Policy-relevant models for central banks

Nicolas A. Cuche-Curti, Research,
Swiss National Bank, Zurich

Introduction[1]

In the autumn of 2005, the Swiss National Bank (SNB) hosted an academic conference entitled "Policy-relevant models for central banks". This event, bringing together outstanding academics and central bankers from all over the world, was the fourth gathering to be co-organised together with the Federal Reserve Bank of Cleveland (FRBC) and the Bank of Canada (BC).[2]

Such meetings are valuable for both central bankers and academics, because researchers from both groups complement one another in terms of their expertise. On the one hand, the central banks base their monetary policy decisions upon theory-based models and constantly adapt these models to new advances in monetary economics research. Thus, central bankers provide academics with constructive feedback, while testing, using, and improving their prototype models. On the other hand, academics continuously develop the central bank models of the future. Therefore, such academic conferences help participants maintain and further develop their current models as well as design future ones.

After presenting the portfolio of forecasting models used at the SNB, this paper reviews the different methodological approaches to economic modelling in central banks. It then briefly discusses and sums up the papers presented at the conference,[3] revealing the links between the models used in central banks and the various topics touched upon at the conference.

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2 Cf. Amstad and Berentsen (2002) for a summary of the first workshop on monetary economics, which took place at the SNB. The second conference was held at the BC (2003, Dynamic models useful for policy) and the third one at the FRBC (2004, Dynamic models and policymaking). Presented contributions are available on the Swiss National Bank website.
(http://www.snb.ch/e/publikationen/forschung/forschung.html).

3 Although invited participants discussed each paper, this summary does not consider these discussions. It is based exclusively on the paper versions available during the conference.

1 Why do central bank economists use models?

Economists generally cannot perform experiments as natural scientists usually do.[4] Instead, they view reality in a simplified form, using models. A quantitative economic model is a set of behavioural equations, combined with definitional relationships, representing the mechanisms of an economy. Thus, in the form of equations, quantitative economic models reflect a set of thoughts about how an economy works.

Virtually all central banks have to ensure price stability and, in so doing, take due account of the business cycle. The transmission mechanism from monetary policy actions to the economy, in terms of inflation and economic activity, is subject to time lags and uncertainty. Hence, before taking monetary policy decisions, central bankers assess the economic outlook and the probable extent of the inflationary pressures that will prevail in the coming quarters. In order to ensure this forward-looking orientation of their policy, central banks thoroughly analyse economic and financial data so that they can react to all kinds of developments and make the appropriate monetary policy decisions.

The centrepiece of this analysis consists of quantitative economic models.[5] Models do not, however, replace judgment in the conduct of monetary policy. In assessing the output of their models, central bankers enjoy considerable scope for judgmental adjustments. Yet quantitative economic models support the judgment capability of central bankers in several ways. First, with a representation of the mechanisms at work in the economy, models give an understanding of the determinative forces in the economy. Second, models help to formulate monetary policy decisions and simulate alternatives. They also help central banks communicate their decisions. Third, central banks use models for forecasting purposes. Finally, models contribute to enhancing the consistency of the debate among central bank economists.

4 Experimental economics is a notable exception. Cf. Hagel and Roth (1995) for an introduction.

5 Cf. e.g. Blinder (1998), Coletti and Murchison (2002), and Stockton (2002) for an introduction to the use of models in central banks.

2 One model is no model

The eclectic conference programme reflected the pluralistic approach to economic modelling observed in the main central banks. Various factors have led central bankers to use a suite of models instead of a single one. The main explanation lies in the uncertainty regarding the true structure of the economy and the shocks faced by it. In order to minimise the risk linked to a wrongly specified model, central banks generally use several models and weight them according to either their characteristics or the topic examined, or both. Another aspect relates to the fact that, being gross simplifications of a complex reality, no single model answers all relevant questions for monetary authorities. Most models are designed to address a set of specific questions or problems that need to be investigated. Finally, the presence of many models in central banks encourages sound competition among modellers.

