Exchange Rate Dynamics in an Estimated Small Open Economy DSGE Model*

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Abstract

In this paper, I investigate what are the main features of a rich theoretical model needed to explain exchange rate dynamics. As a theoretical framework, I use a small open economy dynamic stochastic general equilibrium (DSGE) model. The model is estimated using Bayesian techniques. I use post Bretton-Woods data for the following three countries: Australia, Canada, and the United Kingdom (UK). The performance of the benchmark model in replicating both real exchange rate persistence and volatility is rather good. I show that the domestic and importing sector price stickiness and indexation parameters are the most important features of the model for a successful replication of the real exchange rate dynamics. The importance of the importing sector price stickiness and indexation parameters is increasing in the share of importing goods in the consumption basket. The most important shocks for explaining the exchange rate volatility at business cycle frequency are the investment specific technology shock, monetary policy shock, and labor supply shock, among domestic economy shocks, and the shock to the interest rate among the foreign shocks.

Keywords: Exchange Rate Dynamics, DSGE Models, Bayesian Estimation
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1 Introduction

Understanding exchange rates dynamics is one of the central questions in the international macroeconomics. Over the last decade there have been numerous studies trying to understand what are the necessary aspects of the model that would reproduce real exchange rate movements present in the data (for example, Bouakez (2007), Chari et al. (2002), Corsetti et al. (2006), Kollman (2001), Obstfeld and Rogoff (2000)). Since most of these papers use calibrated models, this paper contributes to this literature by estimating a full-fledged small open economy DSGE model that features various real and nominal rigidities. This framework allows me to evaluate the importance of different features of the model in explaining observed exchange rate dynamics. Furthermore, I also investigate which are the main shocks that contribute to the volatility of the main macroeconomic variables, with the emphasis on the volatility of the real exchange rate.

In particular, I estimate a small open economy DSGE model, which builds on the model of Christiano et al. (2005), by incorporating an open economy component into it. In particular, the model features exporting and importing firms, which face price stickiness a lá Calvo (1983) and Yun (1996), implying a low exchange rate pass through.[1] The model incorporates various nominal and real frictions: variable capacity utilization, habit persistence in consumption, adjustment cost to investment, wage and price stickiness, and wage and price indexation. This allows me to assess the importance of different frictions in different dimensions, especially in replicating exchange rate movements. To do so, I compare implied real exchange rate persistence of the model that excludes a particular rigidity or rigidities with the one implied by the benchmark model.

My results are as follows. The benchmark model performs rather well in replicating the persistence of the real exchange rate in all three countries, while the exchange rate volatility is explained relatively better in the case of Australia and Canada than in the case of UK. Futhermore, the most important model frictions in the replication of the real exchange rate persistence are the price stickiness parameters, in particular the domestic price stickiness parameter, importing price stickiness, and indexation parameter. The relevance of the importing price stickiness is increasing in the share of imports in the total consumption basket. One possible explanation for this result might be as follows. As described in my model, the real exchange rate is defined as the nominal exchange rate corrected by the relative price of the domestic and world economy. Since my model is a small open economy model, world price cannot be altered by the economic decisions of the agents in a small domestic economy and can be considered constant. Therefore, all movements in the relative price come from the movements in the domestic CPI level. Higher degree of domestic price stickiness implies that on average domestic firms are allowed to change prices less often, suggesting higher persistence of inflation (measured by the change in domestic CPI). This higher inflation persistence implies higher persistence of the real exchange rate. The same intuition follows when I consider the price stickiness of the importing goods, which are the part of the aggregate price index

[1] Convensional wisdom suggests that the higher value of these parameters, the lower exchange rate pass through.

in the domestic economy. Since I allow for the local currency pricing, i.e. domestic importers set prices of imported goods in their own currency, the frequency with which they change their prices will undoubtedly influence the real exchange rate persistence through its effect on the persistence of domestic inflation. In addition, wage stickiness and wage indexation parameters also play an important role for the replication of the exchange rate dynamics. Moreover, all these frictions are important for explaining volatility of the real exchange rate as well. Finally, I find that among the domestic shocks, the most important shocks for explaining the volatility of the exchange rate are the investment-specific technology shock and the monetary policy shock, while among the so-called world shocks the most important is the foreign interest rate shock.

