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# Decisions in Designing an Australian Macroeconomic Model*

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*This paper discusses the decisions made in designing a new Australian macroeconometric model to be used for both policy analysis and forecasting. Serving these dual functions requires a reasonable level of consistency with both macroeconomic theory (emphasised in New Keynesian dynamic stochastic general equilibrium models) and macroeconomic data (emphasised in vector autoregression models). The key decisions made in modelling household, business, government and foreign behaviour are explained. The design decisions taken are reflected in the new model, which is the latest in a series developed by the author. The use of the latest model is illustrated in optimal control simulations.*

## I Introduction

The appropriate design of any economy-wide model depends on its intended applications. This paper is about the design of a macro model of the Australian economy used for both policy analysis and forecasting. Policy analysis requires consistency with macroeconomic theory, as emphasised in (New Keynesian) dynamic stochastic general equilibrium (DSGE) models. Forecasting requires consistency with macroeconomic data, as emphasised in vector autoregression (VAR) models. The aim of using the same model for both policy analysis and forecasting necessitates balancing the theory and data, and here that leads to an eclectic approach based on a macroeconometric model.

Macroeconometric models continue to be popular in government, notwithstanding the emergence of VAR and DSGE models. The current use of macroeconometric models in the fiscal authorities of advanced economies is documented in Murphy (2017). Also, the FRB/US macroeconometric model housed at the US Federal Reserve (Laforte, 2018) is well known, and operates alongside the Fed's DSGE models. In Australia, the continued interest in macroeconometric models is demonstrated in the recent development of MARTIN at the Reserve Bank (Ballantyne *et al.*, 2019) and EMMA at the Treasury.

*This paper draws on consulting advice that I have provided to the Australian Treasury on their overall economic modelling capability (Murphy, 2017) and, more recently, on the development of their new macroeconometric model, EMMA. I would like to thank Adrian Pagan and Australian Treasury officers for helpful discussions and comments regarding that consulting advice. I would also like to thank participants at the University of Tasmania Macroeconomic Modelling and Forecasting Workshop and at an Arndt-Corden Department of Economics, ANU, seminar for their useful comments on earlier versions of this paper. Finally, I would like to thank two anonymous referees for many helpful comments.

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While generally DSGE models are designed primarily for policy analysis[1] and VAR models for forecasting, macroeconometric models are an eclectic compromise. However, they have their own advantages in both applications, which may explain their continued popularity. Policy-makers can find it reassuring that the model they are relying on for policy analysis is sufficiently realistic that it can produce credible forecasts. Similarly, economic forecasts can be more readily accepted when they are supported by an economic story coming from a structural model.

The new macroeconometric model ('the macro model') that is the subject of this paper is the latest in a series of macroeconometric models of Australia developed by the author. These New Keynesian models include the TARGET model developed in the Australian Treasury in 1982–3, the AMPS model developed at the Office of the Economic Planning Advisory Council (Murphy *et al.*, 1986), the Murphy Model (MM; Murphy, 1988a, 1988b) developed at the Australian National University (ANU) and Murphy Model 2 (MM2; Powell & Murphy, 1997) developed at Econtech, a former private economic consultancy. In their detailed documentation of MM and MM2, Powell and Murphy (1997) emphasise the eclectic nature of the modelling approach arrived at from balancing the theory and data. Mardi Dungey was an important member of the Econtech MM2 modelling team in the late 1990s.

The new macro model was developed from scratch. While starting again was time-consuming, it provided an opportunity to reconsider all aspects of the modelling approach. The new model was initially developed in 2013–15 in collaboration with Dinar Prihardini. The model takes into account the experience with MM2, insights from DSGE and VAR modelling, and developments in the Australian economy and macro policy-making since the development of MM2. More recently, the estimation period of the model has been extended to 2018Q2 and various aspects of the model have been refined. The resulting 2019 version of the macro model, which is based at the ANU, is the subject of this paper.

The paper does not attempt to fully document the new macro model because of space limitations, and in any case MM2 has already been fully documented. Rather, the focus is on the key decisions made in designing the new model, as these are of potential interest to macro modellers generally. Where design decisions are similar to those made in MM2, they are dealt with more briefly. The decisions that are new to the new macro model are explained in more detail.

The main features that the new macro model shares with MM2 are as follows. For theory consistency, prices are sticky on domestic markets but flexible on international markets, expectations in financial markets are model consistent and there is a well-defined steady state in which a representative firm in each industry maximises profits and markets clear. Also, the intertemporal budget constraints of the private and government sectors are incorporated. For data consistency, there is residual-based diagnostic testing and error-correction mechanisms (ECMs) are used for dynamics.

At the same time, the new macro model has its own distinctive features compared to MM2. Industry detail is now included only to the extent that it is expected to improve policy analysis and forecasting at the macro level, leading to a smaller number of industries. Land and mineral resources are recognised as fixed factors of production. In the model, the Australian economy is highly open to international flows of goods and services and capital, but not labour. The short-term interest rate equation represents the Reserve Bank's current approach to monetary policy based on targeting consumer price inflation. A new consumption function has been developed that continues to recognise that counter-cyclical tax policy can be effective in the short run, but there is also long-run fiscal neutrality. The new macro model automates the forecasting of model inputs using time series analysis, including using a novel approach to forecasting equation residuals.

The remainder of this paper is structured as follows. Section II discusses how the design of a macro model is influenced by its intended applications. It then explains the key design features of the new macro model, distinguishing between those features that are carried over from MM2 and the new features. Section III demonstrates an application of the model by using it for open loop optimal control of macro policy.

## *II General Approach to Macro Model Design*

This section begins by discussing how the design of a macro model is influenced by its intended applications. It then outlines the

[1] DSGE models may be used for forecasting. For example, at the Bank of England, forecasts are produced from the DSGE model known as COMPASS, a suite of statistical models and the Monetary Policy Committee. Boneva *et al.* (2019, fig. 6) find that COMPASS produces the most accurate forecasts for inflation beyond an horizon of about 1 year, while this is not the case for shorter time horizons and the other two sources of forecasts are more accurate for gross domestic product (GDP) growth over all horizons.

intended applications of the new macro model and explains its key design features. A distinction is made between those features that are carried over from MM2 and the new features.

*(i) Aims and Types of Macro Models*

The first consideration in designing any economy-wide model is its intended applications.

VAR models, with their emphasis on letting the data speak, can provide useful forecasts, especially for a relatively small number of variables and/or over shorter time horizons. VAR models were introduced by Sims (1980). As Stock and Watson (2001) note, 'VARs are powerful tools for describing data and for generating reliable multivariate benchmark forecasts'. In Australia, an early example of a VAR macro model was Smith and Murphy (1994), while the leading example is Dungey and Pagan (2000, 2009). The Dungey and Pagan VARs emphasise the influence of the world economy on the Australian economy and the interactions between financial markets and the real economy. From the author's experience, the Dungey and Pagan style of VAR still performs well in providing short-term forecasts, after some updating for developments in the 2010s, including the shift in the weight of the international economy from the USA to China and the slowdown in labour productivity growth.

New Keynesian DSGE models, with their emphasis on optimising behaviour, are widely used at central banks for analysing monetary policy. The leading Australian DSGE model was developed by Rees *et al.* (2016) at the Reserve Bank of Australia (RBA). A housing sector was added later by Gibbs *et al.* (2018). As a result, the model now includes four industry sectors – housing, non-traded excluding housing, resources and traded excluding resources. A fixed factor is included in the resources sector, recognising the role of natural resource inputs.

While DSGE models are also used at fiscal authorities, this is less common because extensive modifications to the benchmark model of Smets and Wouters (2007) are needed before counter-cyclical tax policy can be meaningfully modelled. The types of modifications needed can be seen in the models described in the paper by Coenen *et al.* (2012).

While DSGE models emphasise theory and VAR models emphasise data, they share a common focus in explaining economic cycles by random shocks. Pagan and Robinson (2016) investigate this relationship between the two types of models. This differs from traditional macroeconometric models, where some economic variables are treated as exogenous rather than endogenous. The exogenous variables typically refer to government policy, the international economy and demography.

One lesson from DSGE and VAR modelling is that macroeconometric modellers could consider modelling the data-generation processes that determine these so-called exogenous variables. Macroeconometric models could then be better used to understand the causes of economic cycles. A further benefit is that the process for forecasting the exogenous variables can be made semi-automatic.

The aim here was to develop a macro model for both short-term forecasting (up to 2 years) and medium-term forecasting (up to 10 or 20 years), analysis of alternative scenarios, and analysis of optimal macro policy. The dual emphasis on forecasting and policy analysis leads to a macroeconometric model, balancing theory with data.

Other types of Australian economy-wide models are better suited for purposes beyond macro forecasting and policy analysis. For example, detailed industry and trade policies are better analysed using the industry-focused style of computable general equilibrium (CGE) models primarily authored by Peter Dixon and developed at the Centre of Policy Studies (see Lkhanaajav, 2016, for an overview).

