Macro-Econometric System Modelling @75

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Contents

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1 Introduction

Macro models are never static. They constantly evolve. "Survival of the fittest" is a good description of the history of models. Each generation of models inherits most of the characteristics of the last. The characteristics are lost when they are perceived to convey no benefit in the current environment. Sometimes however they re-emerge when the environment changes.

The changing design of macroeconometric models reflects the desire to incorporate some features that it is thought desirable that a model should possess. Over the past 75 years we have witnessed eight major themes that have accounted for the changing structure of models. We will describe these as the eightfold way of building macroeconometric system models.

1. Preserving identities. Examples include those in the national accounts, household and government budget constraints, the need for external debt to be sustainable in an open economy, and supply must equal demand.

2. Expectations. These have evolved from informal expressions that involved a simple weighting scheme for past events to cases where the maintained model provides the weights.

3. Dynamics. These have been manifest in two broad forms. Intrinsic dynamics arise from identities such as occur with an evolving capital stock. Extrinsic dynamics augment the intrinsic ones either with flexible forms that are data based, such as empirical error correction models (ECMs), or produce model based forms that follow from agents' choices made under constraints such as habit persistence, capacity utilization etc. The latter will be capable of being formulated as ECMs but the parameters are functions of a more fundamental set of parameters that are contained in the model.

4. The desire that the model should possess a long-run equilibrium solution, either a steady state level or a path.

5. Optimization. Structural models reflect decisions taken by agents. These have either been of an informal nature or determined by postulating some optimization criterion. The latter was originally period by period but increasingly has become inter-temporal. In both cases

there may be some constraints it is felt desirable to apply, such as occurs with credit restrictions or zero bounds on variables such as interest rates.

6. Heterogeneity. Although a representative household/firm producing and consuming a single good has been the most common approach, models have increasingly incorporated some form of heterogeneity.

7. Shocks have become the primary way of understanding the implications of models. There can be quite a range of these, both in terms of the their number and what they aim to capture. Moreover, they have increasingly been used to allow for effects that do not explicitly appear in the model or to enable policy makers to adjust the forecasts made by the model.

8. Financial institutions and the range of financial assets available.

Even if these features had been thought desirable from the beginning of macro-econometric modelling many of them were not feasible. What is feasible reflects computational capabilities and the type of methods we have available to us. Computational capacity has obviously grown, but we should also recognize that one could not solve stochastic optimization or stochastic non-linear models twenty years ago. This meant that the models of those times were essentially deterministic models and experiments performed on them involved treating variables such as the money supply as exogenous, rather than endogenous. Moreover, although inter-temporal optimizing ideas had been around from the 1950s, principally through the permanent income and life cycle approaches to consumption, these were implemented in simple ways, rather than as a precise statement of the theory. Consequently, consumption was taken to depend upon a linear function of lagged financial wealth and expected future labour income, with the weights being given by the data rather than from parameters of utility functions and the labour income process etc.

Fukacs and Pagan (2010) argue that there have been four major generations of models in the past 75 years. These have given particular answers when responding to the eight-fold way above. Our paper discusses these generations of models in sections 2-4. The focus is upon the designs of the models and does not deal with the way they are used, an exception being in the final section. To properly describe the use of models we would need to cover

3

issues about the data used, adaptions made for forecasting, and whether the parameters of the models should be treated as constant or allowed to vary.

There are three other constraints governing the content of our paper. First, we do not deal with the literature involving Structural VARs. This is because these models tend to have a rather rudimentary design and cover only a few of the items listed in the eight themes above. For example, a notable omission from them has been stock variables, although this now seems to be changing. Secondly, we look at models for a single economy. There is a parallel literature for multi-country models, but the design issues are rarely much different. Finally, we will have little to say about estimation issues. These have also followed an evolutionary path, starting with OLS and 2SLS, moving on to a limited use of FIML, followed by an adoption of Bayesian methods. Because the Bayes mode and the MLE differ only by the fact that the optimand used by the former differs from the latter by the log of the prior a preference for one over the other has to weight the advantages to optimization of a smoother function (due to the prior) with the costs of having the prior essentially determine the parameter values. Sensitivity to prior choice was a key issue with Leamer (1978) but sadly this seems of less concern today. It is somewhat disturbing to see references today to 'consensual priors' being invoked for estimation of models in many countries, when these priors originate with US models. Moreover, coming from a long tradition in which "wrong signs" for estimated parameters mostly meant that not enough thought had been given to the model design, the common practice today of using priors to rule out "wrong signs" does not seem helpful.

The first generation began with Tinbergen (1936), approximately 75 years ago. Second generation models were largely being used during the lifetime of the Macro Modelling Bureau (MMB), and so Ken had a significant role in assessing, judging and writing about them. It needs to be said that a previous generation of models often co-exists for a long time with the new generation, just as Homo Sapiens and Neanderthal Man overlapped. Often this is because the skills needed to move to a new generation of models are not readily available, but it also may be that users are more comfortable with the older generation model and feel that adjustments can be made to it so as to make it perform at the level of the new generation version. One of the important tasks of the MMB was to train people in modelling skills independently of the organizations where the models were built and used. Its effectiveness in this can be seen from the number of people employed who are important figures in macro-economic analysis today.

The stimulus to adopting a new model is mostly dissatisfaction with the old. Sometimes this is based on philosophical disagreement with the approach embedded in the older generation model, but often it is simply due to some external event. Models get modified based on what is happening in domestic economies or in the international environment. For this reason it seems natural to ask whether the "great event" of the past decade—the GFC or the "Great Recession"—has stimulated a fifth generation of models. It may be too early to ask this question, but one would expect to see some evidence of thinking along these lines. It is certainly the case that there have been many critiques of 4G models e.g. in the wake of the GFC Caballero (2010), de Grauwe (2010) and Pesaran and Smith (2011). For this reason we look at what the model responses to the GFC have been.

2   In the Beginning: the First Generation (1G) Models of Tinbergen and Klein

Empirical system-based macro modelling began with Tinbergen (1936). It is worth observing that the stimulus to Tinbergen's original modelling work was event-based, namely the desire to evaluate policies proposed to offset the Great Depression. In his 1936 address to the Royal Netherlands Economic Association he was asked to answer the following question

"Is a recovery in domestic economic activity in this country possible, whether or not aided by government intervention, even without an improvement in our export position? What can be learned about this problem from the experience of other countries?"

His later work involving a US model—Tinbergen (1939)—was used to assess business cycle theories. That research received much more attention than the Netherlands work. But in many ways it is the Netherlands model that is the key contribution to the history of systems modelling and so is the one that should be focussed on. This was a 24 equation model describing the macro economy and, in this respect, it seems to have been revolutionary. It is true that the idea of small models, particularly to assess business cycles, had been around for some time, and this is certainly evident in Frisch's (1933) work. But the scale here seems to have had no antecedents. Possibly the scale was forced upon Tinbergen by his need to examine a range of "policy" options - a three year investment programme, limiting imports of consumer

goods, changes in labour productivity and wages, and a devaluation of the guilder. Once one writes down equations for these variables they would be expected to depend on others and so the system grows. Indeed Tinbergen seems to suggest that this was the basis of his methodology when responding to a question in Magnus and Morgan (1987, p 124) where he says that "I think the best way of introducing a model is to start out by taking just one variable, say the price level, and ask yourself how it is to be explained. You write down an equation which indicates what factors determine the fluctuations in prices. Then of course some of these factors ... have to be explained ... And so you add an equation ... That could be a clarification of how the idea of a model comes in almost by necessity".

