Special Feature A

MAS Macroeconomic Modelling Workshop 2014[1]

Introduction

The Economic Policy Group (EPG) at the MAS organised a Macroeconomic Modelling Workshop in August 2014. The event was attended by about 70 participants comprising local academics, private sector analysts, and public sector and MAS economists. The purpose of the Workshop was to promote an appreciation of EPG's macroeconomic models and their use in forecasting and policy analysis. The focus was on the two workhorse models in EPG's suite of macroeconometric models—the Monetary Model of Singapore (MMS) and the Satellite Model of Singapore (SMS). In addition, Douglas Laxton, the Division Chief of the Economic Modelling Division at the IMF, opened the event with a discussion of current work at the Fund on macroprudential policy models.

The aim of this Special Feature is to summarise the key points and issues brought up by discussants and participants at the Workshop. We begin by reviewing the history of modelling at the MAS, tracing how this has paralleled developments and progress in the field at large and, in particular, how it aligns with the four generations of macroeconometric models identified by Hall *et al.* (2013). Some of the new work being done at the IMF on incorporating financial sector linkages into existing models is briefly presented. Next, the economic theory underlying the EPG models and the econometric methodologies employed to estimate them are described, together with the key points raised in the discussions.

Macromodelling at the MAS

MAS' history of modelling goes back to the early 1980s with initial forays into the partial econometric analysis of key behavioural relationships, such as consumption, savings, and crucially, exports. However, it was only after the 1985 recession, that systematic work on building an economy-wide general equilibrium model gained traction. This arose from the need for a robust quantitative framework to assess the effects of external shocks on a small, open economy, and to identify the transmission mechanisms associated with particular policy levers. These early initiatives in macroeconomic model building were guided by Jared Enzler, a former associate director at the Federal Reserve Bank of New York.

The history of macromodelling at MAS has broadly paralleled developments in the field at large. In Hall *et al.* (2013), Adrian Pagan and his

[1] EPG gratefully acknowledges the contributions of the session chairs, presenters, discussants, panellists and participants at the MAS Macroeconomic Modelling Workshop 2014. In particular, we would like to thank Tilak Abeysinghe, Martin Bodenstein, Chia Ngee Choon, Hoon Hian Teck, Douglas Laxton, Dinar Prihardini, Tan Khee Giap, Toh Mun Heng and Peter Wilson.

co-authors identified four generations of macroeconometric models.[2] At least modest variants of their 2G, 3G and 4G models can be seen in terms of MAS' own model developments.

First, the Singmod built by Jared Enzler in 1990, which bears distinct similarities to the MPS model of the US economy, is essentially 2G. Apart from detailed specifications for the GDP expenditure categories in the national accounting identity, the Singmod is supplemented by equations that introduced robust supply-side features. The presence of a non-accelerating inflation rate of unemployment (NAIRU) is another key defining characteristic of Singmod and of 2G models in general. In Singmod, it plays an important role in specifying the price-equilibrating mechanism.

Second, the successor to Singmod launched in 2000, the MMS, was built in collaboration with Chris Murphy of Independent Economics.[3] The MMS comes close to sharing properties with 3G models, which revolve around a steady-state or balanced growth path with extraneous dynamics grafted onto it. In addition, the deviations between long-run equilibria and the current values of macroeconomic variables contain useful information for characterising and forecasting the short-term adjustment of the economy to shocks. 3G models, including the MMS, lend themselves naturally to error-correcting specifications.

Third, the SMS was the outcome of EPG's joint work with Werner Schule, Douglas Laxton and his team from the IMF in 2011, who introduced the possibilities of small-scale Dynamic Stochastic General Equilibrium (DSGE), or New Keynesian, modelling. The SMS marked the incorporation of 4G properties into EPG's modelling work.[4] Thus, shocks are recognised as an explicit part of the model and lagged structures are specified as a function of adjustment costs and agents' expectations. Essentially, the SMS revolves around the three-equation configuration typical of the New Keynesian framework: an aggregate demand schedule, a supply curve, and a monetary policy reaction function.

The current approach at the MAS, which embraces pluralism in modelling, is centred on a 3G model, the MMS, complemented by a limited 4G satellite boost from the SMS.