3 Suite of models used in central banks

A cursory look at the quantitative economic models used by the main central banks shows that they have been developed parallel to advances made in macroeconomics and econometrics in recent decades. Pagan (2003) ranks these models according to their theoretical foundations and their ability to match the data. All models currently used in central banks fulfil, to some extent, both criteria. Nevertheless, depending on their relative strength, central bank models can be sorted in two categories. The first one, with a strong focus on structural foundations, contains simultaneous equation models, which may represent a general equilibrium. The second category of models, with a strong emphasis on data matching, essentially comprises econometric, mostly time series models.

The foundation stone of models belonging to the first category was laid by the Cowles Commission for Research in Economics, founded in the US in the 1930s by Alfred Cowles. The Commission's economists were among the first to dedicate their research to the junction between macroeconomics, mathematics and statistics. In implementing Tinbergen's (1952) idea of quantifying theory in a simultaneous system of equations, they developed the first models that allowed for the economy to be steered by certain economic variables. The work of the Commission was also influenced by Haavelmo (1944), who asserted that models have to assign probability distributions for model variables to best assess the match between a model and the observable data. The main contribution of the Commission was to consolidate economic theory and econometrics, leading to the estimation of large, simultaneous equation models. Almost all central banks have adopted – and still have – one or more of these models in their suite of models.

In the 1950s and 1960s, due to several methodological debates on empirical economics, these large-scale models were the target of an initial wave of criticism. A second wave of criticism came from the rational expectations school in the 1970s, in particular from Lucas (1976). He showed that the parameters of traditional quantitative economic models implicitly depend on economic agents' rational expectations of the policy process in place. These parameters are unlikely to remain stable as policy changes. This makes such models

unsuitable for policy analysis. In order to avoid this critique, models have to be microfounded, i.e. based upon the behaviour of individual economic agents and built on "deep" parameters invariant to policy changes. Finally, a third wave of criticism paved the way for the second category of central bank models. In criticising the structural multiple-equation models – stressing in particular the arbitrary division between endogenous and exogenous variables – Sims (1980, 2005) proposed a powerful, atheoretical alternative: the vector autoregressive (VAR) models. His approach, which underscores the role of data with no particular theoretical foundation, suggests treating all variables as endogenous and exploiting their autoregressive behaviour. Each variable is explained by a linear function of its own lagged values and the lagged values of all other variables.

Since the 1980s, the main central banks have accordingly extended their suite of models. However, VAR models have not ended the development of simultaneous equation models. Nevertheless, both model classes have seen tremendous improvements since the beginning of this coexistence. They have both been evolving into handy models, thanks to a continuous research effort and increased computing power, thus correcting most of the problems that the first model generations had and reducing the gap between the two classes of models.

In the wake of the real business cycles (RBC) crusade, led in particular by Kydland and Prescott (1982) and King et al. (1988), simultaneous equation models have gained better microfoundations. They no longer suffer from the Lucas critique and are suitable for policy analysis and simulation. More recently, in an effort to bring these models closer to reality, economists such as Christiano et al. (2003, 2005) have been extending them by including more shocks and frictions – the so-called New Keynesian features developed by authors such as Mankiw (1985) and Ball and Romer (1990). What separates these recent models from RBC models is their reliance on nominal and real rigidities, which allows monetary policy to have a real effect. These improved simultaneous equation models now exist under the label "dynamic stochastic general equilibrium (DSGE)" models and are the most advanced models currently used or under construction in central banks. Moreover, thanks to their modern estimation procedures, they are credible probabilistic models of the data.

Despite their successful forecasting performance, VAR models were criticised because they lacked an economic structure. This black-box property did not allow central bankers to elaborate realistic stories about how the economy works. To overcome this criticism, VAR models have gained, over the years, better theoretical foundations. This has transformed them into structural VAR models and vector error-correction models (VECM) in the spirit of authors such as Engle and Granger (1987), King et al. (1991), and Watson (1994). These VECM allow modellers to incorporate information from theory about long-run equilibrium forces and, at the same time, allow the data to play an important role in the short-run dynamics. More recently, some economists, such as Del Negro and Schorfheide (2004), have used VAR and DSGE models in a complementary way in order to create models benefiting from the strengths of both model categories.

