Monetary Authority of Singapore

The Satellite Model of Singapore (SMS): A Technical Overview

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1. INTRODUCTION

1.1. In Nov 2009, EPG undertook a feasibility study for a dynamic stochastic general equilibrium (DSGE) model for the Singapore economy, in collaboration with the International Monetary Fund (IMF) Research Department. The first working version of the model was built in June 2010 and thereafter referred to as the Satellite Model of Singapore (SMS). Subsequent enhancements and revisions were made in Feb 2011, which mainly involved introducing financial linkages into the model.

1.2. Since then, the SMS has been used to develop economic forecasts, generate alternative scenarios, and conduct monetary policy analysis. It is seamlessly integrated with the GPM7[1], a global projection model that is maintained by the IMF, which makes it a powerful tool to analyse the impact of global shocks to the Singapore economy.

1.3. Following this introduction, we describe the modelling framework in Section 2, expound on the specification of the SMS in Section 3, and describe the estimation procedures in Section 4. Section 5 highlights the properties of the model using impulse response functions, while Section 6 simulates the impact of a foreign demand shock. Section 7 concludes. This documentation is pitched at a technical level as it details the equation specifications, and accordingly will be of interest to modellers and practitioners working in the area. However, the presentation of the macroeconomic framework adopted in the SMS will have a wider appeal.[2]

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[1] The Global Projection Model, which is used to model global output, is developed and maintained by the IMF. The latest version, GPM7, comprises seven country/regional blocs that include all of Singapore's major trading partners. The GPM7 allows for interactions between the different regions through traditional trade channels as well as a financial channel. A detailed IMF Working Paper on the GPM has been released by the IMF Research Department. (Link: http://www.imf.org/external/pubs/ft/wp/2013/wp1387.pdf).

[2] Interested readers can also refer to a less technical overview of the SMS in October 2011 issue of *Macroeconomic Review.*

2. MODELLING FRAMEWORK

2.1. The SMS blends the New Keynesian concept of imperfect markets with DSGE models that incorporate rational expectations. Nominal and real rigidities are permitted by setting prices to adjust gradually to changing economic conditions. Under these assumptions, the economy may therefore fail to attain full employment in the short run, **suggesting a "stabilisation" role for policy** and allowing the SMS to be used for monetary policy analyses.

2.2. Although the SMS is not explicitly based on microeconomic foundations, many of its features are nonetheless motivated by economic theory. Moreover, certain model parameters are calibrated, so that it captures more realistically existing and expected future economic conditions. The SMS, therefore, adopts a pragmatic approach where modellers engage in theory but not fully for its own sake.

2.3. The SMS has three key behavioural equations: (1) an aggregate demand or output gap equation; (2) a price-setting or New Keynesian Phillips curve equation; and (3) a monetary policy equation motivated by the Taylor rule. A modified uncovered interest rate parity (UIP) equation and a dynamic version of Okun's Law, where **the unemployment gap is related to the output gap**, completes the main equation block of the model. A financial module was added in Feb 2011 to capture the impact of higher capital requirements and credit constraints on the real economy.

3. MODEL SPECIFICATION

3.1. OVERVIEW

3.1.1.1. In the SMS, output, employment, inflation, interest rates and exchange rates are jointly determined. It is fundamentally a gap model, in which the deviations of the variables from their equilibrium values play a crucial role in modelling the dynamics of the economy, alongside a number of key identities.

3.2. DATA DEFINITIONS

3.2.1.1. The model has six observable domestic variables: real GDP, the unemployment rate, CPI inflation, interest rates, exchange rates, and the credit spread indicator (*CSI*). The variables are defined as follows:

(i) *LGDP* is computed as 100 times the log of real GDP. *LGDP_BAR* is equal to 100 times the log of potential output. *Y*, the output gap is obtained in percentage terms as $Y_t = LGDP_t - LGDP\_BAR_t$.[3]

(ii) *UNR_GAP*, the unemployment gap, is defined as the difference between the equilibrium unemployment rate (or NAIRU), *UNR_BAR*, and the actual unemployment rate (*UNR*).

(iii) *LCPI* is equal to 100 times the log of the CPI. *PIE*, the quarterly rate of inflation (annualised) in percent, is defined as 4 times the first difference of *LCPI*. Also, the year-on-year measure of inflation, *PIE4*, is the difference of *LCPI* in the current quarter from its value four quarters earlier.[4]

(iv) *RS* is the nominal interest rate, and *RR* is the real interest rate defined as the difference between the nominal interest rate and the expected rate of inflation for the subsequent quarter i.e. $RR_t = RS_t - PIE_{t+1}$.

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[3] Multiplying the *LGDP* and *LGDP_BAR* variables by 100 permits the output gap to be measured in percentage points.

[4] This is the same as defining *PIE4* as the simple average of the last four quarters' (contemporaneous quarter plus three lagged quarters) annualised q-o-q rate of inflation.

(v) *LS* is equal to 100 times the log of the S$NEER. *LZ* is the log of the real exchange rate, where $LZ_t = LS_t - LCPIF_t + LCPI_t$. *LCPIF* is the foreign CPI computed from the weighted CPI of the various blocs in GPM7 using Singapore's import shares. Both *LS* and *LZ* are defined so that an increase in their values represents a nominal and real appreciation of the S$, respectively.

(vi) *DOT_LS* is the q-o-q rate of change in the S$NEER. *LS* comprises a gap and a trend component, *LS_GAP* and *LS_BAR* respectively. Similarly, *LZ* is the real exchange rate, with a gap and a trend component, *LZ_GAP* and *LZ_BAR,* respectively.

(vii) The Credit Spread Indicator (*CSI*) is a key financial variable in the model that captures the spread between the consumer loan and deposit rates (an indicator of the cyclicality of credit conditions) and banks' net interest margin.

(viii) *PIEF* is the foreign rate of inflation. *YF* is the aggregate foreign output gap.

3.3. STOCHASTIC PROCESSES

3.3.1. Overview of the Bayesian Approach

3.3.1.1. The Bayesian approach to estimation makes it possible to specify and estimate fairly flexible stochastic processes, as well as allowing more stochastic shocks than observable variables to be specified. This is especially useful for modelling unobserved variables in the SMS, for example, in the NAIRU equation which includes stochastic processes for its levels and growth rate. As such, the model is able to capture both temporary and permanent changes to equilibrium levels.

3.3.1.2. In addition, Bayesian techniques have the benefit of placing some weight on the priors of the researchers and some weight on the data over the sample period.

3.3.1.3. This section elaborates on the stochastic processes of the *equilibrium variables* used in the model, namely, for potential output, NAIRU, the equilibrium real interest rate, and exchange rates. The following section focuses on the modelling of *key observable* variables in the SMS.

3.3.2. Potential Output

3.3.2.1. Equations (1) and (2) are formulated so that there can be shocks to both the level and growth rate of potential output – this means that shocks to the level can be permanent, while shocks to the growth rate can result in highly persistent deviations in potential growth from its long-run steady-state growth path.

$$LGDP\_BAR_t = LGDP\_BAR_{t-1} + \frac{G_t}{4} - \frac{\nu}{4} \cdot \left(\frac{CSI\_BAR_t - CSI\_BAR_{t-40}}{40} \right) + RES\_LGDP\_BAR_t \tag{1}$$

$$G_t = \tau \cdot growth\_ss + (1-\tau) \cdot G_{t-1} + RES\_G_t \tag{2}$$

3.3.2.2. Specifically, equation (1) depicts *LGDP_BAR* as a function of its own lagged value and the quarterly growth rate (*G*/4), together with a disturbance term, *RES_LGDP_BAR*, which allows for permanent level shifts in potential GDP. *CSI_BAR*, the trend component of *CSI* (to be elaborated on below), also enters into the potential GDP equation. This allows any trend increase in *CSI* to behave in a similar manner to a negative supply shock, posing a drag to potential output.

3.3.2.3. Equation (2) models the long run growth rate of potential GDP, G_t, to equal its steady-state rate of growth, *growth_ss*. However, it can diverge from this steady-state growth following a positive or negative value of the disturbance term (*RES_G*), and will return to *growth_ss* gradually, with the speed of convergence dependent on the value of τ.