Recent Initiatives

In the wake of the Global Financial Crisis (GFC), newer modelling initiatives are currently being pursued. Hall *et al.* (2013) mooted the idea of a Fifth Generation (5G) of models that could capture interactions between the financial and real sectors of the economy in a parsimonious and effective way. In this regard, the MAPMOD Mark 1 model presented by Douglas Laxton at the MAS Workshop is a good example of such a development.

The MAPMOD is designed specifically to study the risks associated with excessive credit expansions and asset price bubbles. An important feature of the model is its ability to capture non-linear interactions between borrowers' indebtedness, bank balance sheets and the real economy. This is a most relevant feature, as simulations of MAPMOD suggest that the interactions between the real economy, asset prices, and financial conditions could be severely underestimated

[2] First Generation (1G) models began with Jan Tinbergen, who built a 24-equation model to evaluate policies to counter the Great Depression. Following a long period of development that was dominated by the Keynesian orthodoxy of the time, the 1970s saw the emergence of Second Generation (2G) models that explicitly modelled the supply side through the introduction of an aggregate production function. Later, Third Generation (3G) models reversed what had been the common approach to model design by first constructing a steady-state model and then grafting extraneous dynamics onto it to achieve congruence with the data. Finally, the Fourth Generation (4G) models that appeared in the 2000s represent a class of models that has come to be known in the literature as Dynamic Stochastic General Equilibrium models.

[3] For a description of the systemic properties of the MMS, see MAS (2007).

[4] The SMS is presented in more detail in MAS (2011).

in a crisis. In the MAPMOD, the non-linear feedback effects stem essentially from the distribution of aggregate risks on banks' loan books (Benes *et al.*, 2014). First, loan losses can result in a serious erosion of banks' capital adequacy, taking them close to, or even below, their minimal regulatory requirements. This can lead to a rapid contraction in lending and consequently higher credit spreads, as banks replenish their equity buffers.

Second, loan losses also indicate that the balance sheets of borrowers have become more vulnerable as a result of falling asset values. The resulting sharp increases in loan-to-value ratios provide another motivation for a reduction in lending and higher spreads. In this way, the non-linear responses of financial variables act as an amplifying mechanism that exacerbates the balance sheet problems of borrowers and of the banks themselves.

Invariably, the MAPMOD's focus on banks' credit risks that cannot be completely diversified and its ability to replicate the basic features of financial cycles make it a useful framework for assessing macroprudential policy trade-offs.

Theoretical Economic Underpinnings

Despite belonging to different generations, the MMS and the SMS broadly share the same theoretical underpinnings with Keynesian features in the short run and neoclassical characteristics in the long run. The key differences lie in model size and complexity: as the summary in Table 1 shows, the MMS has 353 equations in five equation blocks, compared to 41 equations in the more compact SMS.

The Monetary Model of Singapore (MMS)

The MMS is Keynesian in the short run, with output determined by aggregate demand, but it also has neoclassical long-run properties. First, the economy reverts to its steady-state balanced growth path in the long run. Hence, real variables grow according to the rate of Harrod-neutral technological progress plus the rate of growth of labour. While monetary policy has real effects in the short to medium run, it is neutral in the long run. In Singapore's case, this means that permanent changes in the nominal exchange rate would be offset by corresponding changes in domestic inflation. Finally, the unemployment rate converges to a well-defined NAIRU in the long run.

The MMS can be broadly split into several blocks: domestic demand, consisting of behavioural equations for private consumption and investment; trade, where imports and exports are modelled for broad sectors of the economy; the labour market, which follows a structural modelling approach and includes an aggregate wage equation; fiscal policy, which is exogenously given; and monetary policy, which closes the model.

The MMS provides a detailed and consistent perspective on the Singapore economy. First, the production approach to GDP is integrated with the expenditure approach. For instance, the output produced in the manufacturing sector will either be exported, consumed or invested. Second, employment, investment, exports, imports and domestic supply are disaggregated into sectors and are derived from the optimising behaviour of producers. This is complemented by a third behavioural dimension, which attempts to capture the decisions of households that determine macroeconomic variables such as private consumption, the labour force participation rate and wages.