Despite the burgeoning theoretical literature, not much work has been done on the estimation side. For example, Adolfson et al. (2005) estimate a small open economy DSGE model using the Euro Area data and employing Bayesian techniques. However, their primary interest is to evaluate how well this model fits the European data. In addition, their model features much larger number of shocks than my model. My model features nine shocks, six of which coming from the domestic economy, and three from the foreign economy. Specifically, domestic shocks are: preference shock, labor supply shock, neutral technology shock, investment specific shock, monetary policy shock and asymetric technology shock, whereas the foreign economy shocks are: shock to the interest rate, and shocks to foreign inflation and output.

I estimate the model using the data for the following three countries: Australia, Canada, and UK. I choose these countries as examples of small open developed economies, whereas the rest of the world is approximated by the US data. I use the post Bretton-Woods data, which leads to a sample period 1972:I - 2006:IV. The variables used as observables are: inflation, interest rate, output, consumption, exports, and real exchange rate for each of the three countries, together with inflation, interest rate, and output of the US economy, which is chosen as the approximation of the rest of the world. I estimate the model using Bayesian methods. I use the Kalman filter to evaluate the likelihood of the model, under the assumption that all structural shocks are normally distributed. Then, by combining prior distributions of the structural parameters and the likelihood function, I recover posterior distributions of the parameters. I use a random walk Metropolis-Hastings algorithm to sample from the proposal posterior distribution. For each estimated structural parameter, I obtain the chain of the draws from the posterior distribution. Finally, I take the mean of the chain to be the point estimate of the parameter.[2] A subset of the structural parameters is calibrated in a standard fashion.

This paper is related to several papers in the existing literature. For instance, Chari et al. (2002) show that in the two-country model adding price stickiness is not enough to match the real exchange rate volatility. In fact, only after adding preferences separable in leisure their model

[2]Different moments of the posterior distribution can be chosen as point estimates. The most commonly used moments are mean and the mode of the posterior distribution. Results are not significantly influenced if mode is used as a point estimate.

can reproduce observed exchange rate volatility. Furthermore, Kollmann (2001) shows that sticky nominal wages and prices can help in matching exchange rate volatility. Also, Bergin and Feenstra (2001) show that translogin preference forms can reproduce high degree of volatility of the real exchange rate. Finally, Devereux and Engel (2002) show that allowing for local currency pricing is a key element for matching the exchange rate volatility. None of these papers is successful in replicating the exchange rate persistence very well.

The rest of the paper is organized as follows. Section 2 provides relevant empirical evidence using the data from three mentioned small open economies. Theoretical model is described in Section 3 . Section 4 describes the data, estimation procedure, calibration, prior distributions of the estimated parameters, and estimation results. In Section 5, the model exchange rate dynamics is confronted with the empirical exchange rate dynamics. Section 6 concludes.

2 Empirical Evidence

This section presents empirical evidence regarding the nominal and real exchange rate dynamics. Figures 1-3 show exchange rate series for three countries that serve as examples of developed small open economies, in order to demonstrate that high exchange rate persistence and volatility is the common developed small open economies phenomenon. Specifically, I consider the following three countries: Australia, Canada and UK. The figures display log-levels of nominal and real exchange rates, expressed in domestic currencies to the US dollar, for the post Bretton-Woods sample period 1972:I - 2006:IV. The dashed lines represent nominal exchange rates, which are expressed as the number of home currency units needed to buy one foreign currency unit. This implies that the decrease of the nominal exchange rate corresponds to the appreciation of the home-country currency, whereas increase of the nominal exchange rate corresponds to the depreciation of the home-country currency.

Real exchange rates, represented by the solid lines, are constructed as the consumer price index (CPI) based exchange rates, i.e. as the product of the nominal exchange rate and relative price levels between two countries, where the measure of the price level is the CPI. Specifically,

$$s_t^r = \frac{s_t CPI_t^{foreign}}{CPI_t^{domestic}},$$

where s_t^r represents the real exchange rate, s_t is the nominal exchange rate, $CPI_t^{foreign}$ is the foreign price index, and $CPI_t^{domestic}$ is the domestic price index.

Figures 4-6 display quarterly growth rates of nominal and real exchange rates. Exchange rates are highly volatile in all three countries. The volatility of the series is estimated by the standard deviation of the series, and the persistence of the series is approximated by the first-order autocorrelation coefficient. Table 1 shows the values of these statistics for the three countries. The exchange rate is the most volatile and the least persistent in the UK economy. Exchange rates in Canadian and Australian economy show very similar dynamics, being twice less volatile than exchange rate in the UK economy, and more persistent than the same indicator in the UK economy.

