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Can Exchange Rate Rules be Better than Interest Rate Rules?

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Abstract:

We develop a New Keynesian small open economy model to compare the welfare performances of two classes of monetary policy rules: exchange rate rules and interest rate rules. The expected lifetime utility of the representative household is used as the welfare criterion. The model is solved using second-order approximation methods. We find that under benchmark parameterization, an exchange rate rule delivers lower standard deviations of GDP and inflation compared to an interest rate rule, when the economy has a high degree of openness. However, despite that, an exchange rate rule is welfare inferior to an interest rate rule since it delivers lower mean terms of trade, which leads to lower mean consumption and higher mean labor hours. On the other hand, when the elasticity of substitution for export is high, an exchange rate rule is welfare superior to an interest rate rule, regardless of the degree of openness, as the differences in mean terms of trade for the two classes of rules become smaller.

Keywords: Exchange rate rules, interest rate rules, monetary policy, welfare comparison, small open economy

JEL Classification: E52, F41

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1 Introduction

Ever since the seminal contribution of Taylor (1993), monetary policy discussions have been dominated by "interest rate rules", a class of monetary policy rules where interest rates react endogenously to a small set of macroeconomic variables. An important reason for the success of the Taylor-style interest rate rules is that Taylor (1993) and many subsequent contributions have demonstrated that this class of rules seems to describe the actual monetary policies of many central banks in advanced countries rather well.¹ Another reason for their popularity is that they are simple, easy to understand and implement. As a result, many studies have been devoted to study both the positive and normative implications of interest rate rules.

Despite the popularity of interest rate rules, there are some alternative monetary policy rules that might be worth studying.² One such alternative is "exchange rate rules", defined here to be a class of monetary policy rules where nominal exchange rates react endogenously to a small set of macroeconomic variables. One reason why exchange rate rules deserve some attention is that Parrado (2004) and McCallum (2006, 2007) have shown that this class of rules describes Singapore's monetary policy rather well. The Monetary Authority of Singapore also states that "[i]n Singapore, monetary policy is centered on the management of the exchange rate, rather than money supply or interest rates." (Monetary Authority of Singapore, 2001). Even though Singapore is a very small country, McCallum (2007) argues aptly that its monetary policy deserves attention because Singapore has more population and a larger GDP in dollar term than New Zealand, which is a pioneer in "world-wide surge toward inflation targeting". Parrado (2004) also observes that Singapore's monetary

¹See for example, Clarida et al. (1998, 2000), Lubik and Schorfheide (2004, 2007).

²In addition to the exchange rate rules discussed in this paper, base money rules (e.g. McCallum, 1988) and MCI rules (e.g. Ball, 1999) have also been explored in the literature.

policy "has helped achieve a track record of low inflation with prolonged economic growth". Moreover, using a dynamic stochastic general equilibrium (DSGE) model, McCallum (2006, 2007) shows that for a very open economy like Singapore, an exchange rate rule can deliver a much lower volatility of output gap, compared to an interest rate rule, with only slightly higher volatility of inflation.

The goal of this paper is to compare the welfare implications of exchange rate rules and interest rate rules. Like McCallum (2006, 2007), we construct a New Keynesian small open economy DSGE model for the analysis. In contrast to McCallum (2006, 2007), we will use the expected lifetime utility of the representative household as the welfare criterion, following most of the recent literature. This distinction is important, since the literature has found that monetary policy can have important implications for the representative household's utility beyond the traditional focus on the volatility of inflation and output gap, especially in open economy context.³ By using the expected lifetime utility of the representative household as the welfare criterion, we are able to incorporate effect such as the mean terms of trade, which is not explored in McCallum (2006, 2007), but turns out to be important for the representative household's utility.

Like McCallum (2006, 2007), our results suggest that an exchange rate rule can deliver a lower standard deviation of output, compared to an interest rate rule, when the economy is a very open economy. In addition, unlike McCallum (2006, 2007), we also find that an exchange rate rule can deliver a lower standard deviation of inflation in our model, when the degree of openness is high. The intuition for the results above is as follow. An exchange rate rule tends to lead to a lower volatility of nominal exchange rate, compared to an interest rate rule. The lower volatility of nominal exchange rate leads to a less volatile imported goods price inflation, which can be thought of as more stable supply shocks, since imported goods are inputs in the production process in our model. This effect dominates when the degree

³See for instance, Bacchetta and van Wincoop (2000), Bergin et al. (2007) and Sutherland (2006).

of openness is high, so that imported goods as a share of gross output is high. The lower volatility of inflation also means that an exchange rate rule leads to a lower mean resource cost of price dispersion.

Despite the lower mean resource cost of price dispersion, we find that an exchange rate rule is welfare inferior to an interest rate rule under the benchmark parameterization, regardless of the degree of openness. The result hinges on the effects of the mean terms of trade. Since an interest rate rule delivers a higher standard deviation of nominal exchange rate, it also leads to a more favorable average terms of trade as exporters set a higher price to cushion for nominal exchange rate uncertainty. The more favorable terms of trade leads to a higher mean consumption and lower mean labor hours for an interest rate rule, and hence higher welfare compared to an exchange rate rule.

In spite of the results above, we find that an exchange rate rule can be welfare superior to an interest rate rule for alternative parameterization of the model. Specifically, when the elasticity of substitution for export is high but within the range for empirical estimates, an exchange rate rule can beat an interest rate rule regardless of the degree of openness. This is because when the elasticity of substitution for export is high, exchange rate rules and interest rate rules differ less in terms of the average level of terms of trade, leaving the welfare difference to be dominated by the mean resource cost of price dispersion.

The rest of the paper is organized as follow. We present the model in Section 2. The welfare measure is discussed in Section 3. Section 4 discusses the calibration and solution methods. The results are presented in Section 5. Section 6 concludes.

2 The model

The model that we construct builds on the contribution of McCallum (2006, 2007) and Kollmann (2002). It is a micro-founded, New Keynesian small open economy DSGE model.

Time is discrete and the horizon is infinite. The agents in the economy include a representative household, firms, and the government. The representative household consumes a final goods, supplies labor service, and buys or sells bonds each period. In addition, the representative household also accumulates physical capital and rents the capital to firms.⁴ There is a continuum of monopolistically competitive domestic intermediate firms that produce differentiated products. To facilitate comparison with McCallum (2006, 2007), we follow McCallum and assume that imported goods are used as inputs in the production process of the intermediate firms instead of being a component of the composite final goods as in most other New Open Economy Macroeconomic models.⁵ We will also focus on the case for which there is full pass through for both the export and import prices, following McCallum (2006, 2007).⁶ Price adjustment for the intermediate goods is staggered in the form of Calvo (1983) following the recent literature. Financial market is assumed to be incomplete with only riskless bonds being traded internationally.

Since our goal is to compare exchange rate rules with interest rate rules, we assume that the consolidated government controls the monetary policy using either an interest rate rule or an exchange rate rule. Consistent with the recent literature, we focus on the Woodford (2003) case of a "cashless economy". In what follows, variables without time subscript denote the corresponding steady state of the variables.

2.1 The representative household

There is a representative household in the small open economy. The representative household maximizes expected lifetime utility, which is defined over consumption, C_t , and labor hours,

⁴In contrast, McCallum (2006, 2007) does not have capital accumulation in his model.

⁵However, the qualitative results of this paper will not change if the alternative specification is adopted. The results are available upon request.

⁶While incomplete exchange rate pass-through can have important implications for welfare comparisons of monetary policy regimes (e.g. Devereux and Engel, 2003; Corsetti and Pesenti, 2005), we will leave the case of incomplete pass through for future research.

L_t . Period utility function is specified as separable in consumption and labor hours:

$$E_0 \sum_{t=0}^{t=\infty} \beta^t U(C_t, L_t), \quad (1)$$

$$U(C_t, L_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} - \zeta \frac{L_t^{1+\xi}}{1+\xi}, \quad (2)$$

where E_t is the expectations operator conditional on time t information; $\beta \in (0, 1)$ is the subjective discount factor, $\xi \geq 0$ is the inverse of Frisch labor supply elasticity, and $\zeta > 0$ is a preference parameter.

The representative household owns the capital stock, K_t , in the small open economy. The capital stock evolves according to the law of motion:

$$K_{t+1} + \frac{1}{2} \phi \frac{\{K_{t+1} - K_t\}^2}{K_t} = (1 - \delta) K_t + I_t, \quad (3)$$

where I_t is the gross investment. $\frac{1}{2} \phi \frac{\{K_{t+1} - K_t\}^2}{K_t}$ with $\phi \geq 0$ is a capital adjustment cost. $\delta \in (0, 1)$ is the depreciation rate of the capital.

In addition to choosing consumption, labor hours, capital stock and investment, the representative household also holds a risk-free domestically traded domestic currency denominated bond, A_{t+1} and a risk-free internationally traded foreign currency denominated bond, B_{t+1} . The budget constraint for the representative household is:

$$A_{t+1} + e_t B_{t+1} + P_t C_t + P_t I_t = A_t R_{t-1} + e_t B_t R_{t-1}^f + R_t^k K_t + W_t L_t + D_t, \quad (4)$$

where e_t is the nominal exchange rate, expressed as the number of unit of domestic currency required to purchase one unit of foreign currency. P_t is a price index for the domestic final goods, to be defined formally below. R_t is the nominal interest rate on domestically traded bond. R_t^f is the nominal interest rate on the internationally traded foreign currency

denominated bond. R_t^k is the nominal rental rate of capital. W_t is the nominal wage rate. D_t is the dividend from owning domestic firms.

Following Kollmann (2002), we assume that the interest rate at which the domestic representative household can borrow or lend foreign currency fund, R_t^f , is subjected to a "spread" from the foreign nominal interest rate, R_t^* . The "spread" is assumed to be a decreasing function of the net foreign asset position of the domestic economy:

$$R_t^f = R_t^* - \lambda \frac{B_{t+1}}{P_t^x Q_t^x}, \quad (5)$$

where $P_t^x Q_t^x$ is the nominal value of the small open economy's export in foreign currency term, to be defined formally below. The parameter $\lambda > 0$ captures the extent of financial integration. A lower value of λ corresponds to a higher degree of integration with the international financial markets. The spread term also plays the role of "closing" the small open economy model, to ensure that the small open economy model has a stationary equilibrium (Schmitt-Grohé and Uribe, 2003). R_t^* is assumed to follow an exogenous process in this model.

The first order conditions for the representative household's maximization problems are:

$$\zeta L^\xi = \frac{W_t}{C_t^\sigma P_t}, \quad (6)$$

$$1 = R_t E_t \left\{ \beta \frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}} \right\}, \quad (7)$$

$$1 = \varphi_t R_t^f E_t \left\{ \beta \frac{C_t^\sigma P_t e_{t+1}}{C_{t+1}^\sigma P_{t+1} e_t} \right\}, \quad (8)$$

$$1 + \phi \frac{(K_{t+1} - K_t)}{K_t} = E_t \left\{ \beta \frac{C_t^\sigma}{C_{t+1}^\sigma} \left[\frac{R_{t+1}^k}{P_{t+1}} + 1 - \delta + \phi \frac{(K_{t+2} - K_{t+1})}{K_{t+1}} + \frac{1}{2} \phi \frac{(K_{t+2} - K_{t+1})^2}{K_{t+1}^2} \right] \right\}, \quad (9)$$

Equation (6) equates the marginal disutility and marginal benefit of labor hours. Equa-

tion (7) is the domestic bond's Euler equation. Equation (8) is the Euler equation for internationally traded bond. Following Kollmann (2002), a term, φ_t , is exogenously imposed on the Euler equation for internationally traded bond, so that up to a log-linear approximation, equations (7) and (8) imply, $E_t \Delta \hat{e}_{t+1} = \hat{R}_t - \hat{R}_t^f - \hat{\varphi}_t$, where $\Delta e_t \equiv e_t/e_{t-1}$ and a hat on a variable denote log deviation of that variable from its steady state. The term φ_t , can be interpreted as an uncovered interest parity (UIP) shock, which is designed to capture deviations from the UIP condition. Equation (9) is the capital Euler equation.