3.3.3. NAIRU

3.3.3.1. The specifications for the NAIRU equations corresponding to equations (3) and (4) are similar to those for potential output. It is therefore also affected by both temporary (*RES_UNR_BAR*) and permanent shocks (*RES_UNR_G*).

$$UNR\_BAR_t = (1-\alpha_3) \cdot UNR\_BAR_{t-1} + \alpha_3 \cdot unr\_ss + UNR\_G_t + RES\_UNR\_BAR_t \tag{3}$$

$$UNR\_G_t = (1-\alpha_4) \cdot UNR\_G_{t-1} + RES\_UNR\_G_t \tag{4}$$

3.3.4. Equilibrium Real Interest Rate

3.3.4.1. Equation (5) models the equilibrium real interest rate, *RR_BAR*, as a function of the steady-state real interest rate, *rr_bar_ss* and the lagged value of *RR_BAR*. In this formulation, the equilibrium real interest rate can diverge from its steady state value in response to a stochastic shock given by RES_RR_BAR.

$$RR\_BAR_t = \rho \cdot rr\_bar\_ss + (1-\rho) \cdot RR\_BAR_{t-1} + RES\_RR\_BAR_t \qquad (5)$$

3.3.5. Exchange Rates

3.3.5.1. The q-o-q rate of change in the trend component of the nominal and real exchange rate, *DOT_LS_BAR* and *DOT_LZ_BAR* respectively, is formulated as follows:

$$DOT\_LS\_BAR_t = 4 \cdot (LS\_BAR_t - LS\_BAR_{t-1}) + RES\_LS\_BAR_t \qquad (6)$$

$$DOT\_LZ\_BAR_t = 4 \cdot (LZ\_BAR_t - LZ\_BAR_{t-1}) + RES\_LZ\_BAR_t \qquad (7)$$

3.3.5.2. The stochastic processes that govern both variables are given by equations (8) and (9).

$$\begin{aligned} &DOT\_LZ\_BAR_t = \psi \cdot dot\_lz\_ss + (1-\psi) \cdot DOT\_LZ\_BAR_{t-1} \\ &+RES\_DOT\_LZ\_BAR_t \end{aligned} \qquad (8)$$

$$\begin{aligned} &DOT\_LS\_BAR_t = DOT\_LZ\_BAR_t + (PIETARF - PIETAR) \\ &+RES\_DOT\_LS\_BAR_t \end{aligned} \qquad (9)$$

3.3.5.3. Equation (8) shows that the equilibrium real exchange rate growth converges to its steady state growth rate, *dot_lz_ss*, according to a partial adjustment process. In comparison, the equilibrium nominal exchange rate in equation (9), moves in line with the real exchange rate and the differential between the foreign and domestic inflation targets. The steady state and target variables are calibrated to reflect long-run trends and/or policy choices.

3.4. BEHAVIOURAL EQUATIONS

3.4.1. Output Gap

3.4.1.1. Equation (10) is the aggregate demand (AD) equation with backward and forward looking output gaps which relates to the level of real activity. The level of real activity in Singapore's trading partners, the real exchange rate, and the short-term real interest rate are also included.

$$Y_t = \overbrace{\beta_1 \cdot Y_{t-1} + \beta_2 \cdot Y_{t+1}}^{\text{Domestic Effects}} - \overbrace{\beta_4 \cdot LZ\_GAP_{t-1}}^{\text{Policy Effect}} - \overbrace{\beta_3 \cdot \left(RR_{t-1} - RR\_BAR_{t-1}\right) + \beta_5 \cdot YF_t}^{\text{External Effects}} \underbrace{- \beta_6 \cdot E2\_CSI_t}_{\text{Financial Effect}} + RES\_Y_t \qquad (10)$$

3.4.1.2. Four main effects can be seen in the AD equation, as depicted in the equation above. The **domestic effect**, which is simply a typical AD equation for a closed economy in the New Keynesian Paradigm[5], is captured by the lead and lagged values of the output gap. The own-lag term allows for inertia in the system and permits shocks to have persistent effects, while the lead term allows more complex dynamics and introduces forward-looking elements into AD.

3.4.1.3. Within the SMS, it is the real exchange rate that provides the crucial link between monetary policy and the real economy. The effect of monetary policy on the real economy (**policy effect**) is captured by the effective real exchange rate gap, *LZ_GAP*. As equation (10) shows, a higher real exchange rate will have dampening effects on economic activity and hence the output gap, as given by the negative sign on its coefficient. This could take place as a result of either a stronger nominal exchange rate appreciation or a higher domestic inflation rate.

3.4.1.4. The next two terms capture the open economy influences (or **external effects**) on the output gap, with the real interest rate gap reflecting the indirect external link in the transmission mechanism between monetary

[5] The typical demand equation under this paradigm will also usually include the real interest rate variable. For Singapore, this has been categorised under 'external effects' as interest rates are affected by the exchange-rate centred monetary policy through the UIP condition.

policy actions and the real economy via changes in domestic interest rates. If the domestic real interest rate rises above its equilibrium value, it will have a negative effect on real domestic activity. The foreign output gap that follows, *YF*, captures the direct spillovers from foreign demand effects due to our major trading partners. It is an average of the foreign output gap from the Global Projection Model (GPM7), weighted by Singapore's export shares. This is a particularly important feature of the SMS that allows it to be seamlessly integrated with the GPM7, which enabled the external outlook to be fed directly into the SMS. It thus permits an analysis of external shocks to be introduced in a model-consistent manner.

3.4.1.5. The *CSI* residual or *E2_CSI* term (**financial effect**) represents the financial linkage to the real economy in the SMS, capturing the impact of higher capital requirements and unwarranted changes in credit conditions. There are two channels through which the *CSI* variable impacts the real economy.

3.4.1.6. **First**, it affects AD via the following relationships. Equation (11) defines *CSI_GAP* as the difference between the measured *CSI* and a trend component, *CSI_BAR*. It is modelled in equation (12) to move in line with the future output gap as credit conditions are typically tightened or eased as a result of future economic conditions. If the actions of banks to tighten or loosen credit is typical for the particular stage of the cycle, the interest rate variable would by itself pick up the normal tightening and easing of bank lending conditions, in which case *CSI_GAP* would have little role to play in driving future economic conditions. However, if their actions are greater or less than typical, this could have a direct causal effect on the ability of borrowers to access funds to accommodate their expenditures. The residual term in this equation, *RES_CSI_GAP* (which is equated to *E_CSI* in equation 13), in fact, captures any such unwarranted changes in credit conditions. For example, when credit conditions are tightened by more than warranted by the future path of the economy, *E_CSI* would provide an additional negative impact to AD.

$$CSI\_GAP_t = CSI_t - CSI\_BAR_t \tag{11}$$

$$CSI\_GAP_t = \omega \cdot Y_{t+4} + RES\_CSI\_GAP_t \tag{12}$$

$$E\_CSI_t = RES\_CSI\_GAP_t \tag{13}$$

3.4.1.7. In the output gap equation, the financial effect is captured by *E2_CSI*, which is a function of past values of *E_CSI*. (Equation 14) Thus, if the credit conditions are tougher than warranted by future economic behaviour, *E_CSI* will be positive and the effect will be a smaller output gap.

$$E2\_CSI_t = f\begin{pmatrix} E\_CSI_{t-1}, E\_CSI_{t-2}, E\_CSI_{t-3}, \\ E\_CSI_{t-4}, E\_CSI_{t-5}, E\_CSI_{t-6}, E\_CSI_{t-7} \end{pmatrix} \quad (14)$$

3.4.1.8. The **second** channel through which the *CSI* variable impacts the real economy involves *CSI_BAR*, the trend component of *CSI*, which enters into the potential GDP equation (1). Any trend increase in the *CSI* is captured by *CSI_BAR* and behaves like a negative supply shock. *CSI_BAR* is, in turn, linked to *CAPREQ_BAR* in equation (15), which reflects the Tier-1 capital requirements set by MAS. Should MAS increase these requirements, there will be a trend increase in *CSI_BAR*, which could then have a second order effect on potential output.

$$\begin{aligned} CSI\_BAR_t &= (1-\chi_1)\cdot(\chi_3 - \chi_2\cdot\chi_4) + \chi_1\cdot CSI\_BAR_{t-1} \\ &+(1-\chi_1)\cdot\chi_2\cdot CAPREQ\_BAR_t + RES\_CSI\_BAR_t \end{aligned} \quad (15)$$

3.4.1.9. The values of χ_3 and χ_4 are calibrated at the current Tier-1 capital requirement. If future capital requirements do not change, equation (15) simplifies and *CSI_BAR* will remain unchanged from its historical value. This, in turn, will leave the potential output unchanged.