3 The Model

In this section I describe the model. Specifically, I use a small open economy DSGE model that builds on the model proposed by Christiano et al. (2005), by incorporating small open economy components into it. In addition to a standard closed DSGE model setting, exporting and importing sectors are added into the model. The model features various types of rigidities, such as price and wage stickiness and indexation parameters, variable capacity utilization, investment adjustment costs, and habit persistence in consumption.

3.1 Households

The economy is populated by a continuum of households indexed by $j \in [0,1]$. Household's preferences are defined over consumption, c_{jt}, and labor, l_{jt}. Each household maximizes lifetime utility that takes the following form:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \xi_t \left\{ \log\left(c_{jt} - h c_{jt-1}\right) - \varphi_t \psi \frac{l_{jt}^{1+\gamma}}{1+\gamma} \right\}, \tag{1}$$

where $\beta \in (0,1)$ is the discount factor, h is the habit persistence parameter, γ is the inverse of Frisch labor supply elasticity, while ξ_t and φ_t represent preference shock and labor supply shock, which follow autoregressive processes:

$$\begin{aligned} \log \xi_t &= \rho_\xi \log \xi_{t-1} + \sigma_\xi \varepsilon_{\xi,t} \\ \log \varphi_t &= \rho_\varphi \log \varphi_{t-1} + \sigma_\varphi \varepsilon_{\varphi,t}, \end{aligned}$$

where $\varepsilon_{\xi,t} \sim \mathcal{N}(0,1)$ and $\varepsilon_{\varphi,t} \sim \mathcal{N}(0,1)$. Households consume both domestically produced goods and imported goods.

Aggregate consumption of the household, c_{jt}, is given by the constant elasticity of substitution (CES) index of domestically produced and imported goods:

$$c_{jt} = \left\{ (1-\alpha_c)^{\frac{1}{\eta_c}} \left(c_{jt}^d\right)^{\frac{\eta_c - 1}{\eta_c}} + \alpha_c^{\frac{1}{\eta_c}} \left(c_{jt}^m\right)^{\frac{\eta_c - 1}{\eta_c}} \right\}^{\frac{\eta_c}{\eta_c - 1}},$$

where c_{jt}^d represents the consumption of domestically produced goods, c_{jt}^m is the consumption of imported goods, $(1-\alpha_c)$ is the home bias in consumption, and η_c is the elasticity of substitution between domestic and imported consumption goods. Household chooses the best allocation of its resources between domestically produced and imported consumption goods, by maximizing total consumption subject to the following budget constraint:

$$p_t c_{jt}^d + p_t^m c_{jt}^m = p_t^c c_{jt}, \tag{2}$$

where p_t is the price of domestically produced goods, p_t^m is the price of imported goods in domestic currency, and p_t^c is the aggregate CPI. After some manipulations of the first-order conditions of this problem, demands for domestically produced consumption goods and imported consumption goods are:

$$c_{jt}^d = (1-\alpha_c)\left(\frac{p_t}{p_t^c}\right)^{-\eta_c} c_{jt}, \tag{3}$$

$$c_{jt}^m = \alpha_c \left(\frac{p_t^m}{p_t^c}\right)^{-\eta_c} c_{jt}. \tag{4}$$

The expression for the aggregate CPI, p_t^c, can be obtained by plugging (3) and (4) back into (2) :

$$p_t^c = \left\{(1-\alpha_c)p_t^{1-\eta_c} + \alpha_c (p_t^m)^{1-\eta_c}\right\}^{\frac{1}{1-\eta_c}}.$$

Households are assumed to own physical capital k_{jt}, which accumulates according to the following law of motion:

$$k_{jt+1} = (1-\delta)\, k_{jt} + \mu_t \left(1 - S\left[\frac{i_{jt}}{i_{jt-1}}\right]\right) i_{jt},$$

where i_{jt} denotes gross investment, δ is the parameter denoting the depreciation rate of capital, and μ_t is the investment-specific technological shock that follows an autoregressive process, given by

$$\log \mu_t = \Upsilon_\mu + \log \mu_{t-1} + \sigma_\mu \varepsilon_{\mu,t}\ ,$$

