monetary policy under uncertainty; innovation; productivity, and business cycles. He has collaborated with economists from throughout the country and across the globe to examine economic and policy issues from different perspectives, and has published numerous articles in leading research journals.

Dr. Williams previously served as the Managing Editor of the *International Journal of Central Banking* and as Associate Editor of the *American Economic Review*. Additionally, he served as Senior Economist at the White House Council of Economic Advisers and as a Lecturer at Stanford University's Graduate School of Business. Prior to completing his doctorate at Stanford, he earned a Master's of Science with distinction in economics from the London School of Economics in 1989, and an A.B. with high distinction from the University of California at Berkeley in 1984.

2 Bridging the gap between structural VAR and DSGE models

Katrin Assenmacher
European Central Bank[1]

Introduction

In response to the perceived shortcomings of the large simultaneous equation models of the 1960s, both structural vector autoregressive (SVAR) models and dynamic stochastic general equilibrium (DSGE) models have been developed. Nevertheless, they follow quite different methodologies. DSGE models start from a clearly specified economic structure with microfoundations, optimising individuals and rational expectations. By contrast, VAR models take a statistical approach, treating all variables as endogenous and trying to uncover the statistical process that might have generated the observable data. Put differently, DSGE models strive for theoretical coherence while VAR models aim at empirical coherence. In practice, it has proven difficult to satisfy both aims at the same time and therefore a trade-off between theoretical and empirical coherence is perceived to exist (Pagan 2003, Figure 1).

Though seemingly at opposite ends of this trade-off, DSGE and SVAR models share a similar structure. If a DSGE model is solved with a linear approximation around its steady state, in many cases it can be represented as a VAR model with a particular set of restrictions on its coefficients.[2] It is therefore not surprising that the middle ground between the two modelling approaches has been researched intensively.

1 I am grateful to Nicolas Cuche-Curti and Barbara Rudolf for helpful comments. The views expressed in this paper are those of the author and do not necessarily represent those of the European Central Bank or the Swiss National Bank.

2 If a DSGE model cannot be represented by a SVAR model it is called non-invertible (Sims 2012).

Evidence from VAR models has been used to inform modellers on suitable specifications for DSGE models, whereas DSGE models have provided theoretically founded restrictions that can be imposed on VAR models. Models that are used for policy simulation and forecasting thus often combine features from both approaches.

Bringing DSGE models closer to the data

Early DSGE models were used for considering the consequences of shocks to a stylised economy. They were intended to illustrate the mechanisms at work and not to describe any specific set of data. Such models, however, are of limited value for guiding policy decisions in real-world economies. It is therefore not surprising that research has focused on expanding these models and making them more consistent with the empirical facts.

SVAR models have been an important tool in this effort. The VAR approach has been proposed by Sims (1980) in reaction to the large number of identifying assumptions that were common in the macroeconomic models at the time. Instead, Sims proposed to adopt a time-series perspective by modelling all variables in the model as functions of their own lagged values. Using as few restrictions as possible, a VAR model generates impulse responses that depict the dynamic reaction of the model's variables to a shock in a specific equation.[3] In a VAR model these shocks can be interpreted in the same way as the policy shocks in a DSGE model, provided that they are identified by theoretically motivated restrictions that are imposed on the variance-covariance matrix and/or the coefficients of a VAR.

Rotemberg and Woodford (1997) estimated the parameters of a DSGE model by minimising the distance between the DSGE and the SVAR impulse responses to a policy shock. The DSGE model parameters can only be recovered from the data if the SVAR innovations, on which the empirical impulse responses are based, can be mapped into the structural shocks of the underlying DSGE model.

3 Sims (1980) was aware that the ordering of the variables will affect the dynamic responses of the triangularised system. Pesaran and Shin (1998) developed generalised impulse responses that are invariant to the ordering. Both approaches, however, do not allow for a structural interpretation of the impulse responses.

For the structural shocks and their effects on the economy to be identified in an estimated SVAR model, the data has to contain enough information about these underlying shocks. Otherwise, not all of a DSGE model's structural parameters can be estimated from the data.

SVAR models have been used to assess different specifications of DSGE models, see e.g. Gali (1999) and Christiano *et al*. (2005). Due to the assumption of rational expectations, a DSGE model without frictions generates little persistence in the response to a monetary policy shock. By contrast, SVAR models generally show long, hump-shaped responses of output and inflation to a monetary policy shock, that peak after several quarters and then decline gradually. The evidence from SVAR models has guided researchers in choosing the kind of frictions – for instance price and wage stickiness, investment adjustment costs or habit formation in consumption – that bring the DSGE results closer to the empirical evidence.

Chari *et al*. (2008) took a critical position towards this approach. They raise various objections.[4] First, the identification of the SVAR model should be consistent with the restrictions that are implied by the DSGE model. Second, when restrictions on the long-run behaviour of certain variables are involved, the theoretical model might imply an infinite-order VAR, whereas for data reasons the VAR has to be truncated at a rather short lag length. This truncation can lead to bias, in particular when the shock of interest accounts only for a small fraction of the variation in the variables.

Many DSGE models contain only a small number of economically relevant shocks whereas in a VAR regression there are as many innovation as endogenous variables. It has become common to add additional shocks to DSGE models. These shocks are either given a structural interpretation, such as cost-push or preference shocks (Smets and Wouters 2003), or they are interpreted as measurement errors (Ireland 2004). On the one hand, this leads to a better match with the data. On the other hand, this comes at the expense of theoretical stringency. Conclusions that are derived from such a model can differ strongly from those that are obtained when the data are analysed without pre-imposing such a potentially misspecified model structure (Juselius and Franchi 2007).

4 See also Kilian (2013).

DSGE models as identification device for SVAR models

While SVAR models have been used to improve the empirical coherence of DSGE models, information from DSGE models has also helped to achieve greater theoretical coherence of SVAR models. One obvious use of DSGE models is to derive identifying restrictions that can be imposed on a SVAR model to allow for a better structural interpretation of the results.

This is less straightforward, however, than it might appear at first sight. SVAR models typically rely on zero restrictions on their variance-covariance matrix. It is often difficult to come up with enough zero restrictions from a DSGE model to fully identify a SVAR model. Though long-run restrictions have better theoretical foundations, their application to SVAR models gives rise to a number of statistical problems like lag truncation, non-stationarity and the precision of the estimated coefficients.[5]

As DSGE models are able to make qualitative statements about the directional impact of a shock to a specific variable, the closest match with SVAR models is probably achieved by using sign restrictions (Uhlig 2005). Sign restrictions, however, will be consistent with a whole range of impulse responses and thus fail to map the resulting impulse responses into a model that can be used for policy analysis. A penalty function approach allows for imposing quantitative and sign restrictions from a DSGE model on a SVAR model. In that way, a unique mapping between the theoretical and the empirical shocks is achieved, but the form of the penalty function remains arbitrary and has to be chosen by the researcher (Liu and Theodoridis 2012).

Forecasting

VAR models – in particular Bayesian VAR models which impose some prior information on the often large number of coefficients – have for a long time been known for their good forecasting performance. By contrast, the principal goal of the early DSGE models was policy analysis, not forecasting. The efforts of bringing the DSGE models closer to the data have also resulted in improved forecast performance of these models.

5 For lag truncation see Chari *et al*. (2008), for stationarity issues e.g. Juselius and Franchi (2007), for general problems with using long-run restrictions Faust and Leeper (1997).

Del Negro and Schorfheide (2004) developed a DSGE model that can be used for policy analysis and at the same time forecasts well. To estimate the model, they augment their data set with data generated by the DSGE model. This amounts to a Bayesian prior that drives the empirical parameters towards the parameters implied by the DSGE model, with weights that are determined by the share of simulated relative to actual data used in the estimation.

Smets and Wouters (2007) showed that their DSGE model performs equally well as a Bayesian VAR in forecasting the US economy. Wickens (2014) assesses the ability of DSGE models to predict the 2007 recession and finds that DSGE models are neither more accurate nor worse than time-series models or official forecasts. All three types of forecast failed to predict the recession that started in 2007. Through the inclusion of expected values of future exogenous variables a DSGE model has forward-looking dynamics, but as the expected variables are difficult to predict, this structure does not result in a clear forecasting advantage over time-series models.

Conclusions

Though DSGE and VAR models start from very different philosophies, the gap between both approaches has narrowed. Compared to the first DSGE models, today's variants are able to match the data fairly well and show a reasonable forecasting performance. To a certain extent this has come at the expense of theoretical rigor, which calls the invariance of the DSGE model parameters to policy changes and, therefore, their immunity to the Lucas critique into question.

At the same time, various advances have been made to map the empirical innovations from SVAR models more closely to the structural shock of interest. Christiano *et al.* (2006) conclude that SVAR models can serve as a useful guide to construct and evaluate DSGE models, if the identification restrictions in the SVAR are consistent with those in the DSGE model.

Both types of models thus have their place in policy analysis and forecasting. Nevertheless, the mapping between the theoretical and the empirical shocks remains a contentious question and further research on this issue is warranted.

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3 DSGE models in monetary policy committees

Stefan Gerlach
BSI and CEPR

When many current senior central bankers (and I) first started to study economics almost 40 years ago, macroeconomic text books started by covering national income accounting before focussing on the national income identity, which states that GDP equals the sum of consumption, investment, government spending and net exports. That would be followed by chapters on the consumption and investment functions, a discussion of government spending and the determination of net exports. Next followed chapters on money supply and demand, before everything was put together in the IS-LM model.

That way of thinking about, and modelling econometrically, the macro economy was piece-by-piece. Moreover, it lacked an explicit discussion of dynamics, and of the sources and nature of the disturbances hitting the economy.

That world is long gone. By now, dynamic stochastic general equilibrium (DSGE) models have become completely dominant in macroeconomic research in academia (Wren-Lewis 2012a, 2016). In many ways, central banks are natural homes for DSGE modelling, since they have the financial resources to maintain the large research teams that are helpful for making progress in this area. Indeed, DSGE models are used extensively by researchers in most central banks in OECD countries and in many emerging economies. And forecasts from such models and simulations may be used in preparing for central banks' policy briefings.

However, it is sometimes believed that DSGE models also play a central role in the discussions of monetary policy committees. While that may be the case in one or a few central banks, I doubt whether it is common.

Many policymakers are intensely sceptical about the value of models, including (if not, in particular) DSGE models, in the setting of monetary policy. Reading commentary from senior policymakers, who in many cases have had distinguished academic careers, suggests a laundry list of reasons.

Less helpful than expected in the financial crisis

The most obvious reason for the scepticism is, no doubt, that these models turned out to be much less helpful than their proponents had suggested when Lehman Brothers collapsed and the financial crisis erupted in September 2008. In a speech given in the middle of the crisis, Trichet (2010) discusses the role of models in the ECB's management of policy. It is worthwhile to quote him at some length:

> *"When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. … Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools."*

Trichet goes on to argue that:

> *"[t]he key lesson I would draw from our experience is the danger of relying on a single tool, methodology or paradigm. Policy-makers need to have input from various theoretical perspectives and from a range of empirical approaches. Open debate and a diversity of views must be cultivated – admittedly not always an easy task in an institution such as a central bank. We do not need to throw out our DSGE and asset-pricing models: rather we need to develop complementary tools to improve the robustness of our overall framework."*

Deep structural parameters and stability

There were several reasons why DSGE models were not relied on. One was that their proponents, with their emphasis on the importance of deep structural parameters and optimisation at the micro level, had fostered the belief that the models would be stable even when large shocks occurred, in contrast to earlier generations of *ad hoc* models. That turned out not to be true. Not only are some supposedly "deep parameters", such as the degree of price stickiness, not structural, but the models displayed little stability when the distribution of shocks changed (Dotsey 2013, Hendry and Mizon 2014).

Being subject to shortcomings similar to those found in earlier models, that were so severely criticised in the DSGE literature, made them suspect in the eyes of many senior policymakers. Indeed, the entire emphasis on deep structural parameters is seen as misguided by at least one prominent policymaker (Summers 1991).

A focus on too few economic time series

A further reason why DSGE models hold less sway in monetary policy committees than their proponents may believe is that they focus on a small number of core economic time series, while much of economic policy making involves discussions of a wide range of economic and financial variables. Such discussions are guided and triggered by academic research which has focused on a much richer set of empirical facts than DSGE models do (Wren-Lewis 2012b). Indeed, Blanchard (2017) argues that DSGE models have become too insular and different models are needed for different tasks.[1]

The behaviour of consumption is a case in point. While the canonical DSGE model focuses on the role of the real interest rate and intertemporal substitution, micro econometric research using single equation techniques has had difficulties identifying any such effect. Instead, the focus in the empirical literature is on income flows and on households' access to liquid funds for spending, which may be impaired by financial tensions.