*(ii) Murphy-Style Models*

While DSGE and VAR modelling have influenced the new macro model, experience with the Murphy-style series of macroeconometric models has also been important. As noted in the introduction, this series of models are New Keynesian in style and have endeavoured to balance theory and data, while taking into account developments in macroeconomics and the national economy being modelled.

The first model, the TARGET model, was initially developed at the Australian Treasury by the author in 1982–3 and then further developed as the AMPS model at the Office of the Economic Planning Advisory Council (Murphy *et al.*, 1986). It combined the traditional approach of incorporating a Keynesian short run with what was then a newer approach of incorporating convergence to a neoclassical long run. The econometric approach aimed to achieve consistency with the data by employing error-correction models for dynamics and using diagnostic testing. In an unusual compromise, the AMPS model used half-yearly data rather than quarterly or annual data.

Echoing New Keynesian economics, the MM (Murphy, 1988a, 1988b) incorporated rational expectations in foreign exchange and bond markets. It also made the switch to the more standard choice of quarterly data. Its well-defined long-run properties were studied in detail, through algebraic and simulation analysis (Murphy, 1992). Such investigations are now more commonplace.

Over the period from 1990 to 2010, MM and its successor MM2 were used to produce macroeconomic forecasts to a 10-year horizon for subscribers. MM2 was also used to investigate optimal macro policy using open loop optimal control (Murphy, 1997). MM was summarised in Murphy (1988a, 1988b). It was fully documented in Powell and Murphy (1997) to disseminate the model and support its teaching in universities.

While MM followed the traditional macro modelling approach of being based on a single industry sector, in 1994 one-digit industry detail was introduced in MM2 (Powell & Murphy, 1997, Chapter 28). Unlike traditional macroeconometric models that used top-down, input–output approaches for generating industry detail, for theoretical consistency MM2 was developed as a dynamic CGE model, thus embedding the industry detail in the core model in a fully integrated approach. The industry detail was introduced partly to meet a demand for industry-level policy analysis and forecasts, and partly to improve policy analysis and forecasting at the macro level.

At around the same time, McKibbin and Wilcoxen (1999) independently developed their own dynamic CGE model, but on a multi-country scale. As they state, the aim of dynamic CGE models is to combine 'the attractive features of macro-econometric models and computable general equilibrium models into a unified framework'.

The macro modelling approach used in the MM series of models has been successful transplanted to other countries. Since 1998, the Monetary Authority of Singapore (MAS) has used the Monetary Model of Singapore, which was developed by this author using the MM approach but recognising the important differences between the Australian and Singaporean economies. 'Since its development, the Monetary Model of Singapore . . . has been used by the MAS to develop official economic forecasts every quarter, generate alternative scenarios, and conduct macroeconomic and industry policy analysis' (Monetary Authority of Singapore, 2014). The New Zealand Model has similar origins and has been used by the New Zealand Treasury in a comparable way (Ryan & Szeto, 2009). An MM-style model was also constructed by this author for the Malaysian Ministry of Finance, in a modelling project that is now supported by the World Bank.

For the purposes of this paper, our interest in the MM2 model is confined to its key features that have been carried over to the new macro model. Those features or design decisions are now discussed in turn.[2]

*Sticky domestic prices*

In modelling goods markets, prices are sticky on domestic markets but flexible on export markets. The price stickiness on domestic markets means that output lifts in a Keynesian short run to accommodate a positive domestic demand shock, but then prices gradually adjust to clear the market in convergence to a supply-driven neoclassical long run. The price flexibility on export markets reflects the well-developed nature of international commodity markets and the idea that Australian producers have limited pricing discretion in those markets.

A further source of price stickiness is in the gradual adjustment of wages to clear the labour market. This wage adjustment is implemented using an expectations-augmented Phillips curve. In the long term, sustainable growth in nominal wages is driven by growth in labour efficiency plus the expected inflation rate for prices. Growth in nominal wages departs from this benchmark rate when the unemployment rate deviates from the non-accelerating inflation rate of unemployment (NAIRU).

The NAIRU itself is time-dependent and is estimated in a first-stage regression by fitting an s-curve[3] to the historical time path of the actual unemployment rate. The estimation period is from 1985Q3 to 2018Q2, and over the period from 1993 to 2006 the NAIRU is estimated to have fallen from a high of about 8 per cent to a low of about 5 per cent.[4]

These estimates of the historical path for the NAIRU can be compared with those obtained by Gruen *et al.* (1999) and Chau and Robinson (2018). Both of those studies estimate Phillips

[2] For more detailed information on these features of the MM and MM2 models, see Powell and Murphy (1997).

[3] The s-curve is the four-parameter logistic growth curve in which both lower and upper asymptotes are estimated.

[4] These NAIRU levels correspond to the equilibrium solutions for the unemployment rate in the wage equation at the upper and lower asymptotes of the fitted s-curve.

curves under the assumption that the NAIRU follows a random walk. They both estimate that the NAIRU rose from about 2 per cent in the late 1960s to about 6 per cent in the mid 1970s. The more recent Chau and Robinson (2018) study finds that the NAIRU subsequently fell, to be around 5 per cent since 2006. This historical pattern of rise and fall implies that the s-curve assumption could only be suitable for fitting the period of the fall, which is the way it has been used here. Encouragingly, both the random walk and s-curve approaches lead to the same conclusion that the NAIRU has been around 5 per cent since about 2006.

*Long-run profit maximisation*

In domestic markets, a hierarchical adjustment approach is employed in using the first-order conditions for profit maximisation to drive the economy from the Keynesian short run to the neoclassical long run. In each industry, equilibrium employment demand is obtained by inverting the production function. Equilibrium prices are based on short-run marginal cost, which ensures that the marginal product of labour condition is satisfied once actual prices have adjusted to equilibrium prices. Investment demand is based on Tobin's $Q$, so that the zero pure profit condition is satisfied in the long run. Hence, in the neoclassical long run, all profit-maximising first-order conditions are satisfied.

*Model-consistent expectations in financial markets*

Perhaps the strongest evidence for the presence of forward-looking expectations, rather than backward-looking expectations, comes from situations where variables are observed to 'jump' in response to new information about the future. Such evidence is readily observed in the pricing behaviour of foreign exchange, bond and equity markets. This makes financial markets natural candidates for model-consistent expectations. While this assumption should only be viewed as an approximation to reality, it remains popular in economy-wide models because of the lack of competitive alternatives for capturing the evident forward-looking behaviour.

In MM-style models, there are model-consistent expectations in the foreign exchange and bond markets. Specifically, uncovered interest parity (UIP) is used to determine the nominal exchange rate and the expectations theory of the term structure to determine the long-term interest rate. The underlying assumption is that long-term domestic securities, short-term domestic securities and short-term foreign securities are perfectly substitutable and financial markets have model consistent expectations.

UIP sets the local short-term interest rate equal to the foreign short-term interest rate less the expected rate of appreciation in the Australian dollar. However, since the local short-term interest rate is determined by the RBA, the UIP condition effectively determines the nominal exchange rate in the short run. This means that an unanticipated tightening of monetary policy leads to an immediate appreciation of the Australian dollar.

The expectations theory of the term structure is used to model the 10-year bond rate. The modelling of the long-term interest rate is important because it is this interest rate that drives investment decisions in the model. The term structure equation sets the 10-year bond yield equal to the model-consistent expectations for the return from a parallel sequence of 90-day bank bills. Hence the bond rate adjusts instantaneously to new, relevant information.

Assuming model-consistent expectations in financial markets complicates forecasting. In the absence of adjustments, asset prices will 'jump' (up or down) at the start of the forecast. However, these initial jumps can be ironed out through adjustments, and such adjustments can be semi-automated.

There is not the same obvious evidence for assuming forward-looking expectations in the labour market. However, inflation expectations in labour markets appear to be better anchored in countries where monetary authorities have a clear track record in targeting inflation. This observation leads to an eclectic approach to modelling inflation expectations in the labour market that uses a weighted average of forward-looking and backward-looking expectations, where forward-looking inflation expectations are proxied by the RBA inflation target of 2.5 per cent.

The weight used for forward-looking expectations is imposed at 0.8. This is higher than the freely estimated weight of 0.50 but falls within an 80 per cent confidence interval. Use of this higher weight on forward-looking expectations means that the model converges more quickly to its new long-run equilibrium path in simulation experiments.

*Government intertemporal budget constraint*

Macro models typically enforce the government's intertemporal budget constraint by setting a fiscal target that is gradually achieved by adjusting a swing fiscal policy instrument. This can involve setting a target ratio to GDP for government assets/debt or for the budget surplus/deficit. Here the fiscal target refers to the ratio of public debt to smoothed GDP and the swing fiscal instrument is the rate of labour income tax. Further details are given in Section III on optimal macro policy.