where $\varepsilon_{\mu,t} \sim \mathcal{N}(0,1)$. The function $S[\cdot]$ introduces investment adjustment costs and satisfies following properties in the steady state: $S[\Upsilon_\mu] = S'[\Upsilon_\mu] = 0$, and $S''[\Upsilon_\mu] > 0$, where Υ_μ represents steady state growth rate. These assumptions imply no adjustment cost up to the first-order in the vicinity of a steady state. Household chooses optimal level of investment in each period, as well as the optimal allocation of investment resources. As in the case of total consumption index, I analogously define total investment index as the CES aggregate of domestic and imported investment goods given as:

$$i_{jt} = \left\{(1-\alpha_i)^{\frac{1}{\eta_i}} (i_{jt}^d)^{\frac{\eta_i-1}{\eta_i}} + \alpha_i^{\frac{1}{\eta_i}} (i_{jt}^m)^{\frac{\eta_i-1}{\eta_i}}\right\}^{\frac{\eta_i}{\eta_i-1}}, \tag{5}$$

where i_{jt}^d denotes domestic investment goods, i_{jt}^m denotes imported investment goods, η_i is the elasticity of substitution between domestic and imported investment goods, and $(1-\alpha_i)$ is the home bias in investment goods. Then, household's demands for these two types of investment goods are the following:

$$i_{jt}^{d}=(1-\alpha_i)\left(\frac{p_t}{p_t^i}\right)^{-\eta_i} i_{jt}, \tag{6}$$

$$i_{jt}^{m}=\alpha_i\left(\frac{p_t^m}{p_t^i}\right)^{-\eta_i} i_{jt}, \tag{7}$$

where p_t^i is the aggregate investment price index obtained by plugging (6) and (7) into (5):

$$p_t^i=\left\{(1-\alpha_i)p_t^{1-\eta_i}+\alpha_i(p_t^m)^{1-\eta_i}\right\}^{\frac{1}{1-\eta_i}}.$$

Households can trade on the whole set of possible Arrow-Debreu securities, which are indexed both by household j and by time t in order to capture both idiosyncratic and aggregate risk. In addition, households hold an amount b_{jt+1} of domestic government bonds that pay a nominal gross interest rate of R_t between periods t and $t+1$, and amount b_{jt+1}^* of foreign government bonds that pay a nominal gross interest rate R_t^*. Furthermore, to ensure a well-defined steady state of the model, I assume that the foreign interest rate is increasing in the level of the country debt.[3] To capture this fact I introduce a function $\Phi(\cdot)$, which is assumed to be a decreasing function of foreign asset holdings, a_t^f[4], where $a_t^f=\frac{s_t b_{jt}^*}{p_t}$. This formulation implies that if the country is a net borrower, it will be charged a premium on the foreign interest rate, whereas if the country is a net lender it will receive remuneration on its savings. The nominal exchange rate is denoted by s_t and is given in terms of domestic currency needed to buy a unit of foreign currency, i.e. increase in s_t implies exchange rate depreciation, whereas decrease in s_t implies exchange rate appreciation. Considering all stated above, the budget constraint of the $j-th$ household, expressed in the domestic currency terms, is the following:

$$\begin{aligned}
& \frac{p_t^c}{p_t}c_{jt}+\frac{p_t^i}{p_t}i_{jt}+\frac{b_{jt+1}}{p_t}+\frac{s_t b_{jt+1}^*}{p_t}+\int q_{jt+1,t}a_{jt+1}d\omega_{j,t+1,t} \\
= \; & w_{jt}l_{jt}+\left(r_t u_{jt}-\mu_t^{-1}a\left[u_{jt}\right]\right)k_{jt} \\
& +R_{t-1}\frac{b_{jt}}{p_t}+R_{t-1}^*\Phi\left(\frac{s_{t-1}b_t^*}{p_{t-1}}\right)\frac{s_t b_{jt}^*}{p_t}+a_{jt}+T_t+F_t
\end{aligned}$$

where w_{jt} is the real wage, r_t is the real rental price of capital, u_{jt} is the capital utilization, $\mu_t^{-1}a\left[u_{jt}\right]$ is the physical cost of capital utilization in resource terms, T_t is a lump-sum transfer, and F_t are the firms' profits. In addition, I assume that $a[1]=0$, a' and $a''>0$. The Lagrangian associated with this problem is the following:

[3]This is a standard approach in this literature. See Schmitt-Grohe and Uribe (2003), Benigno (2001), Adolfson, et al. (2005).

[4]I use the functional form proposed by Schmitt-Grohé and Uribe (2003), given by $\Phi(a)=-\psi_2(e^{a^f-\bar{a}^f}-1)$, where ψ_2 and $\bar{a}^f$ are constant parameters.

