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Australian Macro-Econometric Models and Their Construction - A Short History

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The paper provides a short account of the major complete macroeconometric models that have been constructed in Australia. Initially these were by academics but later both the Treasury and Reserve Bank of Australia developed these for policy analysis and forecasting, so that the history focusses a good deal on what was developed in those institutions. The basic strategy of the paper is to set out the modelling themes that were occurring overseas and then to discuss the same variants in Australia. In a number of instances Australian research might be considered to have been well ahead of overseas developments.

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Australian Macro-Econometric Models and Their Construction - A Short History*

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Abstract

The paper provides a short account of the major complete macro-econometric models that have been constructed in Australia. Initially these were by academics but later both the Treasury and Reserve Bank of Australia developed these for policy analysis and forecasting, so that the history focusses a good deal on what was developed in those institutions. The basic strategy of the paper is to set out the modelling themes that were occurring overseas and then to discuss the same variants in Australia. In a number of instances Australian research might be considered to have been well ahead of overseas developments.

1 Introduction

Macro-econometric 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. Fukacs and Pagan (2010) and Hall et al (2013) argue that there have been four major generations of models in the past 80 years and the structure set out in those papers is used in this one. A difference is that, after setting the scene with overseas work, we move on to what the Australian models were that either reflected or anticipated those developments.

There are some constraints in this survey. First, it will largely be about aggregate macro-economic outcomes. Quite a few models have been built in Australia that basically take the aggregates and then distribute them across industries and households to determine the responses to issues such as tariff changes. For a long time these aggregates were taken as fixed and hence they were just models in real variables and relative prices. This has now changed, but covering that aspect in a satisfactory way would require another survey. Secondly, we look at models for a single small open economy. There is a parallel literature for multi-country models, but the design issues are rarely much different. The questions users wish to address though are often quite different. Thirdly, in the Australian discussion we focus largely upon the models built in the two major policy institutions - the Reserve Bank of Australia and the Treasury. Finally, we will have little to say about estimation issues, except when they dictated the way a literature developed.

The first generation of models began with Tinbergen (1936), approximately 80 years ago. Second generation models were largely being used during the 1970s and 1980s. The final two generations span the 1990s until now. Lately, there seems to have been a retreat back to earlier generations of models and no obvious fifth generation of model has yet emerged. It needs to be said that a previous generation of models often coexists for a long time with the new generation, just as Homo Sapiens and Neanderthal Man overlapped. This is partly 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. 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 sometimes get modified based on what is happening in domestic economies or in the international environment.

We need to begin with some concepts relating to model size. The distinction between exogenous and endogenous variables is an old one. Often in macro models there are many identities. Each one effectively describes how an endogenous variable relates to other endogenous variables (and perhaps exogenous ones). We can eliminate identities and then the system will be composed of what we will call the *core endogenous variables*. These then require some behavioural or structural equations to be specified in order to describe their evolution. Models are then often summarized in terms of the number of core variables, the total number of endogenous variables, and the total number of exogenous and endogenous variables. There has been an increasing trend to treat all variables as endogenous i.e. a simple model is prescribed for the exogenous variables allowing them to be viewed as being determined *within the system* rather than outside it. This is simply a matter of expanding the definition of the system. Often this is no more than that the exogenous variable can be explained by its own past. So we will refer to the size of models in terms of the number of core variables.

2 In the Beginning: The First Generation (1G) Models

2.1 Overseas

Empirical system-based macro modelling began in The Netherlands 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. 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. Tinbergen's comment in his 1939 book was that in order to answer many questions one needed to devise a system, describing it in these terms: "Such a system of as many relations as there are variables to be explained may be called a *complete system*" (his italics). It was comprised of what he termed the *elementary equations*; what we would call today structural equations and identities. His first work was a model of 24 core variables 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, when responding to a question in Magnus and Morgan (1987, p 124), seems to suggest that this was the basis of his methodology when he says "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".

Tinbergen also recognized the need for the elementary equations to allow for expectations and for non-instantaneous adjustments. In relation to the first, expectations of profits entered into the determination of investment and were 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. 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. Tinbergen's work had not reflected this. 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". The national accounts provided a structure for macro modelling. It led to a distinction between business, households and government expenditures and the foreign or external sector, and made 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 a highly aggregated way, distinguishing a demand for and a supply of money, with demand depending on expenditures and interest rates. Dynamics were handled in two ways. First, there was a Partial Adjustment Mechanism (PAM) where (say) a variable in log terms y_t adjusted to some target value y_t^* as $\Delta y_t = \gamma(y_t^* - y_{t-1})$. Second, a finite distributed lag $y_t = \sum_{j=0}^{p} \beta_j(\theta) y_{t-j}^*$ might be used, where p was small and β_j

might depend on a smaller number of parameters (θ). Much later the latter was the type of set-up in Almon (1965) where θ lay on a polynomial of much lower order than p.

Because the national accounts were in nominal terms and many structural relations were in real terms it was necessary to have equations for quantities such as prices. There was a well established literature that had nominal prices as mark-ups over average variable costs, and generally the latter was taken to be wages. This mark-up might vary over time and Tinbergen related it to the *level* of employment, which Dhaene and Barten pointed out could be an issue. Again it was expected that there would be a target price based on marginal costs but adjustment would take time. Policy in these models was largely focussed on government expenditure and the money supply, both of which were treated as exogenous. If the income side of the national accounts identity was also allowed for then taxes needed to be introduced, and these were taken to be exogenous as well.

There was a varied reaction to 1G models. Keynes pointed out that Tinbergen's use of regression to estimate parameters was doubtful as variables were simultaneously determined. This led to a huge econometric literature on how to do valid estimation in the presence of regressors that were endogenous rather than exogenous.[1] Some of it actually argued that what Tinbergen was doing might be valid. Perhaps the greatest exponent of this viewpoint was Herman Wold (1949), (1951) who argued that macroeconomic systems might be thought of as recursive i.e. one variable such as income was determined before another such as consumption. This was similar to the Scandinavian explanation of Keynesian work as involving sequences of decisions. It is probably fair to say that, when data was on a yearly basis, Wold was ignored. Two other groups probably generated more attention for the purpose of actual modelling than those who focussed on the estimation problems of simultaneous systems. One of these felt that there was not enough theoretical structure in these models. Others thought that the models were too tightly structured, especially in terms of dynamics. They felt that dynamic interactions were more complex than were being allowed for. This led to work on how to produce flexible dynamic interrelations, as we have mentioned above when discussing Tinbergen.