Only a small number of the precepts in the eightfold way appear in the model. In relation to the first Dhaene and Barten (1989 p.206) note that "The model contains nine identities. ... linearized multiplicative, linking the value volume and price of the various concepts. The linearization is around the sample mean. ... The small number of additive accounting identities is another symptom of the fact that the model predates the system of national accounts". For the second, expectations of profits enter into the determination of investment and are proxied by lagged profits. Jolink (2003, p 84) notes that Tinbergen argued that "The notion of an economic plan allowed for the optimization of utility over several periods. In particular producers would determine their present and future supply on the basis of the present information". The wage relation is a dynamic one that has some similarities to the later Phillips curve. Because the model is for a yearly frequency there is only a small amount on dynamics even though Tinbergen in his work of the potato flour market - Tinbergen (1930) had shown a strong interest in dynamics of the "cobweb model" variety. There is no stock of capital and so a completely formulated supply side is lacking. Interest rates did not appear to have an important impact on variables such as investment, so they were dropped from the system, even though it was clear that Tinbergen felt they should be there - Tinbergen's U.K. model done around 1939/1940, but not published until much later, had a range of interest rates and financial assets. One of the most important characteristics of the model was its attention to the fact that the Netherlands was a small open economy. As a beginning to the architecture of macro-economic system modelling the model was truly an impressive achievement.

Not long after Tinbergen's work the structure of national accounts was formalized. This event provided a structure for macro modelling, making

it clear what identities needed to hold. Consequently, after the national accounts identity was stated, one could proceed to specify equations for the variables in it, and this became the dominant strategy in 1G models. By far the greatest architect of the approach was Klein. The models became very large and complex, although in a number of places Klein motivated them as IS-LM constructs, even showing what the implied curves would be, see Duggall *et al.* (1974). Given this IS-LM orientation financial effects were represented in the system via the effects of interest rates in it. Dynamics were handled mainly with a Partial Adjustment Scheme or by using a finite distributed lag which depended on a small number of parameters, as in Almon (1965). Although often not explicitly stated, a form of Phillips curve provided an inflation equation.

As the 1960s wore on, and inflation started to accelerate, more attention had to be paid to the role of expectations, and this inevitably raised the question of the role of money and financial factors. Because the supply side in these models was mostly ignored, there was not a great deal of attention paid to stocks and flows and, consequently, long-run equilibrium relations. Wallis (1995), in an excellent review of these and the 2G models discussed later, notes that there was an implicit assumption underlying them that variables evolved deterministically over longer periods of time, although there wasn't any discussion about whether such paths were consistent. Moreover, their relative magnitudes didn't seem to play a major role in model construction and design.

3   The Models Move on: The Second Generation (2G)

These began to emerge in the early 1970s and stayed around for ten to twenty years. They were not all identical. Modellers chose to emphasize different aspects and also responded in different ways to evolving events such as monetary targeting and flexible exchange rates. But a key element in all of them was an explicit supply side. This involved the introduction of a production function in order to place a constraint on aggregate supply, particularly over longer horizons. Good examples of these models were the RDX2 model of the Canadian economy, Helliwell *et al.* (1971), and the Fed-MIT-Penn (FMP) model (Ando *et al.* (1972)), which was also called MPS in

an earlier incantation—see Gramlich (2004). As mentioned earlier 2G models did evolve. This feature is best illustrated by the replacement of FMP with FRB-US (Brayton and Tinsley, 1996) at the Federal Reserve. The philosophy of FRB-US was much the same as FMP/MPS but there were extensions to the way dynamics and expectations were handled, and some of the difficulties with FMP were eliminated.

In the U.K. context the Treasury, London Business school (LBS) and National Institute models were originally of 1G form. This started to change in the 1980s with the LBS and the newer City University Business School (CUBS) (Beenstock *et al.* (1986)) models reflecting supply side constraints[1]. The first version of the 2G form of LBS was published in 1984 as Budd *et al.* (1984), and it was one of the initial models deposited at the MMB. These models retained much of the structure of the previous generation of models in that demand was captured by dis-aggregated equations stemming from the national income identity. But now they were supplemented with equations which introduced much stronger supply side features. There was also some movement towards deriving the relationships as the consequence of optimization problems solved by agents—in particular the consumption decision and the choice of factors of production were often described in this way. Dynamics were again introduced through a distributed lag on the static relationships determining the desired levels of a variable, and the desired levels were taken to be those reflecting long-run equilibrium values. The advance on previous work was the use of an error correction mechanism (ECM), which, as Wallis (1995) observes, originated in Phillips' control work of the 1950s. Although ECMs were applied by Sargan (1964) when modelling inflation, their widespread use began with Davidson *et al.* (1978). Indeed, UK modellers became so keen on the use of an ECM to bridge the short-run and long-run that their use of it became known as "Hendrification". FRB-US represented an extension to the old ECM structures. Various extensions to the standard ECM approach emerged e.g. it was augmented in FRB-US by the expected future changes in the equilibrium level.

Now, with the introduction of a production function, and a household's decisions coming loosely from a life cycle perspective, the presence of household wealth and the capital stock meant that there were dynamics present

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[1]We have decided to focus upon the evolution of the LBS models rather than others such as HM Treasury and the National Institute simply because the documentation was easier to access.

in the model which stemmed from depreciation and savings. Consequently, dynamic stability of the complete system became a pressing issue. The implication of this was that one needed to keep an eye on system performance when modifying the individual equations. Gramlich (2004) commented on his work with the MPS model that "...the aspect of the model that still recalls frustration was that whenever we ran dynamic full-model simulations, the simulations would blow up". It might be a necessary condition that the individual equations of the system were satisfactory in terms of fitting the data, but it was not a sufficient one. Because 1G modellers had developed software that enabled one to simulate large models, 2G modellers followed the maxim of Chris Higgins that, to be assured of good system performance, modellers should "simulate early and simulate often". For that, computer power and good software were needed.

Like the previous generation of models there was considerable diversity within this class and it grew larger over time. Often this diversity was the result of a slow absorption into practical models of new features that were becoming important in academic research. For example, since many of these models had an array of financial assets—certainly a long and a short rate —model consistent ("rational") expectations were increasingly introduced into the financial markets represented in them. This was certainly true of the second version of the LBS model - Dinenis *et al.* (1989) - lodged at the Bureau.

By the end of the era of 2G models, this development in financial modelling was widely accepted. But, when determining real quantities, expectations were still mainly formulated in an *ad hoc* way. One reason for this was the size of the models. The U.K. models were almost certainly the most advanced in making expectations model-consistent - see the review in Wallis and Whitley (1991). Introduction of this feature was not trivial as the models were non-linear and some terminal conditions needed to be applied to provide a solution. In a number of instances the MMB assessments mentioned the terminal conditions as a serious problem - Wallis (1988). Being developed by the mid 90s the FRB-US model benefited from this earlier work on ensuring stability with forward looking behaviour and it allowed full model consistency, although forward expectations of real variables were mostly made consistent with a small VAR that included output, inflation and an interest rate along with variables that were thought important to the variable expectations were being formed about. It is possible that the FRB-US model could have a VAR as its reduced form but it seems unlikely.

9

As Wallis (1977) and Zellner and Palm (1974) pointed out when examining the derivation of the "final equations" that Tinbergen used for assessing his models for the presence of oscillations it is most likely that the reduced form would have a VARMA structure. So the expectations generated from the VAR would not be model FRB-US model consistent.

