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Monetary regime choice in Singapore: Would a Taylor rule outperform exchange-rate management?

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Abstract

A DSGE-VAR approach was adopted to examine the managed exchange-rate system at work in Singapore and to ask if the country had any reason to fear floating the exchange rate and adopting a Taylor rule. The results showed that, in terms of overall inflation volatility, the exchange rate rule had a comparative advantage over the Taylor rule when export-price shocks were the major sources of real volatility while a Taylor rule was preferable when domestic productivity shocks were dominant. The exchange-rate rule also dominated the Taylor rule for reducing inflation persistence.

Key words: Inflation targeting, Taylor rule, Exchange-rate management, DSGE-VAR estimation

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1 Introduction

Should Singapore fear floating its exchange rate by adopting a Taylor rule? [1] Calvo and Reinhart (2002) noted that many emerging markets retained a preference for a managed float with much less flexibility than is commonly assumed by official exchange-rate classification schemes. Lack of credibility of the monetary authority or liability dollarization, they noted, are major reasons emerging market countries have avoided floating and adopting a Taylor rule. However, there could be other reasons which may be more relevant for a small, highly open and fast growing economy such as Singapore.

Reflecting the small open nature of its economy, Singapore has adopted (effectively, but not officially) an inflation-targeting exchange rate centered monetary policy framework.[2] Given the open-economy trilemma, monetary policy can only achieve two of the following three dimensions: monetary policy independence, fixed exchange rates, and open capital accounts. As a major financial centre, Singapore has chosen free capital mobility and could have chosen to target either the exchange rate or some other monetary variable, but not both. The Monetary Authority of Singapore (MAS) has opted to use the exchange rate as opposed to the more conventional benchmark policy interest rate as its policy operating tool (MAS, 2000).

This is not surprising as the exchange rate could be an effective tool for managing a highly open and trade-dependent economy. Singapore is highly dependent on external demand, which constitutes about seventy percent of aggregate demand. Moreover, domestic consumption has a high import content — out of every Singapore dollar spent domestically, about fifty cents goes to imports. Being a price-taker in international markets, it follows that Singapore is highly susceptible to imported inflation. It appears that Singapore is well served by an inflation-targeting managed exchange rate-centered monetary policy framework. This is a system with free capital mobility and with domestic short-term interest rates determined by foreign interest rates, including a time-varying risk premium.

Managing the exchange rate comes with a cost - the fear of speculative attacks. With the exception of the Asian crisis period in 1997, the MAS has successfully deterred speculators from attacking the domestic currency over the past three decades. But it has been argued that it is the flexibility accorded by the managed exchange rate system that had aided Singapore in escaping from the Asian crisis relatively unscathed. Singapore's acceptance of market driven depreciations in the wake of and amid the deepening of the Asian financial crisis deterred currency speculators from engineering over-depreciation in the

[1] The interest-rate feedback rule for inflation targeting was extensived analyzed by Taylor (1993) and is commonly known as the Taylor rule.

[2] In practice, since 1981, the Monetary Authority of Singapore (MAS) adopts an intermediate exchange rate regime by targeting the Singapore dollar under a basket-band-crawl (BBC) system (Khor et al, 2004; Williamson, 1999). Under this managed float system, the Singapore dollar is related to a trade-weighted basket (termed TWI) of currencies of its major trading partners and competitors. Neither the component currencies, their assigned weights in the basket, the central rate, nor the band limits are disclosed by the MAS.

domestic currency (Yip, 2005). In other words, it was as if the Singapore dollar was on a free float during that period.[3]

The Asian financial crisis raised awareness that pegged exchange rates and its attendant insurance effect exacerbated boom-bust cycles associated with capital flows, thereby contributing to the crisis (Cossetti et al., 1999). This prompted many central banks in East Asia to shift their focus from exchange rate stability to price stability. In particular, crisis-hit countries like Indonesia, (South) Korea, Philippines and Thailand announced the explicit adoption of inflation targeting and moved towards using interest rates as the key monetary policy instrument. However, unless capital controls are imposed, the open economy trilemma dictated that countries that adopted inflation targeting should necessarily have a freely floating exchange rate regime as well. Should Singapore follow suit?[4]

The MAS' stated objective for monetary policy is "to ensure low inflation as a sound basis for sustained economic growth". In practice, then, the exchange rate became the policy instrument to stabilize inflation and output around their desired target levels while the interest rate was effectively tied to the foreign rate. An alternative set-up would have been to use the interest rate as the policy instrument, while the exchange rate adjusted to market forces. Should Singapore float its currency and adopt a Taylor rule?

The aim of the paper is to conduct counter-factual experiments and simulation analysis to determine whether the conduct of monetary policy would have been more welfare enhancing had the interest rate been used as the policy operating instrument instead of the exchange rate. In a VAR analysis of Singapore's monetary transmission mechanism, Chow (2005) found that the exchange rate was more influential than the interest rate as a source of macroeconomic fluctuations. However, the VAR methodology cannot be used to address the question of "what if" had Singapore adopted an alternative policy rule. This has to be examined in a framework where the estimated parameters were not intrinsically linked to the historical policy settings - and thus not subject to the so-called Lucas critique of policy analysis. Hence the framework adopted in this paper belongs to the class of models called dynamic stochastic general equilibrium (DSGE) New Keynesian models of the small open economy.

In the next section we specify a DSGE model of the Singapore economy with its current exchange-rate regime and with nominal and real frictions in the form of sticky wages and prices, habit persistence in consumption, and adjustment costs for investment. We then discuss the results of a Bayesian estimation of the model. Finally we undertake counterfactual simulations assuming a floating

[3] Of course, Singapore's substantial amount of foreign reserves played a critical role in deterring speculative attacks. Further, strong economic fundamentals such as consistent fiscal surplus, large current account surplus, maintenance of stable and consistent macroeconomic policies, and a robust financial system are important explanations why Singapore was relatively less affected by the Asian crisis.

[4] Some market participants have advocated a move to greater flexibility in the exchange rate to guard against the risk of policymakers misjudging the level of Singapore's equilibrium exchange rate. However, others have pointed out that increasing flexibility in the TWI would increase the risk of the Singapore dollar overshooting and is thus, destabilizing.

exchange rate system with a Taylor rule for the interest rate and perform welfare comparisons under the two monetary regimes. The last section concludes.

2 Model

The Singapore macro economy is modelled as the aggregate outcome of the interactions of four sectors. The first sector, the household, provides labor services, owns the capital stock, makes consumption and investment decisions, and holds domestic and foreign bonds. In supplying labor to the firms, the household sets its wage in a monopolistically competitive fashion. All financial interactions are subsumed into this sector. The second sector, the production sector, is mainly responsible for combining capital and labor to produce the goods. It sets the prices of domestic goods in a monopolistically competitive way. The third sector is the external sector. Singapore is a small open economy and takes world prices and interest rates as exogenous variables. Finally, the government sector buys domestic goods and services while collecting lump sum taxes from households, and implements the policies under consideration, namely exchange-rate management.

The equations of the model are standard in the literature, and we have focussed on the key features of the Singapore economy associated with its high degree of openness. We allowed for real-sector frictions, in the form of habit persistence in consumption and adjustment costs in investment. There are two forms of nominal stickiness: one in wage setting and the other in the setting of domestic final-goods prices.

Subsection 2.1 describes the decision rules with respect to the consumption and investment of domestically-produced and imported goods, the holdings of domestic and foreign bonds as well as the determination of the wage rate. The pricing and employment decisions are described in subsection 2.2 along with the determination of the rental price of capital. Subsection 2.3 contains the processes describing the external sector while subsection 2.4 completes the model with equations to describe the fiscal and monetary policies.

2.1 Household sector

The intertemporal welfare (V) and utility function (U) for the household sector are:[5]

$$V = E_0 \sum_{t=0}^{\infty} \beta^t U_t(C_t, L_t) \tag{1}$$

$$U_t(.) = \frac{(C_t - \rho^c \overline{C}_{t-1})^{1-\eta}}{1-\eta} - \gamma \frac{L_t^{1+\varpi}}{1+\varpi} \tag{2}$$

where β is the discount factor, C is consumption with habit persistence parameter ρ^c, L is labor services, η is the coefficient of relative risk aversion, ϖ is the Frisch labor supply elasticity, and γ is the disutility of labor. The habit process

[5] Since the relationships between the micro (many households, differentiated labour, and monopolistic competition) and their macro (aggregate) counterparts are well-known, we have only presented the aggregate equations here.

is an external one, so that the habit stock at time $t+i$ is based on the average past period's consumption, $\rho^c \overline{C}_{t+i-1}$, The symbol E_0 is the expectations operator at time $t=0$.

The household budget equation is:

$$W_t L_t + R_t^k K_t + \Gamma_t + T_t + R_{t-1} B_{t-1} + (R_{t-1}^* + H_{t-1}) S_t B_{t-1}^* = B_t + S_t B_t^* + P_t^c C_t + P_t^i I_t \tag{3}$$

where W is the wage rate, R^k is the nominal rental rate on capital K, Γ is distributed profits, T is taxes and transfers; B (B^*) are domestic (foreign) bonds while R (R^*) are the gross interest rates on domestic and foreign bonds. The exchange rate, S, is expressed as domestic to foreign currency and H is a risk premium. The price index for consumption is given by P^c, and for investment goods by P^i. The financial assets are state-contingent with one period maturity.