1 Romer (2016) launches a scathing attack on the modelling strategy of DSGE models.

Not surprisingly, DSGE models, which at that time typically did not include the financial sector, turned out not to be helpful in discussions of financial market tensions and their likely impact on consumption and aggregate demand as the crisis erupted. Moreover, policymakers are acutely aware that not all households are alike and discussions about distributional effects are prominent in policy meetings.

The consequences of the narrow focus of the canonical DSGE model is illustrated in a quote from Charles Goodhart, a member of the Bank of England's first monetary policy committee, who said that the model *"excludes everything [he is] interested in"* (as quoted by Buiter 2009).

Dealing with new shocks and policy issues

Building models for policy analysis inevitably involves a cat and mouse game, as policymakers are faced with entirely new economic shocks that may not have happened for a generation, if at all previously, as the quote by Trichet illustrates. Large migration flows and the prospect of Brexit are two recent cases in point for monetary policymakers in Europe.

That generates a need for policymakers to adjust their thinking quickly. However, many no doubt feel that DSGE models, with their insistence on logical purity and first principles, are inherently unsuitable for such analysis, since it is a time-consuming process to reengineer them when some new development occurs (Wren-Lewis 2013). They are, in effect, very slow cats.

Pagan (2003), in his report to the Court of Directors of the Bank of England on the modelling within the Bank, asserted that there is a trade-off between the degree of theoretical coherence, where DSGE models do well, and the degree of empirical coherence, where VAR models score highly. Pagan argues that useful modelling for monetary policymaking may require models between these extremes.[2] The need for the quick adjustment of models to deal with entirely new contingencies supports Pagan's point.

2 See also the discussion in Wren-Lewis (2013).

Of course, proponents of fully micro-founded models may argue that the results from ad hoc models are inherently unreliable and untrustworthy. That is being too religious. And it misses a key point: the alternative to using an ad hoc model, if a new type of shock hits, is not to wait for a DSGE model to be developed, but to conduct the policy analysis with no model. That does not seem a desirable outcome.

Ineffective communications devices

Another reason why DSGE models may not be as favoured by the policy community as their developers may have hoped is that it is difficult to communicate their results in a compelling way. Blanchard (2017) argues that what makes these models interesting and relevant is the presence of various distortions. However, for those not involved in model building, it can be very difficult to understand how these distortions influence the results and how they interact. He concludes that that *"DSGE models are bad communication devices."*

In another context, Summers (2016) argues that policy makers should

> *"[d]istrust conclusions reached primarily on the basis of model results. Models are estimated or parameterized on the basis of historical data. They can be expected to go wrong whenever the world changes in important ways. … I pay attention to model results only when the essential conclusion can be justified with some calculation where I can see and follow each step." No doubt, many monetary policymakers would agree with this judgement.*

Conclusions

DSGE models have become dominant in academic discussions of monetary policy. It is easy to see why. They provide internally consistent, micro-founded explanations for the dynamic behaviour of the main macroeconomic variables. They are intellectually elegant, and involve the use of novel and innovative methods of estimation.

Given the need for central banks to follow developments in front-line macroeconomic research, it is not surprising that many central banks have staff working with these models and seeking to develop and estimate national versions of them.[3]

But while some central banks have adopted them for forecasting and model simulations in preparation for the meetings of their monetary policy committees, they play much less of a role in the actual setting of monetary policy than their proponents may believe. Instead of relying on models, let alone DSGE models, Buiter (2009) argues that the setting of policy relies on *"an intellectual potpourri of factoids, partial theories, empirical regularities without firm theoretical foundations, hunches, intuitions and half-developed insights. It is not much, but knowing that you know nothing is the beginning of wisdom."*

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3 When I was with the Central Bank of Ireland in 2011-15 I was supportive of the work on DSGE models, largely because we needed this economic expertise within the Bank and not because I expected the model to be used in the policy process.

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Section II

Lessons from DSGE use in policy analysis

4 Using dynamic stochastic general equilibrium models at the New York Fed

Marco Del Negro and Marc Giannoni
Federal Reserve Bank of New York; Federal Reserve Bank of New York and CEPR [1]

Dynamic stochastic general equilibrium (DSGE) models are, in principle, ideal tools for policy analysis: they merge structural economic relationships, based on clear theoretical underpinnings, with statistical methods that allow using data series to estimate deep structural parameters of the economy, as well as all the shocks that have perturbed it. Such estimated models can then be used to answer numerous questions in policymakers' minds. How will the economy evolve over the next few quarters? What would happen to key economic variables if a given shock hit the economy now? What impact would an alternative policy behaviour have?

Economic models, and the current generation of DSGE models in particular, are, however, very stylised representations of reality, and as such they are necessarily misspecified. This raises the question: are DSGE models actually useful for policy analysis? We will address this question by providing concrete examples of their use at the Federal Reserve Bank of New York. (We should note that, while the results generated by DSGE models serve as inputs in the New York Fed staff forecasts and in the policy process, the DSGE model is one among many tools used for these purposes at the FRBNY.) For each of these examples we will discuss successes, failures, and the work that still needs to be done. Our overall conclusion is that, while models are far from perfect, there are good reasons to be optimistic.

1 The views expressed here do not necessarily reflect those of the Federal Reserve Bank of New York or the Federal Reserve System.

Forecasting

The FRBNY DSGE model has been around for about ten years, but we began using it for forecasting in earnest in 2010, as we moved from a "Mickey-mouse" three-equations New Keynesian model to a medium-scale à la Christiano *et al*. (2005) and Smets and Wouters (2007), with all their trappings and their empirical appeal (see Del Negro *et al*. 2014 for some more details). We began by showing the DSGE forecasts in internal memos and, after four years, we went public, posting the forecasts every six months or so on the FRBNY blog, the Liberty Street Economics.[2]

So why do we use this model for forecasting? Don't we know they are terrible? (Incidentally, we found that critics seem to cherry pick academic findings to make DSGE look bad. For instance, Edge and Gürkaynak (2010) find that DSGEs do as well, or as poorly, at forecasting as the Greenbook – that is, Federal Reserve Board staff's forecasts – and VAR forecasts, and sometimes do better. Yet that paper has been used as an example of how bad DSGEs are for forecasting (Wolfers 2016). Go figure!) In any case, you can judge for yourself: Cocci *et al.* (2014) documented the FRBNY DSGE forecasting performance since its inception, and the forecasts since then are all public. Note that these are true real-time forecasts, not ex-post academic exercises, as done in the paper mentioned above or in Del Negro and Schorfheide (2013). We'd say we had hits and misses. The biggest success was perhaps forecasting a sluggish recovery since 2010, with output growth around 2%, at a time when many private forecasters and the FOMC's own projections saw a booming economy just around the corner (e.g., in 2010 the FOMC's Summary of Economic Projections central tendency for real GDP growth was between 3.5 and 4.5 in both 2011 and 2012). The model also foresaw inflation persistently below the FOMC's long run target of 2% throughout. It was wrong in 2011 and 2012, when the Arab Spring sent oil prices spiking, but over the longer run this assessment was not too far off the mark.

In spite of this arguably decent performance, we are well aware that DSGEs are not the best forecasting tools out there. Still, we strongly believe that forecasting is important because it provides a reality check by confronting the model with the data in the most direct way: if the model's out-of-sample predictions are systematically off the mark, you know that something is wrong.

2 http://libertystreeteconomics.newyorkfed.org/

We realise that the model is very imperfect for many reasons, as critics point out, and therefore that sometimes, in the (possibly not too distant) future, we are going to be embarrassed by the DSGE model forecast. While we constantly work towards improving the model and trying to avoid such embarrassment, we are well aware that we do not have the "true" model of the economy.

Storytelling and unobservable variables

DSGEs are structural models, which means that the data are explained in terms of the fundamental forces driving the economy, also known as "shocks." From an econometric perspective these models are estimated using so-called full information, likelihood-based methods, which implies that we as econometricians can back out from the data the estimates of these unobserved shocks, in addition to the model parameters. Armed with these estimates, we can tell stories about the past (see Sbordone and Tambalotti 2014 about the FRBNY DSGE model interpretation of the Great Recession) and the future (Eusepi *et al*. 2016 explain a recent forecast). For example, Del Negro *et al*. (2016) assessed the impact of the deterioration in financial conditions in 2015 on the US economy, and the role played by monetary policy in counteracting this negative shock.

In addition to the shocks, there are lots of quantities of interest to policymakers that are not directly observed, such as the output gap and the natural rate of interest (Del Negro *et al*. 2015a). The latter, which is also known as r^*, tells us what the real rate of interest in the economy would be, absent any effects from monetary policy. DSGE model-based estimates of r^* reveal that, since the recent financial crisis, financial shocks, as well as other forces that induce households to save more than usual and firms to pare down investment, have been key in pushing real interest rates to low levels. Comparing actual interest rates to the natural rate offers a useful benchmark to decide whether policy is accommodative or not.

DSGE models offer a way to coherently define these objects – so that it is clear what we are talking about – to estimate them from the data, and project them forward. In fact, forecasts for the natural rate and the output gap are an integral part of the FRBNY DSGE projections.

The inference about the shocks and the other unobservable variables, and hence the stories DSGE models tell, are of course only as good as the underlying model. Econometrically, the downside of likelihood-based methods is that, in order to back out the shocks, we need to assume that we have the "true" model of the economy when in fact we don't.[3] In practice, what this means is that we need to take these stories, and the interpretation of the shocks, with more than a grain of salt.

Scenario analysis

DSGE models produce a forecast distribution, which is actually the key object in evaluating a model's performance. Point projections are obviously always wrong – you never get exactly what is going to happen. What matters is how likely ex-post outcomes are from the perspective of the model. For instance, if the Great Recession was in the 1% tail of the model's forecast distribution, we can safely say that the model did not see it coming, and hence that it performed worse over this episode than models for which this event was not so unlikely (see Del Negro *et al*. 2012 for a comparison of different DSGE models' performance over the Great Recession).

There are good reasons to be sceptical that a DSGE model's forecast distribution can place the right probability on future outcomes. No matter how good a model is, its forecast distribution depends on the information you feed into it (Del Negro *et al*. 2015d provide an example of the importance of knowing the behaviour of spreads during the Great Recession). Sometimes policymakers are interested in specific scenarios for some of the variables in the model, possibly because they have superior information relative to the information set available to the econometrician – e.g., there has just been a financial shock and policymakers suspect that, say, because of the shock variables like spreads are likely to increase for a few periods. We can use the DSGE model to back out what shocks are more likely to be behind this scenario, and to simulate a distribution of outcomes given these shocks.[4]

3 Methods for inference about the parameters in presence of model misspecification are presented in Del Negro and Schorfheide (2009)

4 If we have prior knowledge of what kind of shocks may be behind the scenario – financial shocks in the example above – we may simply back out the size of the shocks that are necessary to generate the assumed increase in spreads.

More often than not, however, there are events in the world that do not fit neatly into your model – e.g. think of Brexit. Of course you will never have a model that fits all that is happening – and changing a DSGE is not as easy as adding another variable (e.g., the pound-dollar exchange rate) to your regression.[5] In this case it is useful to pair the DSGE model with a more flexible, reduced-form model such as a large Bayesian VAR. For example, we use the BVAR to simulate a large set of indicators in a particular scenario and compute the path of certain variables in common between the BVAR and the DSGE model (e.g., GDP growth, inflation, credit spreads, …) and then use the DSGE model to make projections for all the variables that the BVAR can't tell you about, such as r^*, the output gap, and most importantly, the potential policy responses to the event.

Policy counterfactuals

Part of the FRBNY DSGE model is an estimated policy-reaction function, which describes how the policy instrument has reacted to the state of the economy — at least in the past. Whether these Taylor-type automatic feedback rules are the proper way of describing policy decisions is an open question (Del Negro and Schorfheide 2009, for instance, found that DSGEs perform worse than, say, the Blue Chip consensus in terms of interest rate forecasts' accuracy, in spite of the fact that they perform equally well, if not better, for output and inflation). Regardless, we can always use the DSGE model to evaluate how the economy would evolve under alternative policy specifications: for instance, we can evaluate the outcomes of a policy that would place more weight than in the past on stabilising inflation or output, or a policy that attempts to stabilise the price level or nominal GDP. We may even simulate the economy under a policy that is optimal according to some criterion (e.g., minimising deviations of inflation and output from the respective targets). In fact, perhaps the most important advantage of DSGEs over reduced form models is that they are, in theory at least, robust to the Lucas critique: since the estimated DSGE parameters are structural, they are not supposed to vary with policy, and so we can compute the path of the economy under alternative policies.