*Data consistency*

To enhance the usefulness of the model for short-term forecasting, there is an emphasis on data consistency.

Behavioural equations in the model are estimated individually using quarterly data starting, in most cases, from the early 1980s and currently extending to 2018Q2.

Further, freely estimated flexible ECMs are used for dynamics, following the general-to-specific approach. That is, we initially specify a general ECM with multiple lags, and then sequentially test restrictions. However, to avoid over-fitting, the approach taken is to err on the side of adopting more parsimonious specifications when testing restrictions. From personal experience, this makes the final equations more robust to new data or to partitioning the sample.

The general aim is to also freely estimate the values of equilibrium parameters. However, values of these parameters are imposed when this is necessary to obtain values consistent with the wider empirical literature and/or for plausible model simulation properties. Imposed values are generally within one or two standard deviations of estimated values.

Finally, diagnostic tests are performed to check if error terms are normally and independently distributed.

DSGE models adopt a different approach to obtaining specifications for dynamics. In particular, they typically incorporate adjustment costs into optimisation problems to derive equations with built-in dynamics. This means that the optimisation problem not only provides long-run equilibrium relationships, but also the form of the dynamic path to reach that equilibrium. Whether dynamic adjustment specifications should be based on theory in this way or more flexible ECMs potentially involves a trade-off between theory consistency and data consistency.

*(iii) New Macro Model*

In addition to the design features of MM2 discussed above, some new design decisions have been made in the new macro model. These decisions reflect experience with the MM-style models, insights from DSGE and VAR modelling, and developments in the Australian economy, including to macroeconomic policy setting. These new decisions, which are now explained in turn, involve using broader industry detail, incorporating fixed factors of production, assuming greater openness to the world economy, recognising the inflation target of monetary policy, adopting a new approach to modelling household consumption and saving, and automating the forecasting of equation residuals.

*Industry detail*

In MM2 there was substantial industry detail, based at the one-digit level, because of a desire to use the model for industry policy analysis and industry forecasting. However, that made the model somewhat cumbersome to use for its main purpose of macro analysis. For example, aggregate employment forecasts were built up from forecasts of employment in 18 separate industries, whereas the main interest was in the aggregate employment forecast itself.

In the new macro model, industry detail is not included for its own sake but rather only to the extent that it contributes to more accurate macro analysis either in forecasting or policy analysis. That leads to distinguishing only six industries, namely agriculture, mining, manufacturing, government services, housing services and other private services, which is the largest industry.

Analysis of agriculture still plays a significant role in assembling a macroeconomic forecast, even though this sector is smaller than in the past. The Australian Bureau of Agricultural and Resource Economics and Sciences forecasts of rural prices and volumes, which can move dramatically with drought and swings in commodity prices, are usually considered in preparing a macro forecast. It is more straightforward to take this information into account in a model-based forecast if agriculture is distinguished as an industry.

Similarly, keeping a close watch on developments in the Australian mining industry was key to preparing forecasts of investment and trade during the world commodity price boom. The minerals and energy forecasts of the Department of Industry, Science, Energy and Resources are important for this. This information can be taken into account more directly by distinguishing mining as a separate industry.

Taking 2017–18 as an example, a high 72 per cent of imports compete with the manufacturing industry. Hence, an understanding of developments in manufacturing is important in preparing import forecasts.

Government services are closely linked to government consumption expenditure. Thus, the forecasts of government consumption expenditure prepared in forecasting GDP(E) provide a strong lead in forecasting the government services component of GDP(P). To take advantage of this link, government services are distinguished as a separate industry.

Housing investment can be modelled more convincingly as a component of GDP(E) if this is done in the context of the market for housing services. New housing investment adds to the supply of housing services flowing from the housing services sector. The demand for housing services can be modelled as part of allocating total consumption across different industries, including the housing services industry. This modelling of the demand and supply of housing services can then be used to jointly determine the price of housing services, which is an important driver of housing investment, leading to more accurate forecasts of that investment.

*Fixed factors of production*

In macro models, industry-level production functions generally involve the use of inputs of labour, capital and intermediate products to produce output. Fixed factors of production are often ignored, including in the MM series of models. However, fixed factors account for substantial shares of factor income in three of the six industries in the new model.

On that basis, in the new macro model there is agricultural land in the agriculture industry, mineral resources in the mining industry and housing land in the housing services industry. Besides giving better modelling of factor incomes, allowing for this presence of fixed factors means supply responses are less flexible and more realistic in the three sectors. As noted above, in a similar vein the RBA DSGE model (Rees *et al.*, 2016) allows for a fixed factor in the resources sector, although net yet in the housing sector (Gibbs *et al.*, 2018, footnote 10).

Fixed factors can be introduced while maintaining a balanced steady-state growth path provided the effective supplies of fixed factors are assumed to grow with the economy. For example, in the new macro model it is assumed that the supplies of the three fixed factors grow at the same rate as population, and there is factor-augmenting technical progress at the same rate as for labour.

*Openness*

The extent to which a model incorporates open economy features affects its properties, especially in the long run. Thus, consideration needs to be given to the degree of openness of the Australian economy with respect to international flows of goods and services (trade), capital and labour.

Australia is widely viewed as a small open economy when it comes to international trade. Hence, in modelling imports, Australia is assumed to be a price-taker on world markets, so import supply is perfectly price elastic. However, there is more controversy among modellers about the magnitude of export price elasticities of demand.

This controversy arises because of the implausible implications of combining high export demand price elasticities with high export supply price elasticities. In particular, small shifts in demand or supply conditions can then lead to implausibly large changes in export volumes.

To overcome this problem of volatile export volumes, some friction needs to be introduced to export markets, either on the supply side or demand side or both. Export supply can be made less price elastic either by introducing a fixed factor of production to the exporting industry or by assuming that there is less than perfect transformability between supplying the domestic and export markets.[5] As a third option, export demand can be made less price elastic simply by using lower export demand elasticities, implying that exporters have some price-making power.

However, caution is needed in adopting this third option. The assumption of less than perfectly price elastic export demand implies there is a positive optimal export tax of $t = 1/(e - 1)$, where $e$ is the absolute value of the price elasticity of export demand; for example, if $e = 4$, then $t = 33.3\%$. In principle, such an

[5] Without such export supply frictions, the implied export supply curve for a particular industry will be close to horizontal in the long run. This is because the price of exports will be driven by the price of production which, under constant returns to scale, perfect competition and perfect labour mobility between industries, will, in the long run, be determined by unit costs that are largely independent of the level of production. If there is a fixed factor of production, the supply curve will be upward sloping. If there is less than perfect transformability between supplying the domestic and export markets, the nexus between the prices charged by an industry on domestic and export markets will be weakened.

export tax allows a country with price-making power to lift its terms of trade. If export demand elasticities are the same for each industry, the same optimal outcome can be achieved through the equivalent optimal tariff. Of course, in practice such trade policies are likely to be far from optimal because of the likelihood that trading partners will retaliate, and policy-makers in most countries are aware of this.

In any case, unless a model's export demand elasticities are quite high, a model will be in a world of second-best tax policy. In that world, many tax policy changes are likely to have implausible effects because of their side effects on the terms of trade. For example, import tariffs are likely to appear attractive because of the optimal tariff argument. Further, policies that expand the economy, such as corporate tax cuts, are likely to appear less attractive because the resulting expansion in exports substantially pushes down the terms of trade.

To avoid these implausible tax policy implications, any dampening down of long-run export demand price elasticities ought to be modest. The better strategy for addressing the problem of volatile export volumes is to consider the two options for dampening export supply price elasticities.

That approach was taken to some extent in MM2 when it was assumed that there was less than perfect transformability between supplying the domestic and export markets. In the new macro model, the approach of emphasising supply-side rather than demand-side frictions in export markets has been taken further. The introduction of agricultural land and mineral resources as fixed factors has appropriately reduced supply-side flexibility. This has allowed the use of generally higher export demand price elasticities than in MM2.

Turning to the openness of capital markets, the new model, like MM2, assumes UIP. Besides introducing model-consistent expectations to the foreign exchange market, this also assumes that there is perfect international capital mobility.

The alternative assumption of imperfect capital mobility would have odd tax policy implications. If higher reliance on foreign investment raises the cost of that investment, it becomes more attractive to tax investment (through corporate tax) and less attractive to tax saving (through personal tax). In reality, corporate tax rates have been trending down in advanced economies, partly in the general belief that there is very high international capital mobility. Indeed, Winner (2005) finds in a panel study of 23 OECD countries between 1965 and 2000 that there is 'a significant negative relationship between capital tax burden and capital mobility'.