[1] These terms were used by Koopmans (1950) and this may have been their earliest use.

2.2 Australia

Perhaps the key theme in the development of 1G models overseas was that of data compatibility i.e. of finding a model that was a reasonable description or summary of the data. In Australia the earliest example of a 1G model is Swan (1989). It was in an early version in 1943 and the final version was done in 1945, but it did not appear until 1989. It was designed to translate Keynes' General Theory into a complete model for policy use, specifically to look at the formulation of demand management in the war years and in post-war reconstruction. It was far ahead of its time. The first model of this type for the US was that of Klein and Goldberger (1955). Swan emphasized a system, taking an aggregate demand/aggregate supply perspective. It began with the familiar GDP identity $Y = C + I + X - M$, where Y was aggregate demand (income in Swan's terms), C was consumption, I was private investment, X was exports plus government expenditure (autonomous expenditure) and M was imports. Simple equations were provided for C, I and M. In particular these depended on lagged quantities. It was assumed that the period of time for decisions was a *quarter*. Variables were classified as dependent and independent rather than endogenous and exogenous/predetermined. In fact Swan had some difficulty with the predetermined lagged values. The national income identity was used to determine aggregate demand. Aggregate supply came from a production function involving output Y and the level of employment, while business maximized profits so that prices were a mark up on marginal cost. Expectations were present through the assumption that business aimed to choose an output level based on their expectations of demand next period, and these equalled demand last period. Such an assumption meant that, after any exogenous move in demand, there would be a dynamic adjustment to a new equilibrium position. The mechanism that drove the system from one equilibrium position to another was implicitly inventory adjustments, a common story in Keynes' analysis.

Interest rates are not present since the argument is made that investment is not very sensitive to them and depends more on the lagged level of income, which aims to capture expectations. Variables are essentially measured in real terms by using wage units, as in the General Theory. Wages are therefore treated as fixed, which accorded well with the institutional arrangement of the time, with the Arbitration Commission effectively setting wages although, as time wore on, earnings tended to drift away from the award wages. The capital stock is fixed, and there is a specific production function that exhibits decreasing returns. Marginal cost is found from this production function. Employers maximize profits in each period i.e. there was static optimization.

So the theoretical structure of the model is very impressive and far ahead of its time. It reminds us that, on the supply side, Keynes was very neo-classical. Swan's model had 6 core endogenous variables (10 endogenous variables in total) and two exogenous ones (X and the landed price of imports). Because both the consumption function and the production function involved non-linearities, this meant that the short run equilibrium was found from the intersection of non-linear aggregate demand and supply curves. Butlin and Gregory (1989) point out that Swan felt that his diagrams were the first applied implementation of the famous 45 degree Keynesian cross, although he took it further, since the 45 degree line only implied a linear supply curve.

The model is remarkable not only for how it is constructed but also for its use in examining historical events such as the Arbitration Court's cutting of the Basic Wage in 1931. What looks odd is that, although the data available was yearly, Swan took the period of time for decisions to be three months, making it essentially a quarterly model. Parameters were assigned to the functional forms but there is no discussion of where they came from. He was largely immune from Keynes' criticism of Tinbergen because his relations involved lags. Swan did mention that he had quarterly income data (Y) and his Figure 3 does plot quarterly data for all series. Looking at the graphs it seems that he may have linearly interpolated items such as consumption and investment from the yearly data. His consumption function was $C_t = 1.56Y_{t-1} - .0006Y_{t-1}^2 - 164$. Doing a crude linear interpolation to get the quarterly data we then ran a regression to get $C_t = 2.06Y_{t-1} - .0009Y_{t-1}^2 - 330$, so the relation resembles his. There are many reasons why they might differ. One is the starting values that were used for the interpolation. Another would be his use of a quarterly income series that we don't have. It should be said that there was substantial serial correlation in the residuals, which was a factor in many 1G models and which led to much research aiming to produce more flexible dynamics. The only other interpretation might be that he varied the parameters until he found a good fit i.e. he used a "calibration" strategy. He does show plots of the "calculated" values.

Because the Swan model was not well known the first Australian 1G models that came to attention were Nevile (1962) and Kmenta (1966). It is useful to look at these models through Tinbergen's approach of filling in the equations. Hence we will start with the GNP (or GDP) identity. Nevile had

9 endogenous variables and five exogenous ones. The exogenous ones were sales tax on cars, the balance of trade, government expenditure, farm income and the change in farm stocks (FS). Basically he set out equations for the variables in the GNP identity

$$Y = I + \Delta FS + \Delta NFS + C + G + B + FE,$$

where B is the balance of trade, NFS is non-farm stocks and FE is expenditure by financial enterprises. Then extra equations might need to be added to provide an explanation for these variables. Swan had recognized the need to look at stocks and non farm quantities but he didn't have such data. The biggest issue with Nevile's model was that, when solved, GNP was an explosive process. Because the model did not allow for growth we would expect this, but it was far more explosive with continually increasing growth rates.

Kementa built a model with 19 endogenous variables and 10 exogenous ones. The key is the GNP identity $Y = I+\Delta NFS+\Delta FS+C+FE+G+(X-M-R)$. Here investment was split into housing and non-housing components, and C into consumption on motor vehicles and non-motor vehicles (as was done by Nevile) The emphasis on dwelling investment was partly because he was interested in the impact of migration, and so housing was closely connected to that. In the identity the trade term is exports (X) less imports (M) and government expenditures on foreign items such as defence (R). Consumption depended on disposable income while investment in dwellings depended on a housing shortage variable that was a function of the level of migration Thus he disaggregated investment and also the components of imports and exports, and did not treat FE as exogenous. There is no production function that is recognizable although employment is linearly related to GDP.