5 Using a wide cross section of data in the estimation of the DSGE models can help address this issue.

With reduced form models, in contrast, you have to worry that parts of the model you are keeping constant may in fact be changing with policy.

Ironically, in our experience DSGEs have often given us puzzling answers when analysing policies that are unlike those pursued in the past. For instance, when studying the effects of various forward guidance experiments we found that the model gave us implausibly strong responses of GDP and inflation (Del Negro *et al*. 2015c). More generally, in the current generation of DSGE models used for policy, current values of key macroeconomic variables appear to be excessively sensitive to changes in expected conditions far into the future. How shall we respond to these problems? Abandoning DSGEs altogether and going back to, say, solely Cowles foundation-type models does not seem a good way forward. After all, this kind of model was discarded by the academic literature some forty years ago (Sims 1980), and arguably for good reasons. However, these failures do point to fundamental problems with the current batch of DSGEs – problems that need to be addressed.

What next? Model diversification

The academic debate on what we called the "forward guidance puzzle" is illustrative of what may be missing from the current batch of DSGEs used in central banks, as the solutions offered to the puzzle involve agents' heterogeneity with borrowing and liquidity constraints, financial considerations such as the demand for "safe assets", deviations from the perfect information or rational expectations paradigm, *et cetera*. In fact, one disappointing development in the DSGE research agenda – at least to the extent that it is developed at central banks – is the degree of model homogeneity. While DSGE models used at central banks differ in many important dimensions, at the core they are all New Keynesian, representative agent, rational expectations models. Of course, there is a reason for this: New Keynesian models fit the data, and can be used for all the purposes described so far, while it is not clear that the alternatives do. And these alternatives are often so hard to solve and estimate that only rudimental versions can be taken to the data.

So, what is the path forward? It seems clear to us that if DSGE models at central banks lose contact with the frontier of macro, this literature will gradually become marginalised, and, in turn, will become less interesting to both academics and policymakers.

Keeping up is costly and difficult, as it requires heavy investment in computational and econometric methods. At the FRBNY, we have made progress in these dimensions by adopting a programming language suitable for these tasks (Del Negro *et al*. 2015b).

No matter how hard we work, however, we will never have the "true" model of the economy. While model misspecification will always be with us, we still need to address it to keep doing quantitative policy analysis. One way to guard against model misspecification is to look across types of DSGE models, possibly also including reduced-form models, with weights on the models in these pools of models possibly varying over time, depending on the question at hand.

In sum, DSGE models have gained considerable ground in the policy world, perhaps for good reasons. However, these models need to be used and interpreted judiciously. They still suffer from misspecification and the next steps to improve them appear challenging. Lots of work lies ahead. That's exciting!

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5 Empirical DSGE Models: from the Great Moderation, to the Great Recession and beyond

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Dynamic stochastic general equilibrium models (DSGEs) are a staple in the toolkit of central banks around the world. Their popularity dates back to the pioneering work of Christiano *et al*. (2005) and Smets and Wouters (2007) . Those papers demonstrated how estimated medium-scale models with nominal frictions, in which therefore monetary policy can play a useful stabilisation role, can be successful in explaining salient features of the aggregate data. The main appeal of DSGEs in the policymaking arena is the combination of this good empirical fit with the ability to "tell stories". They can produce forecasts that are as accurate as those of richly parameterised statistical models, such as VARs. Unlike these reduced-form models, however, the micro-foundations of DSGEs make it possible to decompose their forecast errors into primitive shocks with an economic interpretation. Therefore, these models have become a standard tool with which to interpret the co-movement patterns in the data, to study their underlying sources of fluctuations, as well as to conduct counterfactual policy experiments.

Of course, DSGE models are far from perfect, and their theoretical underpinnings have often been harshly criticised. For example, even if shocks have an economic interpretation within a model, their micro-foundations have often been called into question (e.g. Chari *et al*. 2009). These concerns become particularly poignant as models grow in size and additional disturbances are needed to explain the fluctuations in the data used for estimation.

1 The views expressed in this paper are those of the authors and do not necessarily reflect the position of the Federal Reserve Banks of New York, Chicago or the Federal Reserve System.

Moreover, unless a few disturbances explain the bulk of variation in macro aggregates, story-telling will produce a cacophony of explanations, thereby reducing any model's appeal for interpreting the data. Similarly, the proliferation of frictions without clear micro-foundations – mostly justified as a way of improving the ability to fit the data – is also generally viewed as problematic.

While aware of these criticisms, in the rest of this chapter we briefly summarise some of the main areas of progress in the empirical DSGE literature before the financial crisis, drawing often from our own research. We then highlight the main theoretical and empirical challenges that the crisis and the Great Recession brought about, and the response of the research community to these challenges. One conclusion that we draw from this overview is that, despite significant progress, many challenges remain, and these might be driving a wedge between academic and policy work in this area. Given the virtuous cycle of cooperation between academia and the policy world that has been one of the hallmarks of the development of DSGE models so far, further divergence between the two spheres would likely be a serious setback for this field.

Progress before the financial crisis

The first significant area of progress in DSGE research before the financial crisis that we wish to highlight is its *empirical methodology*. The development of Bayesian techniques for the efficient estimation of DSGEs was an essential ingredient to turn these models into credible tools for data description and forecasting. This empirical approach represents a quantum leap compared to calibration, which judges empirical fit based on a few user-selected moments. The cost of this progress is that estimating medium- to large-scale models with full information methods is a task fraught with difficulties, which at times might appear more like art than science.

One relatively underemphasised aspect of these subtleties, which in our experience can have significant implications for inference, is related to measurement. For example, estimates of the degree of price and wage stickiness, or even of the policy rule coefficients, can be sensitive to the price and wage series used to inform the model. To address this issue, for example, in our work we have pursued the multiple indicator approach suggested by Boivin and Giannoni (2006).

The idea is to use several measures of price and wage inflation to infer common factors corresponding to the respective model-based measures of inflation (e.g. Justiniano *et al*. 2013, Brave *et al*. 2012). In this way, the idiosyncratic quarter-to-quarter gyrations in each series are treated as measurement error, and hence do not need to be explained by the model. One desirable result of this approach is that the contribution of questionable mark-up shocks to fluctuations falls drastically compared to versions of the same model estimated matching only one – often arbitrarily chosen – data series to each observable variable in the model.

A second example illustrating the importance of measurement considerations is the choice of data on hours worked. The standard approach in the literature is to measure hours in the model by hours worked in the non-farm business sector divided by population. In practice, however, this measurement approach includes the low frequency variation of labour force participation, which models cannot typically account for. This matters because the measurement of hours is crucial in informing the deviation of GDP from model-based trend, and this output "gap" measure in turn shapes forecasts of economic activity. One solution to this important issue would be to incorporate the labour force participation margin into the model. An alternative is to use the sum of hours per worker in the non-farm business sector plus the employment rate, which delivers reasonable measures of the output gap (Barsky *et al*. 2014).

A second area of progress in the first generation of empirical DSGE models that intersects with our research is in the identification of the *sources of business cycles*. In Justiniano *et al*. (2010) we found that the bulk of business cycle fluctuations in key macro aggregates is driven by investment shocks – disturbances that affect the transformation of current savings into future capital inputs. In Justiniano *et al*. (2011) we further showed that these shocks may proxy for financial factors and fundamental disturbances to the functioning of the financial sector. Indeed, the estimated sequence of investment shocks in that model is closely correlated with the spread between corporate yields and Treasuries. In addition, Justiniano and Primiceri (2008) demonstrated that a reduction in the volatility of these investment shocks was a crucial factor behind the improved stability of the US economy between the mid-1980s and 2006 – the so-called Great Moderation. These papers, which were mostly written before the financial crisis, highlighted the importance of financial factors in generating business cycles.

This view, of which Christiano *et al*. (2003) is an even earlier example, was fairly marginal during the Great Moderation, but became mainstream after the Great Recession.

Finally, a third area of fruitful development in the pre-crisis DSGE literature, which has had an enormous impact on monetary policy all around the world, is the analysis of the *zero lower bound* (ZLB) on nominal interest rates. In their seminal contribution to this now vast literature, Eggertsson and Woodford (2003) studied optimal policy when the ZLB constrains the central bank's ability to lower the nominal interest rate in a recessionary situation. The policy recommendation emerging from their analysis is that the interest rate should remain low past the time that the economy starts recovering from the shock that pushed it against the ZLB constraint. This policy prescription has become the theoretical underpinning of so-called forward guidance policies, which have been pursued by several central banks during and after the Great Recession.

The financial crisis: challenges and further progress

Despite the significant progress in DSGE modelling pre-crisis, the financial crisis and the Great Recession exposed some major limitations of the first generation of empirical DSGE models. First among them was the fact that most of those models ignored the role of financial frictions and shocks. This omission was actually a reasoned choice in the context of the Great Moderation, a period of remarkable macroeconomic stability that led macroeconomists to discount the probability of severe fluctuations, especially those driven by financial factors (e.g. Chari *et al*. 2007, and Ng and Tambalotti, 2012). The financial crisis, and its propagation into the worst recession since the 1930s, demonstrated that this stance was no longer consistent with reality, spurring a great deal of new and exciting research in both academia and central banks. From where we stand, however, the impression is that the research programmes of academic and central bank economists, working on DSGE modelling since the crisis, have evolved along fairly different paths, which we briefly outline below. We see this divergence as a risk for the field, as further elaborated in our conclusion.

Progress at central banks

Since the financial crisis, an important development in the central banking research agenda is the emergence of a second generation of empirical DSGE models. These models include explicit financial frictions and shocks, building on the work of Bernanke *et al*. (1998) and Kiyotaki and Moore (1997). Good examples of these recent DSGE models used at policy institutions include Brave *et al*. (2012), Del Negro *et al*. (2013), and Christiano *et al*. (2014). This new generation of empirical models attributes the Great Recession to a financial shock associated with the massive spike in credit spreads observed during the crisis. Conditional on such a shock, the model is quite successful in predicting the severity of the recession as well as the relatively modest decline in inflation observed during this period (e.g. Del Negro *et al*. 2015).

However, the success of these second generation of models has been more mixed during the sluggish recovery that followed the Great Recession. The reason is that these DSGEs associate tight financial conditions to elevated credit spreads, which was a salient feature of the data only until 2010. Since then, credit spreads have reverted to pre-crisis levels, but GDP is still well below its old trend. Therefore, capturing such a slow recovery, despite seemingly improved financial conditions, requires a persistent sequence of adverse shocks, since propagation mechanisms in linearised DSGE models are not powerful enough to generate highly persistent deviations of output from trend (Justiniano 2013).

A separate, but complementary front of development has sought to enhance the description of monetary policy in DSGEs. Given the ZLB constraint, several central banks responded to the financial crisis by adopting non-standard policy measures. Therefore, the policy dimension in DSGEs can no longer be simply reduced to an interest-rate rule. One step in this direction is the inclusion of forward guidance through policy signals – i.e. anticipated deviations from the policy rule – which can be informed by market-based forecasts of the policy rate, as for instance in Campbell *et al.* (2012) and Del Negro *et al.* (2013). In this way, model-based forecasts are conditional on the expected path of policy, which, at least in the US, does not violate the ZLB. Furthermore, shock decompositions can be used to tease out the extent to which the ZLB has constrained policy, and to quantify the important contribution of forward guidance to macroeconomic outcomes (Campbell *et al*. forthcoming).

This way of modelling forward guidance can be readily included in the fairly rich models used in policy institutions, providing an alternative to formal treatment of the nonlinearities imposed by the ZLB constraint. This last issue has been explicitly tackled by the recent breakthrough solution and estimation work of Gust *et al.* (2016) and Aruoba *et al*. (2016). However, the technical complexities involved in using full nonlinear solutions are formidable, limiting the size of usable models. These considerations are likely to render those methods of limited appeal for policymaking in the very near future, especially given the tendency to build models of increasing complexity.[2]

Progress in academia

The academic literature has also dealt with issues related to unconventional monetary policy. Important recent contributions have developed models of how financial intermediation interacts with real activity, and of how the size and composition of the central bank balance sheet can affect this interaction (Gertler and Karadi 2011, Gertler and Kiyotaki 2011, Del Negro *et al*. forthcoming). However, most models used for policymaking have so far abstracted from these considerations, making them deficient in addressing issues such as the unwinding of balance sheets, or the extent to which asset purchases affect the macroeconomy.