Following Devereux, Lane and Xu (2006), capital evolves according to the following law of motion:

$$K_t = \left[\frac{I_t}{K_{t-1}} - \frac{\phi}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \right] K_{t-1} + (1-\delta) K_{t-1} \tag{4}$$

where δ is the depreciation rate and ϕ is an adjustment cost factor, $\phi > 0$. The household purchases consumption C_t and investment goods I_t,as well as government and foreign bonds and pays lump sum taxes T_t. It rents capital and supplies labor to firms, and receives wage income $W_t L_t$ and rental income from capital, $R_t^k K_t$.

The household sector takes $P^i, P^c, W, R^k, R, R^*, H$ and S as given variables and the paths for consumption (C), capital (K), domestic (B) and foreign (B^*) bond holdings are obtained by solving the Lagrangean problem (maximize present value of utility (2) subject to the budget constraint (3) and the law of motion for capital (4)). The Euler equations are below:

$$\frac{(C_t - \rho^c C_{t-1})^{-\eta}}{P_t^c} = \beta \frac{(C_{t+1} - \rho^c C_t)^{-\eta}}{P_{t+1}^c} R_t \tag{5}$$

$$R_t S_t = (R_t^* + H_t) S_{t+1} \tag{6}$$

$$Q_t \left[1 - \phi \left(\frac{I_t}{K_{t-1}} - \delta \right) \right] = \left[\frac{(C_t - \rho^c C_{t-1})^{-\eta}}{P_t^c} \right] P_t^i \tag{7}$$

$$\begin{aligned} Q_t &= \left[\frac{(C_t - \rho^c C_{t-1})^{-\eta}}{P_t^c} \right] R_t^k \\ &+ \beta Q_{t+1} \left[\begin{array}{c} \frac{\phi}{2} \left(\frac{I_{t+1}^2}{K_t^2} \right) \\ -\frac{\phi}{2} \delta^2 + (1-\delta) \end{array} \right] \end{aligned} \tag{8}$$

where Q_t is a Lagrange multiplier at time t for the law of motion of the capital stock.

Household expenditures are for consumption (C) or for investment (I) at respective prices P^c, P^i. Consumption and investment goods are mainly, but not totally, imported and they are modelled respectively as CES functions:

$$C_t = \left[(1-\theta_c)^{1/\mu_c}\left(C_t^d\right)^{(\mu_c-1)/\mu_c} + \theta_c^{1/\mu_c}\left(C_t^m\right)^{(\mu_c-1)/\mu_c}\right]^{\mu_c/(1-\mu_c)} \tag{9}$$

$$C_t^d = (1-\theta_c)\left(\frac{P_t^d}{P_t^c}\right)^{-\mu_c} C_t \tag{10}$$

$$C_t^m = \theta_c\left(\frac{P_t^m}{P_t^c}\right)^{-\mu_c} C_t \tag{11}$$

$$P_t^c = \left[(1-\theta_c)\left(P_t^d\right)^{1-\mu_c} + \theta_c\left(P_t^m\right)^{1-\mu_c}\right]^{1/(1-\mu_c)} \tag{12}$$

$$I_t = \left[(1-\theta_i)^{1/\mu_i}\left(I_t^d\right)^{(\mu_i-1)/\mu_i} + \theta_i^{1/\mu_i}\left(I_t^m\right)^{(\mu_i-1)/\mu_i}\right]^{\mu_i/(1-\mu_i)} \tag{13}$$

$$I_t^d = (1-\theta_i)\left(\frac{P_t^d}{P_t^i}\right)^{-\mu_i} I_t \tag{14}$$

$$I_t^m = \theta_i\left(\frac{P_t^m}{P_t^i}\right)^{-\mu_i} I_t \tag{15}$$

$$P_t^i = \left[(1-\theta_i)\left(P_t^d\right)^{1-\mu_i} + \theta_i\left(P_t^m\right)^{1-\mu_i}\right]^{1/(1-\mu_i)} \tag{16}$$

where θ_c, θ_i are the respective share parameters and μ_c, μ_i represent the intratemporal elasticities of substitution for consumption and investment. Equation (9) shows aggregate consumption C_t as comprising a domestic component C_t^d and an imported component C_t^m while equation (13) shows aggregate investment I_t as comprising a domestic component I_t^d and an imported component I_t^m. The world (domestic) price for the imported (domestic) consumption and investment goods are highly correlated and are represented as P^m (P^d).

The Singaporean labor market does not clear, and wages are modelled as staggered contracts with a fraction $(1-\xi_w)$ renegotiated each period. Household h chooses the optimal wage W_t^o by maximizing the expected discounted utility subject to the demand for its labor $L_t^h = L_t\left(W_t^o/W_t\right)^{-\zeta_w}$ where ζ_w is a parameter governing the degree of substitution. In aggregate, this behavior is modelled in a similar manner to the Calvo sticky prices and the model is written in recursive form as:

$$W_t^{num} = (W_t)^{\zeta_w+\zeta_w\varpi}\left(L_t^{1+\varpi}\right) + \xi_w\beta.W_{t+1}^{num} \tag{17}$$

$$W_t^{den} = \left(\frac{(C_t-\rho^c C_{t-1})^{-\eta}}{P_t^c}\right)(W_t)^{\zeta} L_t + \xi_w\beta.W_{t+1}^{den} \tag{18}$$

$$\left(W_t^o\right)^{1+\zeta_w\varpi} = \frac{W_t^{num}}{W_t^{den}} \tag{19}$$

$$W_t = \left[\xi_w\left(W_{t-1}\right)^{1-\zeta_w} + (1-\xi_w)(W_t^o)^{1-\zeta_w}\right]^{\frac{1}{1-\zeta_w}} \tag{20}$$

where, W_t^{num} and W_t^{den} are auxiliary variables in the formula.

2.2 Production sector

Aggregate demand (Y_t) comes from domestic consumption (C_t^d), government spending (G), exports (X) and investment (I_t^d):[6]

$$Y_t = C_t^d + G_t + X_t + I_t^d \tag{21}$$

Aggregate supply is a function of capital and labor:

$$Y_t = K_t^\alpha (Z_t L_t)^{1-\alpha} \tag{22}$$

$$\log(Z_t) = \log(Z_{t-1}) + \epsilon_t^z; \quad \epsilon_t^z \sim N(0, \sigma_z^2) \tag{23}$$

where Z_t is an economy-wide unit-root technology shock and α is a parameter that determines the degree of capital intensity for production. The profits of the firms is given by the following aggregate relationship, and distributed to the households:

$$\Gamma_t = P_t Y_t - W_t L_t - R_t^k K_t \tag{24}$$

Maximizing profits also implies the following relationship:

$$\frac{\alpha W_t}{(1-\alpha) R_t^k} = \frac{K_t}{L_t} \tag{25}$$

Firms are monopolistically competitive and they set the price for goods sold both domestically and in foreign markets. According to the Calvo price setting system, there are forward-looking price setters and backward looking price setters. Let ξ_p be the probability of persistence. Then since the demand for the product from firm j is given by $Y_t \left(P_t^j / P_t\right)^{-\zeta_p}$, we may write the optimal (aggregate) price, P_t^o in recursive form as follows:[7]

$$A_t = \frac{\left(R_t^k\right)^\alpha W_t^{1-\alpha}}{Z_t} \left(\frac{1}{(\alpha)^\alpha (1-\alpha)^{1-\alpha}} \right) \tag{26}$$

$$P_t^o = \frac{P_t^{num}}{P_t^{den}} \tag{27}$$

$$P_t^{num} = Y_t \left(P_t\right)^{\zeta_p} A_t + \beta \xi_p P_{t+1}^{num} \tag{28}$$

$$P_t^{den} = Y_t \left(P_t\right)^{\zeta_p} + \beta \xi_p P_{t+1}^{den} \tag{29}$$

$$P_t = \left[\xi_p \left(P_{t-1}\right)^{1-\zeta_p} + (1-\xi_p) \left(P_t^o\right)^{1-\zeta_p} \right]^{\frac{1}{1-\zeta_p}} \tag{30}$$

where A is the marginal cost and ζ_p is a substitution parameter; P_t^{num} and P_t^{den} are auxiliary variables in the formula.

[6] To simplify the analysis, we assume that output is transformed into goods for different end-users and that the markets are segmented.