Perhaps the most interesting development in the LBS and other U.K. 2G models (such as that of the Bank of England (1987)) was the provision of a complete set of equations for the financial system which used the newly developed flow of funds accounts. Within the evolving LBS structures this was initially motivated by the need to account for flexible exchange rates. A monetary approach to determining the exchange rate had led to the introduction of a money demand function into the model and it was a natural progression to extend this to a range of financial assets. The flow of funds essentially described the balance sheets of a number of sectors - households, non-financial corporations, banks and other financial institutions etc. The assets on the balance sheets were normally separated into items such as cash, loans, government securities, equity etc. It was envisaged that the portfolio decisions made by households for example would impact upon their expenditures, so that the consumption decision would depend in some way upon the nature of the portfolio and whether it was in "equilibrium". The classic paper to deal with these issues was Brainard and Tobin (1968). Some of the analysis was a little ad-hoc; e.g. Backus and Purvis (1980) assumed that the portfolio of households adjusted to the equilibrium values via a partial adjustment mechanism, and this meant that the consumption-income ratio depended upon the different assets in the portfolio with different coefficients (due to different adjustment responses). The problem with this formulation is that, if there was no adjustment, it would have consumption being independent of wealth, which would be a return to the old Keynesian consumption function. Generally the portfolio decisions were made using some criterion e.g. in the LBS model this involved trading off return and variance. It was recognized that the actual decisions might deviate from these and so an error correction framework was applied to handle any missing dynamics. If one followed the Brainard and Tobin route then one was essentially specifying demand and supply curves for the financial quantities to find the interest rates that cleared markets. This meant that there were quite few interest rates present in the second version of the LBS model.

It is probably no wonder then that when financial crises started to come along in the 1970s attention was focussed on how one might profitably use

the flow of funds data. An example was Australia, where there had been had a credit squeeze in 1974 which had led the Treasury modellers to produce detailed models of the financial sector - see Johnston (1978). Even if there hadn't been any financial crisis modellers might still have been interested in items such as the level of public debt and the implications for the exchange rate of capital inflows from overseas failing to *ex ante* match a trade account balance. Later 2G models however dropped a complete modelling of the financial sector and replaced the latter by arbitrage conditions between the yields appearing in the system. This meant that what needed to be modelled was the risk or liquidity premium that was represented by the spreads. FRB-US is a good example of this approach with the risk premium being taken to be a function of excess demand.

The NAIRU was a key concept in 2G models as it determined whether inflation was accelerating or not. Often the value was prescribed and it became the object of attention. Naturally questions arose as to whether one could get convergence back to it once a policy changed. In models with rational expectations dynamic stability questions such as these assume great importance. If expectations are to be model consistent, then one needed the model to converge to some quantity. Of course one might circumvent this process by simply making the model converge to some pre-specified terminal conditions, but that did not seem entirely satisfactory. By the mid 1980s however it appeared that many of the models had been designed (at least in the U.K.) to exhibit dynamic stability, and would converge to a steady state (or an equilibrium deterministic path).

4 Reverse Engineering: The Third Generation (3G) Models

Third generation (3G) models reversed what had been the common approach to model design by first constructing a steady state model (more often a steady state deterministic growth path, or balanced growth path) and then later asking if extra dynamics needed to be grafted on to it in order to broadly represent the data. One of the problems with some 2G models was getting stocks to change in such a way as to eventually exhibit constant ratios to flows. Hence, it was felt that stock-flow consistency would be more likely if decisions about expenditure items came from well-defined optimization

choices for households and firms, and if rules were implemented to describe the policy decisions of monetary and fiscal authorities. Strictly, there was no need to have a formal optimizing framework - it was more a device to solve the problem of individual equations appearing satisfactory but making the system perform poorly. Some standard rules were for external debt to be taken to be a fixed proportion of GDP and for fiscal policy to be varied to attain this. By the time the MMB was finishing up a number of papers were written concerning fiscal rules in the models that were being examined. Monetary authorities needed to respond vigorously enough to expected inflation - ultimately more than one-to-one to movements in inflation.

There are many versions of 3G models, with an early one being an Australian model by Murphy (1988) and a multi-country model (MSG) by McKibbin and Sachs - McKibbin (1988), and McKibbin and Sachs (1989). Murphy's model was more fully described in Powell and Murphy (1997). 3G models became dominant in the 1990s. The most influential of these was QPM (Quarterly Projection Model) built at the Bank of Canada in the early to mid 1990s and described in a series of papers (e.g., Black *et al.*, 1994, Coletti *et al.*, 1996). A variant of it was later implemented at the Reserve Bank of New Zealand (FPS, Black *et al.* 1997). Later versions were BEQM (Bank of England Quarterly Model, Harrison *et al.*, 2005) and the Bank of Japan Model (JEM, Fujiwara *et al.* (2004). There were a number of models that straddled 2G and 3G models. They adopted much of the orientation of 3G models but not all e.g. inter-temporal optimization might not be used and, whilst they did have a long-run equilibrium solution, they were not designed that way. FRB-US mentioned in the previous section is a good illustration of such an in-between model.

As a simple example of the change in emphasis between 2G and 3G models, take the determination of equilibrium consumption. It was still the case that consumption ultimately depends on financial wealth and labour income, but now the coefficients attached to these were explicitly recognized to be functions of a deeper set of parameters - the steady state real rate of return, utility function parameters and the discount factor. It is this difference that accounts for our classification of FRB-US as a 2G model. Because these parameters also affect other decisions made by agents, one cannot easily vary any given relationship, such as between consumption and wealth, without being forced to account for the impact on other variables of such a decision.

Thus a steady state model was at the core of 3G models. As in 2G models nominal quantities were handled by making prices a mark-up on marginal

costs and then structuring the relation to handle dynamics and expectations. Early in their history there was sometimes an hostility towards a precise use of data to determine the parameters in them, so that Colletti *et al..* (1996, p 14) say about modelling in the Bank of Canada: "There had been a systematic tendency to overfitting equations and too little attention paid to capturing the underlying economics. It was concluded that the model should focus on capturing the fundamental economics necessary to describe how the macro economy functions and, in particular, how policy works, and that it should be calibrated to reflect staff judgement on appropriate properties rather than estimated by econometric techniques".

"Calibrating the model" was certainly an early response but by the time but, by the time BEQM and JEM emerged, a variety of methods was employed to quantify the parameters.

One of the key developments in 3G models was that attention was centered upon the "gap" between the model variables and their long-run equilibrium values. One could always write an error correction model in this way but now the separation of the current and long-run equilibrium values was thought useful for forecasting and policy analysis. Over time this emphasis on "gaps" gave rise to the miniature models known as New Keynesian. Although these were never used as a main macro model (they lacked any stocks for example) they were often used for training purposes and to think about issues, much like the role IS-LM had played for 1G models and AS-AD for 2G models. In some ways the philosophy underlying 3G models had much in common with that stream of Computable General Equilibrium (CGE) modelling stemming from Johansen (1960). In that literature models were log-linearized around some "steady state" values and the computation of these steady states (often termed the benchmark data set) involved substantial manipulation of data from input-output tables etc. Of course the CGE models were not in "real time" and so transition paths were essentially irrelevant. It was simply assumed that enough time had elapsed for a new steady state to be attained once a policy change was made.