Another important dimension that these recent DSGE models deployed at central banks fail to capture is the possible "fragility" of the system. This is the idea that an economy might be more vulnerable to shocks in certain circumstances, such as when banks or households are more leveraged. This omission from the current generation of empirical models mostly stems from the fact that capturing this state dependence requires nonlinear models, which are arduous to solve and estimate. Nonetheless, a set of recent influential papers studies these issues by characterising some important nonlinearities that are prevalent in crisis states, and the fragility of the economic system leading up to those states (Brunnermeier and Sannikov 2014, He and Krishnamurthy 2013, Gertler and Kiyotaki 2015). This analysis, in turn, opens the way for an integrated treatment of financial stability and monetary policy.

2 Alternatively, the ZLB can also be modelled using the piece-wise linear solution of Guerrieri and Iacoviello (2015), which can be more easily incorporated into existing models.

Finally, another area of active research in the academic literature focuses on the role of uninsurable idiosyncratic risk and the ensuing heterogeneity across households in the transmission of monetary and fiscal policy (e.g. Kaplan *et al*. 2015). This line of research has been, at least in part, spurred by macroeconomic developments associated with the financial crisis, including evidence on how the marginal propensity to consume out of wealth varies across households, especially for housing. The ultimate objective here is to provide insights into questions related to inequality and the role of policy. These issues are now front and centre in the public debate, but the current vintage of representative agent policy models is silent about them.

Relative to the standard empirical DSGE modelling framework, these last two strands of research involve substantial modifications of the solution and estimation methods. As a consequence, working with these models becomes significantly more challenging, restricting the size of the models that can be entertained.

Looking forward: Maintaining an active dialogue between academia and central banks

The success of DSGE models used for policy analysis over the last twenty years was spurred by a close partnership between academia and central banks. Academic researchers have provided seminal contributions that have shaped this literature, while also training a generation of graduate students working in this field inside and outside policy institutions. However, the future of this tight collaboration is somewhat uncertain.

The empirical validation of quantitative models through estimation, as opposed to calibration, is one of the main strengths of the DSGE literature and a key source of its ability to tell stories that are relevant to policymakers. Therefore, this aspect of the DSGE literature is likely to continue attracting state-of-the-art research in the areas of efficient estimation, identification, and, hopefully, measurement.

However, there appears to be a growing gap between the modelling approaches pursued in academia and at policy institutions. On the one hand, central banks are developing DSGEs of increasing scale and complexity, with a growing number of observable variables and shocks, in the attempt to address an ever-expanding set of questions and empirical facts within one coherent structure.

On the other hand, the academic modelling style continues to put great emphasis on the transparency and crispness of the theoretical intuition, which tends to be lost as models increase in size. In this respect, the DSGE literature faces a trade-off between integrating more features within a single large-scale framework, and focusing instead on smaller models that may provide more transparent laboratories to study particular questions. The latter approach would seem more conducive towards maintaining an active and constructive dialogue between central bank and academic researchers, and thereby continued progress in this field.

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6 Policy packages: Challenge and opportunity for DSGE research

Fabio Ghironi

University of Washington, CEPR, and NBER [1]

Calls for comprehensive policy packages have become the latest mantra in the world of policymaking. Policymakers around the world are urged (or they promise) to deploy wide menus of instruments to lift economies out of the doldrums where they have been stuck since the 2008-2009 crisis. Draghi (2016a,b), G20 (2016), Lagarde (2016a,b), and Praet (2016) are some of the latest examples of high-profile speeches or communiqués featuring such calls or promises. In many instances, calls for multi-pronged policymaking are combined with exhortations (or promises) to engage in stronger international coordination of economic policies (for instance, see G20 2016, and Lagarde 2016a,b). Draghi (2016c) contains an explicit call for research on how monetary policy interacts with the other policies that are part of the menu he and other policymakers have been calling for.[2] These calls (or promises) present a challenge, but also an opportunity for policy-relevant macroeconomic research – a challenge that I believe DSGE models are well-suited to rise to.

The challenge of analysing packages

Analysis of policy packages presents a challenge for macroeconomic modelling because it requires models to include all those features that are key to disentangling and understanding the effects of different policies, and how they interact with each other.

1 I am grateful to Refet Gurkaynak and Cedric Tille for helpful comments. The views in this chapter are personal and do not reflect the views or policies of the CEPR, NBER, and the Central Bank Research Association.

2 Draghi (2016c) refers to this as "interdependence in interdependence", which he defined in Draghi (2016a) as the interdependence of central banks' policies with other types of economic policies.

Coordination of policies across countries – or across policymakers within a given country – requires attention to specifying strategy spaces, policymaker objectives, and asymmetries across countries (or policymakers) that can impinge on the evaluation of possible gains from coordinating policies.

Dynamic stochastic general equilibrium (DSGE) models have the potential to fulfil these tasks successfully. By building on the appropriate level of microfoundation, they stand the best chance of disentangling the various channels through which the policies that are called for (usually packages of monetary and fiscal policies, and structural reforms) are transmitted and interact with each other. By being dynamic, the models can help us understand the differences between short- and long-run effects of different policy actions – and how different parts of policy packages can complement or substitute for each other over time. By being stochastic, the models recognise that policy operates in an uncertain environment, where consumers, firms, and policymakers take their decisions without perfect knowledge of the future, the effects of reforms can depend on business cycle conditions, and reforms themselves can alter the characteristics of the business cycle. Finally, general equilibrium implies that prices and quantities are jointly determined by the constraints and optimality conditions of the model, with no imposition of a-priori assumptions on how policy should affect any price or quantity.

Importantly, the defining characteristics of DSGE modelling that I just mentioned (microfoundation – even if, strictly speaking, there is no M in DSGE –, dynamics, uncertainty, and joint determination of prices and quantities by the model's constraints and optimality condition) do *not* necessarily include rational expectations or reliance on exogenous productivity shocks as the sole source – or even as *a* source – of cyclical fluctuations. (Nor do DSGE models impose reliance on a plethora of shocks to fit a desired number of data series as in Bayesian estimation exercises.) DSGE analysis does *not* require the most standard Euler equation that ties expected growth in the marginal utility of consumption to the ex-ante real interest rate; it does *not* require equilibrium uniqueness, complete markets, no meaningful role for financial intermediation, frictionless market clearing with zero unemployment, fully flexible prices and wages or Calvo-style nominal rigidity. It does *not* require that monetary policy be described by a Taylor rule. Finally, DSGE research does *not* require solving models by using log-linearisation or other low-order approximations.

These are all ingredients (or solution techniques) for which DSGE research has become the object of a barrage of criticism from academics, bloggers, and journalists.[3] We *may* want to use some or, all of those ingredients and techniques because, after all, models are never meant to be photographs of reality, and it is useful to establish benchmark, transparent results in simplified frameworks that can then guide our understanding of the implications of working with more realistic assumptions. But nothing in the DSGE approach *constrains* us to using any of those ingredients. Even the level of microfoundation we want to embed in our models is ultimately a decision that must be taken based on the balance between complication, clarity, and empirical plausibility of results.[4]

In this context, the calls for policy packages that have been raining on us provide a great occasion for thinking about what model-ingredients we would *need* in order to make a start at studying the consequences of such policy packages while preserving the most important mechanisms through which those policies will operate.

Structural reforms

Consider the repeated calls for structural reforms in conjunction with more traditional, demand-side policy support. The menu of structural reforms that policymakers have advocated is wide. It includes, but is not restricted to, reforms of product and labour markets, reform of financial markets, and changes in trade policy – such as the TPP agreement – that go much beyond standard tariff-based trade policy and are best characterised as structural reforms.[5] I will focus on product and labour market reforms.

3 I am sure I am forgetting other sins for which DSGE models have been criticised. I apologise to the authors of such criticisms for unintentionally omitting their points. Since the barrage of criticism has been so wide, and, frankly, the media coverage so blatantly unbalanced across differing views, rather than failing to do justice to anyone specific by forgetting to cite the authors of some criticisms, I will do injustice to all critics by not citing anyone in the limited space of this column. Quick Google searches for "DSGE critics" and "trouble with macroeconomics" will give you the names and contributions of many authors,

4 This implies that, contrary to widespread claims, there is nothing that prevents us from writing DSGE "toy" models that can be solved with pencil and paper.

5 See Ghironi (2016).

These reforms are intended to improve economic performance by facilitating business creation and the reallocation of resources; they are intended to make economies more flexible and resilient to shocks – capable of absorbing them more quickly and with less cost to households and firms. Reforms are supposed to achieve these objectives by reducing bureaucratic barriers to market entry, by combating monopolies, by reducing (or removing) counterproductive labour market regulation that impinges negatively on firms' incentives to create jobs and on workers' incentives to take them. Any macro model of structural reforms ought to include features that make it possible to study how these policy changes affect the markets they are intended to affect – and how effects spill over to other markets in the model. Models should be dynamic, to inform us about short- versus long-run effects of reforms; they should be stochastic, to allow us to evaluate the impact of reforms on properties of the business cycle, and on welfare; and they should determine prices and quantities within the model rather than confounding policy actions and policy outcomes by assuming that reforms automatically cause prices (or markups, or quantities, or anything else that should be endogenously determined by the economy) to move in a certain direction. To accomplish this, the models should include a characterisation of micro-level product and labour market dynamics that allows for producer entry and exit, job creation and job destruction. Cacciatore and Fiori (2016 – CF below) give us an excellent starting point for this type of analysis by extending Bilbiie *et al*. (2012) to include search-and-matching labour market frictions and studying the consequences of lowering entry barriers and/or reducing firing costs and unemployment benefits.[6]

The mix with monetary policy

Consider now the task of studying the implementation of labour and product market reforms in conjunction with the conduct of monetary policy. Eggertsson *et al*. (2014 – EFR below) addressed this question in a plain vanilla New Keynesian (NK) model with no underlying micro-level product and labour market dynamics, and in which the reforms are modelled as, de-facto, exogenous cuts to price and wage markups.

6 It would not be complicated to extend the Cacciatore-Fiori model to incorporate rationing unemployment along the lines of Michaillat (2012).

Not surprisingly, they find that reforms are deflationary (and they automatically depreciate the terms of trade and improve the trade balance). Because the reforms are deflationary, they can exacerbate the problem posed by the zero lower bound on interest rates for the conduct of monetary policy: At the zero lower bound, reforming can be costly because deflation causes the real interest to rise, and this reduces aggregate demand.

EFR's plain-vanilla NK-DSGE analysis of structural reforms and monetary policy is a useful starting point for discussion, and it has received much attention in the policy world, but the very reduced-form modelling of structural reforms confounds outcome (a reduction in markups) and policy actions (the reforms — intended, as policymakers think of them, as reductions in entry barriers, or increases in labour market flexibility). If we embed CF-type product and labour market modelling in the NK model and we study the effects of reducing product entry barriers or making the labour market more flexible at the zero lower bound, we find striking differences in results.[7] Most notably, reforms need not be deflationary. In fact, they can help the economy move away from the zero lower bound on interest rates by having an inflationary effect. (Specifically, this is the case of a product market reform, which increases aggregate demand by boosting investment in producer entry and product creation.) Moreover, in an international context, reforms do not necessarily imply terms-of-trade depreciation (because increased demand for domestic factors of production can cause the price of domestic goods to rise) nor an improvement in the external balance (because, for instance, it is optimal to borrow to finance increased producer entry after a reduction in entry barriers). Price markups do decline, but they do so endogenously and gradually, as increased producer entry reduces markups by making products closer substitutes.

Do DSGE models have something sensible to say about how macroeconomic policy *should* be conducted in response to structural reforms? In Cacciatore *et al*. (2016 –CFG below), we address this question with reference to monetary policy by the central bank of a model-monetary union. Our DSGE model shows that the optimal policy response to reform is expansionary, to smooth transition costs and to bring forward the long-run gains from reforms.