2.2 Firms

There is a continuum of monopolistically competitive domestic intermediate goods firms, indexed by $i \in [0, 1]$. The production function for an intermediate goods firm i is:

$$Y_{i,t} = \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{\vartheta}{\vartheta-1}}, \quad (10)$$

where $Y_{i,t}$ is the output of firm i , $K_{i,t}$ and $L_{i,t}$ denote the capital stock and labor hours used by firm i , respectively. θ_t is an exogenous economy-wide technology process. $\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi}$ is the domestic value added in the production. $Q_{i,t}^m$ is the amount of imported goods used as input by firm i . $\alpha \in (0, 1)$ is a parameter that determines the share of domestic value added in the production. $\vartheta > 0$ is the elasticity of substitution between domestic value added and imported goods in the production. The parameter $\psi \in (0, 1)$ determines the share of rental income in domestic value added.

Firm i chooses $K_{i,t}$, $L_{i,t}$ and $Q_{i,t}^m$ by solving a cost minimization problem:

$$\min R_t^k K_{i,t} + W_t L_{i,t} + P_t^m Q_{i,t}^m, \quad (11)$$

$$\text{s.t. } \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{\vartheta}{\vartheta-1}} = y_{i,t}, \quad (12)$$

where P_t^m is the price of the imported goods in domestic currency term. The first order conditions are:

$$R_t^k = \psi MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} \alpha^{\frac{1}{\vartheta}} \frac{\left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}}}{K_{i,t}}, \quad (13)$$

$$W_t = (1-\psi) MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} \alpha^{\frac{1}{\vartheta}} \frac{\left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}}}{L_{i,t}}, \quad (14)$$

$$P_t^m = MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{-1}{\vartheta}}, \quad (15)$$

where MC_t is the Lagrange multiplier associated with the constraint (12), which can also be interpreted as the nominal marginal cost.⁷

Following the literature, we assume that the intermediate goods are aggregated into composite final domestic goods, Y_t , via the Dixit-Stiglitz aggregator:

$$Y_t = \left\{ \int_0^1 Y_{i,t}^{\frac{\nu-1}{\nu}} di \right\}^{\frac{\nu}{\nu-1}}, \quad (16)$$

where ν is the elasticity of substitution between different varieties of intermediate goods. Cost minimization leads to the following demand function for $Y_{i,t}$:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\nu} Y_t, \quad (17)$$

where $P_{i,t}$ is the price of $Y_{i,t}$ while P_t is a price index for Y_t given by:

$$P_t \equiv \left\{ \int_0^1 P_{i,t}^{1-\nu} di \right\}^{\frac{1}{1-\nu}}. \quad (18)$$

⁷Given the structure of the model, nominal marginal cost will be equalized across firms, so there is no subscript i on MC_t .

The composite final domestic goods is demanded as consumption and investment goods in the domestic market as well as exported:

$$Y_t = C_t + I_t + Q_t^x, \quad (19)$$

where Q_t^x is the export demand. Following McCallum (2006, 2007), McCallum and Nelson (1999) and Kollmann (2002), we assume that Q_t^x depends on the ratio of export price in foreign currency term, P_t^x , relative to the foreign price level, P_t^* :

$$Q_t^x = \kappa \left(\frac{P_t^x}{P_t^*} \right)^{-\eta}, \quad (20)$$

where $\eta > 0$ is the elasticity of substitution for export; $\kappa > 0$ is a scaling factor. P_t^* is an exogenous process in this model. Following McCallum (2006, 2007) and McCallum and Nelson (1999), we assume that firms cannot price discriminate across markets, so that the export price in foreign currency is simply the final domestic goods price divided by the nominal exchange rate, $P_t^x = P_t/e_t$. Similarly, following McCallum (2006, 2007) and McCallum and Nelson (1999), the price for imported goods in domestic currency term is simply the product of foreign price level and nominal exchange rate, $P_t^m = e_t P_t^*$.

We assume that price adjustment for the intermediate goods firms is staggered à la Calvo (1983). Each period, each intermediate goods firm i faces a random probability of $(1 - \gamma)$, $\gamma \in [0, 1]$, of resetting its price, $P_{i,t}$. If $P_{i,t}$ is not reset, it is updated by the steady state inflation rate, π , according to the rule $P_{i,t} = \pi P_{i,t-1}$. Let $\tilde{P}_{i,t}$ denote the new price that is reset in period t . After resetting the price at period t , there is γ^τ probability that the price has not been reset at period $t + \tau$, and hence $P_{i,t+\tau} = \pi^\tau \tilde{P}_{i,t}$. Using the demand function, (17),

and the price updating rule, the optimization problem for firm i in the domestic market is:

$$\max_{\tilde{P}_t} \sum_{\tau=0}^{\infty} (\gamma)^\tau E_t \frac{\rho_{t,t+\tau}}{P_{t+\tau}} \left\{ \pi^\tau \tilde{P}_t \left(\frac{\pi^\tau \tilde{P}_t}{P_{t+\tau}} \right)^{-\nu} Y_{t+\tau} - TC_{t+\tau} \left[\left(\frac{\pi^\tau \tilde{P}_t}{P_{t+\tau}} \right)^{-\nu} Y_{t+\tau} \right] \right\},$$

where $\rho_{t,t+\tau} \equiv \beta^\tau \frac{C_t^\sigma}{C_{t+\tau}^\sigma}$ is a discount factor for evaluating profit streams, $TC(\cdot)$ is the total cost as a function of the demand. The first order condition for the optimization problem is:

$$\tilde{P}_t = \frac{\nu}{\nu - 1} \frac{E_t \sum_{\tau=0}^{\infty} (\gamma \pi^{-\nu})^\tau \frac{\rho_{t,t+\tau}}{P_{t+\tau}} MC_{t+\tau} (P_{t+\tau})^\nu Y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} (\gamma \pi^{1-\nu})^\tau \frac{\rho_{t,t+\tau}}{P_{t+\tau}} (P_{t+\tau})^\nu Y_{t+\tau}}. \quad (21)$$

2.3 Market clearing and aggregation

Market clearing for the labor, capital and imported goods markets requires the supplies, L_t , K_t and Q_t^m , equal the sum of demand from all domestic intermediate goods firms:

$$L_t = \int_0^1 L_{i,t} di, \quad (22)$$

$$K_t = \int_0^1 K_{i,t} di, \quad (23)$$

$$Q_t^m = \int_0^1 Q_{i,t}^m di. \quad (24)$$

Since the domestic bonds, A_t , is assumed to be traded only domestically, its net supply is zero in equilibrium:

$$A_t = 0. \quad (25)$$

Defining $Y_t^A \equiv \int_0^1 Y_{i,t} di$, equation (17) can be aggregated across firms as:

$$Y_t^A = u_t Y_t, \quad (26)$$

where

$$u_t \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\nu} di. \quad (27)$$

As noted in Schmitt-Grohé and Uribe (2004a, 2005, 2006b, 2007), u_t can be interpreted as resource cost of price dispersion associated with the Calvo-style staggered price adjustment. It can be shown that $u_t \geq 1$ for all t . Higher values of u_t correspond to higher resource costs of price dispersion as a given sum of intermediate goods, Y_t^A , gives rise to lower supply of final goods, Y_t . It can also be shown that u_t is increasing in the standard deviation of π_t .

For ease of discussion below, it is useful to define here the constant price real GDP as:

$$GDP_t = Y_t - p^m Q_t^m, \quad (28)$$

where p^m is the steady state value of the ratio of import price to domestic final goods price. In the equation above, the price of domestic goods P has been normalized to 1 in the base year, while the price of import have been set to its steady state value in the base year. It is also useful to define the terms of trade, S_t , as the ratio of export price to import price:

$$S_t = \frac{e_t P_t^x}{P_t^m}. \quad (29)$$

Note that since we assume full pass through, we have $e_t P_t^x = P_t$ and $P_t^m = e_t P_t^*$, so the terms of trade also equals the inverse of real exchange rate in this paper.⁸

2.4 The government

We assume that the consolidated government conducts monetary policy using either a Taylor (1993)-type interest rate rule or an exchange rate rule. For the case of interest rate rule, the

⁸The equivalence of terms of trade and real exchange rate will not hold if there is incomplete pass-through (e.g. Sutherland, 2005) or multi-stage production (e.g. Devereux and Engel, 2007).

policy rule is of the form:

$$\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP), \quad (30)$$

where Γ_π , Γ_{GDP} are policy parameters while $\pi_t \equiv P_t/P_{t-1}$ is the gross domestic final goods price inflation rate.⁹ For the case of exchange rate rule, the policy rule is of the form:

$$\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP), \quad (31)$$

where $\Delta e_t \equiv e_t/e_{t-1}$ is the gross rate of nominal depreciation. Negative signs are put in front of Γ_π and Γ_{GDP} for the exchange rate rule so that positive values of Γ_π and Γ_{GDP} correspond to counter-cyclical policies.

Since the optimal values of Γ_π and Γ_{GDP} for the interest rate rule and exchange rate rule might be different, we search for the optimal values of Γ_π and Γ_{GDP} for the two classes of rules in this paper. Following Schmitt-Grohé and Uribe (2006a,b, 2007), we search numerically for the optimal values of Γ_π and Γ_{GDP} using grid search with grid points in the interval of $[0, 3]$ and a step size of 0.1. As Schmitt-Grohé and Uribe (2006b, 2007) argue, while the interval of $[0, 3]$ is arbitrary, policy coefficients larger than 3 or negative would be hard to communicate to the public. In the search for the optimal policy coefficients, we also impose a condition that the monetary policy rule must yield a locally unique rational expectations equilibrium. It is worthwhile to note that for the case of the exchange rate rule, $\Gamma_\pi = \Gamma_{GDP} = 0$ corresponds to a fixed exchange rate regime.

⁹Note that allowing the interest rate rule to react to the exchange rate will not change the qualitative results in this paper.

2.5 Exogenous processes

Following Kollmann (2002), we assume that the productivity, foreign inflation, foreign interest rate and the UIP shocks follow exogenous first-order autoregressive processes:

$$\ln \theta_t = (1 - \rho^\theta) \ln \theta + \rho^\theta \ln \theta_{t-1} + \varepsilon_t^\theta, \quad (32)$$

$$\ln \pi_t^* = (1 - \rho^*) \ln \pi^* + \rho^* \ln \pi_{t-1}^* + \varepsilon_t^*, \quad (33)$$

$$\ln R_t^* = (1 - \rho^{R^*}) \ln R^* + \rho^{R^*} \ln R_{t-1}^* + \varepsilon_t^{R^*}, \quad (34)$$

$$\ln \varphi_t = (1 - \rho^\varphi) \ln \varphi + \rho^\varphi \ln \varphi_{t-1} + \varepsilon_t^\varphi, \quad (35)$$

where $\pi_t^* \equiv P_t^*/P_{t-1}^*$ is the gross foreign inflation rate. ε_t^θ , ε_t^* , $\varepsilon_t^{R^*}$ and ε_t^φ are i.i.d. shocks with standard deviations σ^θ , σ^* , σ^{R^*} and σ^φ , respectively.