Tuning to the openness of the labour market, the new macro model, like MM2, includes a demographic module that projects the population based on age- and gender-specific fertility and mortality rates and net overseas migration. However, net overseas migration is taken to be exogenous to the economy. In that sense, the macro model takes a closed-economy view of the Australian labour market. In reality, there is an endogenous component to overseas migration. However, this is not to the extent that induced migration substantially lessens wage differentials between Australia and other countries, so the current approach probably provides a reasonable approximation to reality.

*Monetary policy*

MM assumed that the RBA sets monetary policy to target a trend in nominal spending. However, in the mid 1990s the RBA introduced a target for consumer price inflation. Hence, the new macro model includes a monetary policy rule based on inflation targeting. Details are given in Section III.

*Household consumption and saving*

A new consumption function has been developed for the new macro model. It is designed to recognise that counter-cyclical tax policy is effective in the short run, while at the same time there is fiscal neutrality in the long run.

The MM-style models used the popular Ando–Modigliani (AM) consumption function in which consumption depends on current labour income (after taxes and transfers) and non-human wealth or assets. Under this approach, a personal tax cut lifts current after-tax labour income, leading to higher consumption. Hence, use of an AM consumption function means that counter-cyclical tax policy can be effective in the short run. However, the associated long-run fiscal properties are questionable.

The connection between the choice of consumption function and the long-run fiscal properties of a model can be seen by considering the steady-state form of a generic macro model of a small open economy. This simple model consists of the GDP(E) identity, the relationship for GDP (I) based on Euler's theorem applied under constant returns to scale and perfect competition, and the long-run forms of the stock-flow identities for accumulation of capital, government bonds and foreign liabilities:

$$Y = C + I + G + NX,$$

$$Y = (d + r) \cdot K + W \cdot L,$$

$$I = (d + g) \cdot K,$$

$$T = G + (r - g) \cdot B,$$

$$NX = (r - g) \cdot (K - A).$$

Here $NX$ refers to net exports, $A$ to nationally owned assets, $d$ to the depreciation rate and $g$ to the normal rate of growth in GDP (equal to the sum of $n$, the growth rate in the labour supply, and $p$, the rate of Harrod neutral technical progress), while other notation is standard. From this long-run model, the solution for household consumption, $C$, can be written as

$$C = W \cdot L + (r - g) \cdot A - G.$$

This is the long-run form of the national income constraint, which applies irrespective of the choice of household consumption function. It states that the sustainable level of household consumption ($C$) plus government consumption ($G$) equals labour income ($W{\cdot}L$) plus asset income ($r{\cdot}A$) net of the level of saving required to maintain the ratio of assets to GDP in the steady state ($g{\cdot}A$).

Thus, from a long-run perspective, one can think of $C$ as being determined more by the national income constraint than by the consumption function itself. However, the consumption function exerts an indirect influence on the determination of $C$ in the national income constraint because its saving decisions drive $A$. Under reasonable small open economy assumptions, the choice of consumption function will not influence the other long-run drivers of $C$, including $W$, $L$, $r$, $g$ and $G$.

We now consider how choosing an AM consumption function influences the long-run fiscal properties of a model. The simplest form of the AM consumption function, from equation (2.4) of Aron *et al.* (2012), is

$$C = \omega \cdot (W \cdot L - T) + \phi \cdot (A + B).$$

This can be solved simultaneously with the long form of the national income constraint and the government budget constraint to determine the long-run solution for $A$. The long-run solution for $A$ depends on two fiscal variables, $B$ and $G$:

$$A = \frac{(1-\omega) \cdot [W \cdot L - G] - [\phi - \omega \cdot (r-g)] \cdot B}{\phi - (r-g)}.$$

Hence, an increase in the stock of government bonds, $B$, reduces $A$, leading via the national income constraint to a reduction in $C$. Thus, under an AM consumption function, we have the well-known result that Ricardian equivalence does not hold. While this is reasonable as a short-run proposition, it is somewhat questionable as a long-run proposition because households may eventually see through the government veil and regard government debt not only as an asset but also as a liability.

Of greater concern is the long-run effect of changes in $G$. The solution for $A$ shows that an increase in $G$ leads to a fall in $A$. Thus, an increase in $G$ not only directly leads to a one-for-one fall in $C$ in the national income constraint, but also leads to a further fall in $C$ via $A$.

Thus, using an AM consumption function means that an increase in government consumption, even when fully funded by a lump-sum tax, leads to a more than matching fall in household consumption in the long run. This result of over-full crowding out lacks a convincing economic rationale. The same long-run problem arises if consumption is assumed to be a fixed proportion of current income, as in the traditional Keynesian consumption function.

The new macro model achieves long-run fiscal neutrality, defined as Ricardian equivalence in the long run, and exact crowding out of private consumption by government consumption in the long run, by using the new consumption function shown below, which is made up of two components as follows:

$$C = W \cdot L - T + (r-g) \cdot (A+B) + \phi \cdot (A - \theta \cdot W \cdot L).$$

The first component models household behaviour in a short run in which a flow equilibrium is achieved. This flow equilibrium is obtained by combining the steady-state forms of the national income constraint and the government budget constraint by eliminating $G$:

$$C = W \cdot L - T + (r-g) \cdot (A + B).$$

The economic interpretation of this is that equilibrium consumption is equal to current household income, $W{\cdot}L - T + r{\cdot}(A + B)$, net of a normal amount of saving ($g \cdot (A + B)$). This is similar to the traditional Keynesian consumption function, except that saving is modelled as a ratio to assets rather than to income. There is also a resemblance to the consumption function for liquidity constrained households that sets their consumption equal to after-tax labour income, $W \cdot L - T$ (e.g. McKibbin & Sachs, 1989).

Under this flow equilibrium approach, the level of asset holdings is indeterminate. This is addressed in the second component of the consumption function in which consumption responds to disequilibrium between the actual stock of national assets, $A$, and the target stock of those assets, which is assumed to be a ratio, $\theta$, of pre-tax labour income, $W \cdot L$. Similar to Aron *et al.* (2012) when they advocate the AM consumption function, it can be said this approach requires that households have 'only a rudimentary comprehension of life-cycle budget constraints', in contrast to the assumed 'well-informed households' of the Euler equation. The idea is that the asset-accumulation aims of households, for retirement living and other purposes, are driven by their labour incomes.

This raises the issues of which assets to include in the target and the measure of labour income on which the target is based.

The targeted asset holdings include national assets but not government bonds. Government bonds are excluded on the assumption that households eventually see through the government veil.

The national assets target is based on labour income before income tax is considered. Again, this is on the basis that households eventually see through the government veil. They value the government services funded out of personal income tax similarly to the private services they fund out of their remaining income. Thus, they consider that their living standards depend on both private and government services and hence are determined by their labour income before personal income tax.

The new consumption function, which might be described as a national asset target (NAT) consumption equation, is treated as an equilibrium relationship. Hence, the standard partial adjustment model is used in which actual consumption adjusts to this equilibrium, and this can be justified in the usual way by adjustment costs or consumer habit. One implication of this is that the marginal propensity to consume out of a fall in $T$ (i.e. a personal income tax cut or a government transfers increase) is unity in equilibrium but less than that initially.

Counter-cyclical fiscal policy is effective under the NAT consumption function because $T$ appears in the flow equilibrium component. At the same time, there is long-run fiscal neutrality in the sense defined above. This is because (unlike under an AM consumption function) the target for $A$ is independent of the fiscal variables ($B$ and $G$) in the stock equilibrium component.

Consistent with the life-cycle nature of asset accumulation decisions, stock equilibrium is achieved gradually. The quarterly rate of adjustment, $\phi$, is estimated at 0.027, implying a mean lag of 9 years. In that long-run equilibrium, consumption is stable relative to asset holdings and hence is following a sustainable path consistent with the intertemporal budget constraint.

The consumption equation in the model includes two additional refinements. First, the target ratio of national assets to labour income is modelled to depend positively on the real short-term interest rate. This introduces an additional transmission mechanism for monetary policy without disturbing the property of long-run fiscal neutrality.[6] Second, unanticipated inflation reduces consumption, an idea introduced by Deaton (1977). This affects the equation's dynamics, but not its long-run properties, because unanticipated inflation is zero in the steady state.

An alternative approach to obtaining long-run fiscal neutrality is to model consumption using the Euler equation, as in DSGE models. However, that removes the link from current income to consumption, so counter-cyclical tax policy is ineffective. Thus, those using DSGE models for fiscal policy analysis usually substantially modify the basic Euler equation. For example, in the models in Coenen *et al.* (2012), it is typically assumed that 20–50 per cent of households are financially constrained, introducing a link from current income to consumption.[7]

[6] It also means that we can accept that there is a cointegrating relationship between actual and target national assets. Without the real interest rate effect and an allowance for a structural shift in 1997, the Kwiatkowski–Phillips–Schmidt–Shin test for stationarity can be rejected at the 1 per cent level of significance, whereas with those effects stationarity cannot be rejected even at the 10 per cent level of significance.