4 Conference papers – DSGE models

The next two sections present short summaries of the conference papers.[6] Of ten papers, seven focus on general equilibrium models, and can be split into two groups. The first papers describe new features added to existing DSGE models. These extensions focus, first, on financial frictions faced by households (Gammoudi and Mendes, 2005) and firms (De Fiore and Uhlig, 2005), on better modelling of firms' behaviour (De Walque et al., 2005, Bilbiie et al., 2005), on stabilisation policy (Berentsen and Waller, 2005) and on the integration of monetary aggregates into this class of models (Andrés et al., 2004). The second group consists of a new estimation procedure for DSGE models (Boivin and Giannoni, 2005).

Over the past few years, economists have been improving general equilibrium models to capture empirical facts that are important to central banks. In this respect, Mohamed Gammoudi and Rhys Mendes offer a good example with their paper *"Household sector financial frictions in Canada"*. Observing that, in recent years, real estate prices have rapidly increased, the authors are concerned with the link between this phenomenon and monetary policy. Moreover, there exists some empirical evidence that household financial restrictions may amplify and propagate the effects of monetary policy shocks on residential investment, house prices and consumption.

The authors analyse these problems in a DSGE model for a small open economy, Canada. They complete the traditional DSGE framework with financial frictions in the household sector and introduce them by splitting the households into two groups. Some households can only borrow up to a fraction of the value of their housing assets, while others do not face this constraint. The authors find that the model extended this way better fits the Canadian data in several dimensions. In particular, the financial frictions generate significant house price volatility and a positive correlation between consumption and house prices. Finally, house prices are sensitive to monetary policy shocks. The authors estimate that a change of 250 basis points in the short-term interest rate causes a decline in real house prices of almost ten percent.

In *"Bank finance versus bond finance: What explains the differences between US and Europe"*, Fiorella De Fiore and Harald Uhlig look at another market imperfection: credit restrictions faced by the corporate sector. The authors analyse firms' external finance and its composition, as an important channel through which firms affect the economy. Moreover, the empirical evidence reveals some differences in the financial structure across countries. The traditional distinction between bank-based (credits) and market-based (bonds) financial systems applies to the euro area and the US. According to the authors, corporate investment relies more on bank credits in the euro area than in the US.

The authors introduce heterogeneous firms and agency costs in a DSGE model. In the presence of such costs, financial intermediaries reduce the information asymmetry between lenders and borrowers and offer financing instruments that best fit the needs of each borrower. Thus, bank-based and market-based systems differ, because banks spend resources to acquire information about the firms' risk of defaulting, while bond buyers do not. This implies that bond finance is less costly for firms than financing through banks. However, bond finance is a risky choice, because a situation of financial distress can only be solved through liquidation. Hence, the firms' optimal choice of financing instruments endogenously determines the financial structure of the economy.

Calibrating their model, the authors are able to explain the observed differences between Europe and America. They find that a higher share of bank finance in the euro area relative to the US is, first, due to lower availability of public information about firms' creditworthiness and, second, due to higher efficiency of banks in acquiring such information. Finally, the authors find that differences in the financial structure have a non-negligible impact on GDP per capita.

Another DSGE improvement is better modelling of the behaviour of firms, in particular their price setting behaviour. Gregory De Walque, Frank Smets and Raf Wouters reveal, in *"Firm-specific production factors in a DSGE model with Taylor price setting"*, a disturbing feature of most DSGE models. The estimated parameters lead to an implausibly high degree of nominal price stickiness. Firms would not re-optimise their price during an average period of more than two years. This implication is not in line with the empirical evidence showing that prices are generally sticky for less than one year.

6 All papers are listed at the end of this article. These summaries are solely the responsibility of the author of this article and not of the authors of the papers.

The main idea of the paper is to allow firm-specific production factors to create real rigidities, i.e. less factor mobility between firms, and help reduce the nominal price stickiness. Firm-specific factors imply that firms no longer share the same marginal cost. This means that not only does a change in demand for the firm's output influence its optimal price, it also affects its marginal cost. A fall in the marginal cost can thus reduce the incentive to raise prices. The combination of the two effects is to reduce the overall price effect of various shocks. On the one hand, the elasticity of substitution between the goods produced by the firm and those produced by its competitors governs the price effect. On the other hand, the elasticity of the individual firm's marginal cost with respect to the demand for its products governs the marginal cost effect. Consequently, high elasticities maximise the marginal cost effect and minimise the price effect, thereby reducing the need for a high estimated degree of nominal price stickiness.