3 The welfare measure

For a given monetary policy regime, a , we use the conditional expected lifetime utility of the representative household at time zero as the welfare measure, CV_0^a :

$$CV_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t u(C_t^a, H_t^a). \quad (36)$$

Following Schmitt-Grohé and Uribe (2006b, 2007), we compute the expected lifetime utility conditional on the initial state being the deterministic steady state. This ensures that the economy always starts from the same initial point, since for a given set of parameter values, the steady states of this model are the same for all monetary policy rules considered in this paper.

Following Lucas (1987), we report the welfare as the fraction, ζ^c , of steady state con-

sumption that the household is willing to give up to be as well off under the steady state, as under a given monetary policy regime a , with CV_0^a as the welfare measure. Formally, ζ^c is given implicitly by:

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{[(1 - \zeta^c) C]^{1-\sigma} - 1}{1 - \sigma} - \zeta \frac{L^{1+\xi}}{1 + \xi} \right) = CV_0^a. \quad (37)$$

Higher values of ζ^c correspond to lower welfare.

4 Solution method and calibration

The model is solved numerically by taking second order Taylor approximations (Kim and Kim, 2003; Schmitt-Grohé and Uribe, 2004b) of the model equations around a deterministic steady state. The second-order accurate solutions are computed using the software package, Dynare (Juillard, 1996).

The model is calibrated with time unit being one quarter. σ , the coefficient of risk aversion, is set to 2, as is commonly assumed in the literature. The subjective discount factor, β , is set at 0.99, so that the steady state annual real interest rate is 4%. ξ , the inverse of Frisch labor elasticity, is set to 1, following Christiano et al. (2005).

Following McCallum (2005, 2006, 2007), the elasticity of substitution between domestic value added and imported input, ϑ , is set to 0.6. We also follow McCallum in setting the elasticity of substitution for export, η , to 0.6 in the benchmark, but we will investigate the robustness of results for alternative values of η . The parameter a affects the steady state ratio of imports to GDP and we will consider two cases in this paper. In case 1, we set a so that the steady state ratio of imports to GDP is 60%, which matches the figure for Singapore (McCallum 2006, 2007). We will call that case a "high-openness" economy. In case 2, we set a so that the steady state ratio of imports to GDP is 15%, which matches the figure for a "typical" industrial economy (McCallum, 2006, 2007). We will call that case a "low-

openness" economy. Given the value of ϑ , a is set to 0.58 for the high-openness economy and 0.855 for the low-openness economy. The share of capital income in value added, ψ , is set to 0.3, as is commonly assumed in the literature. The elasticity of substitution across different variety of goods, v , is set to 6, following McCallum and Nelson (1999) and Kollmann (2002). The scale factor for export demand, κ , in equation (20), is set to 0.391 and 0.103 for the high-openness economy and low-openness economy, respectively, so that there is balanced trade in the steady state. The preference parameter, ζ , is set to 12.376 and 13.413 for the high-openness economy and low-openness economy, respectively, so that the representative household spends 30% of its time working in the steady state.

We set the depreciation rate of capital, δ , to 0.025, as is commonly assumed in the literature. We set the capital adjustment cost parameter, ϕ , to 15, so that the standard deviation of investment is about 2 to 3 times the standard deviation of GDP. Following Kollmann (2002), the fractions of firms not setting the prices optimally in each period, γ is set to 0.75, so that the average price change duration is one year. The steady state gross inflation rate, π , is set to 1, as is commonly assumed in the literature.¹⁰ The extent of financial integration, λ , in equation (5), is set to 0.0019, following Kollmann (2002).

Finally, for the exogenous shock processes, we use the same calibration as Kollmann (2002) and set $\rho^\theta = 0.9$, $\rho^* = 0.8$, $\rho^{R^*} = 0.75$, $\rho^\varphi = 0.5$, $\sigma^\theta = 0.01$, $\sigma^* = 0.005$, $\sigma^{R^*} = 0.004$ and $\sigma^\varphi = 0.033$. Table 1 summarizes the benchmark parameter values for the high-openness economy.

(Table 1 about here)

¹⁰Since we assume there is full indexation to steady state inflation rate when prices are not reset, the results will be robust to the steady state inflation rate. Recently, Ascari (2004) argues that the dynamics of a model might be affected by the steady state inflation rate if there is partial or no indexation to the inflation rate. We do not consider partial or no indexation in this paper and leave that for future research.

5 Results

We report the simulation results in this section. First, we will discuss the results under the benchmark parameterization. We will show that the terms of trade play an important role in the results. Next, we will explore the robustness of the results to alternative parameterization of the model.

5.1 Benchmark results

Table 2 shows the results for the benchmark model. There are several interesting results. First, we find that the optimized exchange rate rules lead to lower standard deviations of nominal depreciation (Δe_t), compared to the optimized interest rate rules, regardless of the degrees of openness. This result is consistent with the findings of McCallum (2006, 2007). Second, like McCallum (2006, 2007), we find that an exchange rate rule can deliver lower volatility of output, compared to an interest rate rule, when the degree of openness is high. The standard deviation¹¹ of GDP is 1.79% for the optimized exchange rate rule (with $\Gamma_\pi = 3.0$, $\Gamma_{GDP} = 1.0$) compared to 2.30% for the optimized interest rate rule (with $\Gamma_\pi = 1.8$, $\Gamma_{GDP} = 0$) for the high openness economy. In contrast, for the low openness economy, the standard deviation of GDP is higher, at 2.56%, for the optimized exchange rate rule (with $\Gamma_\pi = 3.0$, $\Gamma_{GDP} = 0.8$), compared to 2.15% for the optimized interest rate rule (with $\Gamma_\pi = 2.9$, $\Gamma_{GDP} = 0$). Third, unlike McCallum (2006, 2007), we also find that the optimized exchange rate rule delivers a lower (2.00%) standard deviation of domestic final goods price inflation (π_t) compared to the optimized interest rate rule (2.86%), when the degree of openness is high.¹² However, when the degree of openness is low, the optimized

¹¹Standard deviations reported in this paper are in terms of log deviation of variables from their steady state values.

¹²In contrast, McCallum (2006, 2007) find that the standard deviation of π_t is higher for an exchange rate rule, even though the difference relative to an interest rate rule becomes smaller as the degree of openness increases.

exchange rate rule leads to a higher (2.54%) standard deviation of domestic final goods price inflation compared to the optimized interest rate rule (0.87%).

(Table 2 about here)

Why does the optimized exchange rate rule deliver lower standard deviations of GDP and domestic final goods price inflation when the degree of openness is high? The intuition can be inferred from the standard deviations of nominal depreciation and import price inflation ($\pi_t^m \equiv P_t^m / P_{t-1}^m$). As noted above, the optimized exchange rate rule delivers a lower standard deviation of nominal depreciation compared to the optimized interest rate rule, regardless of the degree of openness. This can affect the volatility of GDP and domestic final goods price inflation through two channels. On the one hand, the nominal exchange rate can play the role of shock absorber. This means that the less variable and hence less flexible nominal exchange rate for the optimized exchange rate rule restricts the ability of nominal exchange rate to stabilize GDP through expenditure switching effects. On the other hand, the lower standard deviation of nominal depreciation leads to a lower standard deviation of import price inflation for the optimized exchange rate rule since there is full exchange rate pass through into the import price. Since the imported goods are inputs in the production process, the import price inflation can be thought of as a supply shock. Hence, the lower standard deviation of import price inflation tends to lead to lower standard deviations of domestic final goods price inflation and GDP. When the degree of openness is high (so that imported input as a share of gross output is high), the pass-through effect dominates, which leads to lower standard deviations of GDP and domestic final goods price inflation for the optimized exchange rate rule. When the degree of openness is low, the shock absorber role of nominal exchange rate dominates, so the standard deviations of GDP and domestic final goods price inflation for the optimized exchange rate rule is higher, compared to the optimized interest rate rule.

For the high openness economy, the lower standard deviation of domestic final goods price inflation (π_t) leads to a lower mean resource cost of price dispersion (u_t), for the optimized exchange rate rule (0.09% versus 0.18% for the optimized interest rate rule). However, surprisingly, despite the lower mean resource cost of price dispersion, the optimized exchange rate rule leads to much higher welfare cost compared to the optimized interest rate rule. The welfare cost of the optimized exchange rate rule is 0.34% of steady state consumption while it is -0.31% for the optimized interest rate rule. The welfare difference of 0.65% of steady state consumption is large in the realm of business cycle analysis.¹³ The better performance of the optimized interest rate rule seems to stem from the terms of trade effect. The expected value¹⁴ of terms of trade, S_t , for the optimized interest rate rule (3.24%) is higher than that of the optimized exchange rate rule (1.28%). The more favorable terms of trade for the optimized interest rate rule stems from its higher volatility of nominal depreciation. A higher volatility of nominal depreciation leads to a more favorable terms of trade since it induces exporters to set higher export price to compensate for the exchange rate uncertainty. The more favorable terms of trade for the optimized interest rate rule in turn allows the representative household to consume more and work less, compared to the optimized exchange rate rule.¹⁵ Hence, the optimized interest rate rule delivers higher mean consumption (2.01%), lower mean labor hours (-1.33%) and hence lower welfare cost (-0.31%), compared to the optimized exchange rate rule (0.97%, -0.54% and 0.34%, respectively).

For the low openness economy, in addition to the lower expected value of terms of trade, the optimized exchange rate rule leads to a higher mean resource cost of price dispersion, since

¹³For comparison, the classic estimate of welfare cost of business cycle in Lucas (1987) is 0.17% for a coefficient of risk aversion, σ , of 20, while $\sigma = 2$ in our model.

¹⁴Expected value of a variable is reported in terms of log deviation from its steady state value in this paper.

¹⁵Using a simpler model for which imported goods are not inputs into the production of intermediate goods but combine with a composite domestic goods to form a constant elasticity of substitution composite final goods, Sutherland (2006) show that the mean terms of trade can increase or decrease the welfare depending on the parameter values. However, the model in this paper cannot be directly compared with Sutherland (2006) since the production structure is different.

it leads to a higher standard deviation of domestic final goods price inflation as mentioned above. The less favorable terms of trade and the higher mean resource cost of price dispersion both lead to a higher welfare cost for the optimized exchange rate rule.

5.2 High elasticity of substitution for export

The subsection above has shown that under the benchmark model, an optimized exchange rate rule is welfare inferior to an optimized interest rate rule, regardless of the degrees of openness. This is true even though the optimized exchange rate rule delivers lower standard deviations of GDP and domestic final goods price inflation for the high openness economy. The reason is that an optimized exchange rate rule delivers lower volatility of nominal depreciation and hence less favorable mean terms of trade, compared to an optimized interest rate rule. Since the terms of trade effect plays an important role in the results, it is natural to ask whether the results will continue to hold for alternative parameterization of the model, for which the terms of trade effect might play a smaller role.