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \xi_t \left\{ \log\left(c_{jt} - hc_{jt-1}\right) - \varphi_t \psi \frac{l_{jt}^{1+\gamma}}{1+\gamma} \right\} \\ -\lambda_{jt} \left\{ \begin{array}{c} \frac{p_t^c}{p_t} c_{jt} + \frac{p_t^i}{p_t} i_{jt} + \frac{b_{jt+1}}{p_t} + \frac{s_t b_{jt+1}^*}{p_t} \\ + \int q_{jt+1,t} a_{jt+1} d\omega_{j,t+1,t} - w_{jt} l_{jt} \\ - \left(r_t u_{jt} - \mu_t^{-1} a\left[u_{jt}\right]\right) k_{jt} - R_{t-1} \frac{b_{jt}}{p_t} - R_{t-1}^* \Phi\left(\frac{s_{t-1} b_t^*}{p_{t-1}}\right) \frac{s_t b_{jt}^*}{p_t} \\ -a_{jt} - T_t - F_t \end{array} \right\} \\ -Q_{jt} \left\{ k_{jt+1} - (1-\delta) k_{jt} - \mu_t \left(1 - S\left[\frac{i_{jt}}{i_{jt-1}}\right]\right) i_{jt} \right\} \end{array} \right].$$

Household chooses c_{jt}, b_{jt}, b_{jt}^*, u_{jt}, k_{jt+1}, i_{jt}, w_{jt}, l_{jt} and a_{jt+1}; λ_{jt} represents the Lagrangian multiplier associated with the budget constraint and Q_{jt} represents the Lagrangian multiplier associated with installed capital. If I define the marginal Tobin's Q as the ratio of these two multipliers, i.e. $q_{jt} = \frac{Q_{jt}}{\lambda_{jt}}$, then first-order conditions with respect to c_{jt}, b_{jt}, b_{jt}^*, u_{jt}, k_{jt+1}, and i_{jt} are respectively:

$$\xi_t \left(c_{jt} - hc_{jt-1}\right)^{-1} - h\beta \mathbb{E}_t \xi_{t+1} \left(c_{jt+1} - hc_{jt}\right)^{-1} = \lambda_{jt} \frac{p_t^c}{p_t}$$

$$\lambda_{jt} = \beta \mathbb{E}_t \left\{ \lambda_{jt+1} \frac{R_t}{\Pi_{t+1}} \right\}$$

$$\lambda_{jt} s_t = \beta \mathbb{E}_t \left\{ \lambda_{jt+1} \frac{R_t^* \Phi(a_t^f) s_{t+1}}{\Pi_{t+1}} \right\}$$

$$r_t = \mu_t^{-1} a' \left[u_{jt}\right]$$

$$\lambda_{jt} q_{jt} = \beta \mathbb{E}_t \lambda_{jt+1} \left\{ (1-\delta) q_{jt+1} + \left(r_{t+1} u_{jt+1} - \mu_{t+1}^{-1} a\left[u_{jt+1}\right]\right) \right\}$$

$$-\lambda_{jt} \frac{p_t^i}{p_t} + \lambda_{jt} q_{jt} \mu_t \left(1 - S\left[\frac{i_{jt}}{i_{jt-1}}\right] - S'\left[\frac{i_{jt}}{i_{jt-1}}\right] \frac{i_{jt}}{i_{jt-1}}\right)$$

$$+\beta \mathbb{E}_t \lambda_{jt+1} q_{jt+1} \mu_{t+1} S'\left[\frac{i_{jt+1}}{i_{jt}}\right] \left(\frac{i_{jt+1}}{i_{jt}}\right)^2 = 0.$$

When taking the first-order conditions with respect to wages and labor, I follow the set-up of Erceg et al. (2000) and assume that each household supplies differentiated labor services to the production sector. In order to avoid this heterogeneity spilling over into consumption heterogeneity, they assume that utility is separable in consumption and labor, and that, because of the existence of complete markets, households can fully ensure against the employment risks. Furthermore, in this environment, the equilibrium price of Arrow-Debreu securities ensures that the consumption does not depend on idiosyncractic shocks. In addition, I assume that a representative labor aggregator combines households' labor in the same proportion as firms would choose, which ensures that her demand for $j-th$ household's labor is the same as the sum of the firms' demands for this type of labor. Specifically, the labor aggregator uses the following production technology:

$$l_t^d = \left(\int_0^1 l_{jt}^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta}{\eta-1}}, \tag{8}$$

where $\eta \in [0, \infty)$ is the elasticity of substitution among different types of labor, and l_t^d is the aggregate labor demand. She maximizes profits subject to (8), taking as given all differentiated labor wages w_{jt} and the aggregate wage index w_t. Her demand for the labor of household j is given by,

$$l_{jt} = \left(\frac{w_{jt}}{w_t} \right)^{-\eta} l_t^d \qquad \forall j. \tag{9}$$