[7] Similarly, the MSG model (McKibbin & Sachs, 1989) includes liquidity-constrained households alongside intertemporally optimising households.

In modelling a small open economy such as Australia, a further issue in using the Euler equation is that it requires a knife-edge condition on the rate of time preference (Turnovsky, 2002). In contrast, under the NAT consumption function, asset accumulation is stable and the asset level is positive in the steady state under the straightforward condition $\phi$, $\theta > 0$.

*Forecasting equation residuals*

The new macro model automates the forecasting of model inputs using time series analysis, including using a novel approach to forecasting equation residuals.

Traditionally, forecasts from macroeconometric models are prepared using *ad hoc* inputs for the exogenous variables. These exogenous variables usually include variables for government policy, the foreign sector and demography. However, as noted previously, this approach has been challenged by DSGE and VAR models, which treat these so-called exogenous variables as stochastic.

In response to this, data-generation processes have been developed for the exogenous variables in the new macro model. In this way, the process for forecasting the exogenous variables has been semi-automated. Another advantage is that impulse shocks for the exogenous variables can be devised, so that model shocks are random and calibrated, rather than arbitrary.

A distinguishing feature of this is the approach taken to forecasting the equation residuals. It attempts to bridge the gap between the purist view that residuals should be forecast at zero, and the practitioner's typical approach of eyeballing residuals towards the end of the historical period for evidence that equations have 'run off track' and then judgementally forecasting the off-track residuals.

For the new model, a forecasting equation has been estimated for each equation residual. These equations fit an AR(2) process and use weighted least squares (WLS) to place most weight on more recent data. The weights used decline geometrically back in time starting from the end of the historical estimation period. The decline factor used is 0.925 per quarter. The resulting forecasts for the equation residuals appear similar to what might be obtained using the traditional eyeballing method, but have the advantages of being both quick and reproducible.

These WLS AR(2) regressions for the residuals also provide useful equation diagnostics. Under the null hypothesis that each equation error term is well behaved, all of the parameters of each residual regression should be non-significant, including the constant term. When this is not the case, it signals that more work is required on an equation, when time permits, to bring the equation back 'on track'.

Kapetanios *et al.* (2019) use an alternative approach to placing more weight on the more recent data for forecasting purposes. Using the Bank of England's DSGE model known as COMPASS, they estimate the model allowing for time-varying parameters. The estimation method uses a normal kernel function with a bandwidth parameter of $\sqrt{T}$. The effect of this is that the parameter estimates for the end of the estimation period ($t = T$), which are used for forecasting ($t = T + 1, \ldots$), are obtained by placing weights on the data that decline back in time (as well as Bayesian priors).

This raises the interesting issue of how we should go about placing more weight on more recent data when preparing forecasts – at the estimation stage, the stage of forecasting residuals or both? Doing so at the estimation stage provides a more unified statistical approach, and Kapetanios *et al.* (2019) show that it improves the accuracy of COMPASS forecasts. However, it would still be possible for equations to run off track under the estimation stage approach because it is designed for 'slowly varying parameter processes' rather than abrupt shifts such as those associated with the global financial crisis. Hence it can be speculated that there may be a useful role for both approaches, but whether that is really the case is a subject for further research.

## III *Optimal Policy*

As mentioned in Section II, the new macro model has been set up to support optimal policy simulations. Optimal policy work has been undertaken previously for related models, including MM2 (Powell & Murphy, 1997) and the MMS model of Singapore (Monetary Authority of Singapore, 2017). This section presents optimal policy analysis for the latest (2019) version of the new model. The standard version of the model includes rules for both monetary and fiscal policy, intended to approximately represent the historical behaviour of policy makers. Here we examine how much better inflation and unemployment might be controlled if this historical policy approach is replaced with an optimal policy approach in the presence of certain macroeconomic shocks. The policy approaches are explained first, then the economic shocks are simulated under both policy approaches and finally the main findings are summarised.

*(i) Monetary and Fiscal Policy Rules*

We begin by summarising the historical approach to macro policy incorporated in the model before turning to the optimal policy approach. In the model, the monetary policy rule is estimated using historical data from 1996Q3 and aims to capture, in broad terms, the RBA's approach to monetary policy since the introduction of its targeting of consumer price inflation. In the estimated rule, the short-term interest rate (*RS*) is the monetary policy instrument and it adjusts, relative to the long-term interest rate (*RL*), in response to deviations of the inflation rate and unemployment rate (*URT*) from their respective targets (*INFT* and *NAIRU*). Here the long-term interest rate plays the role of the neutral interest rate.[8] The assumption made earlier that financial securities are perfect substitutes means that, in the long run, this neutral interest rate is determined by the exogenous foreign interest rate.

The inflation rate is constructed using the Consumer Price Index adjusted for the introduction of the goods and services tax in the third quarter of 2000 (*PCPIA*), consistent with Dungey and Pagan (2009). The change in the unemployment gap is also significant, with a negative coefficient. This may indicate that an increase in unemployment leads to expectations of further increases, inducing the RBA to loosen policy.

The monetary policy rule is given by

$$\begin{aligned} &RS(t) - RL(t) \\ &\quad = 0.12 \cdot [(PCPIA(t)/PCPIA(t-4) - 1) \\ &\qquad \cdot 100 - INFT(t)] - 0.43 \cdot [URT(t-1) \\ &\qquad - NAIRU(t-1)] - 0.66 \cdot \Delta[URT(t) \\ &\qquad - NAIRU(t)] + 0.64 \cdot [RS(t-1) - RL(t)] \\ &\qquad + RS\_A. \end{aligned}$$

Interestingly, this monetary policy rule is similar to the one included in the RBA's recently published MARTIN model (Ballantyne *et al.*, 2019), but both rules were developed independently. In both cases the short-term interest rate is modelled relative to a neutral interest rate and depends on inflation and unemployment gaps, the change in the unemployment gap and the lagged short-term interest rate. The main difference is that we estimate the equation's parameters, whereas MARTIN calibrates them.

The government budget must be sustainable in the medium to longer term. In the macro model this is achieved by setting a target government debt to smoothed, nominal GDP ratio (*RPUBLIT*). While in practice the government may achieve its fiscal target through a variety of measures such as tax increases or expenditure cuts, the macro model makes the simplifying assumption that fiscal sustainability is achieved through gradual adjustments in the average rate of personal income tax as it applies to labour income (*POLLAB*). This considerable simplification of choosing a single swing fiscal instrument is common in macro models and means fiscal policy rules are often calibrated, as is the case here, rather than estimated. In the rule used here, the labour income tax rate is increased when the deficit is above the deficit that is implied by the debt target and/or when debt is above its target. Because the tax base is the wage bill (*WBILL*) whereas the debt target refers to nominal GDP (*GDPZ*), changes in the tax rate are re-scaled by the ratio of *GDPZ* to *WBILL*. This maintains the effectiveness of changes in the tax rate in achieving the debt target when the labour share of GDP changes.