Except for Swan all the models above were annual. Towards the end of this period both the Reserve Bank and The Treasury began to construct models based on quarterly data. In the case of the Treasury this was primarily for forecasting purposes, while the RBA's work was more focussed on their use for policy analysis. Higgins in Treasury (1984, p 281) contains a memoir of this, mentioning his presentation in 1970 to the ACT Branch of the Economic Society of what became known as the NIF1 model (NIF for National Income Forecasting), as well as mentioning a paper by Norton from the RBA. The latter had presented a version of the RBA model at the 1969

ANZAAS conference and is termed RBA1 in Norton and Henderson (1973). The NIF model underwent some changes and NIF2 came out in Higgins and Fitzgerald (1973).

There is no stock of capital in Swan or Tinbergen and factor productivity is either fixed or perhaps allowed to follow a time trend, as that variable is in some equations. So a completely formulated supply side is lacking. Because interest rates did not appear to have an important impact on variables such as investment 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 in Tinbergen (1951), had a range of interest rates and financial assets.

Prices were determined in Kmenta's model using the general approach of the time. As Kmenta says " According to the modern theory of inflation, prices can be subjected to the pressure of cost-push or demand-pull, or both. The cost-push element has its main basis in the cost of labour. Its operation is likely to be particularly important in Australia, where minimum wage rates are determined periodically by the arbitration system. Any changes in the basic wage automatically and immediately result in a general wage adjustment..." (p 139). Thus he had wages responding to minimum wages and labour productivity. All of these factors meant that there were some rigidities in prices so that a classical solution in which prices cleared immediately and output was always at its "natural rate" no longer applied. Consequently, Keynesian policies of demand expansion could be effective. This idea of rigidities was to lead to what was later called the New Keynesian approach. In the longer term monetary and fiscal policies could not affect the level of output but in the short run they could.

3 Moving On: The Second Generation (2G) Models

3.1 Overseas

These began to emerge in the early 1970s and stayed around for ten to twenty five 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. These models retained much of the structure of the previous generation of models in that demand was captured by disaggregated 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 static optimization problems solved by agents—in particular the consumption decision and the choice of factors of production were often described in this way. This involved the introduction of a production function in order to place a constraint on aggregate supply, particularly over longer horizons, and with factor demands then being found through optimization. This meant that there was a more complete approach to the determination of capital and labour and it meant that the elementary equations were now sometimes inter-related. 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)), the MPS model (Brayton and Mauskopf (1985)) and FRB-US (Brayton and Tinsley (1996)). The Modigianli-Brumberg (1954) formulation of the life cycle consumption function as set out in Ando and Modigliani (1964) had consumption depending on labour income and past wealth, and it became very popular. Wealth was often not available as data and so it was replaced by some measure of permanent income. Essentially these modifications gave target values for variables so that PAMs could be applied to describe the adjustments between the targets and where one was today. As we will see perhaps the key element in 2G model development was the urge for consistency in a model. This came up in many ways - expectations, budget constraints and the need to integrate stocks and flows.

Once there was an explicit supply side then one naturally thought of a process to determine the change in prices i.e. inflation, and this was made a function of the gap between demand and supply - if the former exceeds the latter prices would rise and the converse. This suggested that one needed to measure that gap and use it to determine inflation in wages. Phillips (1958) seemed to provide one formulation of such a relationship by relating wage inflation to the level of unemployment i.e. to excess demand in the labour market. Prices could then be marked up over unit labour costs. That mark-up could also be dependent on excess product demand. In many of the simpler US models this just became inflation in prices depending on the unemployment rate. Certainly the Phillips curve became a standard feature of macro models. It gradually changed from this form in order to incorporate expectations about inflation and the idea that the level of unemployment in itself was not a good measure of excess demand for labour.[2] Some unemployment would always be with us, so a better measure would be a deviation of the rate of unemployment from some quantity called the natural rate of unemployment or the NAIRU that was not a constant, and that became the standard equation adopted in 2G models. If one thought of expected inflation as past inflation then one could interpret unemployment rates above the NAIRU as implying accelerating inflation, and that was how the latter quantity got its name. The NAIRU was a key concept in 2G models. Often the value was prescribed.

The elemental equations were also modified. With the introduction of more optimization adjustments to a desired level of a variable, the latter were defined by what was often called "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). ECMs are just generalizations of a PAM but provide a clear distinction between short run and long run outcomes. 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. It is also noticeable that often now variables were expressed in logs rather than levels and the ECM had the form $\Delta y_t = \gamma\Delta y_t^* + \alpha(y_{t-1} - y_{t-1}^*)$, where y_t was the log of the levels variable. This was partly to recognize that a use of levels would mean that coefficients were likely to change, and that the variance of the equation errors wouldn't be constant. Log transforms helped in this. Basically, dynamics were introduced on an equation by equation basis. Sometimes the desired levels of variables could be related e.g. factor level choices could come from static profit maximization.

Another source of concern related to expectations of future variables in the elemental equations. Increasingly it was felt that these should agree with what the model was predicting about them. By the end of the era of 2G models, it was widely accepted that model consistent expectations should hold for future financial variables such as interest rates. But, when deter-

[2] Phillips was aware of the need to incorporate expectations of price inflation but decided that this was best measured in the UK by the inflation rate of food products, which were largely imported. He didn't find that to be generally important, but did note some cases when it seemed that there was a breakdown of the curve e.g. during the Korean War boom. Because of this omission the equation was read as a description of nominal rather than real wage inflation.

mining real quantities, expectations were still mainly formulated in simple ways. One reason was concern over whether it was plausible that the expectations of agents would in fact be formed with the complete set of variables in any model. A secondary one involved the weights on the variables making up the expectation implied by the model. The problem was that the model may not be an accurate reflection of the economy and therefore could be also omitting information that agents actually use. Consequently, it might be more appropriate to use much more limited types of information.

In relation to this, one reason for not insisting on model consistent expectations related to 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 the main model used for monetary policy settings in the US - the FRB-US model - expectations of future real variables were mostly made consistent with a small VAR that included output, inflation and an interest rate, supplemented with variables that were thought important to the variable which expectations were being formed about.