[7] For more details of the derivation see for example, Walsh (2003), chapter 5: Money, Output and Inflation in the Short-run

2.3 External Sector

Singapore is a very open economy and highly susceptible to international factors. Since it is a very small open economy external forces are modelled as autoregressive processes. The foreign interest rate R^* is assumed to follow the following autoregressive process (in log terms):

$$\log(R_t^*) = \rho^{r*}\log(R_{t-1}^*) + (1-\rho^{r*})\log(\overline{R^*}) + \epsilon_t^{r*} \quad \epsilon_t^{r*}\tilde{\ } N(0,\sigma_{r*}^2) \tag{31}$$

Following Schmitt-Grohe and Uribe (2003), the small open economy is closed, by allowing the risk premium (H_t) to react to the deviation of foreign debt:

$$\log(H_t) = \rho^h\log(H_{t-1}) + (1-\rho^h)\left(\overline{H} + \varphi\log(B_{t-1}^*/\overline{B_t^*})\right) + \epsilon_t^h; \qquad \epsilon_t^h \sim N(0,\sigma_h^2) \tag{32}$$

with $\varphi < 0$; the greater the deviation of (lagged) foreign assets from its steady-state level, the lower the risk premium. The feedback loop from debt to risk premium also ensures that foreign debt stabilizes. Foreign assets evolve as follows and, following evidence reported in Chew, Ouliaris and Meng (2009), exchange-rate changes are passed on fully to the domestic prices of imported goods.

$$P_t^x X_t - P_t^m(I_t^m + C_t^m) = S_t(B_t^* - B_{t-1}^*(R_{t-1}^* + H_{t-1})) \tag{33}$$

$$P_t^m = S_t P_t^{m^*} \tag{34}$$

$$P_t^x = S_t P_t^{x^*} \tag{35}$$

The internationally determined import prices $P_t^{m^*}$ and export prices $P_t^{x^*}$ are modelled as autoregressive stochastic processes:[8]

$$\log(P_t^{m*}) = \rho^{pm*}\log(P_{t-1}^{m^*}) + (1-\rho^{pm*})\log(\overline{P^{m^*}}) + \epsilon_t^{pm*}; \quad \epsilon_t^{m*}\tilde{\ }N(0,\sigma_{pm*}^2) \tag{36}$$

$$\log(P_t^{x*}) = \rho^{px*}\log(P_{t-1}^{x*}) + (1-\rho^{px*})\log(\overline{P^{x*}}) + \epsilon_t^{px*}; \quad \epsilon_t^{x*} \sim N(0,\sigma_{px*}^2) \tag{37}$$

Since Singapore is a very open economy, the index of openness Θ is obtained from:

$$P_t = P_t^d(1-\Theta) + P_t^x\Theta \tag{38}$$

where Θ is a measure of the share of exports in economic activity (see Monacelli and Gali, 2005).[9]

The Singapore economy is also sensitive to world output. The demand for export goods by trading partners is modelled in a similar way to the Singaporean

[8] In the empirical section, we have also modelled these processes to allow for some cross-effects in a VAR framework. We find that the cross-terms were not significant.

[9] The coefficient γ drops out in the log-linear model, but an estimate can be derived from the steady state conditions. The estimate is used in computing utility/welfare in the counterfactual experiments.

demand for imported goods:

$$X_t = \theta_f \left(\frac{P_t^x}{P_t^w}\right)^{-\mu_f} Y_t^* \tag{39}$$

$$\log(Y_t^*) = \rho^{y*} \log(Y_{t-1}^*) + (1-\rho^{y*}) \log(\overline{Y^*}) + \epsilon_t^{y*}; \quad \epsilon_t^{y*} \sim N(0, \sigma_{y*}^2) \tag{40}$$

where θ_f represents the share of imported goods in the trading partners' total expenditure, μ_f is the intratemporal elasticity of substitution for domestic and imported components, Y_t^* is a measure of the GDP of trading partners, and P_t^w is the world price index, normalized to unity. The trading partners' GDP, Y^*, is, again, modelled as an autoregressive process.

2.4 Government Sector

The Treasury/Central Bank receives taxes and borrows to finance government expenditure. The evolution of domestic bonds (B_t) is below:[10]

$$B_t = P_t^d G_t + B_{t-1} R_{t-1} - T_t \tag{41}$$

where government spending G_t is assumed to follow an exogenous autoregressive process and includes a normally distributed innovation ϵ^g with variance σ_g^2 :

$$\log(G_t) = \rho^g \log(G_{t-1}) + (1-\rho^g) \log(\overline{G}) + \epsilon_t^g; \qquad \epsilon_t^g \sim N(0, \sigma_g^2) \tag{42}$$

The aim of monetary policy is to manage the exchange rate to target inflation, that is the exchange rate is engineered to appreciate to reduce domestic inflation. Following McCallum (2006)[11], the behavior of the Monetary Authority of Singapore is modelled as following an exchange rate rule:[12]

$$\log(S_{t+1}/S_t) = \rho^s \log(S_t/S_{t-1}) - (1-\rho^s)\psi(\log(\Pi_{t+1}^c/\overline{\Pi^c})); \qquad \psi > 0 \tag{43}$$

The parameter ρ^s measures the persistence and ψ is a reaction coefficient, specified so that the exchange rate appreciates when inflation rises. The gross inflation is for the consumer price index, with $\Pi_{t+1}^c = P_{t+1}^c/P_t^c$.[13]

[10] We assume that the exogenous taxes prohibit that debt from becoming non-stationary.

[11] We note that this specification does not include an output-gap term. This does not mean that variations in growth are not considered, only that they are considered via their impact on inflation.

[12] MAS announces its exchange rate policy stance, in its semiannual monetary policy cycle, through a Monetary Policy Statement. Possible adjustments include: changes to the crawl in the central parity, re-centering of the policy band, changing the width of the band of fluctuations. Essentially, the exchange rate is used as an intermediate monetary policy instrument to achieve the primary objective of non-inflationary growth. In a sense, monetary policy is operated in Singapore as sort of a hybrid between the BBC and inflation targeting. In practice, an adjustable band is used to track the movement of its instrument, while setting its instrument in a way to hit intermediate targets as a means to control inflation and achieve non-inflationary growth (Khor et al. 2004). In this way, the BBC system can be operated to achieve the same objectives as inflation targeting.

[13] Note that the term $(1-\rho_s)\log(\overline{S})$ has been dropped because $\log(\overline{S}) = 0$.

In summary, the model may be viewed as containing an aggregate supply equation (22) and an aggregate demand equation (21) with associated equations to describe the determination of consumption, investment government expenditure, exports and imports (of consumption and investment type goods). The model also includes equations to describe the demand for the factors of production (labor and capital) along with the rental price of capital and wage rate with the complication that wages and prices are Calvo-sticky. The international exogeneously determined variables are modelled as autoregressive processes.

2.5 Log-Linear Model

Overall, the model contained 7 processes ($Y_t^*, P_t^{m*}, P_t^{x*}, R_t^*, H_t, G_t, Z_t$) and a number of autoregressive, policy reaction, and deep structural parameters (see Table 2 for list). Following standard practice, the non-stationary variables were transformed into stationary variables using two types of manipulations. The first was to detrend real variables by productivity ($\widetilde{y}_t = \log(Y_t/Z_t)$) and the second was to recast price variables into relative terms (and thus to work with $\Pi_t = \log(P_t/P_{t-1})$). The model was then log-linearized for estimation.

3 Empirical Analysis

We estimated the model for seven stochastic shocks: for government spending, foreign trading partners' weighted GDP, import and export price inflation, foreign interest rates, the risk premium, and productivity. We used seven observables: government spending, weighted GDP of trading partners[14], import price inflation, the foreign interest rate, the risk premium (calculated as the domestic interest differential less the realized change in the exchange rate), domestic GDP growth and inflation. With the exception of the foreign interest rate (LIBOR) and the risk premium, all of the observables were expressed as log first differences. The estimation was carried out for the sample period 1985.1-2009.4.

The results are presented in the following sections. The estimated parameters were based on two methodologies (the DSGE and the DSGE-VAR) as a check for robustness of estimates. We examined the shocks, the impulse response functions and the conditional variance decompositions. Using information from the extracted implied shocks, we also interpreted how they had contributed to changes in the growth of GDP and inflation over the sample period.

3.1 Estimation: DSGE and DSGE/VAR

We estimated the model for Singapore in a pure DSGE framework as well as in a DSGE/VAR framework, following Del Negro, Marco and Schorfheide (2004,

[14]This series is constructed by Abeyshinghe and Forbes (2005) and the data source is http://www.fas.nus.edu.sg/ecs/esu/data.html. It is an export share weighted average of the real GDP of the following countries: Hong Kong, Indonesia, Malaysia, Philippines, Thailand, Taiwan, USA and OECD as one group. To allow for changes in the country composition of Singapore trade, the export shares are computed as 12-quarter moving averages.

2010), Adjemian, Darracq and Moyen (2008), and An and Kang (2009). The intuition for using the hybrid DSGE/VAR approach came from recognizing that a pure DSGE model could suffer from specification errors, and that the explanatory power of the model could be improved by the use of a non-structural VAR model. The weight of the pure VAR, relative to the pure DSGE model, was given by the ratio $1/(1+\lambda)$. If $\lambda = 0$, the pure VAR model explained all the variation in the data, and if $\lambda = \infty$, the pure DSGE explained the variation in the data without any input from the VAR[15]. The advantage of using the hybrid DSGE/VAR Bayesian model was thus to provide a specification test of the DSGE model relative to the widely used non-structural alternative, the VAR, with $0 < \lambda < \infty$ indicating the merit of the DSGE relative to the VAR.