A parameter that is important for the magnitude of the terms of trade effect is the elasticity of substitution for export, η . When the elasticity of substitution for export is high, exporters might be less willing to charge a higher export price to cushion for the exchange rate uncertainties since the demand is more sensitive to the price. This would make the terms of trade effect to vary less with exchange rate volatility. In the subsection above, the elasticity of substitution for export, η , is set to 0.6 following McCallum (2006, 2007) and Kollmann (2002). However, there are a lot of uncertainties regarding the empirical value of η . For instance, using data from a panel of developed and developing countries, Lai and Trefler (2002) find that the estimates for the elasticity of substitution for aggregate manufacturing are between 5 to 8. Using disaggregated data from US and 5 other countries, Hummels (2001) finds that the elasticities of substitution range from 3 to 8 for most goods but can be as high as 79 for some goods. In light of these empirical evidences, we will first check

the robustness of the results in detail for a high elasticity of substitution for export, $\eta = 10$, followed by more robustness checks for other values of η .¹⁶

Table 3 shows the results for the case of $\eta = 10$. Similar to the results in Table 2, for the high openness economy, the optimized exchange rate rule delivers lower standard deviations of GDP and domestic goods price inflation, compared to the optimized interest rate rule. Therefore, the optimized exchange rate rule leads to a lower mean resource cost of price dispersion. However, unlike the results in Table 2, for the high openness economy, the optimized exchange rate rule entails a lower welfare cost compared to the optimized interest rate rule when $\eta = 10$. The intuition for this result can be found in Table 3. When $\eta = 10$, while the optimized interest rate still delivers a higher mean terms of trade (0.25% vs. 0.11% for the optimized exchange rate rule), the difference in the mean terms of trade is much smaller compared to the benchmark results for which $\eta = 0.6$ (3.24% vs. 1.28% for the optimized interest rate rule and the optimized exchange rate rule, respectively). As mentioned above, the reason behind this pattern is that when the elasticity of substitution for export is high, exporters will be less willing to charge a higher price to cushion for the exchange rate volatility and hence the mean terms of trade will vary less with exchange rate volatility. Therefore, the welfare difference between the optimized exchange rate rule and the optimized interest rate rule depends mostly on the mean resource cost of price dispersion. Since the optimized exchange rate rule leads to a lower (0.03%) mean resource cost of price dispersion compared to the optimized interest rate rule (0.20%), the optimized exchange rate rule is welfare superior to the optimized interest rate rule.

(Table 3 about here)

¹⁶Another parameter that might affect the magnitude of the terms of trade effect is the elasticity of substitution between domestic value added and imported inputs, ϑ . However, we do not investigate the robustness of the results for alternative values of ϑ in this paper because for the model in this paper, a change in ϑ would also affect the steady state import to GDP ratio, making it impossible to disentangle the effects of ϑ and the degree of openness for the model.

Interestingly, unlike the results in Table 2, when $\eta = 10$, the optimized exchange rate rule is also welfare superior to the optimized interest rate rule for the low openness economy. Like the case of high openness, the difference in mean terms of trade is smaller for the case of low openness when $\eta = 10$. In addition, the optimized exchange rate also delivers lower standard deviations of GDP and domestic goods price inflation for the case of low openness, when $\eta = 10$. This is because when the elasticity of substitution for export is high, export demand is sensitive to the export price, so exporters will try to make their export prices more stable, leading to more stable export demand. A more stable export demand in turn leads to more stable domestic final goods price inflation and GDP through the linkages between export demand, GDP, and factor prices. The lower standard deviation of domestic final goods price inflation leads to a lower mean resource cost of price dispersion for the optimized exchange rate rule. The lower resource cost of price dispersion translates into a smaller welfare cost for the optimized exchange rate rule.

(Figure 1 about here)

In order to investigate further the robustness of the results for different values of η , we plot the welfare costs for the exchange rate rules and interest rate rules, for η between 0.6 to 20 in Figure 1. For both types of monetary policy rules, we fix Γ_π at 3 and Γ_{GDP} at 0 for all values of η . As can be seen from the figure, for the case of high openness, the exchange rate rule is welfare superior to the interest rate rule for $\eta > 2$. For the case of the low openness, the exchange rate rule is welfare superior to the interest rate rule for $\eta > 7$. These values are within the range of the empirical estimates of the elasticity of substitution. Hence, the results in this paper suggest that high degree of openness by itself does not make an exchange rate rule to be welfare superior to an interest rate rule, when the expected utility of the representative household is used as the welfare criterion. In contrast, for high elasticity of substitution for export, an exchange rate rule can be welfare superior to an

interest rate rule, regardless of the degrees of openness. It is also worthwhile to note that the welfare costs of interest rate rules increase very rapidly as elasticity of substitution for export increases, especially for the case of high openness, while the welfare costs of exchange rate rules change by less as elasticity of substitution for export changes.

6 Conclusion

In this paper, we compare the welfare performances of exchange rate rules with interest rate rules. We develop a New Keynesian small open economy DSGE model for the analysis. We depart from the existing studies on exchange rate rules by using the expected lifetime utility of the representative household as the welfare criterion. We find that while an exchange rate rule delivers lower standard deviations of GDP and inflation compared to an interest rate rule when the degree of openness is high, an exchange rate rule is welfare inferior to an interest rate rule under benchmark parameterization. This is because an exchange rate rule delivers lower mean terms of trade, which leads to lower mean consumption and higher mean labor hours. However, for high elasticity of substitution for export, an exchange rate rule is welfare superior to an interest rate rule, regardless of the degree of openness, as the differences in mean terms of trade for the two classes of rules become smaller.

The results in this paper suggest that elasticity of substitution for export, which can be thought of as the degree of competition in the export market, is more important than the degree of openness in deciding the welfare ranking between exchange rate rules and interest rate rules. They also suggest that an exchange rate rule can be a better monetary policy rule than an interest rate rule for a country that faces intense competition in the export market, which should be relevant for most emerging economies.

We conclude this paper by discussing the directions for future research. First, the paper can be extended to allow for incomplete pass-through of exchange rate. Studies such as

Devereux and Engel (2003) and Corsetti and Pesenti (2005) have shown that incomplete pass-through can alter the welfare ranking of monetary policy regimes. Second, the paper can be extended to incorporate "balance sheet effects". Elekdag and Tchakarov (2007), for example, have shown that balance sheet effects associated with liability dollarization can make it beneficial for emerging markets to stabilize the exchange rate.

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Table 1
Benchmark parameter values for high-openness economy

Parameter	Description	Value
σ	Coefficient of relative risk aversion	2
β	Subjective discount factor	0.99
ξ	Inverse of Frisch labor elasticity	1
ζ	Preference parameter for labor in utility	12.376
ϑ	Elasticity of substitution between value added and imported input	0.6
η	Elasticity of substitution for export	0.6
α	Share of domestic value added in production	0.58
ψ	Capital share in value added	0.3
v	Elasticity of substitution across different variety of goods	6
κ	Scale factor for export	0.391
δ	Depreciation rate of capital	0.025
ϕ	Capital adjustment cost	15
γ	Price stickiness parameter	0.75
π	Steady state gross inflation rate	1
λ	Extent of financial integration	0.0019
ρ^θ	Persistence of technology process	0.9
ρ^*	Persistence of foreign inflation process	0.8
ρ^{R^*}	Persistence of foreign interest rate process	0.75
ρ^φ	Persistence of UIP shock	0.5
σ^θ	Standard deviation of technology shock	0.01
σ^*	Standard deviation of foreign inflation shock	0.005
σ^{R^*}	Standard deviation of foreign interest rate shock	0.004
σ^φ	Standard deviation of UIP shock	0.033

Table 2
Benchmark results

	High openness		Low openness	
	Exchange rate rule	Interest rate rule	Exchange rate rule	Interest rate rule
Γ_π	3.00	1.80	3.00	2.90
Γ_{GDP}	1.00	0.00	0.80	0.00
ζ^c	0.34	-0.31	0.37	0.04
Mean				
C_t	0.97	2.01	0.19	0.57
L_t	-0.54	-1.33	-0.10	-0.33
S_t	1.28	3.24	2.34	3.79
u_t	0.09	0.18	0.15	0.02
Standard deviation				
GDP_t	1.79	2.30	2.56	2.15
C_t	3.01	1.53	2.18	1.22
L_t	1.27	2.83	2.62	0.87
π_t	2.00	2.86	2.54	0.87
π_t^x	7.25	25.90	12.72	28.65
π_t^m	5.56	26.89	10.35	28.59
S_t	3.04	6.99	6.24	8.80
Δe_t	1.59	6.85	2.73	7.25

Notes: (1) The interest rates rules are given by $\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP)$ while the exchange rate rules are given by $\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP)$. (2) In the optimized rules, Γ_π and Γ_{GDP} are restricted to lie in the interval of $[0,3]$. (3) All statistics are in percentage terms, except for the inflation rates, π_t , π_t^x and π_t^m , which are in annualized percentage terms.

Table 3

Results for the case of high elasticity of substitution for export

	High openness		Low openness	
	Exchange rate	Interest rate	Exchange rate	Interest rate
	rule	rule	rule	rule
Γ_π	3.00	3.00	3.00	3.00
Γ_{GDP}	0.00	0.50	0.20	0.30
ζ^c	0.27	0.68	0.29	0.38
Mean				
C_t	0.37	-0.01	0.02	-0.07
L_t	-0.18	-0.04	0.10	0.14
S_t	0.11	0.25	0.26	0.68
u_t	0.03	0.20	0.07	0.12
Standard deviation				
GDP_t	2.76	4.32	2.52	3.32
C_t	3.57	3.03	2.87	2.11
L_t	2.21	5.56	1.67	3.74
π_t	1.11	2.96	1.82	2.30
π_t^x	4.45	8.02	7.75	15.39
π_t^m	2.20	8.21	5.31	15.67
S_t	0.98	1.78	2.17	3.63
Δe_t	0.84	2.29	1.50	4.06

Notes: (1) The interest rates rules are given by $\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP)$ while the exchange rate rules are given by $\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP)$. (2) In the optimized rules, Γ_π and Γ_{GDP} are restricted to lie in the interval of $[0,3]$. (3) All statistics are in percentage terms, except for the inflation rates, π_t , π_t^x and π_t^m , which are in annualized percentage terms.

Figure 1: Welfare costs as elasticity of substitution for export varies
 Legend: Straight lines: Interest rate rules; Crosses: Exchange rate rules

出席國際學術會議心得報告

計畫編號	NSC 95-2415-H-002-020
計畫名稱	臺灣和新加坡的貨幣政策：它們不一樣嗎？為什麼？
出國人員姓名	張永隆
服務機關及職稱	國立台灣大學經濟學系暨研究所 助理教授
會議時間地點	Held at Montreal, Canada on June 14-16, 2007
會議名稱	13 th International Conference on Computing in Economics and Finance
發表論文題目	Revisiting Exchange Rate Rule

一、參加會議經過

我在 2007 年 6 月 14 日在此國際會議的一個 session 發表此計劃的論文。另外，我也在其它 sessions 聽到和這個計劃相關領域的最新研究，並在與會間和多位外國學者交流。

二、與會心得

我在發表論文時得到在座聽眾的許多寶貴意見，並在其它 sessions 得到領域裡最新發展的訊息。和外國學者交流也收穫甚多。

Can Exchange Rate Rules be Better than Interest Rate Rules?