Perhaps the most interesting development in the UK models, such as that of the LBS (Budd(1984)), was the provision of a complete set of equations for the financial system which used the newly developed flow of funds accounts. 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 (say) 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 loose; 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 omitted dynamics. If one followed the Brainard and Tobin route then one was essentially specifying demand and supply curves for the financial quantities in order to find the interest rates that cleared markets. This meant that there were quite a few interest rates present in the second version of the LBS model.

As seen above the expansion of the model and the introduction of many dynamic relationships meant that 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". 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 they would converge to a steady state (or an equilibrium deterministic path). 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.

Like the previous generation of models there was considerable diversity within this class and it grew larger over time. 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. Often this diversity was the result of a slow absorption into practical models of new features that were becoming important in academic research.

3.2 Australia

In the Australian context 2G models were relatively slow to arrive, although many of the 1G versions did add some supply side modelling and expectations (not model consistent). Thus the NIF class continued in a sequence to NIF10 in 1981, growing all the time in size. In NIF2 there were 26 core endogenous variables, 46 in NIF-6 and 80 in NIF-10. The growth from NIF2 until NIF6 basically reflected a more detailed wage, price and incomes structure, the latter being to capture fiscal issues more accurately. That between NIF6 and NIF10 was largely due to the introduction of a more detailed modelling of the financial system. This development probably stemmed from the financial crisis of 1974 and led to attention being paid to how one might profitably use the flow of funds data. So the Treasury modellers produced 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. On the supply side NIF2 incorporated a production function but it is not entirely clear what it did. Labour productivity seems to have adjusted to satisfy the level of product demand. It also seemed to evolve with a deterministic trend. So in many ways one can see that there is a residual stochastic endogenous element in labour productivity.

A key variable in many of the versions of NIF was GUT, which was the ratio of GNP at market prices to potential GNP. This was the "excess demand" measure. It was found by defining potential GNP as linking the peaks of GNP. In many ways it was not too far away from what one would get from just fitting a time trend to the log of GDP. Naturally questions arose as to whether the dynamic structure was such that one could get convergence back to an equilibrium once a policy changed. Dynamic specifications were basically of the single equation variety. In NIF2 Fitzgerald reported that investment needed to be made exogenous for sensible results, and a special version of NIF10 was developed for simulation work. So this matches what Gramlich had said about MPS. Because 1G modellers had developed software that enabled one to simulate large models, 2G modellers in Australia followed the maxim of Chris Higgins that, to be assured of good system performance, modellers should "simulate early and simulate often", so as to assess the systems properties. For that, computer power and good software were needed. It does not seem as if the long-run properties of the NIF models were not entirely reasonable e.g. Simes and Horn (1988) note that money-financed fiscal policy could permanently raise the level of output in NIF10

The last of the NIF models was NIF-88 - Simes and Horn(1988). This dropped almost all the financial equations that emphasized bank portfolio behaviour, replacing them by arbitrage relations between the yields appearing in the model. 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 allowing the risk premium to be a function of excess demand. NIF-88 also attempted to correct some of the flaws in NIF10, in particular those that "..tended to manifest themselves in dubious systems properties of the model". In particular potential GDP (y_y^p) was now defined as a finite moving average of actual GDP (y_t) i.e. $y_t^p = \sum_{j=1}^{K} \omega_j y_{t-j}$ Hence the variable GUT would be related to an average of growth rates in y_t. Because of this GUT could no longer rise permanently. There were other modifications as well - private wealth now appears in NIF-88 so as to influence consumption and to account for the impact of budget deficits upon the current account. Moreover, the supply of commodity exports is given a separate treatment, reflecting the fact that these were mainly related to capacity constraints in the economy, and so were very price inelastic. Nevertheless in many ways the structure of NIF-88 was still that of NIF10.

The Reserve Bank went through a similar evolution. The first of their models RBA1 - Norton and Henderson (1973), (1975) was built very much like Tinbergen and the NIF2 Model. It was much larger than the latter with 46 core variables and it had an extensive fiscal sector. It had a capacity utilization measure much like GUT except that the peak to peak GDP approach to finding potential output was replaced by a time trend and a factor that involved the "full employment level of unemployment" Expectations were also measured using survey data and these were then also modelled as a structural relation. There was a small financial sector that involved advances and deposits.

Helliwell and Norton (1971) put out a paper entitled "Prospectus for RBA2" but the model does not seem to have been developed. Instead, Jonson et al. (1976) presented a "Minimal Model" that became the RBA76 model. RBA76 was a departure from what had been done previously and, as we will see later, in some ways it was well before its time. The idea was to build a macroeconomic model that had its roots in a neo-classical growth model. One might hope that this would solve the stability problems that Gramlich had noted. It basically specified that the macro variables would respond in a PAM form to some equilibrium relations there were motivated by the underlying growth model. These equilibrium positions were not directly derived from a model but were more along the lines that consumption would grow at the same rate as disposable income in the longer term, and would also depend on a real interest rate. An important feature of the model was that it was linear in the logs of variables. All the previous Australian models had relationships involving the levels of variables. There was also a strong emphasis on monetary effects, as befitted the 1970s emphasis on monetary targeting, so that many of the structural equations incorporated deviations of money balances from equilibrium ones. There were 18 core variables so it represented a much smaller model. Unlike the NIF models there was no disaggregation of consumption and investment.

Jonson et al. (1977) start their report with the comment that "The current model also pays more attention than most macro-econometric models to steady state consistency and to stability conditions; this may give it a comparative advantage for medium and long term analysis" (p 10). There did not seem to be any specific production function in it but often the marginal products of factors that appeared in equations of the model seemed to come from a Cobb-Douglas format. There were two other very different features to previous work. Firstly, it was assumed that the PAMs were in continuous time, which meant that in discrete time the model had error terms that were MA(1)s Secondly, estimation was done by FIML and not least squares, as mostly employed by the NIF modellers i.e. the complete system was now estimated. As many commentators emphasized this did require that the system be well specified and they wondered if that was true.

In his summary of the 1977 RBA conference on Applied Economics Helliwell (1977, p318) said "Chris Higgins picked up on a point that had been made in several papers about the lack of evidence as to whether the system possessed the equilibrium growth properties it was intended to have".[3] The problems came from the fact that, even after a long period of time wherein the fiscal effects on GDP were close to zero, there were still movements in the stock of international reserves, money and the capital stock. Consequently, a longer term equilibrium position had not been established. The model was essentially based on the Bergstrom and Wymer (1976) model and, as Wymer (2009) noted, that model had unstable eigenvalues, and so would not converge to a long term equilibrium. He did observe that using second order adjustment schemes rather than the first order of the PAM seemed to improve convergence properties.