3.4.1.10. Even though the *CSI* is modelled in some detail in the SMS, the macro-economic effects of the financial channel are quite small. This suggests that only changes in credit conditions beyond a certain critical threshold, has the capacity to bring about economically significant changes.

3.4.2. Inflation

3.4.2.1. Inflation is modelled according to the hybrid Phillips curve in equation (16), embodying some key ideas from the contemporary macroeconomic synthesis regarding the role of monetary policy, which is to provide a nominal anchor for inflation.

$$\begin{aligned} PIE_t &= \lambda_1\cdot PIE_{t+1} + (1-\lambda_1)\cdot PIE_{t-1} + \lambda_2\cdot Y_t - \lambda_3\cdot LZ\_GAP_t \\ &-\lambda_4\cdot RES\_G_t - \lambda_5\cdot RES\_LGDP\_BAR_t \\ &+\lambda_6\cdot RES\_CAPREQ\_BAR - RES\_PIE_t \end{aligned} \quad (16)$$

3.4.2.2. As such, the equation links inflation to its past and future values, the output gap, the change in the real exchange rate gap, three residuals from other equations, and its own disturbance term, *RES_PIE*.

3.4.2.3. The estimate of λ_1 measures the relative weight attached to forward- and backward-looking elements in the inflation process, with the output gap playing a crucial role in linking the inflation rate to the real economy. Also, the rate of inflation is influenced by the change in the effective real exchange rate gap, with an appreciation having a tightening effect on the economy and hence a negative impact on the inflation rate.

3.4.2.4. In addition, three residuals terms also enter the inflation equation. The first and second residuals are *RES_G*, the shock to the potential growth rate, and *RES_LGDP_BAR*, the shock to the level of potential output. These residual terms capture the notion that a positive supply shock to either the growth rate or the level of potential output will exert downward pressure on costs and prices, and hence reduce the inflation rate. The third residual term, *RES_CAPREQ_BAR*, captures any shock to the Tier-1 capital requirement (modelled as being similar to a 'potential shock'). Thus, if the capital requirement increases, *RES_CAPREQ_BAR* will take a positive value and result in higher inflation. This is similar to a negative supply shock that reduces potential output and increases inflation.

3.4.3. Monetary Policy

3.4.3.1. In models such as the GPM7, monetary policy is often expressed in terms of a rule for setting the nominal policy interest rate. However, in Singapore's context, this default setting has to be modified given Singapore's unique exchange-rate centred monetary policy framework. Following Eric Parrado (2004), the monetary policy reaction function in the SMS is therefore expressed in terms of the trade-weighted exchange rate index, the S$NEER (*LS* in model notation). Accordingly, the dependent variable in the reaction function is the deviation of the growth rate of *LS* from its equilibrium rate, which is consistent with the "Crawl" feature of the BBC framework. As described earlier in equation (9), the equilibrium growth rate of the S$NEER (or *DOT_LS_BAR*) moves in line with the real exchange rate and the difference between the foreign and domestic inflation targets. Altogether, the monetary policy reaction function can be expressed as equation (17):

$$\begin{aligned} &DOT\_LS_t - DOT\_LS\_BAR_t = \gamma_1 \cdot \left(DOT\_LS_{t-1} - DOT\_LS\_BAR_{t-1}\right) \\ &+(1-\gamma_1)\cdot\{\gamma_2 \cdot (PIE^4_{t+3} - PIETAR) - \gamma_3 \cdot LS\_GAP_t + \gamma_4 Y_t\} \\ &+RES\_DOT\_LS_t \end{aligned} \tag{17}$$

3.4.3.2. Here, the rate of change of the S$NEER is expressed as a function of its own lag (a smoothing device), MAS' responses to both the movements in the output gap and the deviation of the expected inflation rate from its target. More precisely, the MAS aims at achieving a S$NEER path over time that is consistent with the required real exchange rate adjustment, but adjusts this rate accordingly in response to deviations of the expected year-on-year rate of inflation three quarters in the future from the inflation target and the current output gap. Also, the disturbance term, *RES_DOT_LS*, allows for the S$NEER to deviate from the path indicated by the causal variables.

3.4.4. Uncovered Interest Parity (Modified)

3.4.4.1. The model also features a modified uncovered interest parity (UIP) equation, from which the local nominal interest rates are determined. (Equation 18)

$$RS_t = \kappa \cdot \begin{Bmatrix} (RR\_US_t + PIEF_{t+1}) - 4 \cdot (LS\_E_t - LS\_E_{t-1}) \\ +(RR\_BAR_{t+1} - RR\_BAR\_US_{t+1}) \end{Bmatrix} + (1-\kappa) \cdot RS_{t-1} + RES\_RS\_DIFF_t \quad (18)$$

3.4.4.2. The local 3-month SIBOR (*RS*) is influenced by the foreign nominal interest, the expected change in the S$NEER, as well as the difference in the equilibrium real interest rates between Singapore and the US.[6] This is the typical UIP condition, with the coefficient κ determining how well the condition is met in the immediate period. The remaining weight (1-κ) is placed on the lag of the nominal interest rate and is used to smooth the series. There is also a disturbance term, *RES_RS_DIFF*, which allows for shocks to the UIP condition. These shocks may be interpreted as a risk premium shock.

3.4.4.3. Finally, expectations about the S$NEER, *LS_E*, is modelled as a function of its past and future values in equation (19).

$$LS\_E_t = \rho \cdot LS_{t+1} + (1-\rho) \cdot LS_{t-1} \quad (19)$$

[6] The foreign nominal interest in this case is simplified by taking the sum of the real interest rate in the US and global inflation. The expected change in the S$NEER is multiplied by four to transform the quarterly rate of change to an annual rate in order to make it comparable to the interest rate differentials. The difference in the equilibrium real interest rates between Singapore and the US is equivalent to an equilibrium risk premium/discount for Singapore vis-à-vis the US.

3.4.5. Unemployment Rate

3.4.5.1. Equation (20) is a dynamic version of Okun's law, in which the unemployment gap is modelled as a function of its own lag, the contemporaneous output gap, and a disturbance term.

$$UNR\_GAP_t = \alpha_1 \cdot UNR\_GAP_{t-1} + \alpha_2 \cdot Y_t + RES\_UNR\_GAP_t \qquad (20)$$

3.4.5.2. This equation is used to measure the output gap in real time by exploiting the correlation between changes in the output gap and the contemporaneous and future changes in the unemployment gap.

4. CONFRONTING THE MODEL WITH DATA

4.1.1. The SMS is estimated using the Bayesian estimation technique, which provides a middle ground between relying on classical estimation methods and calibration of macro models. A key reason behind adopting this approach is that the economic structure of the model is more important than purely fitting the data. Rather than estimating a reduced-form model empirically, the Bayesian approach calls for a wider set of information to help parameterize the structural macroeconomic model. Invariably, Bayesian methods place some weight on the priors of the researchers, as well as the data over the sample period. By specifying the tightness of the distribution on the priors, one can change the relative weights in determining the posterior distribution of the model parameters. In this way, theoretical insights can be incorporated to prevent misguided empirical results, while confronting the model with data. This approach also overcomes the small sample estimation bias, which is particularly important for macro data that tends to be available over shorter 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 important for a small dynamic economy like Singapore.