Another feature of 3G models was that shocks became the focus of attention. Although shocks had been introduced to macro-economics by Frisch (1933) they did not become part of the standard language of macro-economics until the 1970s. Commenting on Frisch in his interview with Magnus and Morgan Tinbergen(1987, p 125) said "...I did not understand the role of shocks as well as Frisch did. But I think he was perfectly right, and of course one could indicate some of the exogenous variables playing the role

of shocks". There is no doubt that in 1G and 2G models the focus was on dynamic multipliers for exogenous variables and it is only in the past few decades that shocks have become the centre of attention. One reason for this shift was that, with the advent of policy rules, one could no longer think about changing variables such as government expenditure or the money supply, since these were now endogenous variables. Only exogenous shocks to them might be varied. However, although the language was changed in such a way that shocks were thought of as stochastic, often the solution methods were essentially deterministic, and so there was no "clean" incorporation of shocks into the models.

5 More Steps Along the Eight-fold Way: Fourth Generation (4G) Models

A fourth generation of models has arisen in the 2000s. Representatives are ToTEM (Bank of Canada, Murchinson and Rennison, 2006); MAS (the Modelling and Simulation model of the Bank of Chile, Medina and Soto, 2007); GEM (the Global Economic Model of the IMF, Laxton and Pesenti, 2003); NEMO (Norwegian Economic Model at the Bank of Norway, Brubakk *et al.*, 2006); The New Area Wide Model at the European Central Bank, Kai *et al.*, 2008); the Ramses model at the Riksbank (Adolfson *et al.*, 2007); AINO at the Bank of Finland (Kilponen *et al.* 2004) and EDO (Chung et al., 2010) at the U.S. Federal Reserve.[2] These models are the counterpart to what have become known in the academic literature as Dynamic Stochastic General Equilibrium (DSGE) models. The difference between them and their academic cousins is largely size. As with 3G models they are designed to have an underlying steady state representation. But other features of their design are different to what was standard with 3G models. Four of these are of particular importance.

Firstly, shocks are now explicitly part of the model rather than being appended at the end of the modelling process. A shock is what remains unpredictable relative to an information set specified within the model, and so it is necessary to be explicit about what this information is. In addition, how persistent the shocks are becomes important to describing the complete

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[2]SIGMA(Erceg *et al.*, 2006) was a multi-country model developed at the Federal Reserve Board.

dynamics of the model, and this makes it necessary to decide on the degree of persistence. Given that shocks are unobservable (they are essentially defined by the model itself) this inevitably points to the need to quantify the parameters of the model from data.

Secondly, there is now no second-stage process to introduce dynamics via polynomial adjustment costs or ECMs. Instead, the adjustment cost terms used to rationalize slow adjustment in 3G models now appear directly in the primary objective functions that lead to the agent's decision rules i.e. the short and long-run responses are found simultaneously rather than sequentially. Of course the logic of the two-stage process used in 3G models was a recognition that adjustment costs (and the parameters associated with them) don't affect the steady state solutions, and it was only the transition paths between steady states that depended on those parameters. In fact, recognition of this feature was the motivation for adapting 3G models to an existing forecasting environment by treating the construction of dynamics in two steps.

Thirdly, the structural equations of the model are often now kept in Euler equation form rather than using a partially solved-out version as was characteristic of 3G models. Thus the optimal inter-temporal rule describing consumption decisions appears in most 4G models as

$$C_t = \beta E_t(C_{t+1} R_{t+1}), \tag{1}$$

which contrasts with the 3G model approach that combines this relation with the wealth accumulation identity to express consumption as a function of financial wealth and labour income. One reason for doing so is that it is easier to modify the model design through its Euler equations e.g. by the introduction of habit persistence that affects the dynamics of the model.

Finally, because shocks were an integral part of some of these models, solution methods needed to be shaped to account for them. Indeed, with this focus on shocks one had to be careful when referring to "forward" and "backward" expectations; all expectations are now formed using information available at time t, and so technically all depend on past observations (unless there are exogenous variables in the system). Thus the important feature becomes the relative weights to be attached to the available information at time t when forming expectations at different periods. A second consequence of the shift to a "shocks" perspective is that the distinction between "parameters" and "shocks" becomes blurry. Thus a depreciation rate might now be

15

regarded as a random variable that evolves stochastically over time with an expected value equal to whatever specified value for it appears in the steady state model. Thus this provides a formal way of allowing some of the model parameters to change, something that was only done in an *ad hoc* way in 3G models.

The modifications above are essentially adjustments to the basic strategies employed in the design of 3G models. But there are also some new features that were more fundamental to the eight-fold way. Two can be mentioned. Firstly, there is now some heterogeneity introduced into the models. There has always been some heterogeneity recognized in macro-econometric models. For example McKibbin and Sachs (1989) had two types of consumers, those who solve an intertemporal optimization problem and those who are liquidity constrained and just have current income available for consumption. FRB-US used this idea as well. An extension to it has some firms being cash flow constrained, and so investment depends on cash flow rather than expected rates of return. But essentially this was a bivariate division of agents. In 4G models the analysis often begins with different types of labour services, many intermediate goods being produced and used to make a final good and many types of imported goods. These are then aggregated into a single representative measure of labour, output and imports. It is envisaged that the operation is performed by an "aggregator". It is then necessary to specify a scheme whereby the aggregation is performed and this generally involves the use of specific forms that make aggregation easy. The method is well known from Dixit and Stiglitz (1977). Basing the model design on a micro-economic structure can potentially expand the range of information available for parameter estimation through the use of studies of micro-economic decision making, although often it is assumed that firms etc. are identical in some aspect such as costs but differ in their ability to price i.e. they are imperfect competitors.

An example of the bivariate type of heterogeneity familiar from older models and extensively used in 4G models was the widespread adoption of the Calvo pricing scheme in which there are two types of firms, one of which can optimally re-set their prices each period while the other needs to follow a simple rule-of-thumb. The key parameter in the aggregate constructed from this scheme is the fraction of firms who are able to optimally adjust their price at each point in time. This produces what has been called the New Keynesian Phillips curve. An appealing argument for building the curve up from a micro-unit level was that it allowed for monopolistic and monopson-

istic behaviour at that level rather than the competitive markets of the 3G models. Thus the rather awkward assumption used in QPM that there was a mark-up of prices over marginal costs in the short run, but that it went to zero in steady state (owing to the competitive markets assumption), can be dispelled with. It should be observed though that, although widespread, it is not always the case that the Calvo pricing structure is used in 4G models. Sometimes the approach used by Rotemberg (1982) is adopted. But the nature of the resulting Phillips curve is similar.

Secondly, the steady state used in 3G models saw real variables such as output, capital etc. as either a constant or following a deterministic growth path. This reflected the fact that labour augmenting technical change was taken as growing at a constant rate, basically following Solow and Swan. Although initially in 4G models technology was treated as stationary, many models now allow the log of technolgy to have a stochastic permanent component as well as a deterministic one e.g. The New Area Wide Model and COMPASS. Thus the "steady state" solution evolves stochastically over time.

6 Modelling After the GFC: Have There Been Any Changes?

In the aftermath of the GFC there has been a lot of criticism of 4G models (under the more general heading of DSGE models) e.g. Caballero (2010), de Grauwe (2010) and Pesaran and Smith (2011). Some of it involves a coherent critique of this class of models with a variety of suggestions being made about how these should be modified in response to the GFC. We describe some of these proposals and then ask how many have found their way into the models used in central banks and finance ministries. As we will see few have become incorporated into 4G models and this leads us to ask why that is the case?