[3]Peter Jonson has told me that Helliwell concluded that the model RBII (as the modellers called it) was 'more nearly maximal than minimal', and that he greatly approved of it. Peter also noted that it had been important for affecting some policy outcomes.

One might also note that some parameters reflecting target growth rates in output and money were estimated and these seemed very high. For example, output growth was between 1.6 and 1.8%. This would imply an extraordinarily high growth rate for the Australian economy if it is quarterly growth (the model is quarterly). If it is annual then it is far too low, unless it is per capita, but the data used does not seem to have been in per capita form. The growth rate of technology was estimated to be .24% so that suggests this is quarterly growth. Another innovative feature of RBA76 was the use of reaction functions for bond rates and the exchange rate (which was fixed over their estimation period). The former depended not on target growth rates in output and prices but rather on money growth.

The model continued to be developed in the RBA with RBA79 being the next in line, and it finally finished with RBA82 - Fahrer et al. (1984). The structural equations did get modified in these moves but the philosophy remained the same. Particularly noticeable was the fact that the target growth rates were no longer estimated but were instead prescribed, and the equation for the exchange rate tended to start to resemble something like uncovered interest parity as the equilibrium relation. The prescribed growth rate of output at 4.8% per annum still seems high.

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

4.1 Overseas

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 capture the data more closely. 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 the implementation of rules to describe the policy decisions of monetary and fiscal authorities. Some standard rules were for external debt to be set as a fixed proportion of GDP and for fiscal policy to be varied to attain this. 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 in fact making the system perform poorly. Duguay and Longworth (1998) say "The trend in macroeconometric model building at the Bank of Canada has been away from the large-scale disaggregated models of the 1970s towards focused, well-articulated small- and medium-sized models, suitable for medium-term policy analysis and for short-term monetary policy setting under conditions of uncertainty about the future". In constructing these models they say the Bank staff were influenced by the MSG model of McKibbin and Sachs(1989).

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 representation 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 these relations, 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".

Duguay and Longworth (1998) note that "The steady-state of QPM is calibrated, not estimated. This allows other criteria in addition to the minimization of short-run prediction errors to play a role in assigning parameters. Such criteria include short-run and long-run economic properties such as elasticities or shares, speeds of adjustment, and the ability of the parametrized model to replicate certain stylized facts. There is, of course, an inherent tension among the various criteria. However, the decision was made to give priority to the overall macroeconomic properties and to the ability of the model to mimic the response to certain shocks, especially monetary shocks, that come out of vector autoregressions. As part of the trade-off, it was decided that judgment should heavily influence the first two quarters of the staff economic projection."[4]

One of the key developments in 3G models was that attention was more firmly 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 into macro-economics by Frisch (1933) they did not become part of the standard language of it 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

[4]QPM was the Quarterly Projection Model of the Bank of Canada that evolved out of the model that was set out for policy analysis.

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.

4.2 Australia

It is perhaps not surprising that the first 3G type model to be used in an institution in Australia was an extended version of the RBA82 model. As mentioned earlier the class of models RBA76→RBA82 had many of the characteristics of 3G models, but there were doubts about whether they would return to what was supposed to be their long term path after a shock. There were also further problems, since stocks and flows were not properly integrated. Edey et al. (1987) adapted the RBA82 model - naming the new variant RBII - by introducing monetary and fiscal rules to deal with any lack of convergence. Although the published simulations suggest that there might still be issues they report that, provided a long period was used, convergence did occur (a 10 year horizon being too short). Many of the parameters in RBII were pre-set in order to ensure convergence.

As mentioned earlier Warwick McKibbin's work on the MSG2 model was very influential for those building the 3G Canadian model QPM. The MSG2 model was a multi-country model that had an Australian sector and it was used in McKibbin (1988). It did have a steady state path and featured inter-temporal decisions by both consumers and firms. The consumption decision resulted in the same type of relation as that used in many 2G models, namely it depended on wealth and labour income. To reduce the dependence on wealth some heterogeneity among agents was introduced. Thus McKibbin and Sachs (1989) had two types of consumers, those who solve an inter-temporal optimization problem and those who are liquidity constrained and just have current income available for consumption (this was also used in QPM). Investment decisions were also mixed with a fraction of firms responding to Tobin's q and others to current profits. Because there was inter-temporal optimization expectations now need to be formed about future variables as well as contemporaneous ones. In McKibbin (1988) the expectations for Australian agents was an average of these.

Unlike previous models MSG2 was a yearly model. Although some share data was used to determine parameter values, mostly the latter were set to values based on previous work. In many computable general equilibrium models such as ORANI there is a benchmark data set that replicates a steady state, with the consequence that results are deviations from that benchmark. This was also roughly true of MSG2, in that 1986 was the year chosen for a benchmark. However, it was hard to do this exactly because variables such as exchange rates reflected future expected outcomes. The model worked with aggregates such as consumption and investment and had three tax rates, so it was much smaller than the Australian 2G models (at least in terms of the number of Australian variables that were determined). Stocks and flows were precisely demarcated and policy rules ensured convergence. It was particularly useful for analyzing the outcomes for Australia of world shocks.

Perhaps the earliest example of a model used in practice that had the size of 2G models but which had 3G features was the Murphy Model (MM) - Murphy (1988).[5] This model did not have the strong calibration emphasis followed by the Canadians but rather merged 2G and 3G ideas i.e. equations were often specified as in 2G models but additions were made to them or to the system to make sure that there was ultimate convergence. Just as for QPM the MM essentially had two models - one describing the longer term and the other how the adjustments to that would take place. Nevertheless, specifying a steady state path and making sure that the model returns to it after a shock are two different issues. The Canadian Model QPM had parameters that were chosen (calibrated) to ensure that this happened. Once one allows the data to determine some of the parameters it may be a much harder task. The MM was possibly the first 3G model with parameters largely estimated from the data to feature an explicit steady state path. A key element in it was the NAIRU and, in the original model MM, that was set to 6.8%. MM had 16 core endogenous variables but 96 in total. MM2 was described in Powell and Murphy (1997) where it was extended to have 24 core and 165 variables in total. MM did not have model consistent expectations except in financial markets.