4.1.2. In the SMS, Bayesian estimation is also complemented by the calibration of certain model parameters. This enables the model to readily accommodate policymakers' views about the economy that are derived from a variety of sources, including policy choices and information from the literature. This eclectic approach helps to ensure that the SMS has reasonable fit, obtains appropriate results from a theoretical perspective, and is able to produce sensible forecasts and results for policy simulations.

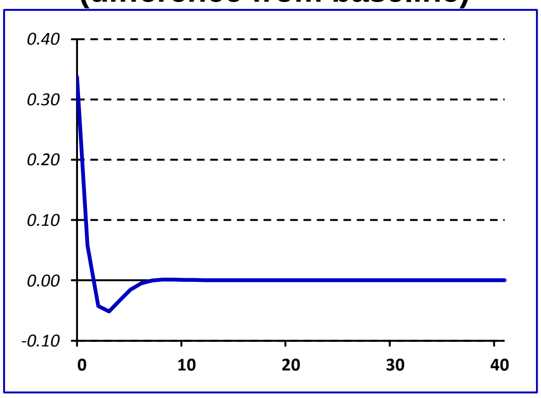
5. IMPULSE RESPONSE FUNCTIONS

5.1.1. Impulse Response Functions (IRFs) are used to trace the reaction of the endogenous variables in the system to exogenous shocks. Charts 5.1 to 5.6 present a few selected IRFs from the SMS model simulations, where all shocks are set equal to one standard deviation of the disturbance term of the corresponding equation over the sample period.

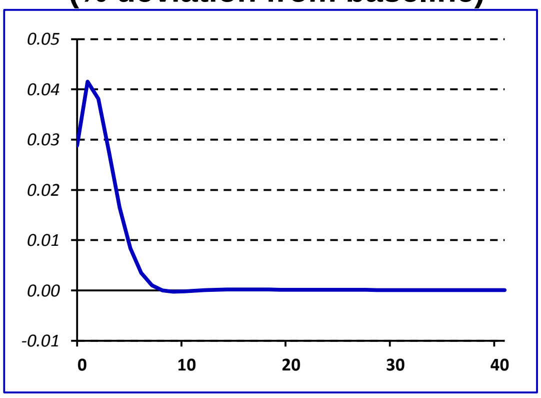
5.1.2. Chart 5.1 shows the effect of a shock to the output gap (*RES_Y* shock), which reflects an increase in AD. The AD shock leads to an immediate increase of about 0.34% in domestic GDP, with real activity remaining above baseline for an additional quarter. The higher output results in a more persistent increase in price levels that lasts for about 10 quarters and a consequent fall in unemployment rate below the baseline. Also, the S$NEER appreciates in response to this positive demand shock. As expected, all variables revert to their baseline values in the long run.

Chart 5.1
Shock to RES_Y

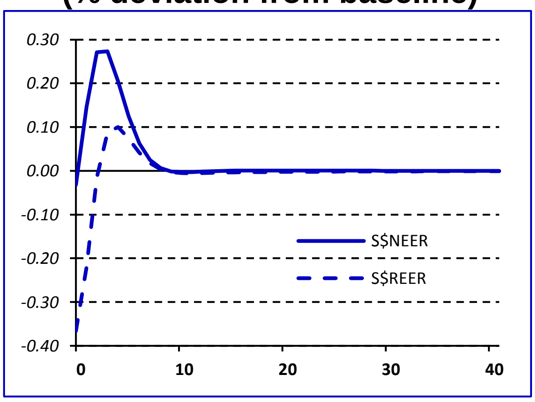
(a) Output Gap
(difference from baseline)



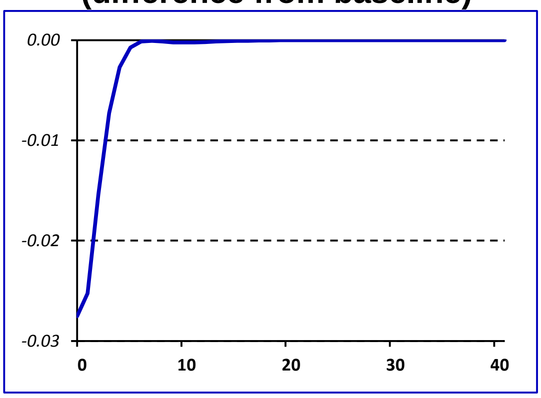
(b) CPI
(% deviation from baseline)



(c) S$NEER
(% deviation from baseline)

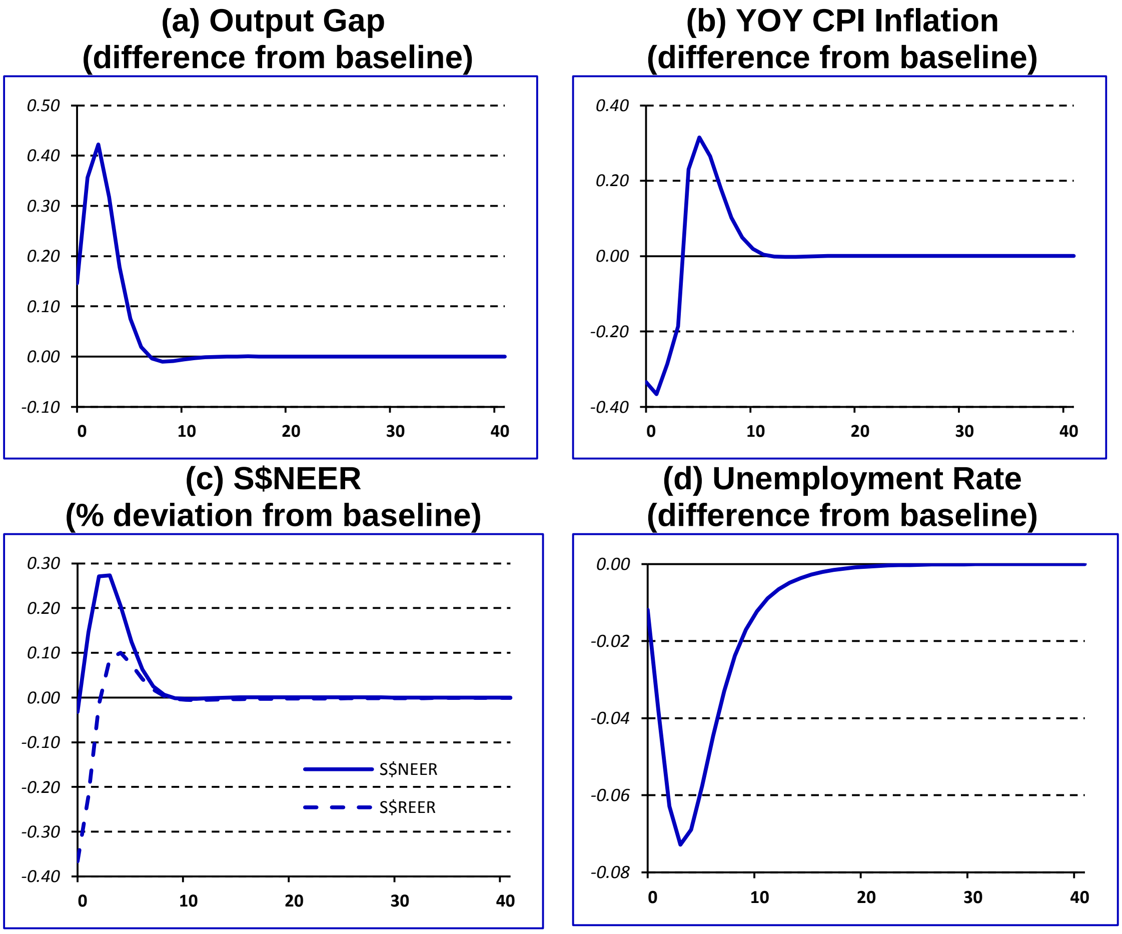


(d) Unemployment Rate
(difference from baseline)