Table 1: Marginal Likelihood

	DSGE	DSGE/VAR
	$--$	$\lambda = 1.303$
Laplace Approximation	2127.049	2185.322
Modified Harmonic Mean	2124.905	2182.981

Notes: Data sources for all tables and figures in this paper are IMF, International Financial Statistics, Singapore Department of Statistics online time series database, Sinstat Time Seres Online, https://app.sts.singstat.gov.sg/dots_index.asp, and authors' calculations based on monte-carlo markov chain simulations

Table 1 show the relative fit of the DSGE model to a VAR model. The best fit was a median $\lambda = 1.303$ based on both the Laplace and Harmonic Mean measurements of the Marginal Likelihood. As expected, the DSGE/VAR had a higher marginal likelihood than the pure DSGE model. Given this result, we made use of the DSGE/VAR parameters for more detailed model analysis.

3.2 Parameter and Volatility Estimates

All of the structural parameters (for example behavioral parameters η, ϖ, dynamic parameters ρ^g, ρ^{r*}, standard deviations of the shocks parameters σ_z^2, σ_g^2, were estimated, except for the discount factor β which was calibrated for a steady-state annual gross interest rate of 1.04.[16] In the log-linearized model, we specified the steady-state share of consumption to GDP at 0.6, and the steady-state share of government spending to GDP at 0.1. These ratios were the mean values of actual data. The net export ratio was set at 0.3.

Table 2 shows the priors and the posterior estimates under the pure DSGE and the DSGE/VAR framework for the median $\lambda = 1.303$. The table contains the median and mean values of the Bayesian estimates for 200,000 simulations

[15] However, we also note that stimating a pure DSGE is not identical to estimation of a DSGE/VAR with $\lambda = \infty$, since the DSGE/VAR relies on a finite lag structure.

[16] Since the model is in log-linear deviations, there is no need to calibrate the model for parameters which affect the steady state, as suggested by Christiano, Motto, and Rostagno (2007). We also abstract from tax effects because they are small and only affect the bond accummulation equation. The shares are sample averages.

in four blocks, including the infimum and supremum of each estimate for a 95% confidence interval.

The priors were those commonly used in Bayesian models. We followed closely the specifications of Teo (2009) who estimated a DSGE model for Taiwan. The intratemporal elasticity of substitution for investment and for foreign demand, μ_i and μ_f were set at 1.5 while the intratemporal elasticity for consumption, μ_c was set at 5, following evidence for this parameter presented by Alolfson, Laseen, Linde and Villani (2007). The prior for the adjustment cost coefficient for investment, ϕ, was set at 200, in order to ensure that the volatility of investment matched the observed volatility in the data.

With respect to the differences between the DSGE and DSGE/VAR estimates, the parameters ρ^g, ρ^{y*} for the autoregressive process for government spending and foreign GDP growth showed more persistence in the pure DSGE than in the DSGE/VAR framework. For the remaining parameters, the 95% confidence interval estimates for the DSGE and DSGE/VAR frameworks showed considerable overlaps.

Looking at the degrees of price and wage stickiness, the results showed that the Calvo price stickiness parameter estimate was much lower than those commonly found in models of the US or UK, but its 95% confidence interval was within the corresponding confidence interval for Taiwan [0.48 0.77], reported by Teo (2009). It would appear, however that wages was a lot more flexible than prices in the Singapore economy. Reforms were implemented in the Singapore labor market (around late 1980s) to promote a more flexible wage system by encouraging companies to pay both a base rate and a variable component linked to productivity and profitability.

Table 2 also contain the volatility estimates. In general, with the exception of σ_{px*}, the estimated volatilities were slightly lower in the DSGE/VAR model than in the DSGE model.

Table 2: Prior and Posterior Estimates

Coefficient Estimates	Priors			Posteriors DSGE			Posteriors DSGE/VAR		
	Dist	Mean	Std.Dev.	Mean	.025	.975	Mean	.025	.975
ρ^g	Beta	0.500	0.200	0.902	0.867	0.937	0.649	0.517	0.777
ρ^{y*}	Beta	0.500	0.200	0.897	0.860	0.932	0.732	0.627	0.832
ρ^r	Beta	0.500	0.200	0.956	0.931	0.985	0.927	0.872	0.974
ρ^{px*}	Beta	0.500	0.200	0.947	0.924	0.972	0.842	0.749	0.935
ρ^{pm*}	Beta	0.500	0.200	0.211	0.095	0.316	0.201	0.067	0.326
ρ^s	Beta	0.500	0.200	0.104	0.023	0.180	0.158	0.030	0.282
ρ^h	Beta	0.500	0.200	0.424	0.278	0.569	0.253	0.088	0.410
φ	Beta	0.010	0.100	0.005	0.002	0.008	0.007	0.002	0.013
θ_c	Beta	0.500	0.200	0.487	0.406	0.568	0.496	0.413	0.577
θ_i	Beta	0.800	0.200	0.799	0.709	0.889	0.799	0.721	0.881
ξ_p	Beta	0.500	0.200	0.441	0.333	0.545	0.435	0.321	0.554
ξ_w	Beta	0.500	0.200	0.290	0.191	0.379	0.246	0.163	0.333
ζ_w	Normal	6.000	1.000	5.662	3.920	7.468	5.626	3.869	7.537
η	Normal	2.500	0.200	2.682	2.395	2.995	2.578	2.255	2.925
ϖ	Beta	0.500	0.200	0.176	0.019	0.339	0.233	0.009	0.514
α	Beta	0.500	0.050	0.415	0.340	0.496	0.445	0.362	0.523
ψ	Normal	1.500	0.200	1.558	1.195	1.900	1.754	1.277	2.194
δ	Beta	0.020	0.005	0.019	0.011	0.027	0.020	0.013	0.028
μ_c	Normal	5.000	0.500	2.305	2.012	2.619	2.312	2.061	2.573
μ_i	Normal	1.500	0.200	1.261	1.004	1.497	1.249	1.017	1.453
μ_f	Normal	1.500	0.200	1.395	1.165	1.640	1.332	1.069	1.573
ϕ	Normal	200	50	245.166	162.138	324.906	251.325	165.709	337.836
ρ^c	Beta	0.500	0.200	0.756	0.637	0.887	0.736	0.605	0.869
Θ	Normal	0.700	0.300	0.696	0.663	0.723	0.698	0.663	0.726
λ	Uniform	[0 5]		–	–	–	1.330	0.996	1.654

Volatility Estimates

	Priors			Posteriors DSGE			Posteriors DSGE/VAR		
	Dist	Mean	Std.Dev.	Mean	.025	.975	Mean	.025	.975
σ^z	Inv.gamma	0.01	0.5	0.005	0.004	0.006	0.004	0.003	0.005
σ^g	Inv.gamma	0.01	0.5	0.025	0.022	0.028	0.019	0.016	0.022
σ^{y^*}	Inv.gamma	0.01	0.5	0.007	0.006	0.008	0.004	0.004	0.005
σ^r	Inv.gamma	0.01	0.5	0.002	0.001	0.002	0.001	0.001	0.001
σ^{p^x}	Inv.gamma	0.01	0.5	0.004	0.003	0.006	0.009	0.004	0.013
σ^{p^m}	Inv.gamma	0.01	0.5	0.024	0.021	0.026	0.018	0.015	0.021
σ^q	Inv.gamma	0.01	0.5	0.015	0.013	0.017	0.012	0.010	0.014

Notes: $\rho^g, \rho^{y*}, \rho^{r*}, \rho^{px*}, \rho^{pm*}, \rho^s, \rho^h$ are the autoregressive parameters for government spending, foreign GDP, foreign interest rate, import prices, export prices, exchange rate and risk premium; φ is the feeback parameter from debt to risk premium; θ_c, θ_i are the share parameters for consumption and investment; ξ_p is the probability of persistence; ξ_w is the fraction of wage contracts not renegotiated each period; ζ_w is the degree of substitution for optimum wage; η is the coefficient of relative risk aversion; ϖ is the Frisch labor supply elasticity; α is the degree of capital intensity for production; ψ is a reaction coefficient of exchange rate to inflation; δ is the depreciation rate; μ_c, μ_i, μ_f are the intratemporal elasticity of substitution for consumption, investment, and domestic versus imported components; ϕ is an adjustment cost factor ρ^c is the consumption habit persistence parameter; Θ is a measure of the share of exports in economic activity; λ is related to the weight of the pure VAR, relative to the pure DSGE model; and $\sigma^z, \sigma^g, \sigma^{y*}, \sigma^{r*}, \sigma^{px}, \sigma^{pm}, \sigma^h$ are the standard deviation of the shocks to productivity, government spending, foreign GDP, foreign interest rate, import prices, export prices and risk premium.

3.3 Estimated Shocks

Figure 1 shows the smoothed shocks extracted from the estimation of the DSGE/VAR model and they appear to confirm our a priori perceptions. As reflected in the negative shocks in foreign GDP, the economy of Singapore was hit by a succession of external shocks from mid 1990's to early 2000. These included the 1996-97 downturn in the global electronics industry, the 1997-98 Asian financial crisis, the 2001 burst of the information technology dot.com bubble and the 2003 outbreak of the SARS respiratory disease. In response to the various episodes of economic slowdown, the government introduced cost-cutting measures and brought forward various social infrastructure projects. Hence, government shocks were economic drivers from mid 1990s until early 2000.