6.1 Heterogeneity

As mentioned in connection with 4G models there has been an increasing interest in allowing for some heterogeneity in models. Within 4G models the type of heterogeneity allowed was limited to that which could be easily collapsed to a single representative measure. Agent Based Models (ABMs) provide another way of getting a tractable form of agent heterogeneity. Within

the finance literature ABMs are often bivariate with chartists and fundamentalists - chartists trade assets according to some rule of thumb while fundamentalists use fundamental values. This idea has been adopted in a bivariate form in macro models e.g. de Grauwe (2010) and Gelain *et al.* (2012) use it to allow expectations to vary across agents. The key feature is to describe the fraction of each type of agent. Sometimes the fraction depends upon the success of each rule and this means that the models become non-linear. In other cases the fraction is fixed - one type of household has a simple rule of thumb while the other uses model consistent expectations. This latter adaption has been a response to criticisms of DSGE models concerning the limited rationality of agents and can be broadly thought of as distinguishing between expectations and beliefs i.e. agents might believe that a particular model is correct and form expectations with it rather than with the true model. ABMs can have many more agents than two e.g. the EU-RACE model (Deissenberg *et al.*, 2008) has millions of agents, each of whom has a different rule, with the survival of rules depending on their profitability - see Fagiolo and Roventini (2012) for a review of this literature. It would be fair to say that the large scale versions of ABM have not exactly taken macro economics by storm, despite calls from those who see it as a way of introducing behavioural economics into macro. This may be because, as de Grauwe (2010) observes, behavioural economics has often been introduced into DSGE models simply by changing utility and profit functions and then performing optimization with these i.e. DSGE models have proven to have considerable flexibility in this regard.

6.2 Financial Factors

6.2.1 Credit, Collateral and Spreads

The GFC certainly re-ignited interest in looking at ways in which the financial sector can impact upon the real economy. One way of modifying the transmission mechanism was the strategy provided by Bernanke, Gertler and Gilchrist (1999; BGG) where there was asymmetric information about business prospects between lenders and borrowers. This led to the introduction of a second interest rate, the lending rate, with the spread between this and the borrowing rate (mostly set equal to the policy rate) being the external finance premium. As the external premium varies it has effects upon investment. Of course one could also set it up to apply to households as well, but

the asymmetry in information is probably not as marked.

A second approach grew out of Kiyotaki and Moore's (1997) emphasis on collateral. In practice collateral was always present in financial decisions but it was not analyzed much by macro modellers. In the past decade however we have seen many models that incorporate collateral effects, particularly through the housing market and housing prices. Classic papers are Iacoviello (2005) and Iacoviello and Neri (2010). Heterogeneity is introduced into these models through lenders and borrowers having different discount rates. The models feature a credit constraint rather than the extra interest rate in BGG, although there will be a shadow price attached to the constraint that might be considered as a finance premium. Only a certain amount of loans can be made to each sector and the amount depends on the price of the collateral assets. As the price varies so does the impact of the financial constraint.

The role of credit has been given increasing prominence. Borio (2012, p 1) argues that "...macroeconomics without the financial cycle is like Hamlet without the Prince" and says that "...the most parsimonious description of the financial cycle is in terms of credit and property prices ..." (p.2). This suggests that one should build models that incorporate both of these features. Both of the approaches discussed above have such variables in them, so one might view that as a potential response, although Borio would not seem to agree with this saying (p 1) that "...the prevailing, in fact exclusive, strategy is a conservative one. It is to graft additional so-called financial 'frictions" on otherwise fully well behaved equilibrium macroeconomic models". Instead he thinks that the correct response "...calls for booms that do not precede but generate subsequent busts, for the explicit treatment of disequilibrium debt and capital stock overhangs during the busts...This suggest moving away from model-consistent expectations, thereby allowing the endemic uncertainty and disagreement over the workings of the economy. It suggests incorporating perceptions of risk and attitudes towards risk that vary systematically over the cycle, interacting tightly with the waxing and waning of financing constraints" (p 23).

It seems that existing models incorporating the financial accelerator and collateral fail to generate the outcomes one would desire. Pagan and Robinson (2012) considered two aspects of this in relation to the Gilchrist *et al.* (2009) (GOZ) model that just featured a financial accelerator. First, they asked how the probability of recession at $t+1$ (given the economy was in an expansion at t) varied with the external finance premium, finding that it did not rise much even for very high values of the premium. This test involved

19

computing $\Pr(R_t = 1|s_{t-j})$, where $j \geq 0$ and R_t, s_t were generated from the GOZ model. To get R_t one needs an algorithm to locate turning points in the level of simulated GDP and the one selected was BBQ, described in Harding and Pagan (2002). One could compute this non-parametrically or by some parametric method. Given the binary nature of R_t it is attractive to use functions such as the Probit form i.e. $\Phi(\alpha + \beta s_t)$, where $\Phi(\cdot)$ is the cumulative standard normal distribution function. Of course there is nothing which guarantees that this is a good representation of the functional form for the probability, so it is always useful to check it against a non-parametric estimate. Because $\Pr(R_t = 1|s_t) = E(R_t|s_t)$ the conditional probability can be found by applying standard non-parametric methods to estimate a conditional expectation. The non-parametric estimator's limitations are that there may be few observations for extreme values of s_{t-j} and the estimated functional form may not be monotonic. For the GOZ model the probability of recessions did not rise much with the external finance premium and were relatively small even for extreme values of the premium.[3]

Following Harding (2008) it is worth noting that the R_t generated by BBQ (and this is also true for NBER recession indicators) follow a recursive process of the form

$$
\begin{aligned}
R_t &= 1 - (1 - R_{t-1})R_{t-2} - (1 - R_{t-1})(1 - R_{t-2})(1 - \wedge_{t-1}) \\
&\quad - R_{t-1}R_{t-2}\vee_{t-1},
\end{aligned}
\tag{2}
$$

where $\wedge_t$ is a binary variable taking the value unity if a peak occurs at t and zero otherwise, while $\vee_t$ indicates a trough. By definition $\wedge_t = (1 - R_t)R_{t+1}$ and $\vee_t = (1 - R_{t+1})R_t$. In BBQ,

$$
\begin{aligned}
\wedge_t &= 1(\{\Delta y_t > 0, \Delta_2 y_t > 0, \Delta y_{t+1} < 0, \Delta_2 y_{t+2} < 0\}) \\
\vee_t &= 1(\{\Delta y_t < 0, \Delta_2 y_t < 0, \Delta y_{t+1} > 0, \Delta_2 y_{t+2} > 0\}),
\end{aligned}
$$

where $\Delta_2 y_t = y_t - y_{t-2}$ will be six-monthly growth.

A second question they looked at was whether the duration of recessions depended upon the magnitude of the external finance premium. This was done by computing $\Pr(\vee_{t+m} = 1|\wedge_t = 1, s_{t-j})$, i.e. the probability that, conditional on the external finance premium, in m periods time the economy will be at a trough, given it was at a peak at time t. m is clearly the duration

---

[3]Lagged values of the premium were tried as well. The value was chosen to maximize the probability of a recession. It would be expected that some lag would be needed as time has to elapse before a high premium impacts upon output.