[5]Earlier Murphy et al. (1986) had constructed the AMPS model for the Economic Planning Advisory Council (EPAC) and it had a well defined steady state. In many ways it can be thought of as the first 3G model that combined both a steady state path and parameters largely estimated from the data. It was a semi-annual model but does not seem to have been used, although it clearly had a major influence on the direction of later Australian models. It seems very difficult to find a copy of it today and I am indebted to Chris Murphy for providing me with one.

A stable foreign debt to gdp ratio is achieved in MM by shocks reducing non-human wealth and thereby consumption. Money is set exogenously and it grows at a constant long term rate of 4% pa. The demand for money can then be inverted to determine the short term interest rate (this also seems to be how MSG2 worked, although there the demand for money comes from optimization, as it is included in utility and production functions and not just made a function of the velocity of money). This is different to QPM which used an interest rate rule in which the interest rate was used to target inflation. A 10 year bond rate appears in MM as an average of the model predicted short rates over the following 10 years. MM was used extensively in the private sector and it ultimately became very large, being extended to handle multiple sectors. MM2 was a multisector version with originally 12, then 18, industries.

The first model developed by the Treasury that had a 3G orientation was TRYM - Taplin et al (1993) and Downes (1997). It was used from 1994-2011. It was very close in structure to the Murphy model and the differences were more in its size (23 core variables and probably about 130 variables in total) and the specification of some of the equations. In MM UIP was expressed in terms of short rates while TRYM based it on a 10 year bond rate. Because the solution for these models was essentially a VARX process (the X for exogenous variables), then basically using model consistent expectations was effectively using a VAR projection into the future with the VAR parameters set to those derived from the 3G model. The FRB-US model used VAR forecasts as expectations but with a much smaller number of variables than in the full model, and still does. Just as for MM the NAIRU was a crucial variable for getting convergence in TRYM and it changed value from around 8.5% to around 6% as the 1990s and 2000s wore on.

5 Fourth Generation (4G) Models: Getting the Stories to More Closely Match the Data

5.1 Overseas

A fourth generation of models rose in the 2000s. Representatives were 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, Christoffel *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.[6] These models are the counterparts to what have become known in the academic literature as Dynamic Stochastic General Equilibrium (DSGE) models.

Inter-temporal optimization was now used to develop decision rules and were 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 dynamics of the model, and this makes it necessary to decide on the degree of persistence. 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.

Firstly, there is now no second-stage process that introduced 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.[7] 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.

Secondly, the structural equations of the model are often now kept in

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

[7] Tinsley (2002) derived polynomial adjustment cost dynamics by formulating a decision problem in which not only the current adjustment costs featured in a quadratic way but also m future expected period adjustment costs. This led to the ECM involving expected future values of the target and he termed this "rational error correction". In the special case $m = 1$ we would get the standard error correction model that would just feature the current value of the target.

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 (C_t) decisions appears in most 4G models as

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

where R_t is a rate of return, 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 expected labour income. One reason for doing that may be because it is easier to modify the model design through its Euler equations e.g. by the introduction of habit persistence to affect 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 (and any contemporaneous and lagged exogenous variables in the system). This is different to (say) MSG2 where one had to specify the values of all future outcomes for the exogenous variables Thus the important feature becomes the relative weights to be attached to the available information at time t when forming expectations at different periods.

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. Two can be mentioned. Firstly, there is now some heterogeneity introduced into the models. 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" or "packager". 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 its price 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 monopsonistic 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 technology to have a stochastic permanent component as well as a deterministic one e.g. The New Area Wide Model and COMPASS (Burgess et al.(2013)). This meant that endogenous variables no longer just co-trended but also co-integrated and this needed to be allowed for in the solution of models.

5.2 Australia

The first of the 4G models developed for Australia is probably Nimark (2009), but the form in which it seems to have been used in the RBA is the model called ER-DSGE set out in Jääskelä and Nimark (2011) (JN). This was based on Adolfson et al. (2007). One difference to the latter was that exports in JN were constructed as a weighted average of commodity and non-commodity exports. The quantities and prices of commodity exports were exogenous. As for Adolfson et al. estimation was performed with Bayesian methods, requiring some prior distributions for the DSGE model parameters to be stated. A strange feature was that, following the Swedes, they included a time-varying inflation target, even though the estimation period was post 1993, by which point the RBA had decided on a target. There was persistence introduced into saving decisions by habit, adjustment costs slowed investment, and the level of foreign debt impacted upon the deviation from UIP i.e. the real exchange rate responded to debt levels and hence became a method for stabilizing foreign debt in the longer term - see Schmidt-Grohe and Uribe(2003). Prices reacted to marginal costs and were re-set with a Calvo scheme.

So the model reflected overseas developments, except for its attention to the fact that Australia was mainly an exporter of commodities (JN give a weight of .7 to commodity exports in the aggregate). There were 13 core endogenous (observable) variables from which about another 35 could be constructed. Later versions of the model prepared in the RBA allowed for a fiscal sector, dropped the time varying inflation target, and added hours to the set of observable variables. This seemed to improve the parameter estimates. In JN there were two shocks with estimated AR(1) coefficients of .998 and .999 with incredibly small standard deviations, so it was hard to escape the conclusion that these shocks were really permanent and not transitory, as called for in the model theory. With the changed assumptions these values declined to around .95 (the coefficient priors remained the same in estimation).

Subsequently a multi-sector model of the Australian economy (MSM) was developed by Rees et al (2016). This DSGE model featured seventeen core endogenous variables with three production sectors: (i) non-traded commodities and services, (ii) traded non-resource commodities and services, and, (iii) traded resources. Like JN it has a unit root process for the log of technology, so that some of the variables in the model follow integrated processes that are also co-integrated e.g. the log of domestic and foreign GDP. What makes the model innovative is the presence of three sectors, and in many ways it can be seen as an extension of the dependent economy model whose origins are strongly Australian - see Metaxas and Weber (2016). It also completes the JN model in that there is now a sector that produces the exported commodities and hence there is a supply as well as a demand curve.