Export demand was on an uptrend from mid 2000 till the lead up to the global financial crisis, not least because of the growing importance of China as a market for Singaporean goods as well as because of the intensifying trade linkages in the region through an expansion of cross-border production networks. In fact, changes in external demand accounted for approximately 75% of the changes in Singapore's real total demand during that period. This explained the climb in export prices prior to 2008. Following the onset of the global financial crisis (accompanied by a huge drop in foreign GDP), the Singapore economy experienced a sharp contraction with GDP growth plunging to -9.5% in the first quarter of 2009. In addition to the high import content of exports, the propensity to import goods for domestic production or consumption in Singapore was also very high and estimated to be around 0.8. Reflecting the very high propensity to import, import prices collapsed following the onset of the global financial crisis.

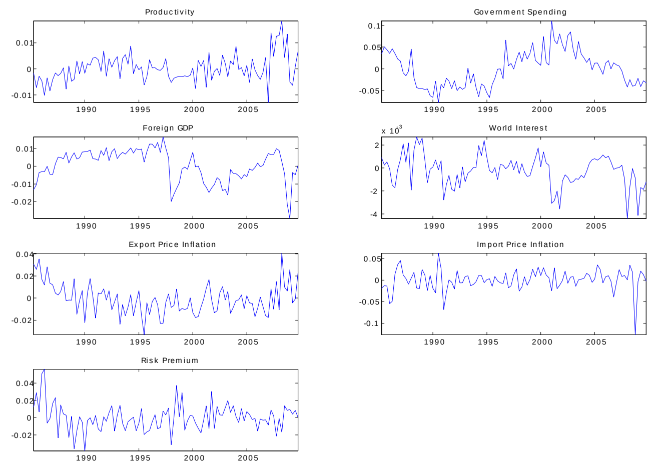

Figure 1: Smoothed Shocks. Source: Calculations from Model Predictions

As for the shocks to productivity, there was a noticeable surge prior to the lead up of the global financial crisis. This could be partly attributed to the influx of foreign labor, including high skilled ones, into Singapore during that period. For instance, permanent residents grew by 8.1% between 2004 and 2009 while non-local workers made up 35% of the workforce by 2009.

With respect to the other shocks, the model showed declines in world interest rates after 2000 and again in 2008. There was a huge shock to the risk premium in the mid 1980s as Singapore entered into a deep recession in 1985 caused by uncompetitive exports and high labor costs. Subsequently, the uncertainty around late 1990s could be attributed to the onset of the 1997-98 Asian financial crisis.

3.4 Impulse Response Paths

Figures 2 and 3 show the response paths generated by shocks for GDP and inflation. The grey areas represent the 95% uncertainty bands. The results are in keeping with theoretical propositions. Productivity, government spending, and foreign GDP unambiguously affected GDP growth positively, while foreign interest rates and the risk premium had negligible impact effects (the confidence bands include zero even in the short run). An increase in export price inflation had negative effects on GDP growth through the export demand channel while a positive shock to import price inflation resulted in a switch in demand to domestic products by consumers.

For inflation, an increase in demand via either government spending or foreign GDP led to higher inflation. Import price inflation, foreign interest rates and the risk premium generated higher inflation through the cost channel. Since most of the inflation in Singapore was imported, it is not surprising that higher inflation would be positively related to higher foreign interest rates, which in turn were related to higher world inflation. An increase in export price inflation caused a fall in foreign demand, which led to a fall in domestic inflation. Productivity shocks generated higher inflation in this model because the demand effects dominated the supply effects.

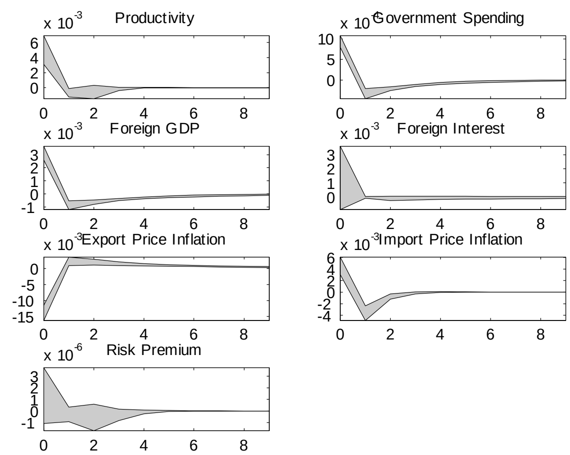

Figure 2: Impulse Response Paths for GDP Growth.
Source: Calculations from Monte Carlo markov chain simulations.

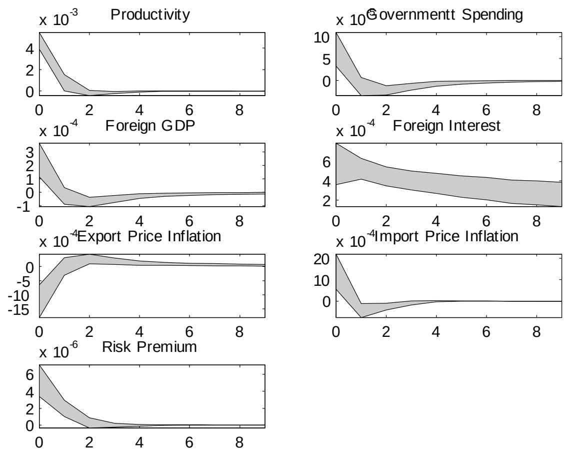

Figure 3: Impulse Response Paths for Inflation. Source: Calculations from Monte Carlo markov chain simulations.

3.5 Conditional Variance Decomposition

Table 3 gives the conditional variance decomposition of GDP and inflation for the seven shocks of the model for horizons of one, four, eight, twelve, sixteen and twenty quarters. The results showed that export-price inflation shocks dominated the variability of GDP at all of the horizons, explaining more than seventy percent of the total variation. The only other shocks that matter, in decreasing order of importance, were import-price inflation (affecting the cost of investment goods), productivity, and foreign GDP. Government spending and the risk premium had negligible effects. For inflation, productivity shocks mattered the most, with some contribution from import and export price inflation and world interest rate shocks.

Table 3: Variance Decomposition						
Shock:	1	4	8	12	16	20
			GDP			
ϵ^z	0.080	0.074	0.073	0.072	0.072	0.072
ϵ^g	0.003	0.004	0.004	0.004	0.004	0.004
ϵ^{y^*}	0.044	0.045	0.045	0.045	0.045	0.045
ϵ^{r*}	0.008	0.008	0.008	0.008	0.008	0.008
ϵ^{px*}	0.773	0.734	0.737	0.738	0.738	0.738
ϵ^{pm*}	0.091	0.136	0.134	0.134	0.134	0.134
ϵ^h	0.000	0.000	0.000	0.000	0.000	0.000
			Inflation			
ϵ^z	0.811	0.775	0.756	0.745	0.739	0.736
ϵ^g	0.000	0.000	0.000	0.000	0.000	0.000
ϵ^{y^*}	0.003	0.003	0.003	0.003	0.003	0.003
ϵ^{r*}	0.020	0.050	0.071	0.084	0.091	0.095
ϵ^{px*}	0.066	0.065	0.066	0.065	0.065	0.065
ϵ^{pm*}	0.100	0.107	0.104	0.103	0.102	0.102
ϵ^h	0.000	0.000	0.000	0.000	0.000	0.000

Notes: $\epsilon^z, \epsilon^g, \epsilon^{y*}, \epsilon^{r*}, \epsilon^{px}, \epsilon^{pm}, \epsilon^h$ are the standard deviation of the shocks to productivity, government spending, foreign GDP, foreign interest rate, import prices, export prices and risk premium. Source: Calculations from Monte Carlo markov chain simulations.

3.6 Historical Shock Decomposition

This section presents historical shock decompositions to gauge the relative importance of each of the exogenous shocks for key endogenous variables of the model. The decompositions also show when, during the sample periods, particular shocks became more important.

Figures 4 and 5 picture the historical shock decomposition for GDP growth and inflation for the sample. Consider first the historical decomposition of output. As discussed earlier in section 3.1.3, Singapore went into deep recession in 1985 as high wage costs eroded export competitiveness. This was reflected in the negative shocks from productivity and export prices at the beginning of the sample period. The subsequent recovery was aided by a boost to external demand, with foreign GDP playing an important positive role in the late 1980s, as well as a rebound in export price. However, the role of foreign GDP turned negative as the recession in the US and parts of Europe in the early 1990s dampened growth in Singapore in that period. Meanwhile, the large import price shocks in the early 1990s could be attributed to high oil prices precipitated by the 1991 Gulf war.