Table 1: **Probability of Recession for** m **Periods as External Premium Varies in GOZ Model**

External premium $\tilde{s}_t$ (basis points)	m = 2	m = 3	m = 4
24	0.30	0.18	0.14
305	0.36	0.21	0.17
481	0.40	0.23	0.18

of the recession. So, if a financial crisis produces long duration recessions we might expect to see the probabilities of getting longer recessions increase markedly with the level of the external finance premium. But this did not seem to be the case for either the Gilchrist *et al.* (2009) or the Iacoviello and Neri (2010) models. Table 1 shows the probability that a recession will last at least four or five quarters once it has begun for the GOZ model and there is no evidence that high premiums produce longer duration recessions.

One possibility is that stronger effects might come if there was a combination of a financial accelerator and collateral in models. Such a model is The New Area Wide Model, as augmented with finance variables by Lombardo and McAdam (2012). We repeat the tests of Pagan and Robinson (2012) mentioned above with data simulated from that model.[4] Figure 1 shows that the unconditional probability of a recession is quite small even with large values of the external finance premium (based on their Table 4 the value of 1.12 is around the highest value in the data) and, in fact, are numerically very similar to what was found for the GOZ model.[5]

So it is clear that, whilst it seems important to have these features built into any extensions of 4G models, they are unlikely to replicate the nature of the financial cycle. Some extensions of the models seem necessary and this will be discussed under the financial intermediary sub-section.

In many ways the features just discussed work through spreads between interest rates in the economy and this raises the issue of how to determine

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[4]We thank Giovanni Lombardo for providing us with the Dynare code to simulate this model.

[5]The Probit form is given as the NP estimates agreed except at the extremes where there were few observations but the NO estimates were not monotonic.
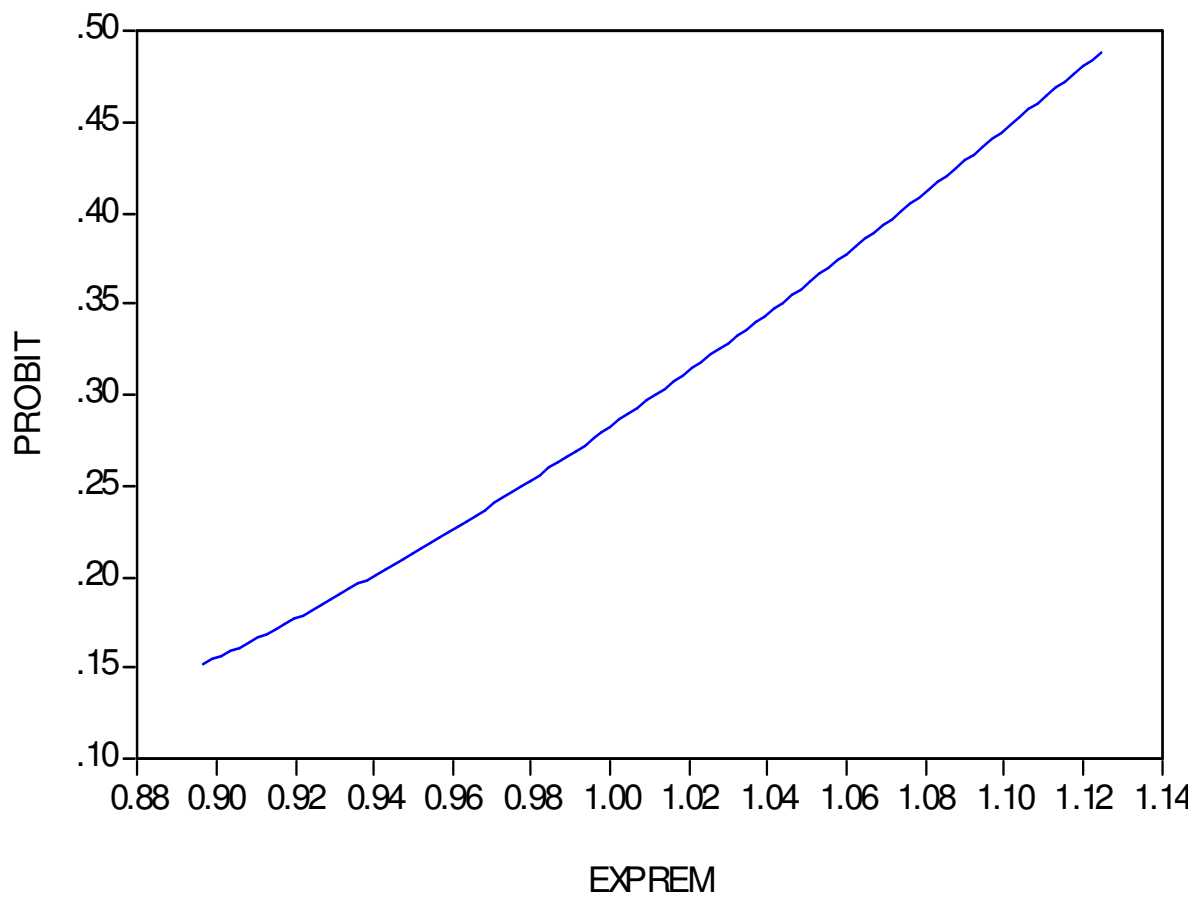
21

Figure 1: Probability of a Recession Given External Finance Premium

interest rates and thereby spreads. Of course the short rate is generally set by the central bank so it is longer term rates that need to be modelled. As we mentioned earlier one of the characteristics of some of the U.K. models of the 1980s was the use of flow of funds data to model the financial sector. The equations were essentially determining interest rates and the exchange rate. This was given up because many equations were involved so it made models larger and, since there were no more financial crises, the modification just made models complex and delivered little benefit. As a result models such as FRB-US replaced a model of the financial sector with a set of spreads. It would seem that the reason for this replacement was parsimony. Having a detailed model of the financial sector made models large and hard to handle, so assuming that all the portfolio aspects simply ended up as arbitrage between different rates seemed to be a useful simplification. In a model such as EDO there is variation in risk premia that determine the spreads between the interest rates of the model but these are purely exogenous. It should be noted that in small open economy work the spread between the domestic and foreign interest rate on bonds was made endogenous by having it depend upon the level of debt to GDP of the small economy. Without such a mechanism (or alternatives such as those set out in Schmitt-Grohe and Uribe (2003)) open economy 4G models would not have the stocks of foreign debt to GDP converging to a constant ratio, as there has to be some penalty on households borrowing overseas to finance consumption.

Of course the flow of funds may be used in a different way. Muellbauer and Duca (2012, p 3) say "Data from the financial flow of funds, previously relatively neglected, are now seen as crucial to the data monitoring carried out by central banks", so this suggests that they be used in other ways than for modelling spreads. Often models have the consumption decision depending upon aggregate wealth and total wealth and this is then allocated among assets by some portfolio approach. In Duca and Muellbauer changes in the components of wealth have different effects on the consumption income ratio and the effects vary with time and the degree to which households are credit constrained. The argument is that the latter has changed over time due to financial de-regulation and the development of arrangements such as equity withdrawal. They construct two indices measuring the ease of getting credit by a consumer (from the Fed's Senior Loan Officer Survey) and a Housing Liquidity Index (HLI) designed to capture the increasing liquidity of housing due to equity drawdown and financial conditions. These are then used to allow for shifting marginal effects by having them interact with regressors

in the consumption-income relation. This is an implementation of criticisms that Muellbauer (2010) makes of DSGE models i.e. that the consumption Euler equation in most models can be rejected using relatively simple tests and that models like Iacoviello (2005) imply behaviour for mortgage equity withdrawal that is inconsistent with the facts. He says (p 27), "To conclude, evidence-based macro research needs to replace faith-based models". DSGE models need to reflect summaries of the data. There is no point in providing an interpretation of events if they fail to match what has been observed.