After estimation, the authors find that firm-specific capital leads to a fall in the estimated stickiness period to four quarters. This specificity also improves the empirical fit of the model. However, the results with sector-specific labour are less promising. The reason is that sector-specific labour markets only reduce the overall price effect if wages strongly respond to changes in the demand for labour. However, according to the authors, such wage flexibility is incompatible with the empirical evidence concerning the aggregate wage behaviour.

In *"Business cycles and firm dynamics"*, Florin Bilbiie, Fabio Ghironi and Marc Melitz model the empirical fact that the number of firms in the economy varies over the business cycle. Net entry – at least in the US – is strongly procyclical and comoves with real profits. This means that firm entry and exit may play an important role in propagating shocks and influencing the business cycle. The authors build a DSGE model, which endogenously determinates the number of producers over the business cycle. On the one hand, economic expansion induces higher entry rates in the expectation of future profits. Firms are, on the other hand, subject to irreversible investment costs associated with market entry.

The main results are twofold. First, the authors show that net entry plays an important role in the propagation of shocks. Their model is thus consistent with the data. Second, they design an innovative mechanism of labour relocation between existing and new firms. A GDP expansion initially takes place with an output increase from existing firms (the so-called intensive margin). Entry then becomes more attractive and labour is relocated to the creation of new firms. Existing firms' output decreases, while the number of firms in the economy increases (the so-called extensive margin).

Stabilisation of the economy in case of aggregate shocks has always been an important issue among central bankers. Aleksander Berentsen and Christopher Waller, in *"Optimal stabilization policy with flexible prices"*, analyse this issue in a model with flexible prices. Generally, the design and implementation of stabilising monetary policies take place in models with sticky prices due to the presence of nominal rigidities. Without them, there is no role for stabilisation policy because money is always neutral. Thus, one may be tempted to conclude that price stickiness is necessary to generate a role for stabilisation policy.

In a DSGE model with search markets, the authors show that this is not necessarily the case and that there is a welfare-improving role for stabilisation policy even if prices are fully flexible. The key element for an effective stabilisation policy is the central bank's commitment to a price path allowing it to control inflation expectations. The optimal policy then involves smoothing nominal interest rates, which in turn smooths consumption across the aggregate shocks.

In the last paper of the group focusing on DSGE extensions: *"Money and the natural rate of interest: Structural estimates for the UK, the US, and the euro area"*, Javier Andrés, David López-Salido and Edward Nelson give money an explicit role in the DSGE framework. Generally, in standard DSGE models, money shows up as a noisy indicator of current output, hardly a role that conveys great significance to money in prospective macroeconomic analysis. The authors assert the monetarist view that money contains information about determinants of aggregate demand, e.g. the natural rate of interest, which is neglected in the current DSGE models.

The authors propose different money demand equations in the same DSGE framework. They demonstrate that money is better able to capture the transmission mechanism of monetary policy when money demand has a forward-looking element.

Hence, they illustrate that the role of money, as a proxy for future variations in the natural interest rate, is increased. Their econometric analysis of the US, the euro area, and the UK shows that the relationship between real balances and the natural rate of interest is negative. The rationale is that money demand fundamentally depends upon the expected path of nominal rates. If expected future values of the natural rate move in the same direction as the nominal rate in response to shocks, a negative relationship between real balances and the natural rate emerges.

The second group focused on estimation methods. In *"DSGE models in a data-rich environment"*, Jean Boivin and Marc Giannoni challenge the standard practice for the estimation of DSGE models, whereby economists generally assume that each model variable is properly measured by a single observed indicator. Such an assumption implies that a small number of time series adequately summarises all necessary information for the estimation. However, research has shown that information contained in large data sets is relevant for the evolution of time series. Moreover, central banks analyse hundreds of series and, for almost every model variable, are confronted with several series. There exist, for example, various measures of real economic activity, which is calculated and deflated using different methods. Ignoring this fact may distort the model estimates and the inference based on them.