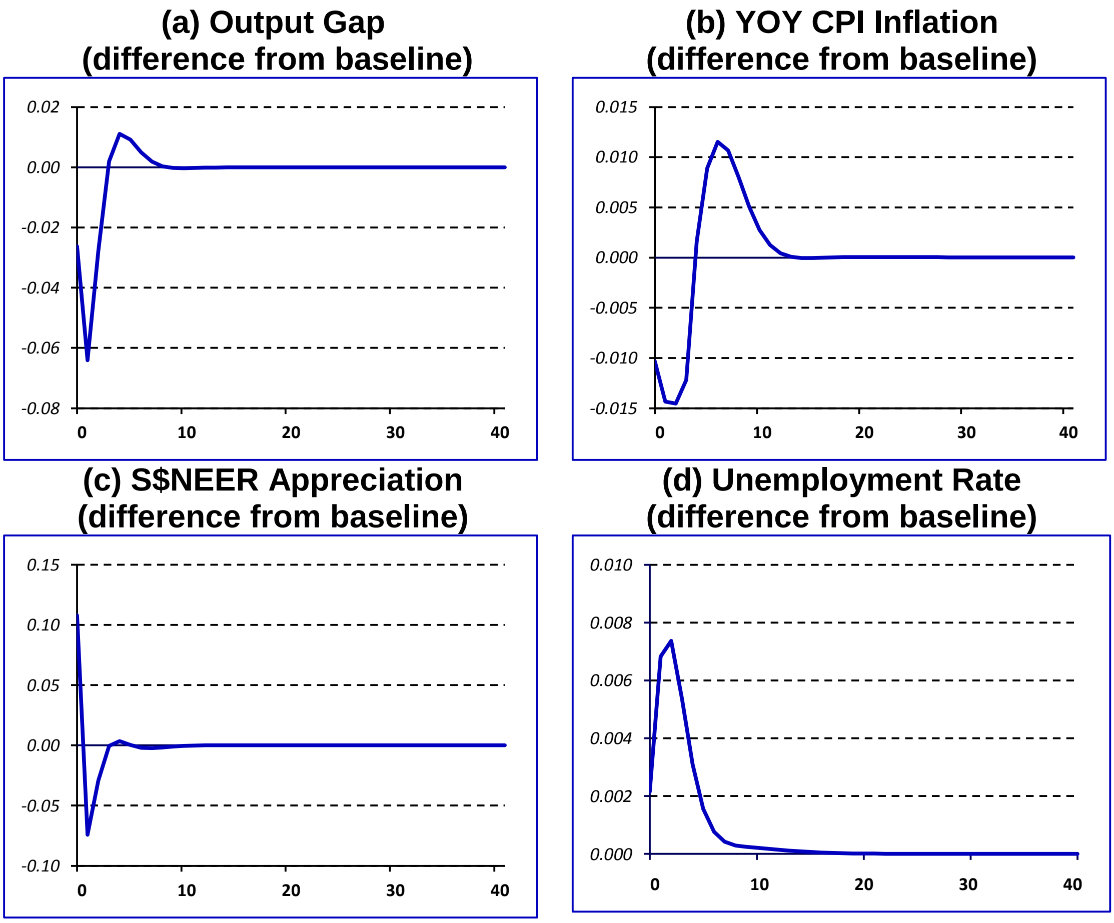
5.1.3. Chart 5.2 shows the results of a negative shock to the inflation rate (*RES_PIE* shock), which leads to a depreciation of the real exchange rate. Consequently, domestic GDP increases above baseline and stays elevated for almost two years. While S$NEER depreciates slightly at the time of the shock, it goes above baseline from the next quarter as domestic GDP and future inflation (in y-o-y terms) are higher than the baseline. This monetary policy response helps to equilibrate the model variables back to baseline in the long run.

Chart 5.2
Shock to RES_PIE



5.1.4. The results of a higher rate of appreciation of the S$NEER is shown in Chart 5.3, in which the slope coefficient is effectively increased at *t=0*, through a shock to the residual term, *RES_DOT_LS*, and thereafter determined endogenously according to the monetary policy reaction function. The initial appreciation of the S$NEER leads to lower GDP growth and lower YOY CPI inflation, which then triggers a monetary policy response in the form of a lower rate of appreciation of the S$NEER than the baseline.

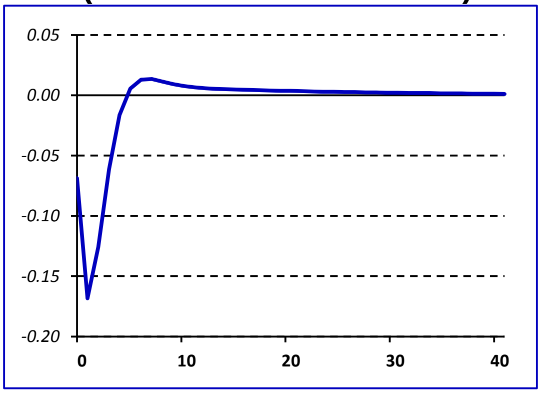
Chart 5.3
Shock to RES_DOT_LS



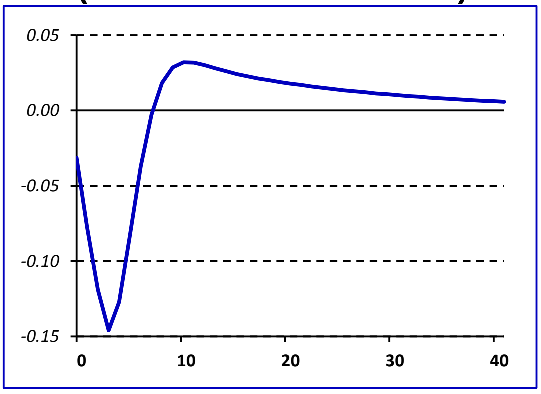
5.1.5. A risk premium shock (*RES_RS_DIFF*) is depicted in Chart 5.4. As the profile of this IRF shows, the shock results in a persistently higher interest rate which only returns to the baseline slowly in the long run. This constrains domestic activity, with GDP and inflation falling below baseline, hence triggering a lower rate of appreciation of the S$NEER in the initial periods.

Chart 5.4
Shock to RES_RS_DIFF

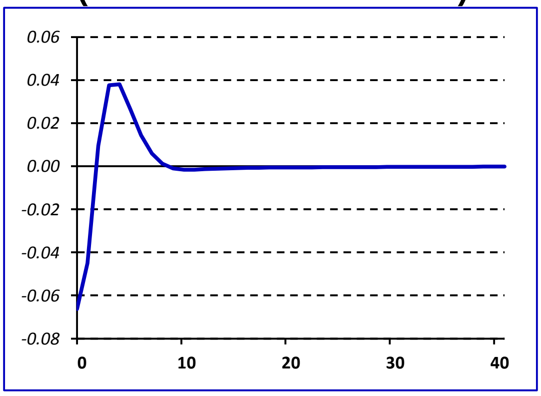
(a) Output Gap
(difference from baseline)



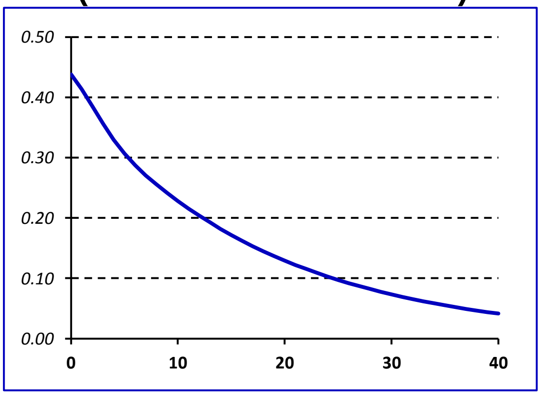
(b) YOY CPI Inflation
(difference from baseline)



(c) S$NEER Appreciation
(difference from baseline)