7 This is what we do in Cacciatore *et al*. (2016b).

An optimising policymaker anticipates that reforms will result in higher GDP and consumption in the long run, and expands policy in order to bring those long-term gains closer to the present. This result is exactly in line with Draghi's (2015) argument that policy expansion brings forward the gains from reforms. Intuitively, the same result should hold for the Ramsey-optimal fiscal policy response to structural reforms, as the policymaker would face the same incentive to bring forward long term gains. This result (as well as others in our research) has been echoed in a plethora of IMF documents in the last year – often incorrectly attributing the results to "IMF research".[8]

Since the April 2016 issue of the *World Economic Outlook* (IMF, 2016a), the IMF has been giving advice on structural reforms and their interdependence with macroeconomic policy that builds explicitly on the results of these and other papers.[9] The IMF advises that attention should be paid to economic conditions at the time of reform implementation; that this makes it important to prioritise and sequence reforms; and that reforms should be combined with expansionary monetary and fiscal policy. We obtained those results in DSGE models that include many ingredients that have been the target of scathing criticism. I would challenge any of those critics to tell me that the policy advice the models have provided is unreasonable and should be discarded because they are grounded also in DSGE analysis. From my perspective, our results show that DSGE models can rise to the challenge of studying policy packages and delivering eminently sensible policy guidance.[10]

Going forward

Much needs to be done. The work that I did with Cacciatore, Fiori, and Duval, and other work I am aware of, does not address the issue of optimal structural reforms and the optimal level of product and labour (or financial) market regulation; it does not address strategic interactions between policymakers within a country (or a monetary union);

8 See, for example, IMF (2016b,c) and Lipton (2016). More recently, implications of our research have been reiterated by Gaspar *et al*. (2016) — with references to some of our work.

9 In particular, see Cacciatore *et al*. (2016a).

10 El-Erian (2016) refers to the combination of structural reforms with supportive monetary and fiscal policies, and international coordination, as "better economics" relative to the basic Washington Consensus of the 1990s and 2000s. Our models provide theoretical backing for this intuitive, "better economics."

and it does not address strategic interactions across countries and several dimensions of possible gains from international coordination. These are all questions for the next stages of this research agenda – for us or other scholars to address. So too is modification of the models by making them more realistic in other directions mentioned by the many critics of DSGE analysis. For now, I view it as a significant success that our DSGE research delivered mechanisms and prescriptions in line with the intuitive thinking of "non-DSGE" policymakers. It should bolster the confidence of both researchers and policymakers that partial-equilibrium and – sometimes – model-free intuitions survived the scrutiny of general equilibrium analysis. And, if the more complicated, more realistic models to come ultimately deliver the same prescriptions, I will be quite satisfied to continue working with the simpler framework, mindful that models are never meant to be photographs of reality, and mindful of the KISS principle: "Keep It Simple…Sir (or Señorita)".

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7 DSGE models and counterfactual analysis

Günter Coenen*, Roberto Motto*, Massimo Rostagno*, Sebastian Schmidt* and Frank Smets**
*European Central Bank; **European Central Bank and CEPR [1]

Introduction

Almost a decade since their first introduction and after a deep and prolonged financial crisis, estimated DSGE models are still popular and widely used in central banks. Why is that, considering the vehement criticism DSGE models have received since the financial crisis? The main reason is that they satisfy a basic need in policy analysis: the need to do counterfactuals. Counterfactual analysis, whether explicit or implicit, is at the core of effective policymaking. In order to inform their policy decisions, policymakers constantly ask questions of a counterfactual nature: what risk does a protracted period of low inflation entail for the anchoring of inflation expectations? How have structural reforms affected the Phillips curve and the outlook for inflation? What is the contribution of our new credit easing measures to current credit and money market developments? How will a certain fiscal consolidation package affect the economy and the need for monetary policy action? What would be the impact of a supply-driven rise in oil prices? Policymakers have a continuous need to understand how the economy might have evolved, if the shocks, the structural relationships and/or the policy reaction had been different.

1 The views expressed are our own and should not be attributed to the European Central bank.

Bayesian DSGE models are very suitable to do this type of counterfactual analysis for two main reasons. First, these models have a well-identified structural interpretation, being specified on the basis of clear decision problems by economic agents and institutions, technical constraints, market clearing conditions and structural stochastic shocks to the economy. This includes a well-specified role for expectations. Each structural model is a simplification of reality and thus needs to be taken with a grain of salt. But it needs a structural model to beat a structural model: only on the basis of structural interpretation of the data, can one identify which parameters to change for counterfactual analysis and have a discussion on implications and plausibility. Counterfactual analysis can also be and is being done using more reduced-form macro-econometric models such as structural VARs, but because of the reduced-form nature of the model the clarity about the structural interpretation of the exercise will not be the same.

Second, estimated DSGE models fit the data reasonably well. This is important because many of the policy questions are of a quantitative nature. Answers to counterfactual questions will only be a credible benchmark for discussion if they are perceived to be quantitatively plausible. For that, one needs a model that speaks to the data reasonably well. There is by now a sizeable literature that tests empirical DSGE models for their forecasting performance and finds that these models can compete with some of the best reduced-form models such as BVARs.[2]

Of course, to be useful, DSGE models, like any macro model, need to adapt to the policy issues of the day. The early generation of DSGE models were developed in the context of the Great Moderation and following the establishment of inflation targeting regimes and, therefore, focused on price and wage setting frictions as the key propagation mechanism. However, the financial crisis and the experience with reaching the lower bound on interest rates and unconventional monetary policy has led to the need to change the structure of these models. These changes are often not easy to implement because they challenge the simplicity of the first generation of New Keynesian DSGE models: the representative agent framework, the assumption of monopolistically competitive goods and labour markets, the efficiency of financial markets, the rational expectations assumption and the quasi-linearity of the estimated models.

2 See, for example, Smets *et al*. (2014) and the references therein.

But research both at central banks and in academia is making progress to adjust those features. The challenge for their use in policy making is to keep these extensions tractable and estimable.[3]

In the rest of this chapter we illustrate the use of the ECB's two main estimated euro area DSGE models with two examples.[4] The first example uses the New Area-Wide Model (NAWM) which is regularly used in the ECB's staff quarterly macroeconomic projection exercises. It analyses the impact of a de-anchoring of inflation expectations on the economy in an environment where the lower bound on the short-term interest rate is binding. From a methodological perspective, it illustrates how existing DSGE models can be modified to allow for both small deviations from rational expectations and non-linear constraints on interest rates. The second example uses the Christiano, Motto and Rostagno (CMR) model, which incorporates a more explicit financial sector and is mainly used in the context of the ECB's monetary analysis. It analyses the impact of deteriorating financial conditions in early 2016 on the euro area economy and quantifies the contribution of policy easing in countering this effect.

The impact of a de-anchoring of inflation expectations[5]

Following the announcement of the ECB's expanded Asset Purchase Programme (APP) in January 2015, the downward trend in both market-based and, to a lesser extent, survey-based indicators of longer-term inflation expectations in the euro area observed during the year 2014 came to a halt. According to the signalling channel of monetary policy transmission, the announcement of the APP has most probably contributed materially to the stabilisation of longer-term inflation expectations by reinforcing the ECB's commitment to deliver on its price stability mandate to keep inflation below, but close to, 2% over the medium term.[6] Yet how severe could the consequences of a potential de-anchoring of inflation expectations have been in the absence of the APP?

3 For a recent review see Lindé *et al.* (2016).

4 For a description and their use see Coenen *et al*. (2010).

5 See also Coenen and Schmidt (2016).

6 For some evidence on the impact of the APP see Andrade *et al*. (2016)and Praet (2017).

To address this question, the NAWM is used to conduct a counterfactual simulation with the aim of illustrating the possible impact of a further decline in longer-term inflation expectations on actual inflation outcomes. Such a decline in expectations may reflect a growing private sector concern that the central bank's ability to achieve, and commitment to achieving, its inflation objective over the medium term has weakened against the background of a prolonged period of low inflation. The counterfactual de-anchoring of longer-term expectations is modelled within the NAWM through a gradual shift in the private sector's perceptions of the central bank's inflation objective, which provides the long-run "anchor" for the formation of inflation expectations. At the same time, it is assumed that the central bank's actual inflation objective, guiding its monetary policy decisions, remains unchanged.

The counterfactual de-anchoring simulation is conducted relative to a baseline, which represents actual economic developments until the end of 2014 and economic predictions for the following years, incorporating the anticipated effects of the APP announcement in January 2015 and its subsequent implementation. In the baseline, the gradual decline in inflation expectations observed in 2014 is captured in a stylised way by an exogenous commensurate downward shift in the inflation anchor of 0.2 percentage point. In contrast, the announcement and implementation of the APP is assumed to re-anchor longer-term inflation expectations. Accordingly, in the baseline the fall in the inflation anchor comes to a halt at the end of 2014 and it gradually recovers towards levels closer to 2% over the following years. In the counterfactual simulation the evolution of the inflation anchor from the beginning of 2015 onwards is, instead, determined endogenously. Specifically, the inflation anchor is assumed to respond in an adaptive manner to developments in inflation outcomes which run persistently below the perceived inflation objective over the simulation horizon.

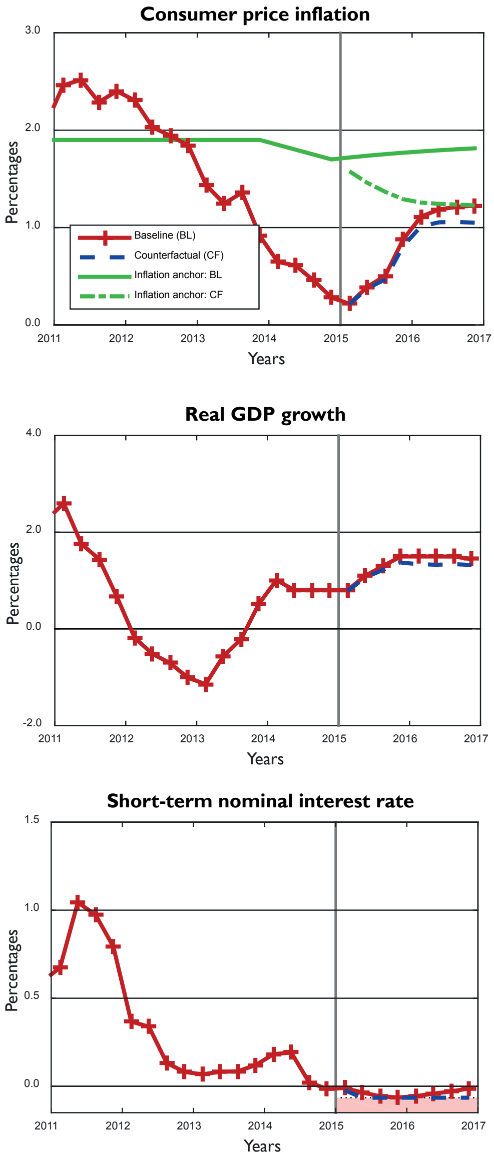
The graphs in Chart 1 portray the adverse consequences of the counterfactual de-anchoring of longer-term inflation expectations in comparison with the baseline paths for consumer price inflation, real GDP growth and the short-term nominal interest rate. These baseline paths have been extended beyond the year 2014 using Consensus Forecasts surveyed from financial and economic forecasters as well as market-based interest rate expectations.

They are represented by the red solid lines with plus markers, while the model-based outcomes of the counterfactual de-anchoring simulation are given by the blue dashed lines. The green solid and dash-dotted lines in the upper-left graph of Chart 1 depict the baseline and counterfactual paths of the inflation anchor, respectively.

In the counterfactual simulation, the persistently low inflation outcomes recorded over the simulation horizon lead to a sizeable additional downward shift in longer-term inflation expectations. The forward-looking private sector responds to the decline in expected inflation rates by further reducing prices and wages, giving rise to self-reinforcing second-round effects. The resulting mild, but lasting, moderation in price and wage inflation towards levels consistent with the lower inflation anchor is exacerbated by the binding effective lower bound on nominal interest rates (marked by the pink-shaded area in the lower panel), which prevents the central bank from offsetting the further decline in inflation by lowering its policy rate. As a consequence, the real interest rate rises (and the real effective exchange rate of the euro appreciates), so that aggregate demand is dampened and real GDP grows more slowly than in the baseline. Over and above the direct expectations effects, the emerging slack lowers price pressures and further hampers the adjustment in inflation towards levels closer to 2%.

All in all, the counterfactual simulation clearly illustrates the important role of the APP in forestalling a potential de-anchoring of inflation expectations by means of credibly signalling the ECB’s commitment to deliver on its price stability mandate. This, in turn, is instrumental for preventing a further prolongation of the period of low inflation outcomes through second-round effects.