The authors propose a procedure that exploits the information contained in large data sets. They treat the model variables as unobserved common factors for which various observed time series are merely imperfect indicators. The authors apply this procedure to different DSGE models and show that the estimates of some parameters differ significantly, depending on the assumed link between model variables and data. Thus, the additional information provided by the data-rich environment is highly relevant for the model estimation. Finally, the proposed procedure improves the forecasts of some US indicators such as inflation, consumption, output and interest rates.

5 Conference papers – Econometric models

Three authors presented papers with econometric models. These papers focus on the role of monetary aggregates in predicting inflation (Reynard, 2005), on the VAR approach for helping design DSGE models (Christiano et al., 2005), and on the recovery of market expectations from financial data (Carlson et al., 2005).

In *"Money and the great disinflation"*, Samuel Reynard challenges the main empirical studies that take in the post-1980 period – a low inflation period – and that tend to reject the idea that money growth has a significant impact on inflation. It seems that both the link between money and inflation and stable money demand have vanished. According to the author, the cause of the weak relationship between money growth and inflation is the neglect of equilibrium interest rates changes associated with disinflation. One should consider that the opportunity cost of holding money has dramatically decreased during the past twenty-five years. As the level of money balances has shifted upwards following this development, not controlling for the change in money velocity may lead to long-run money demand misspecifications.

Using long-run money demand estimates to adjust monetary aggregates for changes in velocity, the author finds a proportional link between money growth and inflation in the US and the euro area. Moreover, ignoring such changes allows the author to show the insignificant influence of money growth on inflation reported in the literature. Finally, he shows that inflation responds significantly to a money growth shock, but that an inflation shock does not significantly affect money growth. The author reports that the estimated impact of changes in money growth rates on inflation includes longer lags in the US than in the euro area.

Central banks have been using VAR models essentially for forecasting purposes. In their paper *"Assessing structural VARs"*, Lawrence Christiano, Martin Eichenbaum and Robert Vigfusson focus on another potential of structural VAR models, namely their use for DSGE modellers. They respond to recent critical literature – in particular by Chari et al. (2005) – which challenges the idea that structural VAR models allow modellers to estimate

the dynamic effects of economic shocks and that the impulse response functions (IRF) provide an appropriate way to assess the empirical plausibility of a DSGE model under construction.

The link between VAR and DSGE models works as follows. Modellers estimate a VAR model using the data and impose some identifying assumptions to compute IRF for various shocks. Then, these IRF are compared with theoretical IRF from a DSGE model and a good fit validates the structural model. The reverse approach, artificial data generated by the structural model and then used in a VAR model to compute the dynamics, should allow modellers to retrieve the dynamics of their model. When performed by Chari et al. (2005), this test fails. Therefore, they conclude that structural VAR models are misleading.

According to the authors, this experiment fails for two reasons. First, Chari et al. (2005) do not consider the case when structural VAR models are identified using short-run restrictions, and only focus on long-run restrictions. Based on different DSGE variants, Christiano et al. (2005) find that structural VAR models perform remarkably well for their purpose as a checking tool. Second, the choice of the model is crucial, in the sense that misspecification or simplicity of the model are not solved by the experiment with standard VAR models. Accordingly, the authors develop a modification to the usual VAR methods, which works well with artificial data generated by the models used by Chari et al. (2005).

For many years, central banks have been screening the financial markets in order to extract market expectations about key variables, in particular inflation and interest rates. In *"Recovering market expectations of FOMC rate changes with options on federal funds futures"*, John Carlson, Ben Craig and William Melick demonstrate that options on federal funds futures provide more information about expected moves of the FOMC than the expectations extracted from futures alone. Futures do not allow for the extraction of anything more than information on whether the market expects the central bank to move its interest rate or not. Options, however, allow for the extraction of market expectations for various possible outcomes of FOMC meetings.

The authors present an estimator of the probabilities for an array of federal funds rate outcomes before a specific FOMC meeting. Their procedure also allows for the estimation of probabilities for two or more upcoming meetings. The suggested technique is a valuable way for central banks to ascertain the view of financial markets on the future stance of monetary policy. Although probabilities extracted from futures are often sufficient, the authors highlight the fact that options-based probabilities are most useful during periods of high uncertainty about the future course of monetary policy, e.g. after an important crisis.

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