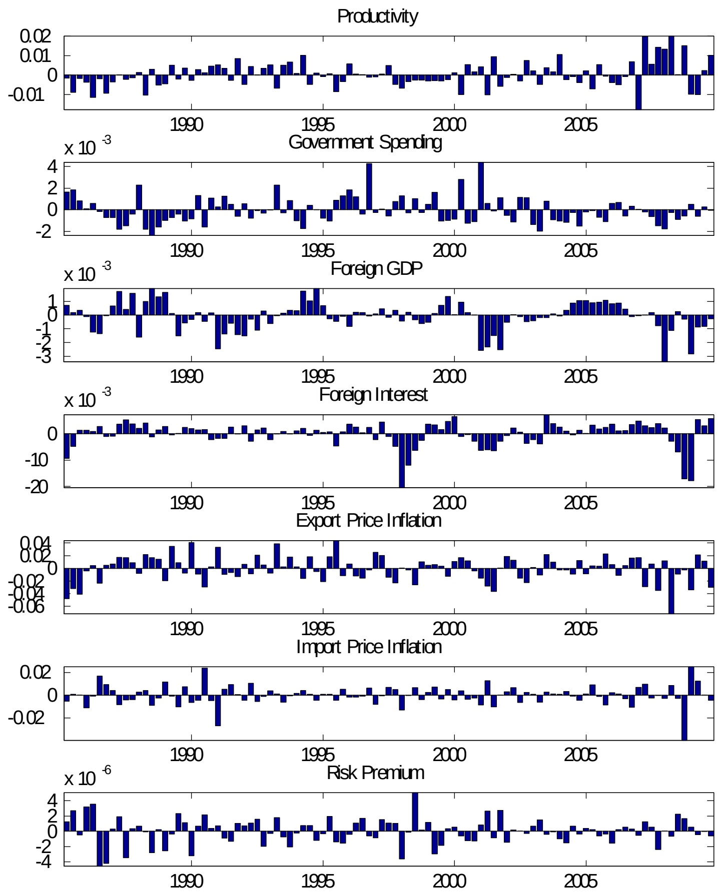

Figure 4: Historical Shock Decomposition of GDP Growth. Source: Calculations from Monte Carlo markov chain simulations.

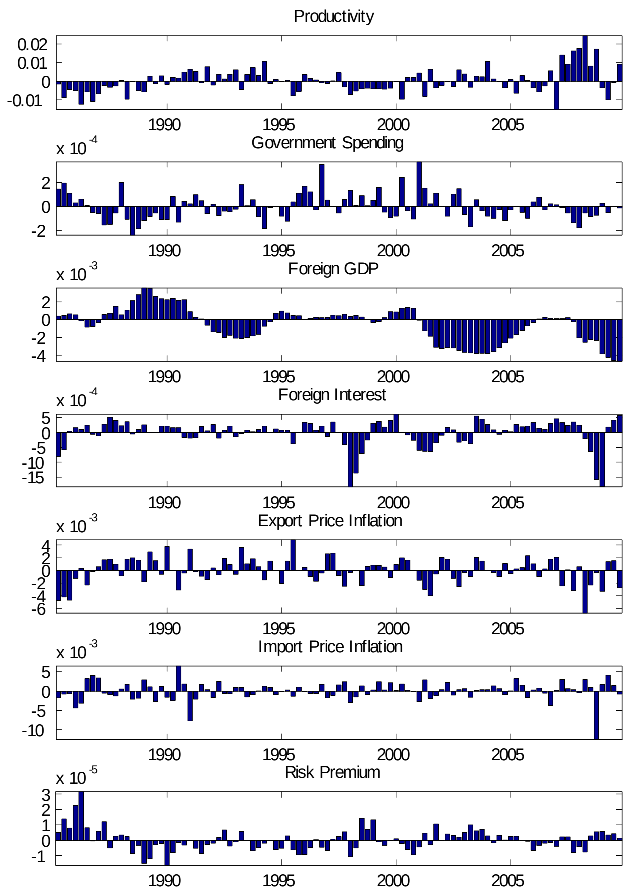

Figure 5: Historical Shock Decomposition of Inflation. Source: Calculations from Monte Carlo markov chain simulations.

In the mid 1990s, the contribution of government spending increased as the Singapore government responded to the economic downswing triggered by the global electronics downturn. Towards the end of 1990s, there was a large negative shock to foreign interest rate at the outbreak of the Asian financial crisis. The Singapore economy was hit by a sequence of external shocks in the early 2000s which prompted the government to implement counter-cyclical measures and boost spending. Hence, both the foreign GDP and government spending played important roles in that period. With the influx of skilled foreign labor from mid 2000's until the onset of the global financial crisis, shocks to productivity became more important after 2005. At the onset of the global financial crisis, foreign interest rate, external demand and export prices collapsed. The noticeable negative effect of export price inflation in 2008/09 stood out very clearly, much more than import price inflation. Overall, the role of the export price inflation shocks were more substantial than the contribution of shocks to government spending, foreign GDP, and foreign interest rate. The contribution of risk premium shocks to growth was of least importance.

With respect to inflation, we saw the strong contribution of productivity driving inflation after 2005. Due to the high import content in all expenditure components, we expected imported inflation to play an important role in Singapore's inflation. Similarly, the openness of the Singapore economy suggested that external demand contributed significantly to Singapore's aggregate demand which in turn added to domestic price pressures. However, the historical decomposition showed that the collapse in the foreign GDP of trading partners, and shocks emanating from import prices, especially in the early 1990's (after the Gulf War), and in 2008, at the time of the financial crisis, were of lesser magnitudes. This was a reflection of the central bank's ability to maintain price stability through the use of the exchange rate as a policy tool to target low inflation. Firstly, an exchange rate appreciation had a direct effect on domestic prices by lowering the prices of imported services as well as imported intermediate and final products. Secondly, a reduction in aggregate demand, caused by an appreciation of the local currency, alleviated inflationary pressures indirectly through the easing of domestic costs such as wages. The central bank was effective in managing the exchange rate in response to shocks to import price inflation and external demand conditions throughout the sample period.

4 Counterfactual Taylor Rule

Before examining whether the interest rate could be used to conduct monetary policy, we checked whether the Singapore economy was interest rate sensitive. Singapore's extensive network of international financial and trade linkages with the attendant huge and rapid capital flows, including a very liberal policy towards foreign direct investment, may have resulted in an economy that was not responsive to interest rate changes.

Figure 6, which depicts the ex post three-month uncovered interest differential between the LIBOR and Singapore, revealed that the differentials were quite different from zero. As pointed out by Yip (2003) they were substantially larger in magnitude compared with corresponding figures from Hong Kong. These fluctuations in the differentials suggested some scope for managing the domestic interest rate, that is the MAS could have exercised a degree of control over domestic interest rates by varying the amount of liquidity injections.

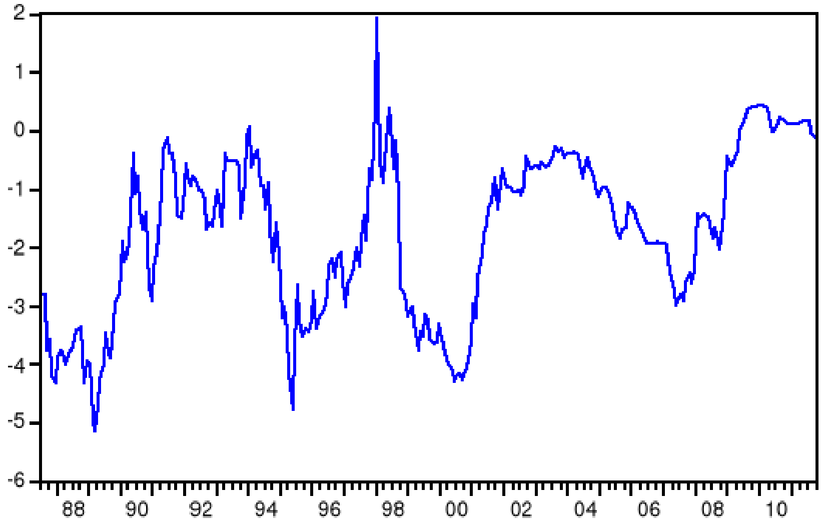

Figure 6: Interest Differentials between 3-month SIBOR and Singapore Dollar 3-Month Interbank Rate. SIBOR is the US Dollar Deposit Rate in Singapore. Source: Monetary Authority of Singapore Financial Database.

It is natural to ask then, if Singapore could have done better with an inflation targeting rule based on the Taylor rule? The typical formulation of the Taylor rule has the interest rate as a function of its own lag, as well as a function of the deviation of inflation from its target rate, and an output gap measure:

$$\log(R_t) = \rho^r \log(R_{t-1}) + (1-\rho^r)\rho^\pi(\log(\Pi_t^c/\overline{\Pi^c})) + (1-\rho^r)\rho^y(\log(Y_t/Y_t^{flex}))$$
$$0 \leq \rho^r \leq 1; \quad \rho^\pi > 1, \quad \rho^y \geq 0 \qquad (44)$$

where Π_t^c is the gross consumption price inflation rate, $\overline{\Pi^c}$ is the target (steady-state) inflation rate. The output gap is defined as $(\log(Y_t/Y_t^{flex}))$, where Y_t is GDP and Y_t^{flex} is the level of output in a flexible wage and price economy. The parameter ρ^r is the smoothing coefficient, ρ^π is the inflation coefficient and ρ^y is the output gap coefficient. Determinacy of inflation requires that the inflation rate coefficient be greater than unity, hence $\rho^\pi > 1$.