Gibbs et al.(2018) added a housing sector to the MSM to produce a model - DSGE_RENO. This involved putting the stock of housing into a household's utility function, which is useful for capturing the portfolio aspect of housing purchases. They also have an intermediate producer of housing services who rents the stock of houses from households and then combines this with capital and labour to produce housing services. These services are further combined to produce the consumption of dwellings final demand product. The modification produces new variables in the MSM and enables one to track how the impact of shocks would change when there is a housing sector. The impact of monetary shocks on GDP and inflation in DSGE_RENO didn't seem to be greatly different from those in MSM for the first few years, but they did have far more persistence after that. It is also unclear whether the addition of the extra sector solves some of the problems that were evident in the MSM, in particular the over-statement of the volatility of GDP growth by the model, as no direct comparison was made in the paper. The only evidence was that some of the forecasts tend to suggest that the problem remains, although it might have ameliorated.

It is worth dwelling on this model a little more as it demonstrates some issues for 4G models that arise in the next section. First, in DSGE_RENO there are now 26 series used for estimating its parameters, 26 model shocks and another 19 measurement error shocks. The latter are the difference between what the value a model variable would be and what the data says it is, and seems to have the connotation of "theory ahead of measurement". Be that as it may, the problem using these shocks in DSGE models - and they appear in the MSM and also the COMPASSS model of the Bank of England - is that one cannot estimate more shocks than there are data on variables. So the shocks computed with the Kalman filter are linear combinations of the forty five shocks used in DSGE_RENO.[8]

6 Reversing the Trend: Hybrid Models

Pagan (2003) describes some of the 2G and 3G models as being of a hybrid form. By this was meant that they had the characteristics incorporating long term deterministic paths and that there were enough mechanisms in them to ensure convergence to those paths after a temporary shock. There were two types of Hybrid models. In Type I the long term paths were not articulated, leaving error correction mechanisms and policy rules to ensure convergence

[8]Note that we can estimate the impulse responses to the shocks as they reflect the ability to estimate model parameters (assuming they are identified). The problem is in quantifying the shock. It is the presence of the shocks in the model, and not whether their parameters are fixed, which is the source of the inability to separately identify shocks when there are more of them than data series.

to some path. In Type 2 models e.g. those of Chris Murphy, the paths were fully articulated. In recent times 4G models are often seen which use mean corrected growth rates, and this means that there can be many long-term deterministic paths, one for each trending variable. However, when a permanent stochastic component is introduced into the model, it is assumed that this is common to all the I(1) variables. Consequently, the variables may not co-trend in such models but they do co-integrate.

3G and 4G models were attractive for telling a story about likely developments in a vein that was familiar to advisors and, possibly, the decision makers. This was done by using micro theoretical ideas to derive relationships. But the data used in macro-econometric models is aggregated, and is not that for individual units and, as is well known, the properties of demand and supply curves for individual units need not apply to aggregated quantities. Sometimes the micro-theory used in 4G models leads to results that don't sit well with institutional knowledge. Thus, in these models monetary effects are often at their strongest in the first quarter (as with JN and MSM) and often they do not predict well at short horizons. Moreover, for both JN and MSM the standard deviation of GDP growth from the model is almost twice what it is in the data, and so the models tend to be predicting more recessions than is likely. 2G models were better at matching institutional detail, but the story they offered was sometimes hard to follow, partly because there was a great deal of disaggregation of consumption, investment etc., and there were many different types of equations describing these. In addition, as we have noted many times before, there were issues concerning what they were predicting about the longer term, particularly when one had some future values about which expectations need to be formed. Then it is necessary to make sure that there was a reasonable longer-term path. It is probably not surprising that the problems noted in the previous sections about identifying shocks, and the need to have an approach that enables both prediction and policy work while respecting the accumulated judgement within the institution's staff, has led to interest in using many of the insights gained from 3G and 4G models but to adopt a lighter touch.

6.1 Overseas

The strength of 4G models was probably for thinking about policy scenarios and not for prediction. Nevertheless they have often been made the central organizing model (to use the Bank of England's "COM" description in their

COMPASS model set out Burgess et.al.(2013)). Then the challenge became how to utilize them for predicting the much larger set of variables needed for most policy decisions and to incorporate judgement from alternative sources. Traditionally prediction had often been handled in institutions with spreadsheets and specialists in particular areas. These were a key resource for forecasting as they can embody off-model information. One problem that arises with them is that there can be quite a few different equations for any variable that needed to be predicted. Either a single one has to be chosen from one of these equations from the range embodied in the spreadsheet, or they might be averaged in some way. A difficulty with spreadsheets were that they tended to be focussed on the shorter term, and it was not entirely clear what would happen if they were iterated forward, which policy analysis generally requires. What was good about the spreadsheets was that they had a great deal of institutional knowledge embedded in them. A key problem was that of coordinating the results and doing policy scenarios. Often there was a model embedded in them but not a formal one.

Looking at COMPASS the organizing model was a DSGE one of much the same size as DSGE_RENO. This was then supplemented by a "suite" or "zoo" of other models which provided predictions of variables not in the organizing model. Sometimes the predictions from the DSGE model were fed into the suite and, at other times, the suite produced outcomes that could be fed back into the DSGE model. This was particularly true when it came to financial effects. On top of the problems of extra variables there was also the need to impose judgement about model and auxiliary variables. There is nothing new about the latter. In 2G models a lot of attention was paid to "fixes" designed to produce particular paths for endogenous variables that were felt appropriate by policy makers and advisers. These had to be made consistent with any COM. In 2G models this was mostly done by residual adjustments through intercept variations. In COMs of the DSGE variety it has been done by finding values for shocks that would produce these outcomes. Those shocks might be model shocks, such as technology or demand, but could also involve assuming that some future shocks are known. That approach involves manipulating expectations error. In many ways DSGE models are a difficult COM for prediction purposes, and users have to be very skilled at deciding how the shocks are to be set. Consequently, it is probably not surprising that Hybrid models such as MM have proved popular for the task of combining both prediction and policy analysis in Australia.