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March 11, 2008

Abstract:

We develop a New Keynesian small open economy model to compare the welfare performances of two classes of monetary policy rules: exchange rate rules and interest rate rules. The expected lifetime utility of the representative household is used as the welfare criterion. The model is solved using second-order approximation methods. We find that under benchmark parameterization, an exchange rate rule delivers lower standard deviations of GDP and inflation compared to an interest rate rule, when the economy has a high degree of openness. However, despite that, an exchange rate rule is welfare inferior to an interest rate rule since it delivers lower mean terms of trade, which leads to lower mean consumption and higher mean labor hours. On the other hand, when the elasticity of substitution for export is high, an exchange rate rule is welfare superior to an interest rate rule, regardless of the degree of openness, as the differences in mean terms of trade for the two classes of rules become smaller.

Keywords: Exchange rate rules, interest rate rules, monetary policy, welfare comparison, small open economy

JEL Classification: E52, F41

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1 Introduction

Ever since the seminal contribution of Taylor (1993), monetary policy discussions have been dominated by "interest rate rules", a class of monetary policy rules where interest rates react endogenously to a small set of macroeconomic variables. An important reason for the success of the Taylor-style interest rate rules is that Taylor (1993) and many subsequent contributions have demonstrated that this class of rules seems to describe the actual monetary policies of many central banks in advanced countries rather well.¹ Another reason for their popularity is that they are simple, easy to understand and implement. As a result, many studies have been devoted to study both the positive and normative implications of interest rate rules.

Despite the popularity of interest rate rules, there are some alternative monetary policy rules that might be worth studying.² One such alternative is "exchange rate rules", defined here to be a class of monetary policy rules where nominal exchange rates react endogenously to a small set of macroeconomic variables. One reason why exchange rate rules deserve some attention is that Parrado (2004) and McCallum (2006, 2007) have shown that this class of rules describes Singapore's monetary policy rather well. The Monetary Authority of Singapore also states that "[i]n Singapore, monetary policy is centered on the management of the exchange rate, rather than money supply or interest rates." (Monetary Authority of Singapore, 2001). Even though Singapore is a very small country, McCallum (2007) argues aptly that its monetary policy deserves attention because Singapore has more population and a larger GDP in dollar term than New Zealand, which is a pioneer in "world-wide surge toward inflation targeting". Parrado (2004) also observes that Singapore's monetary

¹See for example, Clarida et al. (1998, 2000), Lubik and Schorfheide (2004, 2007).

²In addition to the exchange rate rules discussed in this paper, base money rules (e.g. McCallum, 1988) and MCI rules (e.g. Ball, 1999) have also been explored in the literature.

policy "has helped achieve a track record of low inflation with prolonged economic growth". Moreover, using a dynamic stochastic general equilibrium (DSGE) model, McCallum (2006, 2007) shows that for a very open economy like Singapore, an exchange rate rule can deliver a much lower volatility of output gap, compared to an interest rate rule, with only slightly higher volatility of inflation.

The goal of this paper is to compare the welfare implications of exchange rate rules and interest rate rules. Like McCallum (2006, 2007), we construct a New Keynesian small open economy DSGE model for the analysis. In contrast to McCallum (2006, 2007), we will use the expected lifetime utility of the representative household as the welfare criterion, following most of the recent literature. This distinction is important, since the literature has found that monetary policy can have important implications for the representative household's utility beyond the traditional focus on the volatility of inflation and output gap, especially in open economy context.³ By using the expected lifetime utility of the representative household as the welfare criterion, we are able to incorporate effect such as the mean terms of trade, which is not explored in McCallum (2006, 2007), but turns out to be important for the representative household's utility.

Like McCallum (2006, 2007), our results suggest that an exchange rate rule can deliver a lower standard deviation of output, compared to an interest rate rule, when the economy is a very open economy. In addition, unlike McCallum (2006, 2007), we also find that an exchange rate rule can deliver a lower standard deviation of inflation in our model, when the degree of openness is high. The intuition for the results above is as follow. An exchange rate rule tends to lead to a lower volatility of nominal exchange rate, compared to an interest rate rule. The lower volatility of nominal exchange rate leads to a less volatile imported goods price inflation, which can be thought of as more stable supply shocks, since imported goods are inputs in the production process in our model. This effect dominates when the degree

³See for instance, Bacchetta and van Wincoop (2000), Bergin et al. (2007) and Sutherland (2006).

of openness is high, so that imported goods as a share of gross output is high. The lower volatility of inflation also means that an exchange rate rule leads to a lower mean resource cost of price dispersion.

Despite the lower mean resource cost of price dispersion, we find that an exchange rate rule is welfare inferior to an interest rate rule under the benchmark parameterization, regardless of the degree of openness. The result hinges on the effects of the mean terms of trade. Since an interest rate rule delivers a higher standard deviation of nominal exchange rate, it also leads to a more favorable average terms of trade as exporters set a higher price to cushion for nominal exchange rate uncertainty. The more favorable terms of trade leads to a higher mean consumption and lower mean labor hours for an interest rate rule, and hence higher welfare compared to an exchange rate rule.

In spite of the results above, we find that an exchange rate rule can be welfare superior to an interest rate rule for alternative parameterization of the model. Specifically, when the elasticity of substitution for export is high but within the range for empirical estimates, an exchange rate rule can beat an interest rate rule regardless of the degree of openness. This is because when the elasticity of substitution for export is high, exchange rate rules and interest rate rules differ less in terms of the average level of terms of trade, leaving the welfare difference to be dominated by the mean resource cost of price dispersion.

The rest of the paper is organized as follow. We present the model in Section 2. The welfare measure is discussed in Section 3. Section 4 discusses the calibration and solution methods. The results are presented in Section 5. Section 6 concludes.

2 The model

The model that we construct builds on the contribution of McCallum (2006, 2007) and Kollmann (2002). It is a micro-founded, New Keynesian small open economy DSGE model.

Time is discrete and the horizon is infinite. The agents in the economy include a representative household, firms, and the government. The representative household consumes a final goods, supplies labor service, and buys or sells bonds each period. In addition, the representative household also accumulates physical capital and rents the capital to firms.⁴ There is a continuum of monopolistically competitive domestic intermediate firms that produce differentiated products. To facilitate comparison with McCallum (2006, 2007), we follow McCallum and assume that imported goods are used as inputs in the production process of the intermediate firms instead of being a component of the composite final goods as in most other New Open Economy Macroeconomic models.⁵ We will also focus on the case for which there is full pass through for both the export and import prices, following McCallum (2006, 2007).⁶ Price adjustment for the intermediate goods is staggered in the form of Calvo (1983) following the recent literature. Financial market is assumed to be incomplete with only riskless bonds being traded internationally.

Since our goal is to compare exchange rate rules with interest rate rules, we assume that the consolidated government controls the monetary policy using either an interest rate rule or an exchange rate rule. Consistent with the recent literature, we focus on the Woodford (2003) case of a "cashless economy". In what follows, variables without time subscript denote the corresponding steady state of the variables.

2.1 The representative household

There is a representative household in the small open economy. The representative household maximizes expected lifetime utility, which is defined over consumption, C_t , and labor hours,

⁴In contrast, McCallum (2006, 2007) does not have capital accumulation in his model.

⁵However, the qualitative results of this paper will not change if the alternative specification is adopted. The results are available upon request.

⁶While incomplete exchange rate pass-through can have important implications for welfare comparisons of monetary policy regimes (e.g. Devereux and Engel, 2003; Corsetti and Pesenti, 2005), we will leave the case of incomplete pass through for future research.

L_t . Period utility function is specified as separable in consumption and labor hours:

$$E_0 \sum_{t=0}^{t=\infty} \beta^t U(C_t, L_t), \quad (1)$$

$$U(C_t, L_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} - \zeta \frac{L_t^{1+\xi}}{1+\xi}, \quad (2)$$

where E_t is the expectations operator conditional on time t information; $\beta \in (0, 1)$ is the subjective discount factor, $\xi \geq 0$ is the inverse of Frisch labor supply elasticity, and $\zeta > 0$ is a preference parameter.

The representative household owns the capital stock, K_t , in the small open economy. The capital stock evolves according to the law of motion:

$$K_{t+1} + \frac{1}{2}\phi \frac{\{K_{t+1} - K_t\}^2}{K_t} = (1 - \delta) K_t + I_t, \quad (3)$$

where I_t is the gross investment. $\frac{1}{2}\phi \frac{\{K_{t+1} - K_t\}^2}{K_t}$ with $\phi \geq 0$ is a capital adjustment cost. $\delta \in (0, 1)$ is the depreciation rate of the capital.

In addition to choosing consumption, labor hours, capital stock and investment, the representative household also holds a risk-free domestically traded domestic currency denominated bond, A_{t+1} and a risk-free internationally traded foreign currency denominated bond, B_{t+1} . The budget constraint for the representative household is:

$$A_{t+1} + e_t B_{t+1} + P_t C_t + P_t I_t = A_t R_{t-1} + e_t B_t R_{t-1}^f + R_t^k K_t + W_t L_t + D_t, \quad (4)$$

where e_t is the nominal exchange rate, expressed as the number of unit of domestic currency required to purchase one unit of foreign currency. P_t is a price index for the domestic final goods, to be defined formally below. R_t is the nominal interest rate on domestically traded bond. R_t^f is the nominal interest rate on the internationally traded foreign currency

denominated bond. R_t^k is the nominal rental rate of capital. W_t is the nominal wage rate. D_t is the dividend from owning domestic firms.

Following Kollmann (2002), we assume that the interest rate at which the domestic representative household can borrow or lend foreign currency fund, R_t^f , is subjected to a "spread" from the foreign nominal interest rate, R_t^* . The "spread" is assumed to be a decreasing function of the net foreign asset position of the domestic economy:

$$R_t^f = R_t^* - \lambda \frac{B_{t+1}}{P_t^x Q_t^x}, \quad (5)$$

where $P_t^x Q_t^x$ is the nominal value of the small open economy's export in foreign currency term, to be defined formally below. The parameter $\lambda > 0$ captures the extent of financial integration. A lower value of λ corresponds to a higher degree of integration with the international financial markets. The spread term also plays the role of "closing" the small open economy model, to ensure that the small open economy model has a stationary equilibrium (Schmitt-Grohé and Uribe, 2003). R_t^* is assumed to follow an exogenous process in this model.