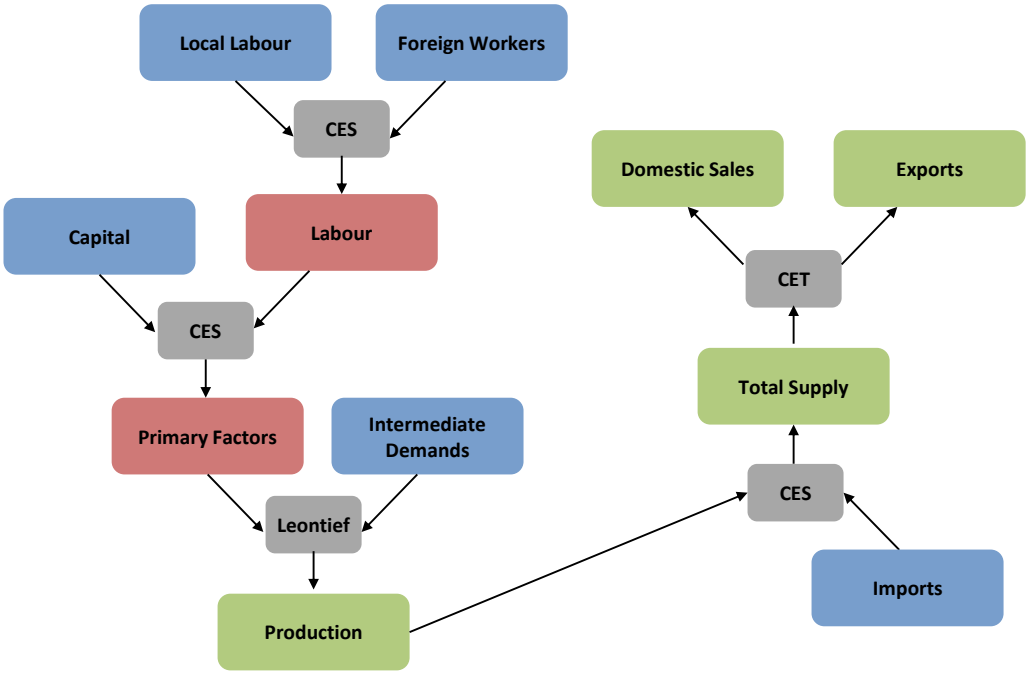
In the MMS, GDP viewed from the supply side is disaggregated into five sectors, linked via input-output relationships calibrated from Singapore's Input-Output tables. Each sector has its own production function, such that exogenous shocks work through the production side of the economy. This allows the impact of policy changes to be assessed on a sectoral basis.

To match Singapore's economic circumstances, the traditional closed economy production function has been modified in the MMS to allow for an explicit role for exports and imports, as depicted in Figure 1 below. Primary factors of production, including local labour, foreign workers and capital inputs, are first combined using a Constant Elasticity of Substitution (CES) function. Next, the primary factors and intermediate inputs are transformed into output via a Leontief production function. Lastly, domestic production and imports are brought together in another CES function to yield total supply, which is then allocated to domestic sales and exports using a Constant Elasticity of Transformation (CET) function.

The MMS recognises that firms may not always be in equilibrium. Firms' optimising behaviour is captured in the 47 behavioural equations for variables such as exports, imports, and local and foreign labour demand. These equations follow error-correction specifications which clearly distinguish between long-run equilibria and short-run dynamics. In the model, disequilibria result from nominal rigidities which are, in turn, due to sticky wages and prices.

Forward-looking expectations in the financial markets are also incorporated into the MMS, albeit in a limited fashion, through two key relationships. The first dictates that short-term interest rates are determined by the uncovered interest parity (UIP) condition, which links domestic interest rates to foreign interest rates and expected exchange rate movements. The second makes long-term bond rates dependent on short-term interest rates, following the expectations theory of the term structure. In all other markets, expectations are assumed to be mainly adaptive.

Figure 1
Open Economy Production Function in the MMS



In the MMS, the Singapore economy interacts with the external environment through several channels. First, GDP growth in Singapore's major trading partners and the global electronics book-to-bill ratio influence the demand for manufacturing exports. Second, as a small open economy, Singapore is assumed to be a price taker. This means that foreign export and import prices enter the model primarily through their influence on the demand for Singapore's exports and imports used in domestic production and consumption. Third, foreign short-term interest rates and exchange rates affect the domestic economy, via the UIP condition. Fourth, the

demand for foreign workers is an important variable in producers' decisions.