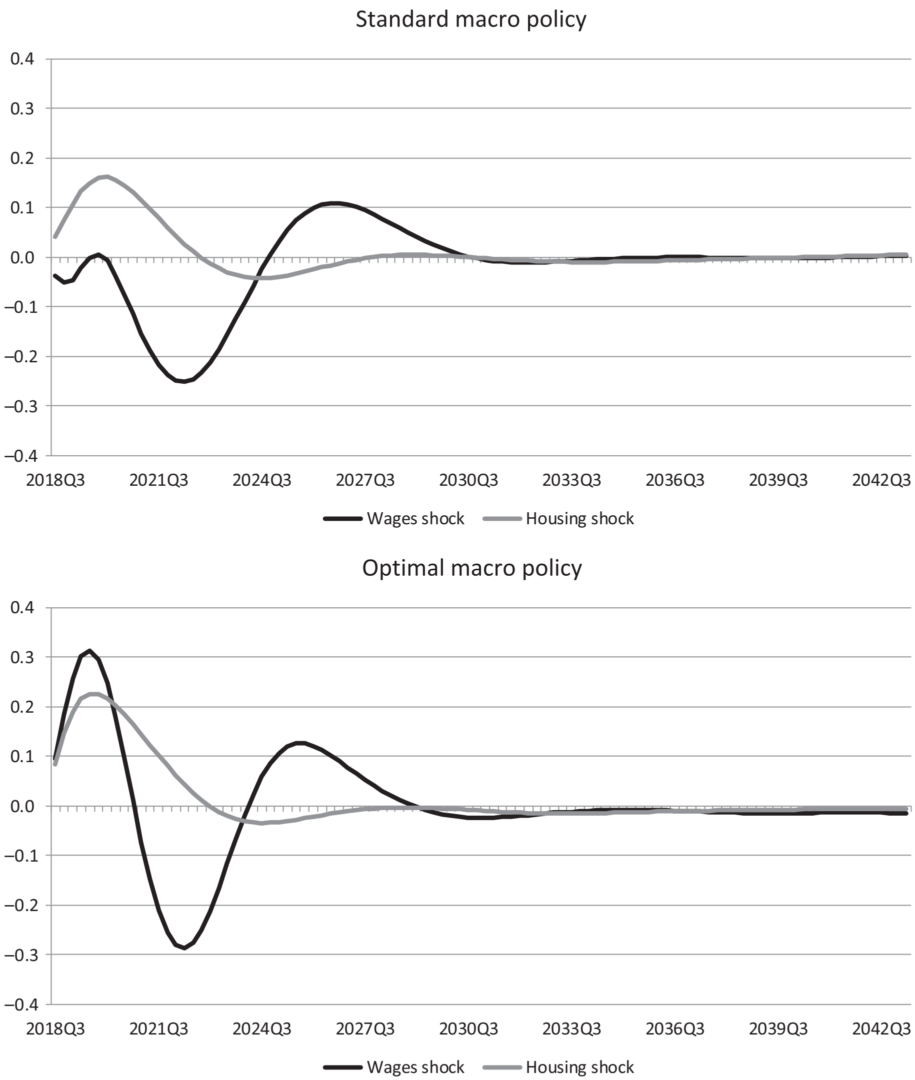
In calibrating the parameters of the fiscal policy rule, the parameter values are chosen so that, following a shock, public debt (*PUBLI*) returns to target in about 5 years. Besides the debt target, the rule includes a consistent target for the deficit (*PUBD*) involving the equilibrium rate of growth in nominal GDP (*GRZ*). This extension improves the performance of the tax rate in targeting debt. In addition to this endogenous modelling of the personal income tax rate (*POLLABN*), the rate can also be shocked exogenously (*POLLABX*). Thus, there is the fiscal policy rule and the final tax rate is obtained by adding the endogenous and exogenous components together in a second equation.

$$\begin{aligned} &\Delta POLLABN(t) \\ &\quad = \frac{GDPZ(t)}{WBILL(t)}\{0.125 \\ &\qquad \cdot \left[\frac{PUBD(t-1)}{SGDPZ(t-1)} - \frac{GRZ(t)}{1+GRZ(t)} \cdot RPUBLIT(t)\right] \\ &\qquad + 0.006 \cdot \left[\frac{PUBLI(t)}{SGDPZ(t)} - \frac{RPUBLIT(t)}{1+GRZ(t)}\right]\Big\}, \\ &\quad POLLAB(t) = POLLABN(t) + POLLABX(t). \end{aligned}$$

These representations of monetary and fiscal policy ensure that, in the long term, inflation is at the mid-point of the RBA's target range and that

[8] I owe this observation to Warwick McKibbin.

Figure 1
*Interest Rate Responses (% p.a.).*

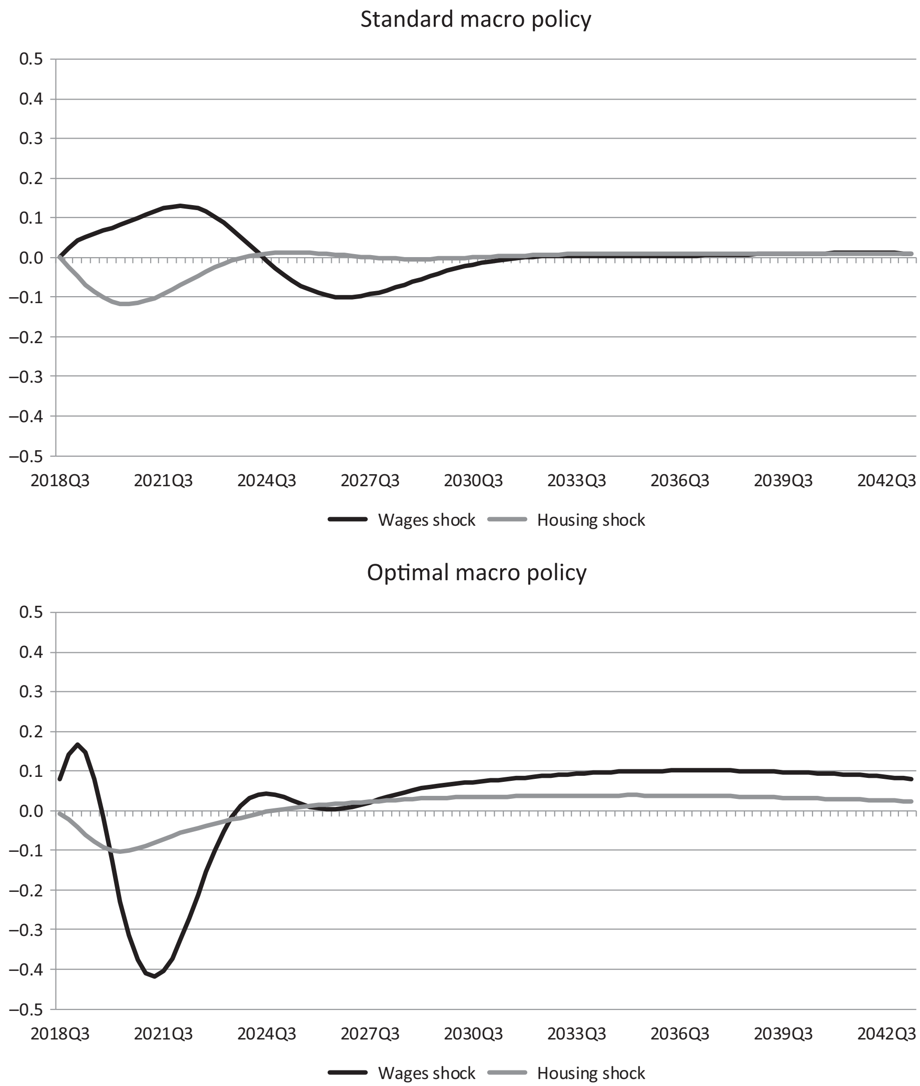



the government meets its inter-temporal budget constraint.

However, generally governments strive to set monetary and fiscal policy to minimise variability in inflation and unemployment in the face of economic shocks. Optimal control is a way of designing such macroeconomic policies. This involves minimising an appropriate social loss function, in which losses are incurred when inflation or unemployment deviate from their targets.

This loss minimisation problem can be approached in either of two ways. Closed loop

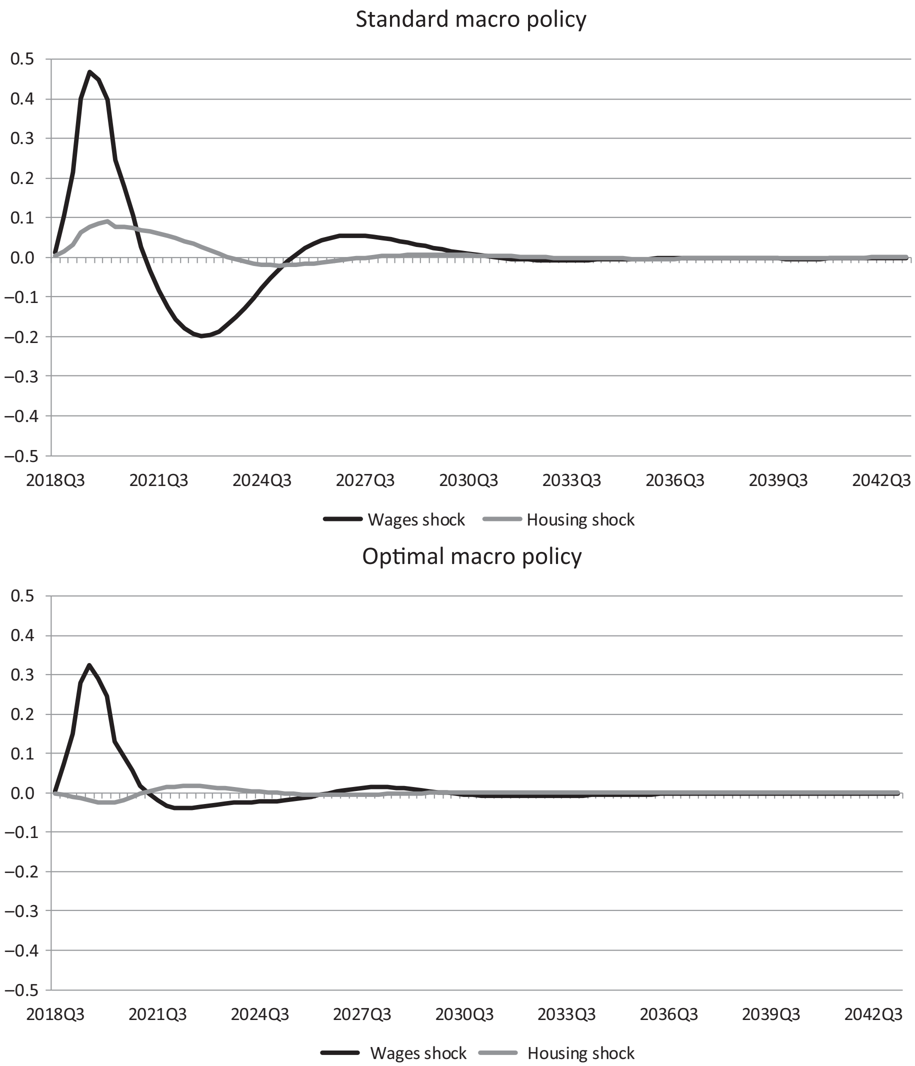
Figure 2
*Income Tax Rate Responses (Proportion of Income).*




optimal control searches for the optimal parameters for the policy rules in the face of the multiplicity of shocks represented in the model. Open loop optimal control discards the policy rules and instead optimises the quarter-by-quarter policy responses to each type of shock.