Chart 1: Consequences of a counterfactual de-anchoring of longer-term inflation expectations

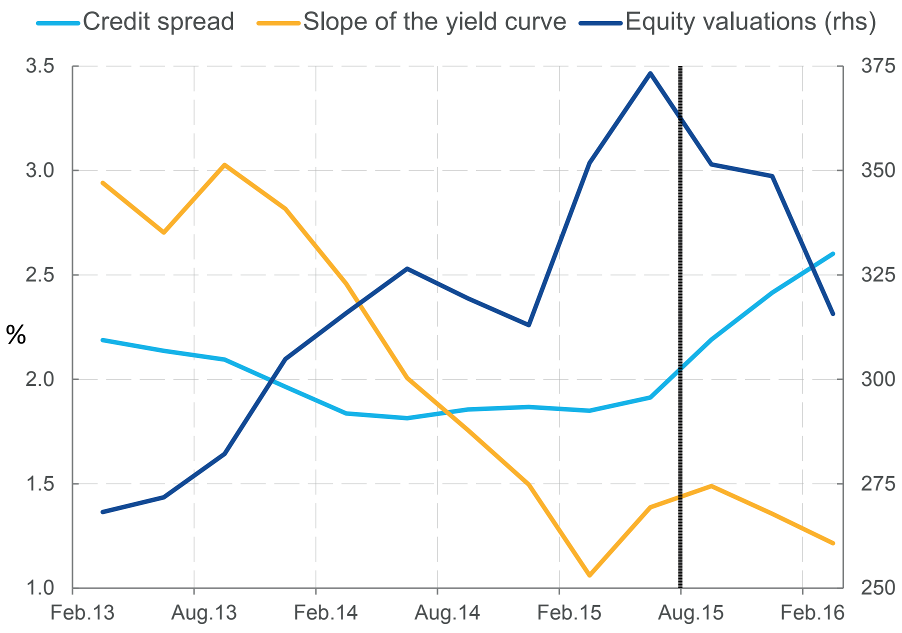


Note: This chart shows the results of a counterfactual simulation with the NAWM. In the baseline (BL) the model assumes an exogenous path for the inflation anchor, which falls 0.2 percentage point below the central bank's inflation objective of 1.9% during the year 2014 before gradually recovering thereafter. In the counterfactual (CF) simulation the inflation anchor is obtained endogenously from a simple adaptive scheme, with the weight on lagged consumer price inflation set equal to 0.1. Consumer price inflation (measured in terms of the private consumption deflator) and real GDP growth are expressed in year-on-year percentage changes, and the short-term nominal interest rate (corresponding to the EONIA) is expressed in annualised percentages. The effective lower bound on the short-term nominal interest rate is imposed at an interest rate level of -6.5 basis points (set equal to the minimum of the EONIA forward curve over the extended baseline horizon).

Understanding the impact of financial markets deterioration from 2015Q2 to 2016Q1

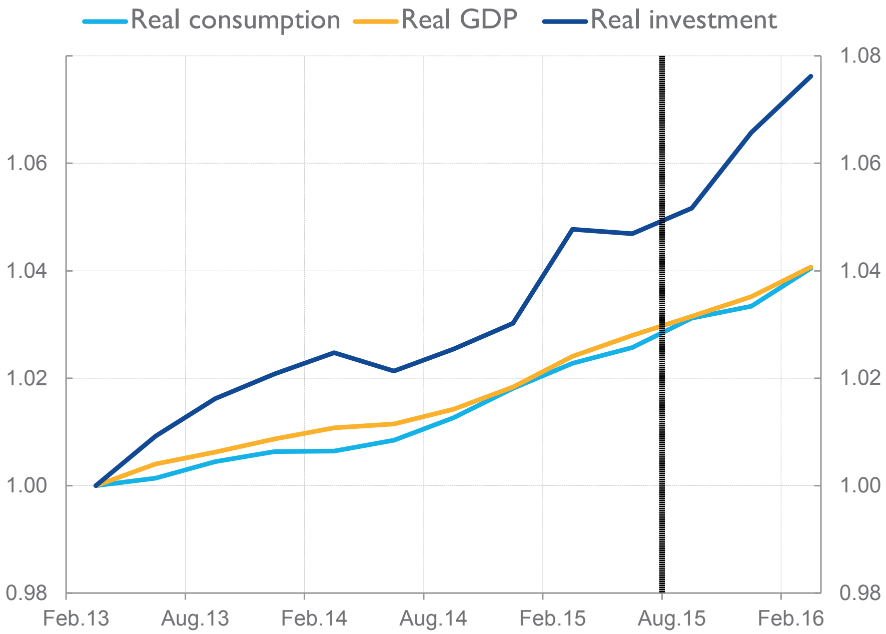
Starting in summer 2015, downside risks to the outlook for growth and inflation increased amid heightened uncertainty about emerging market economies' growth prospects and sharp movements in financial and commodity markets. Focusing on the euro area, from 2015Q2 to 2016Q1 credit market spreads, measured as the option-adjusted spread between non-financial corporate bond yields and the swap rate of corresponding maturity, increased by 70 basis points and euro area equity prices declined by 15% (Chart 2). Based on historical regularities, strong deterioration in risky assets has the potential to significantly weigh on the economy. But, despite tightening domestic financial conditions and renewed weakness in global trade, domestic aggregate demand remained resilient – consumption and investment kept increasing (Chart 3).

Chart 2: Developments in euro area risky assets and the slope of the yield curve



Note: Last observation is 2016Q1.

Chart 3: Real GDP and main components in the euro area



Note: Variables are normalised to 1 in 2013Q1. Last observation is 2016Q1.

We use the CMR model to discriminate between two possible explanations. One maintains that this episode is different in that the properties of financial shocks or their transmission have changed. The alternative explanation rests on the occurrence of other forces that have offset the typical impact of financial shocks. We find evidence in favour of the latter explanation, with monetary policy playing an important role in supporting economic activity and preventing a fall-out.

The model is estimated on 16 variables for the euro area, using quarterly data over the sample 1999Q1 to 2014Q2.[7] We use the model to understand the key features of the deterioration in risky assets over 2015Q2 to 2016Q1 and their transmission to the economy. To put this episode into perspective, we also provide a model assessment of previous episodes of financial distress such as the Great Recession and the 2011-2012 euro area recession.

7 The end of the estimation sample is chosen so as to coincide with the start of a new wave of monetary policy accommodation in June 2014. We assess down below whether this has led to a change in the transmission of financial shocks. The variables included in the model span the main macro variables and on the financial side: interest rates of different maturities, credit spread, equity prices, credit to the private sector, and central bank reserves. For an overview of the model, see Christiano *et al*. (2010 and 2014).

The model allows for forward guidance in monetary policy by means of expectational shocks that are revealed in each period and span the following eight quarters.[8]

According to the model, the Great Recession in the euro area can be fully accounted for by three shocks. The first is the risk shock (Chart 4, green bars). The second is a negative neutral technology shock (Chart 4, blue bars), which pushed investment and consumption down, and raised inflation. Owing to the transitory nature of this shock, wealth effects do not dampen inflation dynamics. Absent this shock, the decline in inflation brought about by the risk shock would have been much stronger. The third shock is an absorption shock that captures net exports and government consumption.[9]

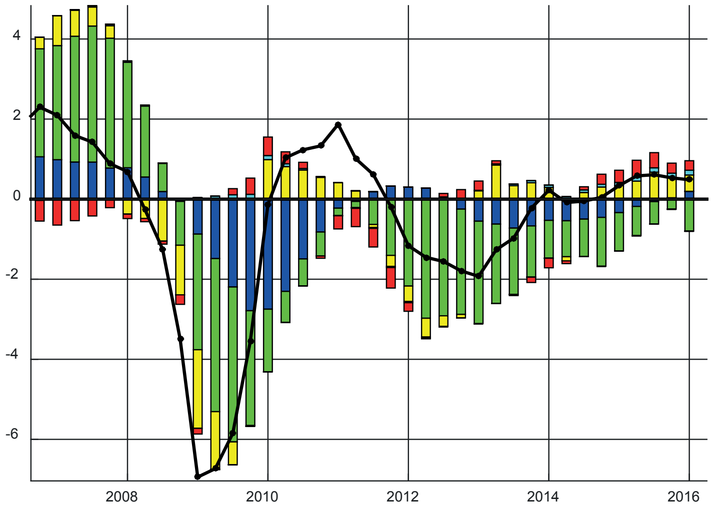
The 2011-2012 euro area recession is largely explained by one shock, the risk shock, which is responsible for the depth as well as persistence of the recession. According to the model, the economic contraction has been aggravated by monetary policy with the 50 basis point hike in the ECB's monetary policy corridor in the first half of 2011 (Chart 4, red bars).

In the episode of heightened uncertainty that started in late summer 2015, the risk shock subtracts almost a percentage point from GDP growth by 2016Q1. Economic activity, however, has remained resilient. The model attributes this outcome to the offsetting impact of supportive monetary policy and initially to the absorption shock (its contribution fades away though). The timing of the monetary policy contribution uncovered by the model clearly reflects the new wave of policy accommodation that started in mid-2014 with the cut of the Deposit Facility Rate to a negative level and the beginning of credit easing. This was followed later by the launch of quantitative easing in January 2015 and further rate cuts, accompanied, from the beginning of 2016, by a reinforced formulation of the ECB's forward guidance concerning the direction of its monetary policy interest rates.The model suggests that since mid-2014 monetary policy has become a strong countercyclical force, reabsorbing the tightening of the previous few years, as made evident in the contribution to GDP as well as inflation (Charts 4 and 5).

8 Expectational shocks are modelled as in Christiano *et al*. (2010); Laséen and Svensson (2011) applied a similar set-up to monetary policy.

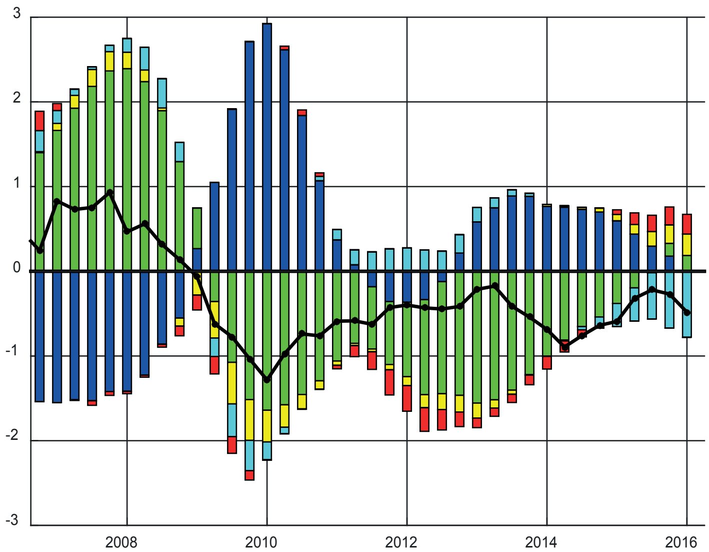
9 See Christiano *et al*. (2015) and Campbell *et al*. (2016) for recent examples of DSGE models employed for assessing the driving forces of the Great Recession in the United States.

Chart 4: Shocks' contributions to real GDP growth



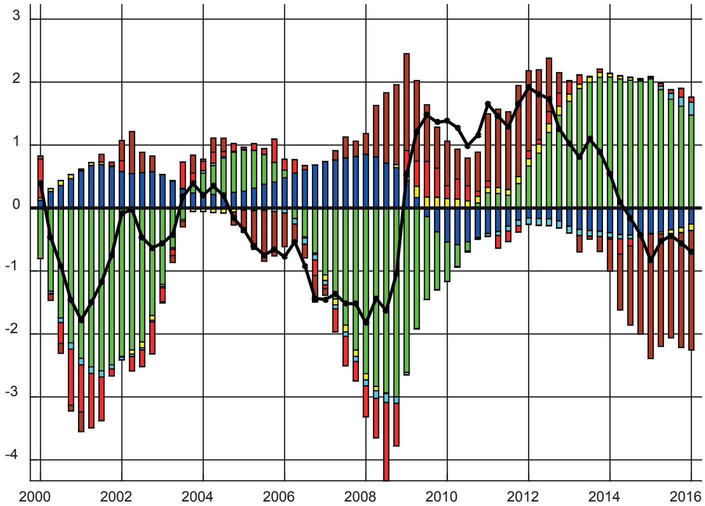
Note: GDP growth is year-on-year deviation from the mean. The green bars represent the risk shock, the blue bars the neutral technology shock, the yellow bars the absorption shock, the red bars the monetary policy shock and the light blue the oil price shock. The contributions do not add up to the variable itself (solid line) because the chart considers a subset of the models' shocks.