The Satellite Model of Singapore (SMS)

In the modelling spectrum, the SMS lies midway between DSGE and reduced-form econometric models. In accord with the New Keynesian concept of imperfect markets, output is determined in the short run by aggregate demand, due to nominal and real wage rigidities. However, agents are forward-looking in the model, and form rational expectations of the future trajectories of output and monetary policy. The fundamental role of monetary policy is to provide a nominal anchor for inflation. Although it lacks the detailed structure of the MMS, the SMS shares some key long-run properties with its larger counterpart. The economy converges to its potential growth rate, while unemployment converges to the NAIRU. Further, monetary policy does not affect real variables in the long run due to the neutrality of money.

In terms of modelling strategy, the SMS is fundamentally a gap model in which most of the key variables are expressed as deviations from their equilibrium values. There are three key behavioural equations: an aggregate demand or output gap equation, a supply equation or New Keynesian Phillips curve, and a monetary policy equation motivated by the Taylor rule. This reaction function is specifically designed for Singapore's unique circumstances, in which monetary policy is centred on the trade-weighted nominal exchange rate.

A modified UIP equation and a dynamic version of Okun's Law relating the unemployment gap to the output gap, complete the main equation block of the model. More recently, the SMS has been enhanced by the inclusion of financial variables that capture the impact of higher capital requirements and credit constraints on the real economy. These variables provide crucial links between the financial and real parts of the model.

Discussion

In terms of economic underpinnings, the Workshop discussion focused on the following issues: (1) modelling the tradable and non-tradable sectors of the economy separately; (2) specifying reaction functions for households and firms; and (3) ensuring that the models reflect the unique characteristics of the Singapore economy.

With regard to the first issue, it was suggested that an adequate modelling of the real effective exchange rate required a distinction to be made between the tradable and non-tradable sectors of the economy. The main concern was that Baumol's "cost disease" could arise, even with monetary neutrality and purchasing power parity holding in the long run.[5] Thus, such a distinction would allow tradable and non-tradable prices to be determined endogenously in the model, taking into account the Baumol effect.

While it was recognised that the MMS does not explicitly distinguish between the two sectors, the model does capture changes in tradable and non-tradable prices within the industry structure of the MMS itself. This is because each of the five sectors modelled incorporate their own structural differences in trade and factor intensities. For instance, the construction sector does not produce for export and is a purely domestic industry. Manufacturing, in comparison, is highly export-oriented, while the services sectors are typically less so. Since the MMS has been calibrated to take into account these differences, the decisions of producers and households are based on relative factor and product prices which reflect varying sectoral trade and factor intensities, as well as productivity levels. Hence, an explicit identification of the tradable and non-tradable sectors (and their price ratio) may not be necessary.

As for reaction functions, both the MMS and SMS models incorporate explicit formulations of central bank behaviour that are variants of the

[5] Baumol's "cost disease", also known as the Baumol-Bowen effect, occurs when rising wages in sectors with slower productivity growth leads to generalised increases in costs that are unmatched by aggregate productivity gains.

Taylor rule. For instance, in the SMS, the equilibrium values of the S$NEER can be solved endogenously as a function of model-consistent values for output and the inflation gap. Alternatively, for policy simulation purposes, the stance of monetary policy can be fixed exogenously by setting a pre-determined path for the S$NEER. The exchange rate policy affects the behaviour of households and firms via its effects on prices. In the MMS, the consumption behaviour of households is based on the Ando-Modigliani theory, with equilibrium consumption determined by current labour income and domestically-owned wealth. Firms are assumed to maximise profits, subject to the production technologies described earlier. In the SMS, however, both households and firms are implicitly assumed to know the monetary policy rule and to take it into account in economic decision-making.

This implies that in both models, agents make decisions with the expectation that the central bank achieves price stability in the medium term. For example, in the MMS, the aggregate consumption function models the dynamic adjustment of actual consumption to its equilibrium level through a Deaton effect, in which real consumption is reduced if inflation exceeds its long-term expected rate.

As far as the third issue is concerned, it was pointed out that the MMS and SMS appear to share broad structural characteristics with their "external" counterparts—the Australian Murphy Model 2 (MM2) and the IMF's Global Projection Model (GPM7). However, great pains have been taken to ensure that these models capture the unique characteristics of the Singapore economy. In the case of the MMS, the model has been acclimatised to local conditions and is calibrated and estimated using Singapore data, including the Input-Output tables.