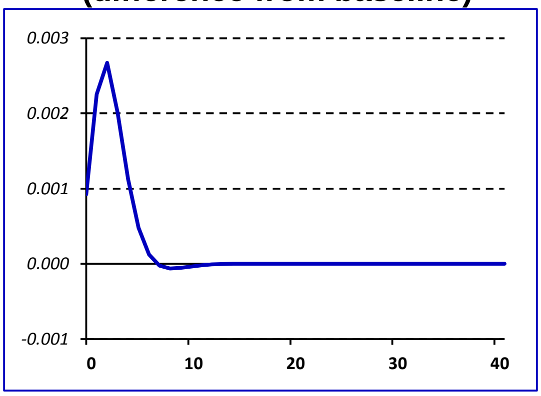
(d) Nominal Interest Rate
(difference from baseline)



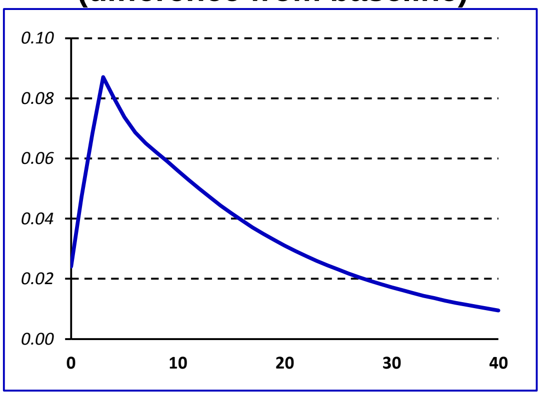
5.1.6. Finally, Charts 5.5 and 5.6 show the difference between two types of shocks to potential GDP. The *RES_G* shock shown in Chart 5.5 permanently alters the growth rate of potential GDP, while the *RES_LGDP_BAR* shock shown in Chart 5.6 is a shock to the level of potential GDP. A comparison of both shocks shows that actual GDP growth rate is permanently higher under a *RES_G* shock, while it quickly reverts to baseline under a *RES_LGDP_BAR* shock. The profile of the output gap is similar across the two shocks, as movements in potential GDP are completely matched by similar movements in actual GDP. CPI inflation and monetary policy reactions therefore have similar profiles under the two supply-side shocks.

Chart 5.5
Shock to RES_G

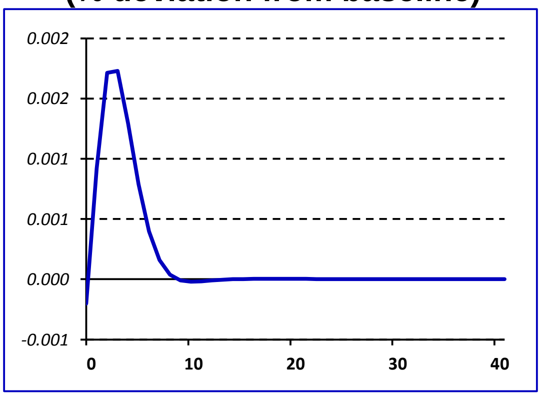
(a) Output Gap (difference from baseline)



(b) YOY GDP Growth (difference from baseline)



(c) S$NEER (% deviation from baseline)



(d) CPI (% deviation from baseline)

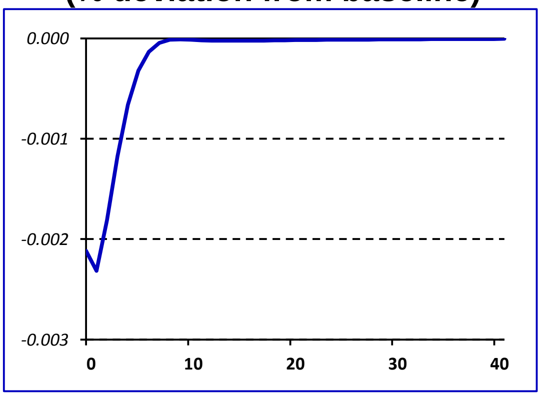
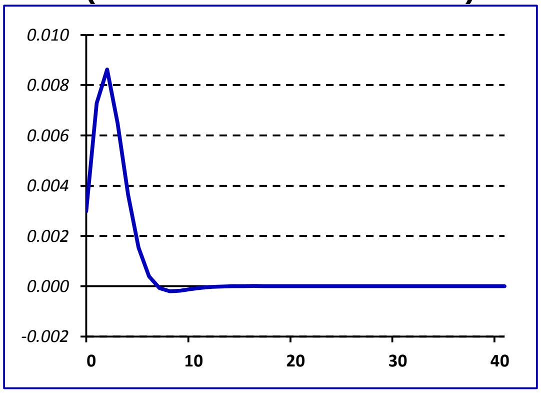
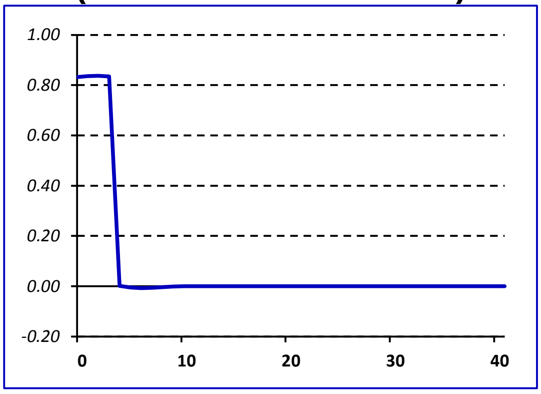


Chart 5.6
Shock to RES_LGDP_BAR

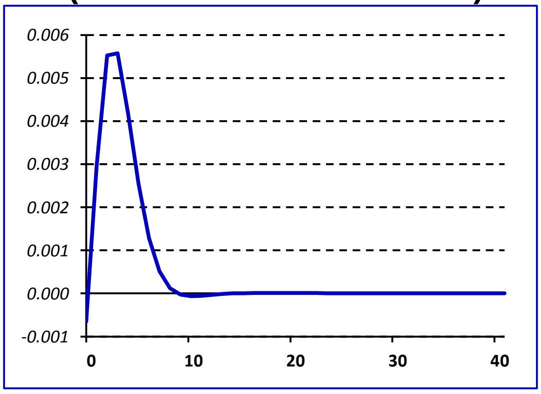
(a) Output Gap
(difference from baseline)



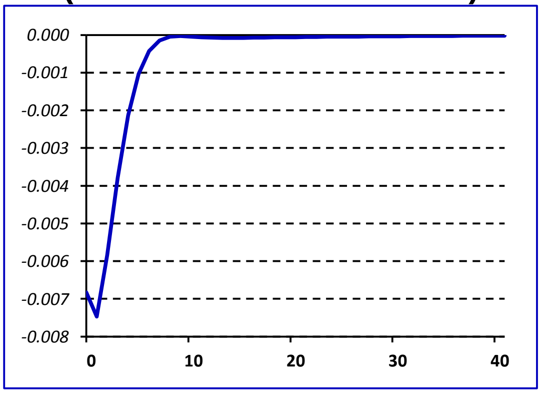
(b) YOY GDP Growth
(difference from baseline)



(c) S$NEER
(% deviation from baseline)



(d) CPI
(% deviation from baseline)