6.2.2 Specific Financial Intermediaries

The flow of funds dealt with a wide range of financial intermediaries. Some models are now appearing that look at the interactions between financial intermediaries themselves as well as the traditional interactions with standard macro-economic agents in the household and business sectors. In their broadest manifestation the models have a retail banking sector that loans to business and to those purchasing a house while raising deposits from households[6]. There is also an investment banking sector that makes loans to business and to households for houses (they are the main agents for this in that they securitize but still hold the mortgages). Investment banks finance their loans from equity raised from households, as well as money raised from an inter-bank market, and have much higher leverage than the retail banks. Models like Gertler and Karadi (2011) and Pariès *et al.* (2011) have this structure. Impulse responses then depend on the degree of leverage and mostly the studies look at what would happen if the loans they make turn bad. This precipitates a "fire sale" of their assets and, as the asset prices decline, less loans are offered because the value of collateral is reduced.

Most of these studies aim to describe a transmission mechanism in response to an exogenous shock to loan values, house prices etc. They serve for that purpose but, because the variables being "shocked" are endogenous variables, one would need to explain where these shocks come from when looking at data e.g. a shock to a variable like consumption involves changing preferences. Such modifications do not only affect consumption but other endogenous variables as well. Indeed this is a necessary consequence when dealing with trying to "shock" an endogenous variable. To the best of our knowledge there is currently no study that assesses the ability of these mod-

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[6]In open economy versions funds may be sourced from overseas.

els to generate actual business cycles outcomes. To date they are more an example of what could happen rather than what did happen. Other studies e.g. Boissay *et al.* (2013) are interested in what the possibility of financial crises bring to the explanation of the business cycle. Again the emphasis is upon impulse responses rather than the business and financial cycles and there are issues about how one defines a crisis i.e. should it correspond with the empirical definitions often used rather than by some definition in terms of theoretical (unobserved) model variables as in Boissay *et al.*.

It is worth noting that a new class of models has emerged that is not a substitute for the existing 4G models but which seeks to augment them with a detailed specification of some financial intermediaries. We refer here to what are termed macro prudential models which seek to determine outcomes in the financial sector with a view to whether there is likely to be a violation of prudential standards by the financial institutions. Perhaps the best developed of these seems to be RAMSI - Alessandri *et al.* (2009). To date these prudential models simply take macroeconomic inputs such as equity prices, short and long interest rates and GDP, and then study how the financial system would respond to movements in them. In a model like RAMSI there are ten banks that interact with one another through an inter-bank market. If one of the banks looks like failing as a consequence of the macroeconomic shocks this leads to a sale of its assets and that can harm those within its network. With big enough shocks there can be widespread failures among financial institutions. This does not however currently feed back into a macro model - the macro risks in RAMSI just come from a VAR in a number of domestic and "world" economic variables. Some small models are now appearing in which risk measures such as system distance to default are driven by output from small macroeconometric models and these measures feed back into the macro model via the IS curve, the exchange rate and the interest rate rule e.g. Gray *et al.* (2011). To date these are not estimated but parameters are largely set to illustrate the effects of such feedback.

6.2.3 Zero Bounds to Interest Rates

A zero bound to interest rates attracted a lot of attention after the experiences in Japan in the 1990s, based both on the macroeconomic consequences and on how monetary policy was to deal with it. Of course this is an old topic that was a key theme in Keynes' work under the heading of a liquidity trap. Recently, the financial crisis has led to a renewed interest in it, see

e.g. Williams (2010). With a few exceptions, notably the JEM models of the Japanese Economy (Fujiwara *et al.* 2005; Fukanaga *et al.* 2011), zero bounds to interest rates do not seem to have been incorporated into the main central bank macroeconometric models yet [7]. In Q-JEM the zero bound is implemented through a modified Taylor rule

$$i_t = \max\{\theta i_{t-1} + (1 - \theta)[\bar{\imath}_t + 0.5 y_t + 1.5(\pi_t - \bar{\pi}_t], 0\},$$

where i_t is the policy interest rate and $\bar{\imath}_t$ is its "equilibrium" value. Thus there is now a non-linear rule although the parameter values showing the reactions to the GDP gap y_t and the inflation gap π_t are set to the original values of Taylor (1993).

Chung *et al.* (2012) investigate the likelihood and severity of the zero lower bound for the United States using three structural models, FRB/US, EDO and Smets and Wouters (2007) as well as three statistical models. They note that imposing the nonlinear zero lower bound constraint on the structural models does not lead to major problems. However, they conclude that the zero lower bound has been an important constraint on monetary policy in the past few years, partly because empirical models were based on the Great Moderation period. Time-varying parameters, measurement error, and parameter uncertainty can raise the estimated probability of hitting the zero lower bound. Hitting the zero bound is likely to be a relatively rare event but there are others like this e.g. shocks may come from way out in the tail of events and so one may need to pay attention to how one is to measure such events.

6.3 New Shocks

4G models had a standard set of shocks that could be broadly classified as technology, preferences, risk, mark-ups and policy. There might be more than one shock in these general categories. Thus there could be mark-up shocks for both wages and prices as well as foreign and domestic technology shocks. In the event that there are sectors in the models one might have different technology shocks for each sector. The sectors that have attracted most attention have been housing and finance. After the GFC a number of extra shocks have been suggested that can be broadly classified as financial shocks.

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[7]The lower bound is mentioned in the New AWM model with financial frictions (Lombardo and McAdam 2012), but it is not clear whether it is actually modelled.

These are Net Worth, credit supply and the loan to value ratio. The first two have arisen from the financial accelerator perspective in Bernanke *et al.* (1999) e.g. see Gilchrist *et al.* (2009), while the last involves collateral for loans, following Iacoviello (2005) and Iacoviello and Neri(2010). Typically many shocks are involved in 4G models e.g. there are 18 shocks in the NAWM, 11 in EDO and 18 in COMPASS.

Although not specifically connected with the GFC the academic literature has spent some time on "news" shocks - Christiano *et al.* (1999), Beaudry and Portier (2006), Fujiwara *et al.* (2011). These have not yet appeared in any policy model. One problem may come from the way in which they have appeared in the literature. In most of this work one sees a shock such as technology a_t having a structure such as

$$a_t - v_{t-N} = \rho(a_{t-1} - v_{t-N}) + \varepsilon_{at} \tag{3}$$

where v_t is a news shock that conveys information about technology at $t + N$, while ε_{at} is the fundamentals shock to technology. The exercises often performed e.g. Beaudry *et al.* (2011) involve setting the shocks v_t to be a deterministic sequence. So at time $t = 1$ information arrives that will change the value of a_5 if $N = 4$. Because models are forward looking this changes consumption, investment etc. Thus there can be a boom in investment. If the news turns out to be false i.e. a_5 is not equal to what had been expected based on the news, it will mean that there is an excess of capital, and this will signal cuts to investment, creating a recession. So it is news that generates both the boom and the bust.