In the SMS, the monetary policy reaction function captures Singapore's exchange rate-centred monetary policy framework, with the nominal exchange rate appearing as the dependent variable in the modified Taylor rule, in place of the policy interest rate. The recently introduced financial variables in the model are also designed specifically to suit the local context. These variables capture the impact of changes in credit conditions on the Singapore economy via cyclical and trend components, with the latter being influenced by the capital requirements stipulated by MAS and other global regulators. Finally, foreign variables, such as the output gaps and price levels in Singapore's trading partners, are brought directly into the SMS, weighted by these countries' relative trade shares with Singapore. These shares are regularly updated with the release of new trade data.

Econometric Methodology

This section describes the econometric methodologies employed in the MMS and SMS, including model calibration, Bayesian estimation and single equation error-correction mechanisms, followed by key points raised at the Workshop discussion.

Model Calibration

The parameters of the behavioural equations in the MMS are mainly estimated by Ordinary Least Squares. In some instances, reasonable values for the parameters need to be calibrated mainly because of data limitations. However, the imposed values are kept strictly within two standard deviations of their freely estimated values. In the MMS, calibration is usually applied to out-of-model sources of information and especially to the elasticities of substitution and transformation. Further, to ensure the robustness of the calibrated equations, diagnostic tests are applied to the equation residuals to ensure that the model is well-specified.

In the SMS, Bayesian estimation is complemented by the calibration of particular model parameters. This enables the model to readily accommodate policymakers' views about the economy that are derived from a variety of sources, including expert judgement and empirical information taken from

other economies. This eclectic approach helps to ensure that the SMS has a reasonable fit, obtains appropriate results from a theoretical perspective, and yet is able to produce sensible forecasts and policy simulation results.

Bayesian Approach

Unlike the MMS, the SMS is estimated using Bayesian methods, which provide a middle ground between classical estimation and the calibration of macroeconomic models. A key reason for adopting this approach is that the economic structure of the model is viewed as being more important than merely fitting the model to data.

Bayesian methods use a wide set of information to parameterise the structural macroeconomic model. As such, some weight is placed on the priors of the researchers, as well as the data. By specifying the tightness of the distributions on the priors, the relative weights for determining the posterior distribution of the model parameters can be changed. In this way, theoretical insights can be incorporated to prevent misguided empirical results, while simultaneously confronting the model with data.

The Bayesian approach also overcomes small sample estimation bias, which is particularly important for macroeconomic data that is often available for only short time periods. The ability to work with small samples means that Bayesian estimation is able to characterise structural or fast-moving changes in the economy more effectively. This is especially pertinent for a small, open economy such as Singapore.

Single Equation Error-correction Models

Many of the behavioural equations in the MMS are estimated as single equation error-correction models (ECMs). Kennedy (2008) describes economic theory as playing two roles in the development of these types of models. First, the theory suggests appropriate explanatory variables to include in the ECM; and second, it identifies long-run equilibrium relationships among economic variables which, if not exactly satisfied, will set in motion economic forces to bring them into equilibrium.

ECMs are typically developed in two stages. First, a standard econometric equation is specified including all the explanatory variables, together with the lagged values of the dependent variable. Second, this equation is reformulated to produce an error-correction term—which represents the extent to which the long-run equilibrium is not met—thus transforming the equation into an error-correction model.

In the MMS, some equations are also specified as partial adjustment models. Murphy and Powell (1997) show that these models are essentially equivalent to ECMs, especially when they involve only first-order differences of the dependent variable.

Discussion

The discussions on econometric methodology covered the following issues: (1) the appropriateness of the model for forecasting and policy analysis; (2) the use of single equation error-correction models; and (3) the choice between classical, Bayesian or calibration approaches in parameter estimation.

It was recognised that the design features of a model used principally for forecasting would usually require more disaggregation and detail than one focused on macroeconomic policy simulation, where theoretical tractability is more important. As such, it is preferable not to overburden models with multiple roles. The approach adopted at MAS is one of pluralism, i.e. different models or modelling styles are best suited for different purposes. As such, MAS does not rely on a single model, but rather a suite of models, depending on the policy objective.

With regard to equation specification, it was suggested that attempting to improve the fit of a single equation could actually worsen the forecasting performance of an entire model. A related concern was that the use of ECMs in

certain situations could lead to spurious conclusions, especially if the short-run dynamics are tagged onto the main model in an *ad hoc* manner. The example cited was that of fiscal policy, since its underlying dynamics are fundamentally intertemporal in nature. In this case, the parameters that influence the short-run dynamics when there is a change in government debt (in a non-Ricardian model) would not be independent of their long-run comparative statics.