The first order conditions for the representative household's maximization problems are:

$$\zeta L^\xi = \frac{W_t}{C_t^\sigma P_t}, \quad (6)$$

$$1 = R_t E_t \left\{ \beta \frac{C_t^\sigma P_t}{C_{t+1}^\sigma P_{t+1}} \right\}, \quad (7)$$

$$1 = \varphi_t R_t^f E_t \left\{ \beta \frac{C_t^\sigma P_t e_{t+1}}{C_{t+1}^\sigma P_{t+1} e_t} \right\}, \quad (8)$$

$$1 + \phi \frac{(K_{t+1} - K_t)}{K_t} = E_t \left\{ \beta \frac{C_t^\sigma}{C_{t+1}^\sigma} \left[\frac{R_{t+1}^k}{P_{t+1}} + 1 - \delta + \phi \frac{(K_{t+2} - K_{t+1})}{K_{t+1}} + \frac{1}{2} \phi \frac{(K_{t+2} - K_{t+1})^2}{K_{t+1}^2} \right] \right\}, \quad (9)$$

Equation (6) equates the marginal disutility and marginal benefit of labor hours. Equa-

tion (7) is the domestic bond's Euler equation. Equation (8) is the Euler equation for internationally traded bond. Following Kollmann (2002), a term, φ_t , is exogenously imposed on the Euler equation for internationally traded bond, so that up to a log-linear approximation, equations (7) and (8) imply, $E_t \Delta \hat{e}_{t+1} = \hat{R}_t - \hat{R}_t^f - \hat{\varphi}_t$, where $\Delta e_t \equiv e_t/e_{t-1}$ and a hat on a variable denote log deviation of that variable from its steady state. The term φ_t , can be interpreted as an uncovered interest parity (UIP) shock, which is designed to capture deviations from the UIP condition. Equation (9) is the capital Euler equation.

2.2 Firms

There is a continuum of monopolistically competitive domestic intermediate goods firms, indexed by $i \in [0, 1]$. The production function for an intermediate goods firm i is:

$$Y_{i,t} = \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{\vartheta}{\vartheta-1}}, \quad (10)$$

where $Y_{i,t}$ is the output of firm i , $K_{i,t}$ and $L_{i,t}$ denote the capital stock and labor hours used by firm i , respectively. θ_t is an exogenous economy-wide technology process. $\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi}$ is the domestic value added in the production. $Q_{i,t}^m$ is the amount of imported goods used as input by firm i . $\alpha \in (0, 1)$ is a parameter that determines the share of domestic value added in the production. $\vartheta > 0$ is the elasticity of substitution between domestic value added and imported goods in the production. The parameter $\psi \in (0, 1)$ determines the share of rental income in domestic value added.

Firm i chooses $K_{i,t}$, $L_{i,t}$ and $Q_{i,t}^m$ by solving a cost minimization problem:

$$\min R_t^k K_{i,t} + W_t L_{i,t} + P_t^m Q_{i,t}^m, \quad (11)$$

$$\text{s.t. } \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{\vartheta}{\vartheta-1}} = y_{i,t}, \quad (12)$$

where P_t^m is the price of the imported goods in domestic currency term. The first order conditions are:

$$R_t^k = \psi MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} \alpha^{\frac{1}{\vartheta}} \frac{\left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}}}{K_{i,t}}, \quad (13)$$

$$W_t = (1-\psi) MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} \alpha^{\frac{1}{\vartheta}} \frac{\left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}}}{L_{i,t}}, \quad (14)$$

$$P_t^m = MC_t \left\{ \alpha^{\frac{1}{\vartheta}} \left[\theta_t K_{i,t}^\psi L_{i,t}^{1-\psi} \right]^{\frac{\vartheta-1}{\vartheta}} + (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{\vartheta-1}{\vartheta}} \right\}^{\frac{1}{\vartheta-1}} (1-\alpha)^{\frac{1}{\vartheta}} (Q_{i,t}^m)^{\frac{-1}{\vartheta}}, \quad (15)$$

where MC_t is the Lagrange multiplier associated with the constraint (12), which can also be interpreted as the nominal marginal cost.⁷

Following the literature, we assume that the intermediate goods are aggregated into composite final domestic goods, Y_t , via the Dixit-Stiglitz aggregator:

$$Y_t = \left\{ \int_0^1 Y_{i,t}^{\frac{\nu-1}{\nu}} di \right\}^{\frac{\nu}{\nu-1}}, \quad (16)$$

where ν is the elasticity of substitution between different varieties of intermediate goods. Cost minimization leads to the following demand function for $Y_{i,t}$:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\nu} Y_t, \quad (17)$$

where $P_{i,t}$ is the price of $Y_{i,t}$ while P_t is a price index for Y_t given by:

$$P_t \equiv \left\{ \int_0^1 P_{i,t}^{1-\nu} di \right\}^{\frac{1}{1-\nu}}. \quad (18)$$

⁷Given the structure of the model, nominal marginal cost will be equalized across firms, so there is no subscript i on MC_t .

The composite final domestic goods is demanded as consumption and investment goods in the domestic market as well as exported:

$$Y_t = C_t + I_t + Q_t^x, \quad (19)$$

where Q_t^x is the export demand. Following McCallum (2006, 2007), McCallum and Nelson (1999) and Kollmann (2002), we assume that Q_t^x depends on the ratio of export price in foreign currency term, P_t^x , relative to the foreign price level, P_t^* :

$$Q_t^x = \kappa \left(\frac{P_t^x}{P_t^*} \right)^{-\eta}, \quad (20)$$

where $\eta > 0$ is the elasticity of substitution for export; $\kappa > 0$ is a scaling factor. P_t^* is an exogenous process in this model. Following McCallum (2006, 2007) and McCallum and Nelson (1999), we assume that firms cannot price discriminate across markets, so that the export price in foreign currency is simply the final domestic goods price divided by the nominal exchange rate, $P_t^x = P_t/e_t$. Similarly, following McCallum (2006, 2007) and McCallum and Nelson (1999), the price for imported goods in domestic currency term is simply the product of foreign price level and nominal exchange rate, $P_t^m = e_t P_t^*$.

We assume that price adjustment for the intermediate goods firms is staggered à la Calvo (1983). Each period, each intermediate goods firm i faces a random probability of $(1 - \gamma)$, $\gamma \in [0, 1]$, of resetting its price, $P_{i,t}$. If $P_{i,t}$ is not reset, it is updated by the steady state inflation rate, π , according to the rule $P_{i,t} = \pi P_{i,t-1}$. Let $\tilde{P}_{i,t}$ denote the new price that is reset in period t . After resetting the price at period t , there is γ^τ probability that the price has not been reset at period $t + \tau$, and hence $P_{i,t+\tau} = \pi^\tau \tilde{P}_{i,t}$. Using the demand function, (17),

and the price updating rule, the optimization problem for firm i in the domestic market is:

$$\max_{\tilde{P}_t} \sum_{\tau=0}^{\infty} (\gamma)^\tau E_t \frac{\rho_{t,t+\tau}}{P_{t+\tau}} \left\{ \pi^\tau \tilde{P}_t \left(\frac{\pi^\tau \tilde{P}_t}{P_{t+\tau}} \right)^{-\nu} Y_{t+\tau} - TC_{t+\tau} \left[\left(\frac{\pi^\tau \tilde{P}_t}{P_{t+\tau}} \right)^{-\nu} Y_{t+\tau} \right] \right\},$$

where $\rho_{t,t+\tau} \equiv \beta^\tau \frac{C_t^\sigma}{C_{t+\tau}^\sigma}$ is a discount factor for evaluating profit streams, $TC(\cdot)$ is the total cost as a function of the demand. The first order condition for the optimization problem is:

$$\tilde{P}_t = \frac{\nu}{\nu - 1} \frac{E_t \sum_{\tau=0}^{\infty} (\gamma \pi^{-\nu})^\tau \frac{\rho_{t,t+\tau}}{P_{t+\tau}} MC_{t+\tau} (P_{t+\tau})^\nu Y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} (\gamma \pi^{1-\nu})^\tau \frac{\rho_{t,t+\tau}}{P_{t+\tau}} (P_{t+\tau})^\nu Y_{t+\tau}}. \quad (21)$$

2.3 Market clearing and aggregation

Market clearing for the labor, capital and imported goods markets requires the supplies, L_t , K_t and Q_t^m , equal the sum of demand from all domestic intermediate goods firms:

$$L_t = \int_0^1 L_{i,t} di, \quad (22)$$

$$K_t = \int_0^1 K_{i,t} di, \quad (23)$$

$$Q_t^m = \int_0^1 Q_{i,t}^m di. \quad (24)$$

Since the domestic bonds, A_t , is assumed to be traded only domestically, its net supply is zero in equilibrium:

$$A_t = 0. \quad (25)$$

Defining $Y_t^A \equiv \int_0^1 Y_{i,t} di$, equation (17) can be aggregated across firms as:

$$Y_t^A = u_t Y_t, \quad (26)$$

where

$$u_t \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\nu} di. \quad (27)$$

As noted in Schmitt-Grohé and Uribe (2004a, 2005, 2006b, 2007), u_t can be interpreted as resource cost of price dispersion associated with the Calvo-style staggered price adjustment. It can be shown that $u_t \geq 1$ for all t . Higher values of u_t correspond to higher resource costs of price dispersion as a given sum of intermediate goods, Y_t^A , gives rise to lower supply of final goods, Y_t . It can also be shown that u_t is increasing in the standard deviation of π_t .

For ease of discussion below, it is useful to define here the constant price real GDP as:

$$GDP_t = Y_t - p^m Q_t^m, \quad (28)$$

where p^m is the steady state value of the ratio of import price to domestic final goods price. In the equation above, the price of domestic goods P has been normalized to 1 in the base year, while the price of import have been set to its steady state value in the base year. It is also useful to define the terms of trade, S_t , as the ratio of export price to import price:

$$S_t = \frac{e_t P_t^x}{P_t^m}. \quad (29)$$

Note that since we assume full pass through, we have $e_t P_t^x = P_t$ and $P_t^m = e_t P_t^*$, so the terms of trade also equals the inverse of real exchange rate in this paper.⁸

2.4 The government

We assume that the consolidated government conducts monetary policy using either a Taylor (1993)-type interest rate rule or an exchange rate rule. For the case of interest rate rule, the

⁸The equivalence of terms of trade and real exchange rate will not hold if there is incomplete pass-through (e.g. Sutherland, 2005) or multi-stage production (e.g. Devereux and Engel, 2007).

policy rule is of the form:

$$\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP), \quad (30)$$

where Γ_π , Γ_{GDP} are policy parameters while $\pi_t \equiv P_t/P_{t-1}$ is the gross domestic final goods price inflation rate.⁹ For the case of exchange rate rule, the policy rule is of the form:

$$\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP), \quad (31)$$

where $\Delta e_t \equiv e_t/e_{t-1}$ is the gross rate of nominal depreciation. Negative signs are put in front of Γ_π and Γ_{GDP} for the exchange rate rule so that positive values of Γ_π and Γ_{GDP} correspond to counter-cyclical policies.

Since the optimal values of Γ_π and Γ_{GDP} for the interest rate rule and exchange rate rule might be different, we search for the optimal values of Γ_π and Γ_{GDP} for the two classes of rules in this paper. Following Schmitt-Grohé and Uribe (2006a,b, 2007), we search numerically for the optimal values of Γ_π and Γ_{GDP} using grid search with grid points in the interval of $[0, 3]$ and a step size of 0.1. As Schmitt-Grohé and Uribe (2006b, 2007) argue, while the interval of $[0, 3]$ is arbitrary, policy coefficients larger than 3 or negative would be hard to communicate to the public. In the search for the optimal policy coefficients, we also impose a condition that the monetary policy rule must yield a locally unique rational expectations equilibrium. It is worthwhile to note that for the case of the exchange rate rule, $\Gamma_\pi = \Gamma_{GDP} = 0$ corresponds to a fixed exchange rate regime.

⁹Note that allowing the interest rate rule to react to the exchange rate will not change the qualitative results in this paper.