If this interest rate rule were to be adopted, it would replace equation (43), and the counterfactual experiment would be for the case with policy-determined interest rate and market determined exchange rate (in contrast to the current practice of a policy determined exchange rate and a market determined interest rate). The relationship between interest and exchange rates, embodied in equation (6) is unaffected.

Hence, in the counterfactual experiment, the exchange rate rule was replaced with an interest rate rule. More specifically, when the exchange rate is managed, the domestic rate is determined to satisfy the interest parity relationship and when the interest rate is managed, the exchange rate is determined to satisfy the interest parity relationship. In both cases, the risk premium is pre-determined as a function of the deviation of the lagged value of foreign assets from its steady-state level.

Given that we had acknowledged a certain degree of model misspecification, by making use of the DSGE/VAR estimates of the model, further assumptions were needed for counterfactual simulation. Del Negro and Schorfheide (2010) explored two alternatives in the context of the DSGE/VAR framework. One was to assume that the discrepancies between the DSGE and empirical VAR model were policy invariant. The second was to take misspecification into account through draws on the prior distributions of the parameters, conditional on the counterfactual policy regime. Given that the DSGE and DSGE/VAR parameter confidence intervals showed a considerable degree of overlap, as noted in our discussion of the results presented in Table 2, we assumed that the relatively small degree of misspecification was policy invariant.

Since the Taylor rule was the counterfactual, we obtained the coefficient values for this policy alternative from optimization of the welfare function, given by equation (2), conditional on the parameters obtained from the DSGE/VAR model. From numerical optimization of the model, the following estimates emerged for the couterfactual optimal Taylor rule: $\widehat{\rho}^{r} = 0.15$, $\widehat{\rho}^{\pi} = 1.025$, $\widehat{\rho}^{y} = 0.425$.

We compared the performance of the model using the actual and counterfactual optimal Taylor rule in three ways. First, the paths of inflation and the output gap were examined over the estimation period, assuming that both regimes were subjected to the same set of smoothed shocks. Second, the impulse response paths for inflation and the output gap, for all of the shocks, were examined under the two regimes. Third, the distributions of inflation and output gap volatility, over 1000 stochastic realizations, were examined with the sample size equal to the historical sample.

4.1 Comparisons

4.1.1 Historical and Counterfactual Simulations

Figures 7 and 8 picture the paths of inflation and the output gap predicted by the model when the smoothed shocks (for productivity, the world interest rate, the risk premium, government spending, world GDP, and export and import price inflation) were used as the innovations in the model. The two paths were quite close.

The standard deviation of inflation in the counterfactual regime was higher than under the actual exchange rate regime (0.089 vs 0.067), while the output gap volatilities were virtually the same (0.025 in both regimes). Figure 5 showed that the drop in the output gap under the counterfactual regime at the time of the Asian crisis was slightly less, but following the world crisis of 2008, the swings in the output gap were of equal magnitude under both regimes. The drop in demand was due to the collapse of foreign GDP, which neither the exchange rate nor the domestic interest rate could stabilize in any way.

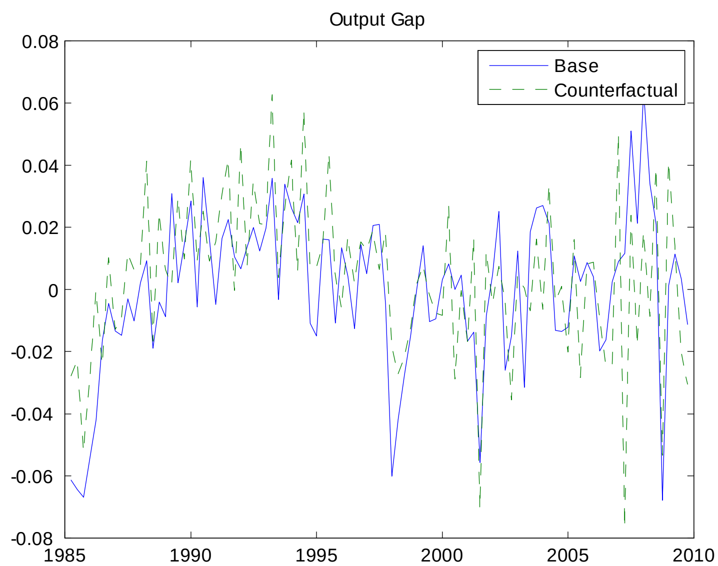

Figure 7: Inflation under Base and Counterfactual Paths. Source: Calculations from Monte Carlo markov chain simulations.

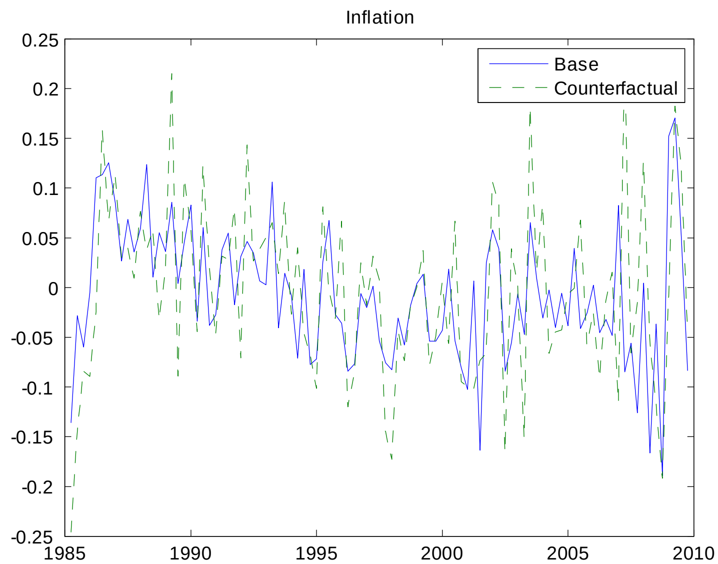

Figure 8: Output Gap under Base and Counterfactual Paths.
Source: Calculations from Monte Carlo markov chain simulations.

4.1.2 Impulse Response Paths

Figures 9 and 10 picture the impulse response paths of and inflation and the output gap under the actual and counterfactual policy regimes for the seven shocks estimated for the model. While the paths were generally close, there were a number of differences in the initial response.

In response to a productivity shock, inflation rose under the exchange-rate rule but fell under the Taylor rule. The reason for the different responses was that the productivity shock also increased the output gap. Since the Taylor rule responded to the output gap, with an increase in the interest rate, inflation fell following the productivity shock in this regime. Inflation was also more responsive to an import-price inflation shock under the Taylor rule than in the base exchange rate regime. The reason for this result is straightforward. While inflation targeting could diminish the effects of import price inflation changes on domestic-currency prices, changes in the exchange rate form a major component of domestic inflation.

The impulse response analysis suggested that one rule might have been more useful than the other for stabilizing inflation, depending on the nature of the shocks affecting the economy. When productivity shocks were dominant, the Taylor rule appeared to be more effective, but when foreign price shocks dominated, the exchange-rate rule was preferable. We discuss this in greater detail, below, where we take up the comparative advantage of the two instruments for productivity and foreign inflation shocks.

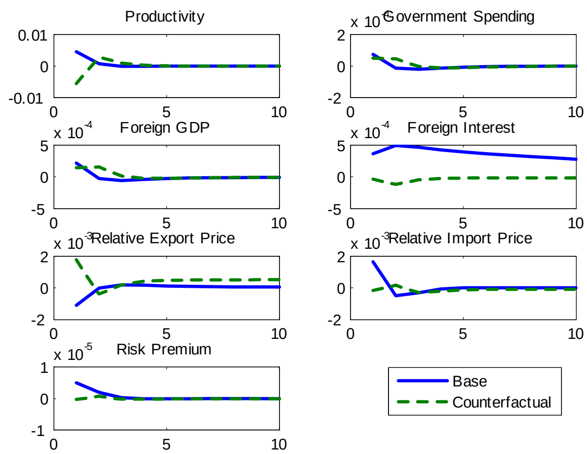

Figure 9: Impulse Response Paths of Inflation for Inflation under Base and Counterfactual Regimes. Source: Calculations from Monte Carlo markov chain simulations.

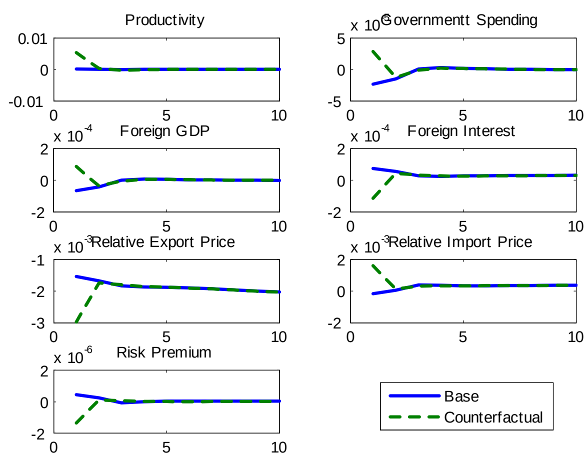

Figure 10: Impulse Response Paths for Output Gap under Base and Counterfactual Regimes. Source: Calculations from Monte Carlo markov chain simulations.