To mitigate this concern, single equation and whole system diagnostics are systematically applied to the large MMS model. In particular, all single equation error-correction models in the MMS are checked to ensure that they lead to plausible model-wide simulation properties.

Finally, the issue of different approaches to estimation focused on the difficulties in applying classical estimation methods to large equation systems, such as the MMS. In some instances, further calibration is required to derive meaningful results. Moreover, in a large model, it is sometimes necessary to adjust the freely-estimated values so that the model as a whole can provide reasonable responses to exogenous shocks. Even so, calibration is mainly applied to the elasticities of substitution and transformation, as these parameters govern the sensitivity of the responses of macroeconomic variables to changes in prices in a macro computable general equilibrium model of the MMS variety. Further, the values of the calibrated parameters should be kept within a reasonable band that is appropriate for a small, open economy like Singapore.

According to the Bayesian view, these issues can be effectively resolved, since when the data is less informative, it will be automatically discounted by using an appropriate Bayesian technique. This is indeed the approach adopted in the SMS, and it represents a pragmatic compromise between classical estimation techniques and the calibration of macroeconomic models.

Sum-up

The MAS Modelling Workshop was organised with the objective of sharing EPG's suite of models with a wider audience of academics and private sector analysts. To this end, valuable feedback has been received from Workshop discussants and participants. Nonetheless, there is clearly scope to enhance the modelling of the Singapore economy, for example to take into account episodic shocks from the financial system, such as during the 2008–09 crisis.

At the MAS, the quest for better models has always been a collaborative endeavour involving a great deal of technological transfer from visitors and consultants. To this effect, the Modelling Workshop was an important platform to further this process, and it underscores EPG's commitment to create opportunities for meaningful collaboration with researchers in academia and industry.[6]

[6] As part of this process, MAS is releasing the documentation for the MMS and the SMS at the following web link: http://www.mas.gov.sg/Monetary-Policy-and-Economics/Education-and-Research.aspx

Table 1
Model Description

	Monetary Model of Singapore (MMS)	Satellite Model of Singapore (SMS)
Year of (Initial) Model Development	1999	2010
Data Frequency	Quarterly	Quarterly
Size		
Total Number of Equations	353	41
Behavioural Equations	47	5
Identity & Other Equations	306	36
Total Number of Variables	486	59
Key Blocks/Equations	**Trade** • Export and import demand functions for three sectors: o Manufacturing o Financial and Business Services o Other Goods and Services **Sectoral** • Production functions for five sectors, with interlinkages: o Manufacturing o Construction o Housing Services o Financial and Business Services o Other Goods and Services **Labour Market** • Inflation expectations-augmented Phillips curve. • Endogenous labour supply of locals and foreigners, given resident demographics. **Households** • Ando-Modigliani Consumption Function **Firms** • CES Production Functions • Tobin's "q" Theory of Investment	**Aggregate Demand** • The level of real GDP is influenced by backward and forward-looking domestic output gaps, the real exchange rate, real interest rate and the composite output gap in our trading partners. • Changes in credit conditions and their effect on GDP are also captured. **Phillips Curve** • The hybrid New Keynesian Phillips curve determines inflation, which is modelled as a function of its past and future values, the output gap, and the real exchange rate. **Monetary Policy Function** • S$NEER path is kept consistent with the required real exchange rate adjustment in the medium term. • The rate of appreciation also responds to the output gap and the deviation of expected inflation from its target.
Theoretical Underpinnings	• New Keynesian in the short run; Neoclassical in the long run.	• New Keynesian in the short run; long-run parameters are calibrated.
Econometric Approach Specification and Estimation	• Partial Adjustment Model • Error Correction Model • Ordinary Least Squares • Estimated using Eviews	• Bayesian Estimation System • Estimated and simulated using Matlab and Iris
Modelling of Expectations	• Rational expectations in the financial markets. Adaptive expectations in others.	• Rational and adaptive expectations in key relationships.
Special Features	• Detailed modelling by sector and expenditure components. • Endogenously determined equilbrium demand for factors of production. • Rational expectations in the financial markets. • Utilises MAS' Demographic Model of Singapore (DMS).	• Can be integrated with the IMF Global Projection Model (GPM7). • Uses an exchange rate-based Taylor rule for optimal monetary policy.

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