2.5 Exogenous processes

Following Kollmann (2002), we assume that the productivity, foreign inflation, foreign interest rate and the UIP shocks follow exogenous first-order autoregressive processes:

$$\ln \theta_t = (1 - \rho^\theta) \ln \theta + \rho^\theta \ln \theta_{t-1} + \varepsilon_t^\theta, \quad (32)$$

$$\ln \pi_t^* = (1 - \rho^*) \ln \pi^* + \rho^* \ln \pi_{t-1}^* + \varepsilon_t^*, \quad (33)$$

$$\ln R_t^* = (1 - \rho^{R^*}) \ln R^* + \rho^{R^*} \ln R_{t-1}^* + \varepsilon_t^{R^*}, \quad (34)$$

$$\ln \varphi_t = (1 - \rho^\varphi) \ln \varphi + \rho^\varphi \ln \varphi_{t-1} + \varepsilon_t^\varphi, \quad (35)$$

where $\pi_t^* \equiv P_t^*/P_{t-1}^*$ is the gross foreign inflation rate. ε_t^θ , ε_t^* , $\varepsilon_t^{R^*}$ and ε_t^φ are i.i.d. shocks with standard deviations σ^θ , σ^* , σ^{R^*} and σ^φ , respectively.

3 The welfare measure

For a given monetary policy regime, a , we use the conditional expected lifetime utility of the representative household at time zero as the welfare measure, CV_0^a :

$$CV_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t u(C_t^a, H_t^a). \quad (36)$$

Following Schmitt-Grohé and Uribe (2006b, 2007), we compute the expected lifetime utility conditional on the initial state being the deterministic steady state. This ensures that the economy always starts from the same initial point, since for a given set of parameter values, the steady states of this model are the same for all monetary policy rules considered in this paper.

Following Lucas (1987), we report the welfare as the fraction, ζ^c , of steady state con-

sumption that the household is willing to give up to be as well off under the steady state, as under a given monetary policy regime a , with CV_0^a as the welfare measure. Formally, ζ^c is given implicitly by:

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{[(1 - \zeta^c) C]^{1-\sigma} - 1}{1 - \sigma} - \zeta \frac{L^{1+\xi}}{1 + \xi} \right) = CV_0^a. \quad (37)$$

Higher values of ζ^c correspond to lower welfare.

4 Solution method and calibration

The model is solved numerically by taking second order Taylor approximations (Kim and Kim, 2003; Schmitt-Grohé and Uribe, 2004b) of the model equations around a deterministic steady state. The second-order accurate solutions are computed using the software package, Dynare (Juillard, 1996).

The model is calibrated with time unit being one quarter. σ , the coefficient of risk aversion, is set to 2, as is commonly assumed in the literature. The subjective discount factor, β , is set at 0.99, so that the steady state annual real interest rate is 4%. ξ , the inverse of Frisch labor elasticity, is set to 1, following Christiano et al. (2005).

Following McCallum (2005, 2006, 2007), the elasticity of substitution between domestic value added and imported input, ϑ , is set to 0.6. We also follow McCallum in setting the elasticity of substitution for export, η , to 0.6 in the benchmark, but we will investigate the robustness of results for alternative values of η . The parameter a affects the steady state ratio of imports to GDP and we will consider two cases in this paper. In case 1, we set a so that the steady state ratio of imports to GDP is 60%, which matches the figure for Singapore (McCallum 2006, 2007). We will call that case a "high-openness" economy. In case 2, we set a so that the steady state ratio of imports to GDP is 15%, which matches the figure for a "typical" industrial economy (McCallum, 2006, 2007). We will call that case a "low-

openness" economy. Given the value of ϑ , a is set to 0.58 for the high-openness economy and 0.855 for the low-openness economy. The share of capital income in value added, ψ , is set to 0.3, as is commonly assumed in the literature. The elasticity of substitution across different variety of goods, v , is set to 6, following McCallum and Nelson (1999) and Kollmann (2002). The scale factor for export demand, κ , in equation (20), is set to 0.391 and 0.103 for the high-openness economy and low-openness economy, respectively, so that there is balanced trade in the steady state. The preference parameter, ζ , is set to 12.376 and 13.413 for the high-openness economy and low-openness economy, respectively, so that the representative household spends 30% of its time working in the steady state.

We set the depreciation rate of capital, δ , to 0.025, as is commonly assumed in the literature. We set the capital adjustment cost parameter, ϕ , to 15, so that the standard deviation of investment is about 2 to 3 times the standard deviation of GDP. Following Kollmann (2002), the fractions of firms not setting the prices optimally in each period, γ is set to 0.75, so that the average price change duration is one year. The steady state gross inflation rate, π , is set to 1, as is commonly assumed in the literature.¹⁰ The extent of financial integration, λ , in equation (5), is set to 0.0019, following Kollmann (2002).

Finally, for the exogenous shock processes, we use the same calibration as Kollmann (2002) and set $\rho^\theta = 0.9$, $\rho^* = 0.8$, $\rho^{R^*} = 0.75$, $\rho^\varphi = 0.5$, $\sigma^\theta = 0.01$, $\sigma^* = 0.005$, $\sigma^{R^*} = 0.004$ and $\sigma^\varphi = 0.033$. Table 1 summarizes the benchmark parameter values for the high-openness economy.

(Table 1 about here)

¹⁰Since we assume there is full indexation to steady state inflation rate when prices are not reset, the results will be robust to the steady state inflation rate. Recently, Ascari (2004) argues that the dynamics of a model might be affected by the steady state inflation rate if there is partial or no indexation to the inflation rate. We do not consider partial or no indexation in this paper and leave that for future research.

5 Results

We report the simulation results in this section. First, we will discuss the results under the benchmark parameterization. We will show that the terms of trade play an important role in the results. Next, we will explore the robustness of the results to alternative parameterization of the model.

5.1 Benchmark results

Table 2 shows the results for the benchmark model. There are several interesting results. First, we find that the optimized exchange rate rules lead to lower standard deviations of nominal depreciation (Δe_t), compared to the optimized interest rate rules, regardless of the degrees of openness. This result is consistent with the findings of McCallum (2006, 2007). Second, like McCallum (2006, 2007), we find that an exchange rate rule can deliver lower volatility of output, compared to an interest rate rule, when the degree of openness is high. The standard deviation¹¹ of GDP is 1.79% for the optimized exchange rate rule (with $\Gamma_\pi = 3.0$, $\Gamma_{GDP} = 1.0$) compared to 2.30% for the optimized interest rate rule (with $\Gamma_\pi = 1.8$, $\Gamma_{GDP} = 0$) for the high openness economy. In contrast, for the low openness economy, the standard deviation of GDP is higher, at 2.56%, for the optimized exchange rate rule (with $\Gamma_\pi = 3.0$, $\Gamma_{GDP} = 0.8$), compared to 2.15% for the optimized interest rate rule (with $\Gamma_\pi = 2.9$, $\Gamma_{GDP} = 0$). Third, unlike McCallum (2006, 2007), we also find that the optimized exchange rate rule delivers a lower (2.00%) standard deviation of domestic final goods price inflation (π_t) compared to the optimized interest rate rule (2.86%), when the degree of openness is high.¹² However, when the degree of openness is low, the optimized

¹¹Standard deviations reported in this paper are in terms of log deviation of variables from their steady state values.

¹²In contrast, McCallum (2006, 2007) find that the standard deviation of π_t is higher for an exchange rate rule, even though the difference relative to an interest rate rule becomes smaller as the degree of openness increases.

exchange rate rule leads to a higher (2.54%) standard deviation of domestic final goods price inflation compared to the optimized interest rate rule (0.87%).

(Table 2 about here)

Why does the optimized exchange rate rule deliver lower standard deviations of GDP and domestic final goods price inflation when the degree of openness is high? The intuition can be inferred from the standard deviations of nominal depreciation and import price inflation ($\pi_t^m \equiv P_t^m / P_{t-1}^m$). As noted above, the optimized exchange rate rule delivers a lower standard deviation of nominal depreciation compared to the optimized interest rate rule, regardless of the degree of openness. This can affect the volatility of GDP and domestic final goods price inflation through two channels. On the one hand, the nominal exchange rate can play the role of shock absorber. This means that the less variable and hence less flexible nominal exchange rate for the optimized exchange rate rule restricts the ability of nominal exchange rate to stabilize GDP through expenditure switching effects. On the other hand, the lower standard deviation of nominal depreciation leads to a lower standard deviation of import price inflation for the optimized exchange rate rule since there is full exchange rate pass through into the import price. Since the imported goods are inputs in the production process, the import price inflation can be thought of as a supply shock. Hence, the lower standard deviation of import price inflation tends to lead to lower standard deviations of domestic final goods price inflation and GDP. When the degree of openness is high (so that imported input as a share of gross output is high), the pass-through effect dominates, which leads to lower standard deviations of GDP and domestic final goods price inflation for the optimized exchange rate rule. When the degree of openness is low, the shock absorber role of nominal exchange rate dominates, so the standard deviations of GDP and domestic final goods price inflation for the optimized exchange rate rule is higher, compared to the optimized interest rate rule.

For the high openness economy, the lower standard deviation of domestic final goods price inflation (π_t) leads to a lower mean resource cost of price dispersion (u_t), for the optimized exchange rate rule (0.09% versus 0.18% for the optimized interest rate rule). However, surprisingly, despite the lower mean resource cost of price dispersion, the optimized exchange rate rule leads to much higher welfare cost compared to the optimized interest rate rule. The welfare cost of the optimized exchange rate rule is 0.34% of steady state consumption while it is -0.31% for the optimized interest rate rule. The welfare difference of 0.65% of steady state consumption is large in the realm of business cycle analysis.¹³ The better performance of the optimized interest rate rule seems to stem from the terms of trade effect. The expected value¹⁴ of terms of trade, S_t , for the optimized interest rate rule (3.24%) is higher than that of the optimized exchange rate rule (1.28%). The more favorable terms of trade for the optimized interest rate rule stems from its higher volatility of nominal depreciation. A higher volatility of nominal depreciation leads to a more favorable terms of trade since it induces exporters to set higher export price to compensate for the exchange rate uncertainty. The more favorable terms of trade for the optimized interest rate rule in turn allows the representative household to consume more and work less, compared to the optimized exchange rate rule.¹⁵ Hence, the optimized interest rate rule delivers higher mean consumption (2.01%), lower mean labor hours (-1.33%) and hence lower welfare cost (-0.31%), compared to the optimized exchange rate rule (0.97%, -0.54% and 0.34%, respectively).

For the low openness economy, in addition to the lower expected value of terms of trade, the optimized exchange rate rule leads to a higher mean resource cost of price dispersion, since

¹³For comparison, the classic estimate of welfare cost of business cycle in Lucas (1987) is 0.17% for a coefficient of risk aversion, σ , of 20, while $\sigma = 2$ in our model.

¹⁴Expected value of a variable is reported in terms of log deviation from its steady state value in this paper.

¹⁵Using a simpler model for which imported goods are not inputs into the production of intermediate goods but combine with a composite domestic goods to form a constant elasticity of substitution composite final goods, Sutherland (2006) show that the mean terms of trade can increase or decrease the welfare depending on the parameter values. However, the model in this paper cannot be directly compared with Sutherland (2006) since the production structure is different.

it leads to a higher standard deviation of domestic final goods price inflation as mentioned above. The less favorable terms of trade and the higher mean resource cost of price dispersion both lead to a higher welfare cost for the optimized exchange rate rule.