6. SIMULATION PROPERTIES

6.1. INTRODUCTION

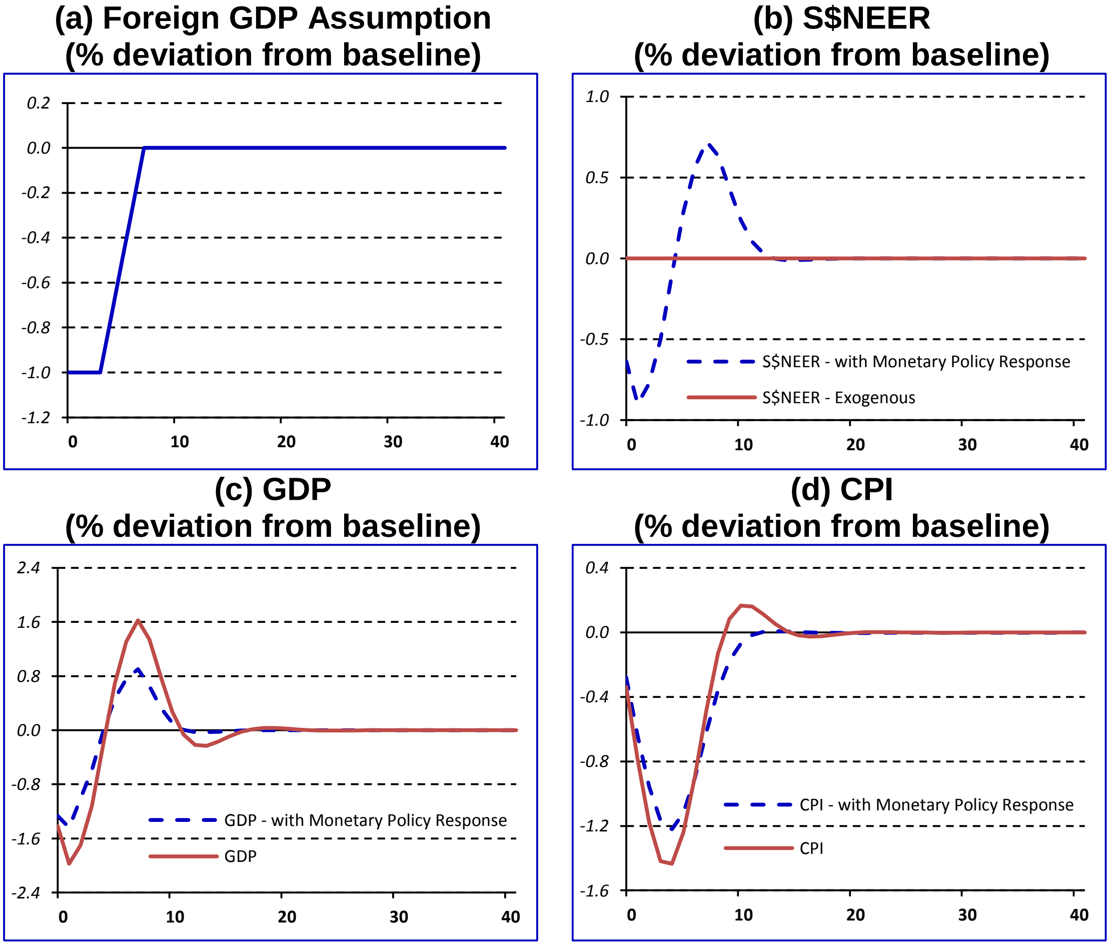
6.1.1. Apart from being able to explore the properties of the model through IRFs, the SMS is also capable of running various simulations. In this section, we simulate the behaviour of key macroeconomic variables as a result of a foreign demand shock. Also, we highlight one of the key features in the SMS that allows the setting for the S$NEER to be altered — keeping monetary policy 'exogenous' or making it 'endogenous' to respond to the shocks to the economy. An exogenous setting leaves the S$NEER unchanged between simulations, thus enabling the pure effects of the shocks to be quantified without any countervailing monetary policy reaction. In reality, monetary policy does respond to shocks and as such, the endogenous setting in the SMS permits a model-based monetary policy response that helps to mute the impact of the shock on the macroeconomic variables.

6.2. FOREIGN DEMAND SHOCK

6.2.1. A fall in foreign demand is introduced in the SMS through a change in the composite foreign GDP (GDPF) index. The shock is assumed to be temporary — GDPF falls by 1% below baseline for four quarters, recovers by 0.25% in each of the subsequent quarters, and finally reverts to the baseline by the end of the second year. Chart 6.1 shows the assumed path for GDPF and also the impact of this shock on the key macroeconomic variables under the two (exogenous and endogenous) monetary policy settings. For the exogenous setting, the path of S$NEER was maintained at its baseline levels. When monetary policy is endogenous, the built-in monetary policy response function is enabled.

6.2.2. The results under the exogenous monetary policy setting (the solid lines in Chart 6.1) show that domestic GDP falls by 1.4% from baseline in the first quarter, with the foreign demand shock having a maximum impact of close to 2.0% after two quarters. CPI remains below baseline for an extended period due to the fall in external demand, reaching its trough at 1.4% below baseline in the fifth quarter. Overall, real GDP declines by 1.6% in the first year as compared to the baseline. CPI falls by 0.9% below baseline in the first year, and remains below it into the second year. The impact on the key macroeconomic variables dissipates in the long run due to the temporary nature of the GDPF shock.

Chart 6.1
Macroeconomic Effects of a Foreign Demand Shock



6.2.3. Under the endogenous monetary policy setting i.e. when monetary policy is allowed to respond to the external shock, the impact on the macro variables becomes more muted as shown by dotted lines in Chart 6.1. This occurs as the S$NEER is lowered in line with the Taylor rule, thus helping to stabilise output and inflation around their respective targets. The resulting looser monetary policy therefore softens the impact of adverse foreign demand shocks, capping the peak decline in GDP and CPI at 1.4% and 1.2% below the baseline, respectively.

7. CONCLUSION

7.1.1. The addition of SMS to MAS' suite of macroeconomic models resonates with our pluralistic approach to modelling and belief that no one model is superior in all possible circumstances. The SMS is a highly aggregated model with no sectoral or expenditure components, with its key properties derived from the three New Keynesian core equations for aggregate demand, inflation, and the monetary policy reaction function. These key macroeconomic relationships are elegantly encapsulated within a tight model-consistent framework and are estimated using Bayesian techniques.

7.1.2. Apart from forecasting key macroeconomic variables, the SMS is also used for policy simulations, such as analysing the impact of GDP and inflation-shocks to the economy. Moreover, its seamless integration with IMF's Global Projection Model makes it a useful tool to analyse the impact of external shocks to the Singapore economy.

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Parrado, E (2004), "Singapore's Unique Monetary Policy: How Does It Work?", *MAS Staff Paper No. 31,* Monetary Authority of Singapore.

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APPENDIX A

VARIABLE DEFINITIONS

Code	Description	Units
G	Natural Growth Rate	%
LCPI	CPI (SA)	Index
LCPIF	Foreign CPI	Index
LGDP	Real Gross Domestic Product (SA)	$m
LGDP_BAR	Real GDP (SA)(Equilibrium)	$m
LS	S$NEER	Index
LS_BAR	Equilibrium S$NEER	Index
LS_GAP	S$NEER Gap	Index
DOT_LS	QOQ S$NEER Appreciation Rate	%
DOT_LS_BAR	Equilibrium S$NEER QOQ Appr. Rate	% p.a.
LS_E	Expectation S$NEER	Index
LZ	S$REER	Index
LZ_BAR	Equilibrium S$REER	Index
DOT_LZ_BAR	Equilibrium S$REER QOQ Appr. Rate	% p.a.
LZ_GAP	S$REER Gap	Index
PIE	QOQ Inflation Rate	% p.a.
PIE4	YOY Inflation Rate	% p.a.
PIETAR	Inflation Target	% p.a.
PIEF	Weighted Foreign Inflation	% p.a.
PIETARF	Foreign Inflation Target	% p.a.
RR	Real Interest Rate	% p.a.
RR_BAR	Real Interest Rate (Equilibrium)	% p.a.
RR_US	US Real Interest Rate	% p.a.
RR_US_BAR	US Real Interest Rate (Equilibrium)	% p.a.
RS	Nominal Interest Rate	% p.a.
UNR	Unemployment Rate (Total)	%
UNR_BAR	Unemployment Rate (Equilibrium)	%
UNR_GAP	Unemployment Rate Gap	%
UNR_G	NAIRU	%
CSI	Credit Spread Indicator	Index
CSI_BAR	Equilibrium CSI	Index
CSI_GAP	CSI Gap	Index
CAPREQ_BAR	Equilibrium Capital Requirement	%
Y	Singapore Output Gap	%
YF	Weighted Foreign Output Gap	%