4.1.3 Stochastic Simulations

So far, we have examined the response of the model to the historical smoothed shocks or to a one period shock, with all other innovations held at zero. For a more complete picture, we examined the volatilities (based on second moments) of inflation and the output gap, as well as the two alternative policy instruments, the rate of depreciation of the exchange rate and the interest rate, for 1000 stochastic simulations based on random draws of the shocks from their underlying distributions. Each draw was the size of the historical sample.

The distributions of the volatility measures in Figure 11 showed a clear volatility trade-off in the choice of policy instrument. Under the exchange-rate rule, the depreciation was much less volatile and the interest rate more volatile, than under an interest-rate based rule.

The volatility of inflation would be slightly increased had the monetary authority switched from an exchange-rate based inflation targeting regime to an interest-rate based regime. However, since both policies were aimed at managing inflation, the differences would be small. What was surprising was the result for the output gap - there was virtually no difference between the volatilities under both regime even though the comparison was between an *estimated* exchange rate depreciation rule with an *optimal* Taylor rule.

To understand this result, we derived an optimal (welfare-maximing) depreciation rule, given the shocks of the model, and we found that the optimal rule delivered an output gap coefficient of zero, with a lower coefficient on inflation (1.05) and a larger smoothing coefficient on lagged depreciation (0.675) than the corresponding estimated coefficients of 1.72 and 0.145. In other words, the base exchange rate rule was close to the optimal rule. Thus, the counterfactual Taylor rule and the exchange-rate rule represented simple optimal rules, with nearly identical results on the output gap.

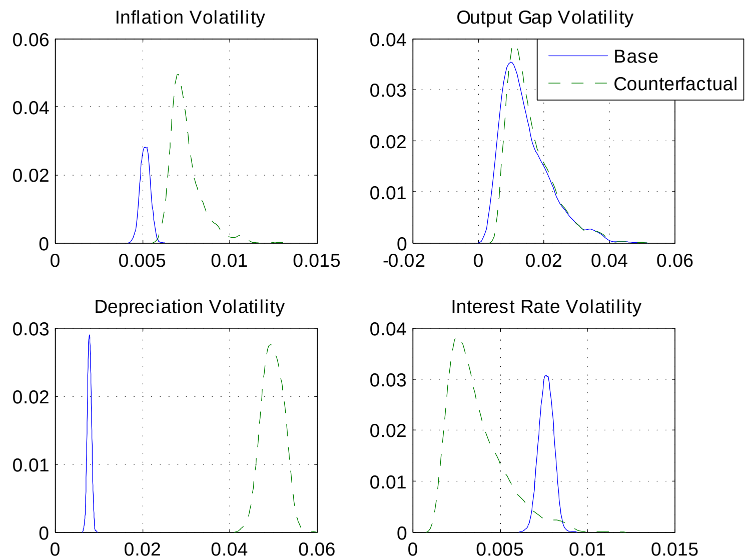

Figure 11: Volatility Distributions under Base and Counterfactual Regimes. Source: Calculations from Monte Carlo markov chain simulations.

To interpret the differences in the welfare between the two regimes, we calculated the implied habit-adjusted consumption compensation index required to equalize the welfare of the representative household in the two regimes, following Schmidt-Grohe and Uribe (2007). A positive value implied that the household in the counterfactual scenario was worse off and needed a positive habit-adjusted consumption compensation to have the same welfare as the household in the base scenario. A negative value meant that the household was better off in the counterfactual scenario, and would require a reduction in consumption to be equal to the welfare realized in the base scenario.

The mean compensation from the stochastic simulations was -0.0025%, implying that the household was only very minimally worse off, a quarter of a percent, of a unit of habit-adjusted consumption, under the base exchange rate regime relative to the counterfactual Taylor rule.

4.2 A Comparative Advantage for Policy Regimes?

The analysis thus far showed that the optimal (welfare-maximizing) Taylor rule, based on the lagged interest rate, inflation and the output gap, reduced inflation in the wake of a productivity shock, while the empirically-estimated exchange rate depreciation rule lowered inflation in the wake of an export price shock. We also saw in Table 6 that real GDP volatility was largely explained by export-price volatility (74 percent) relative to productivity (4 percent). For stabilizing welfare, not just inflation, it made sense for the MAS to make use of the exchange-rate depreciation rule rather than the Taylor rule, especially if export price shocks had dominated. If, however, GDP were driven much more by productivity relative to export price shocks, our analysis suggested that the Taylor rule might have made more sense as a policy regime.

To assess the relative performance or comparative advantage of the two policy regimes, we simulated the estimated model with the two optimal rules, for the case of pure export price shocks and for the case of pure productivity shocks. The volatility measures for inflation, output gap, and the two policy instruments (the interest rate and exchange rate) were computed.

Table 4 shows the comparative advantage of the two policy regimes. The Taylor rule did a much better job in terms of inflation volatility for recurring productivity shocks. But, there was a volatility trade-off with a switch to an interest rate rule (compared to the exchange rate rule), in that inflation volatility fell but output-gap volatility increased. However, for recurring shocks to export prices, we saw that switching from a Taylor rule to a depreciation rule reduced by almost half the volatility of inflation, while the output-gap volatility fell slightly. Thus, for the case of recurrent export price shocks, the policy regime based on inflation-targeting exchange-rate management had the decided comparative advantage over the Taylor rule.

Table 4: Comparing Policy Regimes: Volatility

Shocks	π	$\log\left(Y/Y^{flex}\right)$	r	Δs
		Exchange Rate Rule		
ϵ^z	0.0244	0.0011	0.0247	0.0246
ϵ^{px*}	0.0029	0.0177	0.0028	0.0028
		Taylor Rule		
ϵ^z	0.0172	0.0144	0.0038	0.1214
ϵ^{px*}	0.0047	0.0179	0.0041	0.0161

Source: Calculations from Monte Carlo markov chain simulations.

Gerlach and Tillman (2012) have argued that policy regime changes should also be evaluated on the basis of their effect on inflation persistence. They found that Asian countries which have switched to an inflation-targeting regime (with a Taylor rule) had reduced inflation persistence. What are the effects of alternative inflation-targeting regimes on inflation persistence in Singapore? Following Gerlach and Tillman, the following regression equation was estimated to obtain an estimate of the persistence coefficient γ :

$$\Pi_t = \gamma \Pi_{t-1} + \sum_{i=1}^{k} \delta_i \Delta \Pi_{t-i} + \varepsilon_t \tag{45}$$

where Π_t is inflation, and ε_t is a normally-distributed innovation with variance σ_ε^2.

We estimated the persistence coefficient γ for the actual data, and obtained a bootstrapped 95% confidence interval. We then simulated the model (using the estimated standard errors of all of the shocks), under the two policy regimes, to find the mean, median and confidence intervals of inflation persistence.

Table 5: Inflation Persistence

	$\widehat{\gamma}$	$\widehat{\gamma}_{mean}$	$\widehat{\gamma}_{median}$	$\widehat{\gamma}_{.025}$	$\widehat{\gamma}_{.975}$
Actual Inflation	0.51			0.17	0.85
Exchange-Rate Rule		0.26	0.30	-0.40	0.71
Taylor Rule		0.85	0.94	0.12	1.06

Source: Calculations from Monte Carlo markov chain simulations.

Table 5 showed a confidence interval of [0.17 0.85] for inflation persistence for actual observed data. Based on simulated data, the mean and median of the persistence coefficient for the exchange-rate rule was at the lower end of the actual distribution, while the mean and median under the Taylor-rule regime was at the upper end of the actual distribution. These results indicated that the inflation-targeting regime with the exchange-rate rule had a comparative advantage over the Taylor rule inflation-targeting regime for achieving lower inflation persistence.

5 Conclusion

This paper has specified a dynamic stochastic general equilibrium model of the Singapore economy. The model had seven stochastic shocks, namely: shocks to productivity, government spending, foreign interest rates, foreign GDP, import and export price inflation, and the risk premium. The seven observables used in the Bayesian estimation were domestic GDP growth, CPI inflation, government spending, foreign interest rates, foreign GDP growth, import price inflation and the risk premium. The sample period was from 1985 to 2009.

The Monetary Authority of Singapore (MAS) has adopted an exchange-rate instrument to manage inflation for this period. This paper showed that there would have been no reason for Singapore to fear floating the exchange rate and adopting a Taylor rule to manage inflation. Given the structure of the shocks impinging on the economy, welfare differences would have been very minor. The only trade-off would have been in the volatility of the alternative policy instruments. If the MAS had abandoned the exchange-rate rule in favor of an interest rate rule, there would have been more exchange-rate volatility and less interest-rate volatility, but not much else would have changed. This result should not be surprising, since our Bayesian estimates showed that the degree of price and wage flexibility were relatively high in comparison with most advanced economies. With high nominal flexibility, it should make little or no difference which type of monetary regime had been adopted.

However, this paper also showed that the choice of an exchange rate rule made eminent sense, when export price shocks dominated domestic productivity shocks as the source of real sector volatility. The exchange-rate rule appeared to have a comparative advantage over the Taylor rule for stabilizing both inflation and the output gap in this situation, in addition to achieving lower inflation persistence relative to a Taylor rule.

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