The more flexible approach of open loop optimal control will achieve lower social loss. However, this is because it demands more information; the policy-maker is assumed to instantly know the sources of all macro shocks. In contrast, the closed loop approach only requires that the

Figure 3
*Inflation Effects (% p.a.).*




policy-maker can observe the variables appearing in its policy rules. In reality, the actual information available to policy-makers probably lies somewhere in between. Here, open loop optimal control is used, although closed loop optimal control may be considered in future work.

Open loop optimal control can lead to time inconsistency in which the policy-maker reneges on its announced response to a shock. For example, the announcement of an anti-inflationary monetary policy may reduce inflation expectations, leading to lower wage demands, and this may make it unnecessary to fully implement the original, announced policy. However, such reneging undermines the policy-maker's credibility, so that future announcements may not be fully believed.

Here time inconsistency is avoided by assuming that the policy-maker commits to their original policy plan in response to each type of shock, similar to Brayton *et al.* (2014).

Under this open loop optimal control, paths for *RS* and *POLLAB* are chosen for a series of shocks to minimise a social loss function.

The social loss function penalises deviations in the inflation rate and unemployment rate above or below their target levels of 2.5 per cent per annum and 5.0 per cent, respectively. The target level for the inflation rate is set to the mid-point of the RBA's target range, while the target level for the unemployment rate is the current estimate of the NAIRU. The weight on the inflation rate target is normalised to 1, while the weight on the unemployment rate target is set to 2. This choice of relative weights is discussed later.

The policy instrument path to be chosen is selected as

$$RS\_A(t) \text{ and } POLLABX(t), \quad \text{for } t = 1, \ldots, 126,$$
to minimise social loss $L$,

$$L = \sum [1/(1+\delta)^t] \cdot \{\alpha_1 \cdot [100 \cdot (PCPI(t)/PCPI(t-4) - 1) - \gamma_1]^2 + \alpha_2 \cdot [URT(t) - NAIRU(t)]^2 + \alpha_3 \cdot [\Delta RS(t)]^2 + \alpha_4 \cdot [\Delta POLLAB(t) \cdot 100]^2 + \alpha_5 \cdot [\Delta(100 \cdot PUBLI(t)/SGDPZ)]^2\},$$
$$\text{for } t = 1, \ldots, 138.$$

In the above, the government and the central bank also face small penalties for large swings in the policy instruments and the level of public liabilities relative to smoothed GDP. This reduces the volatility of the optimal policy responses. This is on the basis that we rarely see policy-makers make large, erratic changes to policy instruments for small gains in targeting inflation and unemployment.

Following Brayton *et al.* (2014), future losses are discounted at a quarterly rate of 1 per cent. In practice, the optimal policy has only low sensitivity to the assumed discount rate because the model converges to a steady state in which the social loss is zero.

This set-up for optimal control of macro policy is similar to Murphy (1997) but adapted to the new model. It is also similar to the set-up used at the Fed by Brayton *et al.* (2014), except here the set-up is extended beyond monetary policy to also cover fiscal policy. Optimal control is simulated using the EViews *mcontrol.prg* add-in written by Brayton, customised to allow use of a quasi-Newton method.

*(ii) Shocks and Responses*

This optimal policy exercise aims to provide insights into the optimal policy responses to illustrative demand and supply shocks. This differs from Murphy (1997), who focused on the assignment of policy instruments to targets. Hence he analyses monetary and fiscal policy responses to changes to the inflation and unemployment rate targets, the latter being caused by an assumed change in the NAIRU.

The two illustrative impulse shocks are as follows:

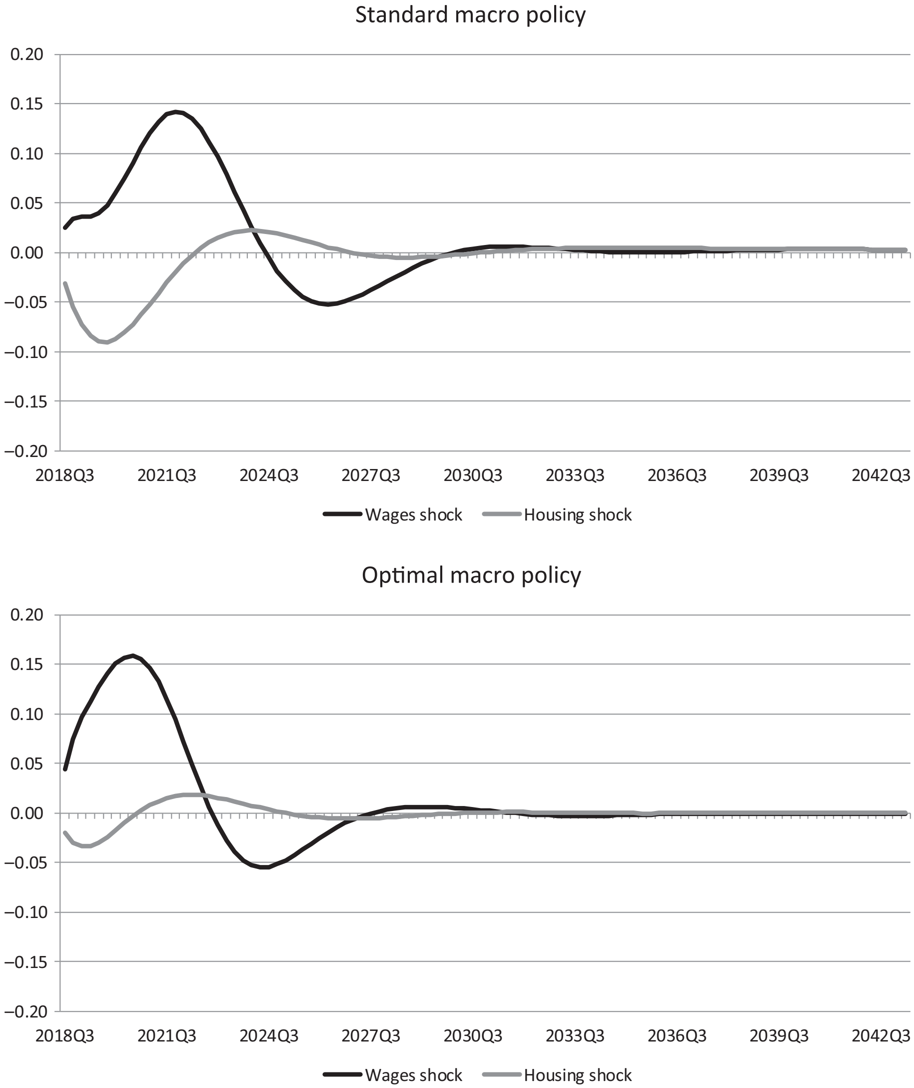
1. *Wage shock*. This impulse shock adds one standard error to the residual of the wage equation for one quarter. This is a type of temporary adverse supply shock. It leads to a simulated increase in wages in the first quarter of 0.79 per cent.
2. *Housing shock*. This shock adds one standard error to the residual of the housing investment equation for one quarter. This is a temporary, positive domestic demand shock. It leads to a simulated increase in housing investment in the first quarter of 3.7 per cent.

These shocks are introduced into two alternative macroeconomic policy environments. The first environment is based on the model's standard policy rules. The second environment replaces these rules with open-loop optimal control. Results under the two policy environments are compared to draw lessons for macroeconomic policy. The main impulse responses are shown in Figures 1–4. These figures show the responses for the two instruments and the two main targets.

The impulse shock to wages lifts inflation directly, and also indirectly through an induced depreciation of the nominal and real exchange rate. Under the standard macro policy response, this leads to a small increase in the short-term interest rate. Inflation is contained only gradually.