APPENDIX B

EQUATION LISTING

BEHAVIOURAL EQUATIONS

Output Gap

$$Y_t = \beta_1 \cdot Y_{t-1} + \beta_2 \cdot Y_{t+1} - \beta_3 \cdot \left(RR_{t-1} - RR\_BAR_{t-1}\right) - \beta_4 \cdot LZ\_GAP_{t-1}$$
$$+ \beta_5 \cdot YF - \beta_6 \cdot E2\_CSI_t + RES\_Y_t$$

Inflation

$$PIE_t = \lambda_1 \cdot PIE_{t+1} + \left(1-\lambda_1\right) \cdot PIE_{t-1} + \lambda_2 \cdot Y - \lambda_3 \cdot \left(LZ\_GAP_t - LZ\_GAP_{t-1}\right)$$
$$-\lambda_4 \cdot RES\_G_t - \lambda_5 \cdot RES\_LGDP\_BAR_t + \lambda_6 \cdot RES\_CAPREQ\_BAR_t$$
$$-RES\_PIE_t$$

Monetary Policy Reaction Function

$$DOT\_LS_t - DOT\_LS\_BAR_t = \gamma_1 \cdot \left(DOT\_LS_{t-1} - DOT\_LS\_BAR_{t-1}\right)$$
$$+ \left(1-\gamma_1\right) \cdot \left\{\gamma_2 \cdot \left(PIE4_{t+3} - PIETAR_t\right) - \gamma_3 \cdot LS\_GAP_t + \gamma_4 \cdot Y_t\right\} + RES\_DOT\_LS_t$$

UIP Condition

$$RS_t = \kappa \cdot \{RR\_US_t + PIEF_{t+1} - 4 \cdot (LS\_E - LS\_E_{t-1}) + RR\_BAR_{t+1}$$
$$-RR\_BAR\_US_{t+1}\} + \left(1-\kappa\right) \cdot RS_{t-1} + RES\_RS\_DIFF_t$$

Unemployment

$$UNR\_GAP_t = \alpha_1 \cdot UNR\_GAP_{t-1} + \alpha_2 \cdot Y_t + RES\_UNR\_GAP_t$$

DEFINITIONS & STOCHASTIC PROCESSES

GDP Growth and Output Gap

$$Y_t = LGDP_t - LGDP\_BAR_t$$

$$GROWTH_t = 4 \cdot (LGDP_t - LGDP_{t-1})$$

$$GROWTH4_t = (LGDP_t - LGDP_{t-4})$$

$$GROWTH\_BAR_t = 4 \cdot (LGDP\_BAR_t - LGDP\_BAR_{t-1})$$

$$GROWTH4\_BAR_t = LGDP\_BAR_t - LGDP\_BAR_{t-4}$$

$$LGDP\_BAR_t = LGDP\_BAR_{t-1} + \frac{G}{4} - \left(\frac{\mu}{4}\right) \cdot \frac{(CSI\_BAR_t - CSI\_BAR_{t-40})}{40}$$

$$+RES\_LGDP\_BAR_t$$

$$G_t = \tau \cdot GROWTH\_SS + (1-\tau) \cdot G_{t-1} + RES\_G_t$$

Foreign Activity

$$YF_t = \omega_{US} \cdot Y_{US,t} + \omega_{EU} \cdot Y_{EU,t} + \omega_{JA} \cdot Y_{JA,t} + \omega_{CH} \cdot Y_{CH,t} + \omega_{EA7} \cdot Y_{EA7,t}$$

$$+\omega_{LA7} \cdot Y_{LA7,t} + \omega_{RC7} \cdot Y_{RC7,t}$$

where $\omega_i =$ export share of country *i.*

$$LCPIF_t = \xi_{\mathrm{US}} \cdot LCPI_{\mathrm{US,t}} + \xi_{EU} \cdot LCPI_{\mathrm{EU,t}} + \xi_{JA} \cdot LCPI_{\mathrm{JA,t}} + \xi_{CH} \cdot LCPI_{\mathrm{CH,t}}$$

$$+ \xi_{EA7} \cdot LCPI_{\mathrm{EA7,t}} + \xi_{LA7} \cdot LCPI_{\mathrm{LA7,t}} + \xi_{RC7} \cdot LCPI_{\mathrm{RC7,t}}$$

where $\xi_i =$ import share of country *i.*

Exchange Rate

$$LS_t = LS_{t-1} + \frac{DOT\_LS_t}{4}$$

$$LS\_E_t = \psi_1 \cdot LS_{t+1} + (1\text{-}\psi_1) \cdot LS_{t-1}$$

$$LZ_t = LS_t - LCPIF_t + LCPI_t$$

$$DOT4\_LS_t = LS_t - LS_{t-4}$$

$$LZ\_GAP_t = LZ_t - LZ\_BAR_t$$

$$LS\_GAP_t = LS_t - LS\_BAR_t$$

$$LZ\_BAR_t = LZ\_BAR_{t-1} + \frac{DOT\_LZ\_BAR_t}{4} + RES\_LZ\_BAR_t$$

$$LS\_BAR_t = LS\_BAR_{t-1} + \frac{DOT\_LS\_BAR_t}{4} + RES\_LS\_BAR_t$$

$$DOT\_LS\_BAR_t = DOT\_LZ\_BAR_t - PIETAR_t + PIETARF_t + RES\_DOT\_LS\_BAR_t$$

$$DOT\_LZ\_BAR_t = \psi_2 \cdot dot\_lz\_ss_t + (1-\psi_2)\cdot DOT\_LZ\_BAR_{t\text{-}1} + RES\_DOT\_LZ\_BAR_t$$

<u>Inflation and Real Interest Rate</u>

$$LCPI_t = LCPI_{t\text{-}1} + \frac{PIE_t}{4}$$

$$PIE4_t = \frac{(PIE_t + PIE_{t\text{-}1} + PIE_{t\text{-}2} + PIE_{t\text{-}3})}{4}$$

$$RR_t = RS_t - PIE_{t+1}$$

$$RR\_BAR_t = \rho \cdot RR\_BAR\_SS_t + (1-\rho)\cdot RR\_BAR_{t\text{-}1} + RES\_RR\_BAR_t$$

$$PIEF_t = 4\cdot(LCPIF - LCPIF_{t\text{-}1})$$

$$LCPIF_t = LCPIF_{t\text{-}1} - \frac{PIETARF_t}{4} + RES\_LCPIF_t$$

$$PIETAR_t = PIETAR\_SS_t$$

$$PIETARF_t = PIETARF\_SS_t$$

<u>Unemployment</u>

$$UNR_t = UNR\_BAR_t + UNR\_GAP_t$$

$$UNR\_BAR_t = (1\text{-}\alpha_3)\cdot UNR\_BAR_{t\text{-}1} + \alpha_3 \cdot UNR\_SS_t + UNR\_G_t + RES\_UNR\_BAR_t$$

$$UNR\_G_t = \left(1-\alpha_4\right)\cdot UNR\_G_{t-1} + RES\_UNR\_G_t$$

<u>Credit Spread Indicator and Capital Requirement</u>

$$CSI\_GAP_t = CSI_t - CSI\_BAR_t$$

$$CSI\_BAR_t = (1\text{-}\theta_1)\cdot(\theta_3 - \theta_2 \cdot \theta_4) + \theta_1 \cdot CSI\_BAR_{t\text{-}1} + (1\text{-}\theta_1)\cdot \theta_2 \cdot CAPREQ\_BAR_{t\text{-}1} + RES\_CSI\_BAR_t$$

$$CSI\_GAP_t = \omega \cdot Y_{t+4} + RES\_CSI\_GAP_t$$

$$E\_CSI_t = RES\_CSI\_GAP_t$$

$$E2\_CSI_t = (0.12\cdot E\_CSI_{t-1} + 0.12\cdot E\_CSI_{t-2} + 0.12\cdot E\_CSI_{t-3} + 0.16\cdot E\_CSI_{t-4} + 0.20\cdot E\_CSI_{t-5} + 0.16\cdot E\_CSI_{t-6} + 0.12\cdot E\_CSI_{t-7})$$

$$CAPREQ\_BAR_t = CAPREQ\_BAR_{t\text{-}1} + RES\_CAPREP\_BAR_t$$

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