Chart 5: Shocks' contribution to inflation



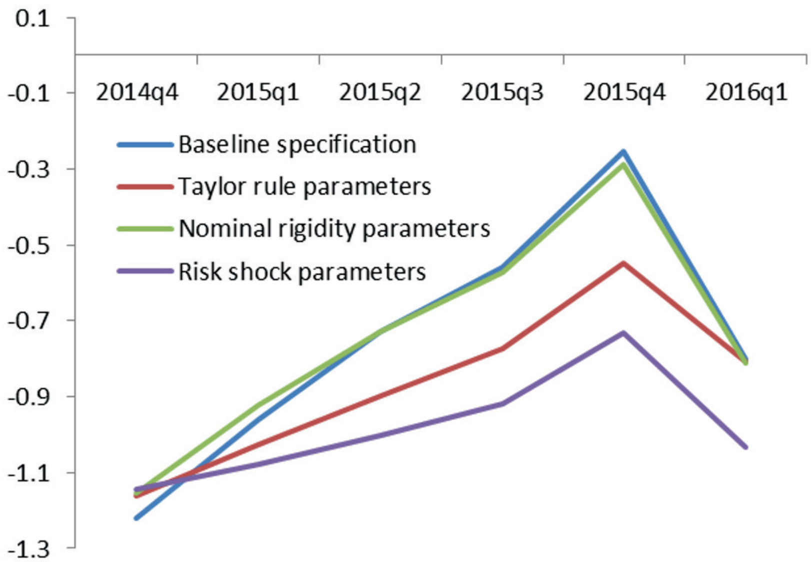
Note: Inflation is year-on-year deviation from the mean, and it is measured in terms of GDP deflator. The green bars represent the risk shock, the blue bars the neutral technology shock, the yellow bars the absorption shock, the red bars the monetary policy shock and the light blue the oil price shock. The contributions do not add up to the variable itself (solid line) because the chart considers a subset of the models' shocks.

Chart 6: Shocks' contributions to slope of the yield curve



Note: The green bars represent the risk shock, the blue bars the neutral technology shock, the yellow bars the absorption shock, the red bars the monetary policy shock, the light blue the oil price shock and the brown bars the term-premium shock. The contributions do not add up to the variable itself (solid line) because the chart considers a subset of the models' shocks.

Chart 7: Risk shock's contribution to real GDP growth across model's specifications



Note: Each model's specifications refers to the case in which a subset of parameters are re-estimated over the recent sample.

The policy contribution to the economy and inflation shown in the charts represents, in all likelihood, an underestimation of the full impact of the policies enacted by the ECB, since the ECB asset purchase programme has put strong downward pressure on the long-end of the yield curve, and this is captured in the model by a term-premium shock (Chart 6), which in the model does not affect the real side.

There is however an alternative explanation of the recent episode of heightened uncertainty: the properties of financial shocks or their transmission to the economy may have changed. To assess this competing explanation, we re-estimate the model over the last couple of years of data, setting all the parameters to their baseline values except for those, in turn, related to: the stochastic process for the risk shock; nominal rigidities; monetary policy. As there are only few observations, we re-estimate only a small sub-set of parameters at the time. We find that the negative impact of the risk shock on economic activity is similar across specifications, ranging between 0.8 and 1 percentage point in 2016Q1 (Chart 7).

Overall, the decline in the price of risky assets from summer 2015 to 2016Q1 is found to lead to the typical macroeconomic effects associated with a risk shock, subtracting almost a percentage point from real economic activity. This however has not affected headline figures for domestic aggregate demand. This is explained by the model in terms of offsetting forces, with monetary policy exerting a strong countercyclical role and compensating previous tightening.

Conclusion

In this essay, we considered two specific examples of how DSGE models are used for counterfactual analysis by central banks. The ability to explore counterfactuals and to provide structural interpretation distinguishes DGSE models from other more reduced-form modelling approaches and has contributed to their success as a basis for informing policymakers and providing advice.

To remain a trusted source of policy advice, DSGE models are continuously evaluated and developed further. This requires both identifying and replacing those features of the models that are challenged by the data, and enhancing the models with a view to be able to address the questions that are on the policymakers' minds.

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Section III

What next?

8 Some scattered thoughts on DSGE models

Jordi Galí
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In recent years, a number of commentators have raised concerns and expressed their criticism over the extensive use of dynamic, stochastic, general equilibrium (DSGE) models in macroeconomics.[1] The critics' concerns seem aggravated, in their view, by the fact that such models have not been completely ignored by central banks, many of which have developed their own in-house DSGE models and have used them in forecasting and policy evaluation exercises.[2] While some of the criticisms are clearly misplaced, and reflect a lack of knowledge of recent developments in the field, the prominence of some the critics and the attention paid by the media to their views, combined with the widespread public scepticism on the usefulness of economics, have triggered some soul-searching among macroeconomists.[3] The present note offers a sample of my (evolving) views on some of these controversies.

What characterises DSGE

Let me start with a question: is there anything inherently wrong about the use of DSGE models in macroeconomics? Given the nature of macroeconomic phenomena and, in particular, of economic fluctuations, it is only natural that the models developed to explain them are dynamic, stochastic and general equilibrium. Static models would necessarily have to abstract from all intertemporal links, and could not deal with central concepts like the interest rate, investment, or budget deficits.

1 See, e.g., Krugman (2009), Stiglitz (2011), and Romer (2016), among others.

2 See, e.g., Smets *et al*. (2010)

3 See, e.g. the symposium on ""Macroeconomics after the Financial Crisis," in the Fall 2010 issue of the *Journal of Economic Perspectives.*

While the literature contains some examples of deterministic models of economic fluctuations, the nature of those models' predictions stands in the face of observed fluctuations, which have a clear unforecastable component. Finally, the widespread reliance on general equilibrium analysis follows naturally from the recognition that macroeconomic phenomena involve, by their very nature, the interaction of a large number of agents, operating simultaneously in several markets (goods, labour, financial). To put it differently, if the models developed at the frontier of macroeconomics were largely static models (or deterministic, or partial equilibrium), wouldn't that fact constitute a (natural) target of all criticisms?

Under the general heading of "DSGE models" one can find a large variety of frameworks, ranging from the early, utopian, RBC models to more recent efforts to incorporate financial frictions, heterogeneity, or learning in a baseline New Keynesian model. Anyone opposing the DSGE approach to macroeconomic modelling, understood in that broad sense, will be at pains to offer an alternative approach to become the central methodology of macroeconomics. However, it is clear that any particular model or modelling choice may be subject to criticism. That criticism, whether focused on a model's counterfactual empirical predictions or on the implausibility of some its assumptions, should remain the engine of progress in macroeconomics. Needless to say, such criticism will be particularly welcome if it is accompanied by constructive proposals to replace the elements of the model that are viewed as flawed, though this requirement is certainly not an indispensable one.

The infinitely-lived representative agent

Let me next offer a dose of criticism of my own. There are two features of standard formulations of DSGE models that I personally see as unpleasant straitjackets: (i) the assumption of an infinitely-lived representative household, and (ii) the stationarity hardwired into most existing models. Next I offer some brief thoughts about them as well as references to some recent efforts to overcome their restrictive implications.

Most macroeconomists have long viewed the assumption of an infinitely-lived representative household, which is pervasive in the literature, as both convenient and innocuous, at least so long as issues pertaining to income distribution or inequality are not the object of study, as is the case in much research on economic fluctuations.

Yet, and motivated by the extreme monetary policies observed in many advanced economies, a wave of recent papers has introduced different forms of household heterogeneity (combined with incomplete financial markets), in order to analyse a variety of issues that lie outside the scope of representative household models. They include the study of the distributional effects of monetary policy (Gornemann *et al*. 2016), the role of heterogeneity in the transmission of monetary policy (Kaplan *et al*. 2016), and its ability to explain the forward guidance puzzle (McKay *et al*. 2016), to mention only three well known examples. The ability of calibrated versions of those models to account for many dimensions of the observed distributions of income, wealth and portfolio holdings is quite impressive. The case made in those papers for the presence of a non-negligible interaction between that heterogeneity and the effects of monetary policy interventions is also pretty convincing. On the negative side, the heavy computational requirements associated with the analysis of those models and the consequent black-box nature of some of their predictions may constitute a hurdle to their widespread adoption, both in the classroom and in policy circles. An interesting avenue of research, in my view, would consist in assessing whether stylised representations of heterogeneity (e.g. in the form of two-agent models, as in Galí *et al*. 2007) might be capable of approximating the positive and normative predictions of richer models, without their heavy computational burden.

Less discussed, but equally important, are, in my opinion, the strong implications of the representative household assumption for the kind of phenomena that can (and cannot) be accounted for by standard DSGE models, beyond the inequality dimension emphasised in the abovementioned papers. Let me briefly discuss two such implications. First, the representative household's Euler equation implies a tight link between the real interest rate and the consumer's time discount rate along a balanced growth path. That relation all but rules out the possibility of a persistently negative natural rate of interest, with the consequent challenges that the latter would pose on a price-stability oriented monetary policy, due to the zero lower bound (ZLB) on nominal interest rates. Second, the assumption of an infinitely-lived representative household rules out the existence of rational bubbles in equilibrium. The reason is that the presence of such bubbles would violate the household's transversality condition, given that, in equilibrium, bubbles (i) would have to be growing at the rate of interest and (ii) would have to be held by the representative household (since there is nobody else around to hold them!).

Given the evidence on the important role played by asset price booms and busts, likely driven by bubbles, as a factor behind financial crises, it is somewhat surprising that standard models are not suitable for the analysis of such phenomena and its interaction with monetary policy.

Two recent papers provide examples of models that can speak to such issues by introducing overlapping generations of finitely-lived individuals in sticky price DSGE models. As shown in Eggertsson and Mehrotra (2014), such a framework makes it possible to analyse the implications for monetary policy of a persistent liquidity trap, resulting from a (potentially permanent) decline in the natural rate well into negative territory as a result of a deleveraging shock or a drop in population growth, among other possibilities. Using a similar framework, Galí (2014) shows that asset price bubbles may emerge in equilibria, with their fluctuations causing welfare-reducing volatility even in the absence of fundamental shocks. In that context one can analyse the implications of alternative monetary policy rules on fluctuations and welfare, since the evolution of bubbles is not independent to that of interest rates.

Departures from the assumption of an infinitely-lived representative household may have implications that go beyond the two aspects mentioned above. Thus, Del Negro *et al*. (2015) study the impact of finite-lived consumers on the so called forward guidance puzzle. Another potentially interesting research avenue, which as far as I know remains unexplored, has to do with the consequences of an overlapping-generations framework on the fiscal theory of the price level, given that, under certain assumptions, such a framework would allow for the possibility of permanent debt roll-overs in equilibrium (or, in other words, the absence of a well defined transversality condition in the government intertemporal budget constraint).

Stationarity

Let me next turn to my second concern. Standard analyses based on DSGE models generally focus on equilibria that take the form of stationary linear fluctuations driven by exogenous shocks. This is also the case in variants of those models that allow for financial frictions of different kinds and which have become quite popular as a result of the financial crisis (e.g. Bernanke *et al*. 1999, Christiano *et al*. 2014).

The introduction of financial frictions in those models often leads to an amplification of the effects of non-financial shocks. It also makes room for additional sources of fluctuations related to the presence of financial frictions (e.g. risk shocks in the reference above). Yet, the kind of fluctuations generated by those models tend to rule out, by construction, some of the more interesting macroeconomic phenomena which are associated with financial crises and which are inherently non-stationary and/or non-linear. Those phenomena include the economic and financial boom that often precedes financial crises, with a gradual build-up of financial imbalances leading to an eventual "crash" characterised by defaults, sudden-stops of credit flows, asset price declines, and a large contraction in aggregate demand, output and employment. By contrast, existing models of "financial crises" generally trace the latter to a *large exogenous shock* that impinges on the economy unexpectedly and triggers a large recession, possibly amplified by a financial accelerator mechanism embedded in the model.

A recent effort to get rid of the linearity *cum* stationarity straitjacket, albeit in the context of a real model, can be found in Boissay *et al*. (2016). In that paper the authors analyse a model with asymmetric information in the interbank market, in which a sequence of small shocks pull an economy towards a region with multiple equilibria, including equilibria characterised by a freeze in the interbank market, a credit crunch and a prolonged recession. Needless to say, I believe this is an area where a lot of work remains to be done, ideally in the context of monetary models, and possibly in conjunction with the abovementioned efforts to introduce asset price bubbles.

In his recent piece on DSGE models in this volume[4], Olivier Blanchard concludes that while "there are many reasons to dislike current DSGE models…[but] they are eminently improvable and central to the future of macroeconomics." I wouldn't know how to disagree.

4 Blanchard (2016)

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9 Do DSGE models have a future?