Under the optimal macro policy, the short-term interest rate increases more sharply, supported by a

Figure 4
*Unemployment Rate Effects (% of Labour Force).*




tightening of fiscal policy. This combination of policy responses moderates the depreciation of the exchange rate. This is successful in reducing the spike in the inflation rate, at the cost of a slightly bigger initial spike in the unemployment rate, but the economy then stabilises more quickly.

The impulse shock to housing investment lifts GDP, thereby reducing unemployment and lifting inflation. Under the standard macro policy response, this automatically leads to a small increase in the short-term interest rate. On the other hand, the boost to government revenue from higher economic activity leads to a cut in the income tax rate under the debt- and deficit-based policy rule. This exacerbates the boost to domestic demand from the housing shock.

Under the optimal macro policy, initially interest rates are raised by more and income tax is cut by less. This tighter macroeconomic policy environment brings inflation under control much more quickly and is associated with greatly reduced fluctuations in unemployment.

*(iii) Summary*

Two main conclusions emerge from the results of the two shocks. First, monetary and fiscal policy are more forward looking under open loop optimal control than under the default policy rules. This is because open loop optimal control assumes that monetary authorities are very well informed, knowing the sources of all economic shocks instantly.

Second, the open loop optimal control, compared to the default policy rules, shows a major improvement in targeting inflation, but not much improvement in targeting unemployment. Two alternative explanations can be offered for this.

It might suggest that the optimal policy places an excessively high weight on inflation stability. However, this does not appear to be the case because the loss function places only half the weight on inflation that it places on unemployment, yet the Fed version places the same weight on both.

Alternatively, it might suggest that the RBA places an unusually low weight on targeting inflation. Even placing a relatively low weight on inflation in our loss function, we are able to target inflation considerably more tightly than under the default policy rule representing the RBA's approach. The fact that at the time of writing the RBA had undershot its inflation target for several consecutive years is consistent with the idea that the weight it places on the inflation target is not high.

Overall, the impulse responses and the optimal policy analysis appears broadly reasonable. This is encouraging in that Pagan (1997) notes that optimal control can be a useful form of model validation.

## REFERENCES


Aron, J., Duca, J.V., Muellbauer, J., Murata, K. and Murphy, A. (2012), 'Credit, Housing, Collateral, and Consumption: Evidence from Japan, the U.K., and the U.S', *Review of Income and Wealth*, **58**, 397–423.

Ballantyne, A., Cusbert, T., Evans, R., Guttmann, R., Hambur, J., Hamilton, A., Kendall, E., McCririck, R., Nodari, G. and Rees, D. (2019), *'MARTIN Has Its Place: A Macroeconometric Model of the Australian Economy'*, Research Discussion Paper 2019-07, Reserve Bank of Australia, Sydney.

Boneva, L., Fawcett, N., Masolo, R. and Waldron, M. (2019), 'Forecasting the UK Economy: Alternative Forecasting Methodologies and the Role of Off-Model Information', *International Journal of Forecasting*, **35**, 100–20.

Brayton, F., Laubach, T. and Reifschneider, D. (2014), 'Optimal-Control Monetary Policy in the FRB/US Model', Fed Notes, 21 November.

Chau, C. and Robinson, T. (2018), 'Why Has Australian Wages Growth Been So Low? A Phillips Curve Perspective', *Economic Record*, **94** (S1), 11–32.

Coenen, G., Erceg, C., Freedman, C., Furceri, D., Kumhof, M., Lalonde, R., Laxton, D., Lindé, J., Mourougane, A., Muir, D., Mursula, S., Resende, C., Roberts, J., Roeger, W., Snudden, S., Trabandt, M. and Veld, J. (2012), 'Effects of Fiscal Stimulus in Structural Models', *American Economic Journal: Macroeconomics*, **4**, 22–68.

Deaton, A. (1977), 'Involuntary Saving through Unanticipated Inflation', *American Economic Review*, **67**, 899–910.

Dungey, M. and Pagan, A. (2000), 'A Structural VAR Model of the Australian Economy', *Economic Record*, **76**, 321–42.

Dungey, M. and Pagan, A. (2009), 'Extending a SVAR Model of the Australian Economy', *Economic Record*, **85**, 1–20.

Gibbs, C., Hambur, J. and Nodari, G. (2018), '*DSGE Reno: Adding a Housing Block to a Small Open Economy Model*', Research Discussion Paper 2018-04. Reserve Bank of Australia, Sydney.

Gruen, D., Pagan, A. and Thompson, C. (1999), 'The Phillips curve in Australia', *Journal of Monetary Economics*, **44**, 223–58.

Kapetanios, G., Masolo, R.M., Petrova, K. and Waldron, M. (2019), 'A Time-Varying Parameter Structural Model of the UK Economy', *Journal of Economic Dynamics and Control*, **106**, 103705.

Laforte, J. (2018), 'Overview of the Changes to the FRB/US Model', *Fed Notes*, 7 December.

Lkhanaajav, E. (2016), '*CoPS Style CGE Modelling and Analysis*', CoPS Working Paper No. G-264, Victoria University, Melbourne.

McKibbin, W. and Sachs, J. (1989), '*The McKibbin-Sachs Global Model: Theory and Specification*', NBER Working Paper No. 3100, National Bureau of Economic Research, Cambridge, MA.

McKibbin, W.J. and Wilcoxen, P.J. (1999), 'The Theoretical and Empirical Structure of the G-Cubed model', *Economic Modelling*, **16**, 123–48.

Monetary Authority of Singapore (2014), '*The Monetary Model of Singapore (MMS): A Technical Overview*', Economic Policy Group, Monetary Authority of Singapore, Singapore. Available from: https://www.mas.gov.sg/monetary-policy/Macroeconometric-Models.

Monetary Authority of Singapore (2017), '*Optimal Control in The Monetary Model of Singapore*', *MAS Macroeconomic Review* (April), 78–84.

Murphy, C. (1988a), 'An Overview of the Murphy Model', *Australian Economic Papers*, **27** (Suppl 1), 175–99.

Murphy, C. (1988b), 'Rational Expectations in Financial Markets and the Murphy Model', *Australian Economic Papers*, **27** (Suppl 1), 61–88.

Murphy, C. (1992), 'The Steady State Properties of a Macro-econometric Model', in Hargreaves, C. (ed), *Macroeconometric Modelling of the Long Run*. Edward Elgar, Aldershot, UK; 159–205.

Murphy, C. (1997), 'Optimal Control of a National Economic Model', *Control Engineering Practice*, **5**, 535–48.

Murphy, C. (2017), *'Review of Economic Modelling at the Treasury', report to the Australian Treasury, March*. Available from: https://cdn.tspace.gov.au/uploads/sites/99/2017/05/Review-of-Economic-Modelling-at-Treasury.pdf.

Murphy, C., Bright, I., Brooker, R., Geeves, W. and Taplin, B. (1986), '*A Macroeconometric Model of the Australian Economy for Medium-Term Policy Analysis*', Technical Paper No. 2, Office of the Economic Planning Advisory Council, Canberra.

Pagan, A. (1997), 'Whatever Happened to Optimal Control of Econometric Models?', *Control Engineering Practice*, **5**, 527–33.

Pagan, A. and Robinson, T. (2016), '*Investigating the Relationship between DSGE and SVAR Models*', NCER Working Paper 112, National Centre for Econometric Research, Brisbane. Available from: http://www.ncer.edu.au/papers/documents/WP112.pdf.

Powell, A. and Murphy, C. (1997), *Inside a Modern Macroeconomic Model — A Guide to the Murphy Model*, 2nd edn. Springer, Berlin.

Rees, D., Smith, P. and Hall, J. (2016), 'A Multi-sector Model of the Australian Economy', *Economic Record*, **92**, 374–408.

Ryan, M. and Szeto, K.L. (2009), '*An Introduction to the New Zealand Treasury Model*', Working Paper 09/02, New Zealand Treasury, Wellington. Available from https://treasury.govt.nz/sites/default/files/2009-09/twp09-02.pdf.

Sims, C. (1980), 'Macroeconomics and Reality', *Econometrica*, **48**, 1–48.

Smets, F. and Wouters, R. (2007), 'Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach', *American Economic Review*, **97**, 586–606.

Smith, J. and Murphy, C. (1994), 'Macroeconomic Fluctuations in the Australian Economy', *Economic Record*, **70**, 133–48.

Stock, J. and Watson, M. (2001), 'Vector Autoregressions', *Journal of Economic Perspectives*, **15**, 101–15.

Turnovsky, S. (2002), 'Knife-Edge Conditions and the Macrodynamics of Small Open Economies', *Macroeconomic Dynamics*, **6**, 307–35.

Winner, A. (2005), ''Has Tax Competition Emerged in OECD Countries? Evidence from Panel Data', *International Tax and Public Finance*, **12**, 667–87.