The Bank of Canada has developed a model, called LENS for Large Empirical and Semi-structural model, that utilizes ideas drawn from FRB/US and the Bank of Canada's projection model of the U.S. economy (MUSE). LENS is essentially a system of rational error correction models for variables, so it does incorporate a long-term path and can be thought of as a Hybrid model. There are many questions about it that relate to the number of parameters being estimated and exactly how estimation is done. It does not seem to have been adopted as a framework outside the Bank of Canada.

6.2 Australia

Although it did not derive from a spreadsheet Beechey et al (2000) constructed a small empirical model of the Australian economy that we could call a Hybrid Type 1 model. The model was called either the ER or EG model. Basically it could be thought of as a VECM form of a New Keynesian model. The five core endogenous variables were GDP growth, inflation, the exchange rate, unit labour costs and import prices. There were 8 other endogenous variables and quite a few "exogenous" variables – cash rate, share price index,. . . .Stone et al (2005) updated it, adding a second measure of inflation and working with an output gap rather than a growth rate in non-farm GDP. Their comment on the model was "In particular, non-farm output continues to be modelled as a single entity, rather than disaggregated into its standard expenditure components. This represents a deliberate decision intended to maintain the simple, linear structure of the model". A steady state path was imposed with an annual 3.8% growth for GDP (in the 2000 version) and 3.25% (in 2005). It was also necessary to set targets for inflation and the real cash rate - 3.5% (2000) and 3.0% for the two models.

The philosophy of formulating small models in EC form and then checking that the implied steady state of the model could be attained was quite common. Because there were no stocks involved any ER/EG model convergence issues could probably be handled with EC terms (although the lack of stocks means we don't know if an equilibrium has been reached). But, when stocks are involved, it would be necessary to impose some extra rules to ensure that property. So, as we have seen from the history above, hybrid models would need to capture all of the features that have been thought important for good models over the years. Thus the state of demand in labour markets was often described by deviations from a NAIRU, monetary policy had to be stabilizing by responding relatively strongly to inflation, if there were fiscal elements in a model then there needed to be some rule to incorporate an inter-temporal budget constraint, and the real exchange rate should reflect a risk premium that rose as external debt increased. Of course it was not just a rule that was needed, the parameters in the rule needed to have the right values so as to ensure the stock/flow equilibria in the longer term. These rules were formulated to describe both monetary and fiscal policy. No longer could one hold variables like the money stock constant, as was typical of many 2G models.

MARTIN is a recent prediction and policy model constructed for the RBA. As a general description it might be thought of as a model of the spreadsheets used in forecasting at the RBA. As Cusbert and Kendall (2018) say " MARTIN's role is to bring together the analytical frameworks of the Bank's analysis" and "A DSGE model was not the appropriate choice ..because the economic mechanisms in such models do not align well with the current analytical framework used for forecasting and analysis". The national income identity is a starting point in it and there are 33 core endogenous variables in the model. There is limited disaggregation in the model itself – investment and exports are variables that are disaggregated- but unlike the NIF models consumption is not. It uses EC mechanisms extensively and ".. incorporates economic theory by using economic intuition to guide its longer-run properties, but is also designed to capture relationships visible in the data". Key items in the model are a NAIRU and a "neutral interest rate".

Unlike models such as the NIF class it allows for both deterministic and stochastic long run paths. These are for the exogenous variables to the model. From a Cobb-Douglas production function we would have $log(LP) = \log(A_t) + (1-\alpha)\log(K_t/(A_tL_t))$, where LP is labour productivity, A_t is labour augmenting technology, K_t is the capital stock and L_t the labour input. In the longer term no relative price shifts would be expected so that $\log(K_t/(A_tL_t))$ should be a stationary process, and therefore $log(LP)$ will have a unit root due to $\log(A_t)$ having one. So one might extract $\log(A_t)$ from observed labour productivity by using an unobserved components model. This is done in other models such as FRB-US, LENS and MARTIN. It may also be that it is necessary to recognize that $L_t = H_tN_t$, where N_t is employment, H_t is average hours worked and L_t should be labour services. In this case labour productivity is generally measured as Y_t/N_t and therefore a separate equation for extracting the permanent component of hours H_t is needed. In most 4G models H_t is a stationary process so the mean is the only permanent component but, in spreadsheets, H_t is often taken to be I(1).

The new Treasury model being built - EMMA - would also seem to be a Type 2 Hybrid model. MARTIN has no fiscal sector and no rules to close the inter-temporal budget constraint or even a current one. One would expect that EMMA would need to address that, and to provide a wider range of fiscal instruments. However at the time of writing EMMA is not complete.

7 Conclusion

The Cowles Commission was very influential in the development of macroeconometric models. They had a "battle song" to encourage thinking about macroeconometric modelling. It ends with the words "So all that we've developed may some day be applied". Macroeconometrics is about application and using developments in theory, statistics and history in a useful way. We have presented a short history of Australian macroeconometric modelling focussing on complete models rather than just parts of them. Often the ideas for these models came from overseas developments so we have tried to locate them in that. There have however always been special characteristics of the Australian economy, such as commodity exports, and these have required special attention. In the table below we provide a summary of all the models that we have discussed in this paper. It should be emphasized that the paper is a selective history with an emphasis upon models developed and used in the two major macro-economic policy setting institutions in Australia and has ignored many in the private sector. Many of the latter were developed by individuals who were responsible for the models described here when they were public servants e.g. Chris Murphy and Peter Downes.

Australian Macro-Econometric Models : A Tabular Survey			
Gen	**RBA**	**Treasury**	**Other**
1			*Swan(1943)*
			Nevile(1962)
			Kmenta(1966)
2	*RBA1(1969)*	*NIF1(1970)*	
	RBA76(1976)	*NIF2(1973)*	
	RBA79(1979)	*NIF10(1980)*	
	RBA82(1982)	*NIF-88(1988)*	
3	*RBII(1987)*		*AMPS(1986)*
		TRYM(1993)	*MM(1988)*
			MM2(1997)
4	*ER-DSGE(2011)*		
	MSM(2016),DSGE_RENO(2018)		
Hybrid	*ER/EG(2000)*	*EMMA(2019)*	
	MARTIN(2018)		

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