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DSGE models have come to play a dominant role in macroeconomic research. Some see them as the sign that macroeconomics has become a mature science, organised around a microfounded common core. Others see them as a dangerous dead end.

I believe that the first claim is exaggerated and the second is wrong. I see the current DSGE models as seriously flawed, but they are eminently improvable and central to the future of macroeconomics. To improve, however, they must become less insular, by drawing on a much broader body of economic research. They must also become less imperialistic and willing to share the scene with other approaches to modelisation.

For those who are not macroeconomists, or for those macroeconomists who have lived on a desert island for the last 20 years, here is a brief refresher. DSGE stands for "dynamic stochastic general equilibrium." The models are indeed dynamic, stochastic, and characterise the general equilibrium of the economy. They make three strategic modelling choices: first, the behaviours of consumers, firms, and financial intermediaries, when present, are formally derived from microfoundations. Second, the underlying economic environment is that of a competitive economy, but with a number of essential distortions added, ranging from nominal rigidities to monopoly power to information problems. Third, the model is estimated as a system, rather than equation by equation as in the previous generations of macroeconomic models.

The earliest DSGE model, representing an economy without distortions, was the Real Business Cycle model, developed by Edward C. Prescott and focused on the effects of productivity shocks.

1 This article was initially published as the Peterson Institute for International Economics policy brief PB 16-11 https://piie.com/publications/policy-briefs/do-dsge-models-have-future

In later incarnations, a wider set of distortions, and a wider set of shocks, has come to play a larger role, and current DSGE models are best seen as large scale versions of the New Keynesian model, which emphasises nominal rigidities and a role for aggregate demand.[2]

Shortcomings of DSGE

There are many reasons to dislike current DSGE models.

First: they are based on unappealing assumptions. Not just simplifying assumptions, as is necessary in any model, but assumptions profoundly at odds with what we know about consumers and firms.

Go back to the benchmark New Keynesian model, from which DSGEs derive their bone structure. The model is composed of three equations: an equation describing aggregate demand; an equation describing price adjustment; and an equation describing the monetary policy rule. At the very least the first two are badly flawed descriptions of reality: aggregate demand is derived as consumption demand by infinitely lived and foresighted consumers. Its implications, with respect to both the degree of foresight and the role of interest rates in twisting the path of consumption, are strongly at odds with the empirical evidence. Price adjustment is characterised by a forward-looking inflation equation, which does not capture the fundamental inertia of inflation.[3]

Current DSGE models extend the New Keynesian model in many ways, allowing for investment and capital accumulation, financial intermediation, interactions with other countries, and so on. The aggregate demand and price adjustment equations remain central, however, although they are modified to better fit the data. In the first case, by allowing, for example, a proportion of consumers to be "hand to mouth" consumers, who simply consume their income.

2 While a "standard DSGE model" does not exist, a standard reference remains the model developed by Frank Smets and Rafael Wouters (2007). See Lindé, Smets, and Wouters (2016) for a recent assessment with many references.

3 More specifically, the equation characterising the behaviour of consumers is the first order condition of the corresponding optimisation problem and is known as the "Euler equation." The equation characterising the behaviour of prices is derived from a formalisation offered by Guillermo Calvo and is thus known as "Calvo pricing."

In the second case, by introducing backward-looking price indexation, which, nearly by assumption, generates inflation inertia. Both, however, are repairs rather than convincing characterisations of the behaviour of consumers or of the behaviour of price and wage setters.

Second: their standard method of estimation, which is a mix of calibration and Bayesian estimation, is unconvincing.

The models are estimated as a system, rather than equation by equation as in previous macroeconometric models. They come, however, with a very large number of parameters to estimate, so that classical estimation of the full set is unfeasible. Thus, a number of parameters are set *a priori*, through "calibration". This approach would be reasonable if these parameters were well established empirically or theoretically. For example, under the assumption that the production function is Cobb-Douglas, using the share of labour as the exponent on labour in the production function may be reasonable. But the list of parameters chosen through calibration is typically much larger, and the evidence often much fuzzier. For example, in the face of substantial differences in the behaviour of inflation across countries, use of the same "standard Calvo parameters" (the parameters determining the effect of unemployment on inflation) in different countries is highly suspicious. In many cases, the choice to rely on a "standard set of parameters" is simply a way of shifting blame for the choice of parameters to previous researchers.

The remaining parameters are estimated through Bayesian estimation of the full model. The problems are twofold. One is standard in any system estimation. Misspecification of part of the model affects estimation of the parameters in other parts of the model. For example, misspecification of aggregate demand may lead to incorrect estimates of price and wage adjustment, and so on. And it does so in ways that are opaque to the reader. The other problem comes from the complexity of mapping from parameters to data. Classical estimation is *de facto* unfeasible, the likelihood function being too flat among many dimensions. Bayesian estimation would certainly seem to be the way to proceed, if indeed we had justifiably tight priors for the coefficients.

In many cases, however, the justification for the tight prior is weak at best, and what is estimated reflects more the prior of the researcher than the likelihood function.[4]

Third: while the models can formally be used for normative purposes, normative implications are not convincing.

A major potential strength of DSGE models is that, to the extent that they are derived from microfoundations, they can be used not only for descriptive but also for normative purposes. Indeed, the single focus on GDP or GDP growth in many policy discussions is misleading: distribution effects, or distortions that affect the composition rather than the size of output, or effects of current policies on future rather than current output, may be as important for welfare as effects on current GDP. Witness the importance of discussions about increasing inequality in the United States, or about the composition of output between investment and consumption in China.

The problem in practice is that the derivation of welfare effects depends on the way distortions are introduced in the model. And, often, for reasons of practicality, these distortions are introduced in ways that are analytically convenient but have unconvincing welfare implications. To take a concrete example, the adverse effects of inflation on welfare in these models depend mostly on their effects on the distribution of relative prices as not all firms adjust nominal prices at the same time. Research on the benefits and costs of inflation suggests, however, a much wider array of effects of inflation on activity and in turn on welfare.

Having looked, in a recent paper (Blanchard *et al.* 2016), at welfare implications of various policies through both an *ad hoc* welfare function reflecting deviations of output from potential and inflation from target and the welfare function implied by the model, I drew two conclusions. First, the exercise of deriving the internally consistent welfare function was useful in showing potential welfare effects I had not thought about but concluded *ex post* was probably relevant. Second, between the two, I still had more confidence in the conclusions of the *ad hoc* welfare function.

4 In some cases, maximum likelihood estimates of the parameters are well identified but highly implausible on theoretical grounds. In this case, tight Bayesian priors lead to more plausible estimates. It is clear, however, that the problem in this case comes from an incorrect specification of the model and that tight Bayesian priors are again a repair rather than a solution.

Fourth: DSGE models are bad communication devices.

A typical DSGE paper adds a particular distortion to an existing core. It starts with an algebra-heavy derivation of the model, then goes through estimation, and ends with various dynamic simulations showing the effects of the distortion on the general equilibrium properties of the model.

These would indeed seem to be the characteristics of a mature science: building on a well understood, agreed upon body of science and exploring modifications and extensions. And, indeed, having a common core enriches the discussion among those who actually produce these models and have acquired, through many simulations, some sense of their entrails (leaving aside whether the common core is the right one, the issue raised in the first criticism above). But, for the more casual reader, it is often extremely hard to understand what a particular distortion does on its own and then how it interacts with other distortions in the model.

Addressing the limits of DSGE

All these objections are serious. Do they add up to a case for discarding DSGEs and exploring other approaches? I do not think so. I believe the DSGEs make the right basic strategic choices and the current flaws can be addressed. Let me develop the two themes.

The pursuit of a widely accepted analytical macroeconomic core, in which to locate discussions and extensions, may be a pipe-dream, but it is a dream surely worth pursuing. If so, the three main modelling choices of DSGEs are the right ones. Starting from explicit microfoundations is clearly essential; where else to start from? *Ad hoc* equations will not do for that purpose. Thinking in terms of a set of distortions to a competitive economy implies a long slog from the competitive model to a reasonably plausible description of the economy. But, again, it is hard to see where else to start from. Turning to estimation, calibrating/estimating the model as a system rather than equation by equation also seems essential. Experience from past equation-by-equation models has shown that their dynamic properties can be very much at odds with the actual dynamics of the system.

That being said, I believe that DSGE modelling has to evolve in two ways.

First: it has to become less insular. Take the consumption example discussed earlier. Rather than looking for repairs, DSGE models should build on the large amount of work on consumer behaviour going on in the various fields of economics, from behavioural economics, to big data empirical work, to macro partial equilibrium estimation. This work is ongoing and should indeed proceed on its own, without worrying about DSGE integration. (Note to journal editors: Not every discussion of a new mechanism should be required to come with a complete general equilibrium closure.) But this body of work should then be built on to give us a better model of consumer behaviour, a sense of its partial equilibrium implications, perhaps a sense of the general equilibrium implications with a simplistic general equilibrium closure, and then and only then be integrated into DSGE models. This would lead to more plausible specifications and more reliable Bayesian priors, and this is what I see as mostly missing. I have focused here on consumption, but the same applies to price and wage setting, investment, financial intermediation, treatment of expectations, etc. In short, DSGEs should be the architecture in which the relevant findings from the various fields of economics are eventually integrated and discussed. This is not the case today.

Second: it has to become less imperialistic. Or, perhaps more fairly, the profession (and again, this is a note to the editors of the major journals) must realise that different model types are needed for different tasks.

Models can have different degrees of theoretical purity. At one end, maximum theoretical purity is indeed the niche of DSGEs. For those models, fitting the data closely is less important than clarity of structure. Next come models used for policy purposes, for example, models by central banks or international organisations. Those must fit the data more closely, and this is likely to require, in particular, more flexible, less microfounded lag structures (an example of such a model is the FRB/US model used by the Federal Reserve, which starts from microfoundations but allows the data to determine the dynamic structure of the various relations). Finally come the models used for forecasting. It may well be that, for that purpose, reduced form models will continue to beat structural models for some time; theoretical purity may be for the moment more of a hindrance than a strength.

Models can also differ in their degree of simplicity. Not all models have to be explicitly microfounded. While this will sound like a *plaidoyer pro domo*, I strongly believe that *ad hoc* macro models, from various versions of the IS-LM to the Mundell-Fleming model, have an important role to play in relation to DSGE models. They can be useful upstream, before DSGE modelling, as a first cut to think about the effects of a particular distortion or a particular policy. They can be useful downstream, after DSGE modelling, to present the major insight of the model in a lighter and pedagogical fashion. Here again, there is room for a variety of models, depending on the degree of ad hocery: One can think, for example, of the New Keynesian model as a hybrid, a microfounded but much simplified version of larger DSGEs. Somebody has said that such *ad hoc* models are more art than science, and I think this is right. In the right hands, they are beautiful art, but not all economists can or should be artists. There is room for both science and art. I have found, for example, that I could often, as a discussant, summarise the findings of a DSGE paper in a simple graph. I had learned something from the formal model, but I was able (and allowed as the discussant) to present the basic insight more simply than the author of the paper. The DSGE and the *ad hoc* models were complements, not substitutes.

Moving forward

So, to return to the initial question: I suspect that even DSGE modellers will agree that current DSGE models are flawed. But DSGE models can fulfil an important need in macroeconomics, that of offering a core structure around which to build and organise discussions. To do that, however, they have to build more on the rest of macroeconomics and agree to share the scene with other types of general equilibrium models.

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Dynamic stochastic general equilibrium (DSGE) models are in wide use yet have come under sharp criticism, given their complex nature and the assumptions they rely on. However, many central banks use them in policy analysis. Is this a misguided use of economists' and policy makers' time?

This ebook reviews the use of DSGE models in policy institutions, the lessons learned, and the desirable ways forward. DSGE models, like any model, are no panacea and one should use them bearing their design and limits in mind. Indeed, these chapters show, policy makers use the analysis based on these models, but as one among many ingredients in their decision. Despite their limits, the models offer an internally consistent view of the economy, and are particularly well suited for "what if" analysis. The people building the cutting edge DSGE models are acutely aware of the uses and shortcoming of these models and these chapters are full of examples of right and wrong ways to use DSGE models. Furthermore, these models are not set in stone and research is addressing their limits and expanding their scope. Fuller treatments of labor markets, financial frictions, finite horizons and long-run effects are emphasized as important avenues for further research that will make DSGE models better tools for policy analysis.

There is much to do in DSGE modeling and estimation. This volume shows these models find appropriate policy use, as intended, and justifies the massive effort needed to further refine them.

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