5.2 High elasticity of substitution for export

The subsection above has shown that under the benchmark model, an optimized exchange rate rule is welfare inferior to an optimized interest rate rule, regardless of the degrees of openness. This is true even though the optimized exchange rate rule delivers lower standard deviations of GDP and domestic final goods price inflation for the high openness economy. The reason is that an optimized exchange rate rule delivers lower volatility of nominal depreciation and hence less favorable mean terms of trade, compared to an optimized interest rate rule. Since the terms of trade effect plays an important role in the results, it is natural to ask whether the results will continue to hold for alternative parameterization of the model, for which the terms of trade effect might play a smaller role.

A parameter that is important for the magnitude of the terms of trade effect is the elasticity of substitution for export, η . When the elasticity of substitution for export is high, exporters might be less willing to charge a higher export price to cushion for the exchange rate uncertainties since the demand is more sensitive to the price. This would make the terms of trade effect to vary less with exchange rate volatility. In the subsection above, the elasticity of substitution for export, η , is set to 0.6 following McCallum (2006, 2007) and Kollmann (2002). However, there are a lot of uncertainties regarding the empirical value of η . For instance, using data from a panel of developed and developing countries, Lai and Trefler (2002) find that the estimates for the elasticity of substitution for aggregate manufacturing are between 5 to 8. Using disaggregated data from US and 5 other countries, Hummels (2001) finds that the elasticities of substitution range from 3 to 8 for most goods but can be as high as 79 for some goods. In light of these empirical evidences, we will first check

the robustness of the results in detail for a high elasticity of substitution for export, $\eta = 10$, followed by more robustness checks for other values of η .¹⁶

Table 3 shows the results for the case of $\eta = 10$. Similar to the results in Table 2, for the high openness economy, the optimized exchange rate rule delivers lower standard deviations of GDP and domestic goods price inflation, compared to the optimized interest rate rule. Therefore, the optimized exchange rate rule leads to a lower mean resource cost of price dispersion. However, unlike the results in Table 2, for the high openness economy, the optimized exchange rate rule entails a lower welfare cost compared to the optimized interest rate rule when $\eta = 10$. The intuition for this result can be found in Table 3. When $\eta = 10$, while the optimized interest rate still delivers a higher mean terms of trade (0.25% vs. 0.11% for the optimized exchange rate rule), the difference in the mean terms of trade is much smaller compared to the benchmark results for which $\eta = 0.6$ (3.24% vs. 1.28% for the optimized interest rate rule and the optimized exchange rate rule, respectively). As mentioned above, the reason behind this pattern is that when the elasticity of substitution for export is high, exporters will be less willing to charge a higher price to cushion for the exchange rate volatility and hence the mean terms of trade will vary less with exchange rate volatility. Therefore, the welfare difference between the optimized exchange rate rule and the optimized interest rate rule depends mostly on the mean resource cost of price dispersion. Since the optimized exchange rate rule leads to a lower (0.03%) mean resource cost of price dispersion compared to the optimized interest rate rule (0.20%), the optimized exchange rate rule is welfare superior to the optimized interest rate rule.

(Table 3 about here)

¹⁶Another parameter that might affect the magnitude of the terms of trade effect is the elasticity of substitution between domestic value added and imported inputs, ϑ . However, we do not investigate the robustness of the results for alternative values of ϑ in this paper because for the model in this paper, a change in ϑ would also affect the steady state import to GDP ratio, making it impossible to disentangle the effects of ϑ and the degree of openness for the model.

Interestingly, unlike the results in Table 2, when $\eta = 10$, the optimized exchange rate rule is also welfare superior to the optimized interest rate rule for the low openness economy. Like the case of high openness, the difference in mean terms of trade is smaller for the case of low openness when $\eta = 10$. In addition, the optimized exchange rate also delivers lower standard deviations of GDP and domestic goods price inflation for the case of low openness, when $\eta = 10$. This is because when the elasticity of substitution for export is high, export demand is sensitive to the export price, so exporters will try to make their export prices more stable, leading to more stable export demand. A more stable export demand in turn leads to more stable domestic final goods price inflation and GDP through the linkages between export demand, GDP, and factor prices. The lower standard deviation of domestic final goods price inflation leads to a lower mean resource cost of price dispersion for the optimized exchange rate rule. The lower resource cost of price dispersion translates into a smaller welfare cost for the optimized exchange rate rule.

(Figure 1 about here)

In order to investigate further the robustness of the results for different values of η , we plot the welfare costs for the exchange rate rules and interest rate rules, for η between 0.6 to 20 in Figure 1. For both types of monetary policy rules, we fix Γ_π at 3 and Γ_{GDP} at 0 for all values of η . As can be seen from the figure, for the case of high openness, the exchange rate rule is welfare superior to the interest rate rule for $\eta > 2$. For the case of the low openness, the exchange rate rule is welfare superior to the interest rate rule for $\eta > 7$. These values are within the range of the empirical estimates of the elasticity of substitution. Hence, the results in this paper suggest that high degree of openness by itself does not make an exchange rate rule to be welfare superior to an interest rate rule, when the expected utility of the representative household is used as the welfare criterion. In contrast, for high elasticity of substitution for export, an exchange rate rule can be welfare superior to an

interest rate rule, regardless of the degrees of openness. It is also worthwhile to note that the welfare costs of interest rate rules increase very rapidly as elasticity of substitution for export increases, especially for the case of high openness, while the welfare costs of exchange rate rules change by less as elasticity of substitution for export changes.

6 Conclusion

In this paper, we compare the welfare performances of exchange rate rules with interest rate rules. We develop a New Keynesian small open economy DSGE model for the analysis. We depart from the existing studies on exchange rate rules by using the expected lifetime utility of the representative household as the welfare criterion. We find that while an exchange rate rule delivers lower standard deviations of GDP and inflation compared to an interest rate rule when the degree of openness is high, an exchange rate rule is welfare inferior to an interest rate rule under benchmark parameterization. This is because an exchange rate rule delivers lower mean terms of trade, which leads to lower mean consumption and higher mean labor hours. However, for high elasticity of substitution for export, an exchange rate rule is welfare superior to an interest rate rule, regardless of the degree of openness, as the differences in mean terms of trade for the two classes of rules become smaller.

The results in this paper suggest that elasticity of substitution for export, which can be thought of as the degree of competition in the export market, is more important than the degree of openness in deciding the welfare ranking between exchange rate rules and interest rate rules. They also suggest that an exchange rate rule can be a better monetary policy rule than an interest rate rule for a country that faces intense competition in the export market, which should be relevant for most emerging economies.

We conclude this paper by discussing the directions for future research. First, the paper can be extended to allow for incomplete pass-through of exchange rate. Studies such as

Devereux and Engel (2003) and Corsetti and Pesenti (2005) have shown that incomplete pass-through can alter the welfare ranking of monetary policy regimes. Second, the paper can be extended to incorporate "balance sheet effects". Elekdag and Tchakarov (2007), for example, have shown that balance sheet effects associated with liability dollarization can make it beneficial for emerging markets to stabilize the exchange rate.

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Table 1
Benchmark parameter values for high-openness economy

Parameter	Description	Value
σ	Coefficient of relative risk aversion	2
β	Subjective discount factor	0.99
ξ	Inverse of Frisch labor elasticity	1
ζ	Preference parameter for labor in utility	12.376
ϑ	Elasticity of substitution between value added and imported input	0.6
η	Elasticity of substitution for export	0.6
α	Share of domestic value added in production	0.58
ψ	Capital share in value added	0.3
v	Elasticity of substitution across different variety of goods	6
κ	Scale factor for export	0.391
δ	Depreciation rate of capital	0.025
ϕ	Capital adjustment cost	15
γ	Price stickiness parameter	0.75
π	Steady state gross inflation rate	1
λ	Extent of financial integration	0.0019
ρ^θ	Persistence of technology process	0.9
ρ^*	Persistence of foreign inflation process	0.8
ρ^{R^*}	Persistence of foreign interest rate process	0.75
ρ^φ	Persistence of UIP shock	0.5
σ^θ	Standard deviation of technology shock	0.01
σ^*	Standard deviation of foreign inflation shock	0.005
σ^{R^*}	Standard deviation of foreign interest rate shock	0.004
σ^φ	Standard deviation of UIP shock	0.033

Table 2
Benchmark results

	High openness		Low openness	
	Exchange rate rule	Interest rate rule	Exchange rate rule	Interest rate rule
Γ_π	3.00	1.80	3.00	2.90
Γ_{GDP}	1.00	0.00	0.80	0.00
ζ^c	0.34	-0.31	0.37	0.04
Mean				
C_t	0.97	2.01	0.19	0.57
L_t	-0.54	-1.33	-0.10	-0.33
S_t	1.28	3.24	2.34	3.79
u_t	0.09	0.18	0.15	0.02
Standard deviation				
GDP_t	1.79	2.30	2.56	2.15
C_t	3.01	1.53	2.18	1.22
L_t	1.27	2.83	2.62	0.87
π_t	2.00	2.86	2.54	0.87
π_t^x	7.25	25.90	12.72	28.65
π_t^m	5.56	26.89	10.35	28.59
S_t	3.04	6.99	6.24	8.80
Δe_t	1.59	6.85	2.73	7.25

Notes: (1) The interest rates rules are given by $\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP)$ while the exchange rate rules are given by $\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP)$. (2) In the optimized rules, Γ_π and Γ_{GDP} are restricted to lie in the interval of [0,3]. (3) All statistics are in percentage terms, except for the inflation rates, π_t , π_t^x and π_t^m , which are in annualized percentage terms.

Table 3

Results for the case of high elasticity of substitution for export

	High openness		Low openness	
	Exchange rate	Interest rate	Exchange rate	Interest rate
	rule	rule	rule	rule
Γ_π	3.00	3.00	3.00	3.00
Γ_{GDP}	0.00	0.50	0.20	0.30
ζ^c	0.27	0.68	0.29	0.38
Mean				
C_t	0.37	-0.01	0.02	-0.07
L_t	-0.18	-0.04	0.10	0.14
S_t	0.11	0.25	0.26	0.68
u_t	0.03	0.20	0.07	0.12
Standard deviation				
GDP_t	2.76	4.32	2.52	3.32
C_t	3.57	3.03	2.87	2.11
L_t	2.21	5.56	1.67	3.74
π_t	1.11	2.96	1.82	2.30
π_t^x	4.45	8.02	7.75	15.39
π_t^m	2.20	8.21	5.31	15.67
S_t	0.98	1.78	2.17	3.63
Δe_t	0.84	2.29	1.50	4.06

Notes: (1) The interest rates rules are given by $\ln(R_t/R) = \Gamma_\pi \ln(\pi_t/\pi) + \Gamma_{GDP} \ln(GDP_t/GDP)$ while the exchange rate rules are given by $\ln(\Delta e_t/\Delta e) = -\Gamma_\pi \ln(\pi_t/\pi) - \Gamma_{GDP} \ln(GDP_t/GDP)$. (2) In the optimized rules, Γ_π and Γ_{GDP} are restricted to lie in the interval of $[0,3]$. (3) All statistics are in percentage terms, except for the inflation rates, π_t , π_t^x and π_t^m , which are in annualized percentage terms.

Figure 1: Welfare costs as elasticity of substitution for export varies
 Legend: Straight lines: Interest rate rules; Crosses: Exchange rate rules