To apply this model to the data one needs to treat news as a random variable. When v_t is stochastic for news shocks to have an impact upon the business cycle they need to affect the DGP of Δy_t, in particular on the magnitudes of the mean, variance and (to a much lesser extent) autocorrelation. In order to assess the potential for this it is worth looking at a model of Ireland (2004). Without news and using the parameter values in Ireland the average duration of recessions and expansions are 4.0 and 11.8 quarters respectively (these are shorter than the standard one because of Ireland's use of per capita output). News is then introduced as in (4) i.e. as a second component to technology growth.

$$z_t = \varepsilon_t^z + v_{t-4}, \tag{4}$$

where we have set $N = 4$. One has to choose the relative variances for ε_t^z and v_t. It seems important to do this without changing the variance of z_t.

We simply make them equal and so $\sigma_{\varepsilon_t^z} = \sigma_v = \frac{\sigma_z}{\sqrt{2}}$. This means we are looking for a pure news effect and not one that comes simply from a more volatile technology growth. Simulating Ireland's with news described in this way produces recessions and expansions of average duration of 4.1 and 11.4 quarters respectively, so that news has little impact on the business cycle. We simulated 20000 observations to ensure that these could be regarded as close to population characteristics.

An alternative type of shock that might be introduced is that of sentiment or "animal spirits". It will be taken to influence expectations. To deal with this we note, following Binder and Pesaran (1995), that the solution to DSGE models is of the form

$$y_t = Py_{t-1} + GE_t \sum_{j=0}^{\infty} \Phi^j u_{t+j},$$

where u_t are the structural shocks to the model. We will denote the expectations of future shocks without news as $\tilde{E}_t(u_{t+j})$. Hence for a scalar shock u_t that follows an AR(1) with innovation ε_t and parameter ρ, $\tilde{E}_t(u_{t+j}) = \rho^j u_t$ and we would have a solution

$$y_t = Py_{t-1} + G\frac{1}{1 - \Phi\rho}u_t,$$

whereupon

$$
\begin{aligned}
\tilde{E}_t(y_{t+1}) &= Py_t + G\frac{\rho}{1 - \Phi\rho}u_t \\
&= P^2 y_{t-1} + (PG\frac{1}{1 - \Phi\rho} + G\frac{\rho}{1 - \Phi\rho})u_t
\end{aligned}
$$

For Ireland's model and his parameters we have

$$
\begin{aligned}
\tilde{E}_t(\pi_{t+1}) &= .1158y_{t-1} - .4565r_{t-1} + .01a_{t-1} - 2.0646e_{t-1} - .4565\varepsilon_{rt} \quad (5) \\
&\quad + .0105\varepsilon_{at} - 2.145\varepsilon_{et} - .1158\varepsilon_{zt} \\
\tilde{E}_t(x_{t+1}) &= .3696y_{t-1} - 1.4574r_{t-1} + .0422a_{t-1} + 4.2123e_{t-1} \quad (6) \\
&\quad - 1.4574\varepsilon_{rt} + .0445\varepsilon_{at} + 4.2837\varepsilon_e - .3696\varepsilon_z
\end{aligned}
$$

In general we can recover G by solving the model under the assumption that $\rho = 0$ as that affects only the dynamics. But since there is no serial

correlation in technology growth shocks in Ireland's model G has the values attached to ε_{zt} above.

Now we need to allow sentiment to affect expectations i.e. $E_t(y_{t+1})$ is the expectation conditioned on sentiment as well as the past history of model variables and so it will vary with the sentiment shock. We suppose that sentiment affects expectations of future u_t with an N period lag, so as to retain comparability with the example above. One might want v_{t-N} to influence the expectations of all future shocks but dying away with some value ϕ^k, where $\phi < 1$, but here we take the simplest case where it just has an effect on u_{t+1}. Then, when u_t is an AR(1), $E_t(u_{t+1}) = \rho u_t + v_{t-N+1}$, and the solution for y_t will be

$$y_t = Py_{t-1} + G\frac{1}{1 - \Phi\rho}u_t + Gv_{t-N+1}.$$

From this it is apparent that the variance of y_t is affected by sentiment while the variances of the fundamental shocks remain unchanged.

Applied to Ireland's model this way of introducing sentiment means that we add on $-.1158v_{t-3}$ and $-.3696v_{t-3}$ to (5) and (6) respectively. To assess the impact of sentiment on the cycle we return to Ireland's model and set σ_v to the value used in first experiment with news above. Then the durations of recessions and expansions are 4.0 and 12.1 quarters respectively. So introducing sentiment can have a larger impact on expansion durations than for news. Moreover, we can vary σ_v more in the sentiment case without changing the volatility of technology growth. So if we make σ_v five times higher we find that expansion durations are now just 9 quarters. There is an upper bound to how much we can change σ_v however, in that one needs to produce a volatility of GDP growth that is in line with the data. It is very hard to make σ_v large in Ireland's model because GDP growth is virtually the same as technology growth. Looking at other models where there is a bigger discrepancy would be helpful. It should be noted that attempts have been made to define the animal spirits invoked by Keynes either through indeterminacies or via ambiguity - see Ilut and Schneider (2012).

6.4   Is there a Fifth Generation of Models?

We ended section 5 with many central banks using 4G models so a natural question to ask is what their response to the GFC has been in terms of producing a new generation of models. It should be said up-front that there

is little evidence that central banks have given up their 4G model structures, despite all the criticism of them. Analysis of trends around the worlds suggest that any new models are DSGE oriented. Examples are the COMPASS framework at the Bank of England, Burgess *et al.* (2013), the NZSIM model at the Reserve Bank of New Zealand (2013) and the new Dutch Central Bank model, Lafourcade and de Wind (2012). Some models seem to have been adapted to include financial factors e.g. ToTEM and the JEM model - details are sketchy on ToTEM but (Fukunaga *et al.* (2011)) describe the JEM adjustments. Perhaps there have been internal adjustments but certainly nothing has appeared to suggest major changes to the existing models. What has often appeared have been various experiments with simplified versions of the models e.g. in Gerke *et al.* (2013) a comparison of five models is provided by people from five central banks, but these all seem to be simpler versions of the bigger models. It may be that there has been a reluctance to expand existing models to capture financial effects for the same reason that the addition of flow of funds equations to 2G models fell out of favour viz. the extra complexity of the model made it hard to interpret and understand. For this reason it seems important that one look at alternative ways of introducing effects into a core model without expanding it too much. Sometimes this can be done relatively easily. So in COMPASS a spread can be introduced between the policy rate and the rate households use in deciding on savings and then this "credit spread" can be measured using data.

The new models have the feature that they are a good deal smaller than their predecessors. This has meant that the suite of models which accompany the core model have grown, and the former are now often quite sophisticated economic models rather than the more statistical BVARs, SVARs etc that used to constitute the suite. In the case of the Bank of England this process of using other models in the suite to analyze outcomes that are not readily interpretable with the core model has been formalized. Examples are given in Burgess *et al.* (2013) of how this is done. So to introduce the financial effects that came with the Great Recession the simulation outcomes from a model with a formal banking sector - Gertler and Karadi (2011) - are imposed on the core model. This is done by finding what values of shocks would be needed in the core model to give these outcomes. Ken and the MMB would recognize this as a Type 2 fix used with 2G models, except now it is done via shocks rather than add-factors, and the target path for some endogenous variables come from another model rather than from judgement. As Burgess *et al.* emphasize which shocks in the core model should be used to make the

30

latter track the suite model outcomes is a decision that requires a good deal of thought and familiarity with both the core and suite model. So shocks have become the vehicle to enable one to jointly work with a general model and a model that is constructed to answer some specific question.

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