Households set their wages following Calvo setting, i. e. in each period, a fraction $\theta_w \in [0, 1)$ of randomly picked households is not allowed to optimally set their wages. Instead, they partially index their wages to the past inflation, which is controlled by the indexation parameter $\chi_w \in [0, 1]$. The remaining fraction of households reset their wages w_{jt} to maximize (1), which leads to the following first order condition:

$$\frac{\eta-1}{\eta} w_t^{opt} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_w)^k \lambda_{t+k} \left(\prod_{s=1}^{k} \frac{\Pi_{t+s-1}^{\chi_w}}{\Pi_{t+s}} \right)^{1-\eta} \left(\frac{w_t^{opt}}{w_{t+k}} \right)^{-\eta} l_{t+k}^d =$$

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_w)^k \left(\xi_{t+k} \varphi_{t+k} \psi \left(\prod_{s=1}^{k} \frac{\Pi_{t+s-1}^{\chi_w}}{\Pi_{t+s}} \frac{w_{opt,t}}{w_{t+k}} \right)^{-\eta(1+\gamma)} \left(l_{t+k}^d \right)^{1+\gamma} \right),$$

which can be expressed recursively as $f_t^1 = f_t^2$, where f_t^1 and f_t^2 are defined as

$$f_t^1 = \frac{\eta-1}{\eta} (w_{opt,t})^{1-\eta} \lambda_t w_t^{\eta} l_t^d + \beta\theta_w \mathbb{E}_t \left(\frac{\Pi_t^{\chi_w}}{\Pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{opt,t+1}}{w_{opt,t}} \right)^{\eta-1} f_{t+1}^1,$$

$$f_t^2 = \psi d_t \varphi_t \left(\frac{w_t}{w_{opt,t}} \right)^{\eta(1+\gamma)} \left(l_t^d \right)^{1+\gamma} + \beta\theta_w \mathbb{E}_t \left(\frac{\Pi_t^{\chi_w}}{\Pi_{t+1}} \right)^{-\eta(1+\gamma)} \left(\frac{w_{opt,t+1}}{w_{opt,t}} \right)^{\eta(1+\gamma)} f_{t+1}^2.$$

3.2 Firms and Price Setting

There are five types of the firms in the model: a final domestic good producer, intermediate goods producers, importing goods producers, and exporting goods producers. In this section, I describe the problems each of these producers faces.

3.2.1 Final Good Producer

The final domestic good producer aggregates intermediate goods into the homogenous final good, using the following production function of the Dixit and Stiglitz (1997):

$$y_t^d = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{10}$$

where ε is the elasticity of substitution between intermediate goods. The final good producer chooses the bundle of goods that minimizes the cost of producing y_t^d, taking all intermediate goods prices p_{it}, final domestic good price p_t, and the quantity of intermediate goods y_{it} as given. The unit price of the output unit is equal to its unit cost p_t :

$$p_t = \left(\int_0^1 p_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}.$$

The input demand function y_{it} for each intermediate good i is then given by:

$$y_{it} = \left(\frac{p_{it}}{p_t} \right)^{-\varepsilon} y_t^d \qquad \forall i,$$

where y_t^d is the aggregate demand.

3.2.2 Intermediate Good Producers

Each differentiated good is produced by a single intermediate firm $i \in [0,1]$ that rents capital services k_{it}, and labor services l_{it}^d, using the production function:

$$y_{it} = A_t k_{it}^{\alpha} \left(l_{it}^d \right)^{1-\alpha} - \phi z_t,$$

where ϕ is the parameter that corresponds to the fixed cost of production, and A_t is the neutral technology process, given by:

$$\log A_t = \Upsilon_A + \log A_{t-1} + \sigma_A \varepsilon_{A,t} \ ,$$

where $\varepsilon_{A,t} \sim \mathcal{N}(0,1)$. Following Altig et al. (2005), I assume that fixed costs are subject to the permanent shock z_t, which ensures that along the balanced-growth path fixed costs do not vanish, and that profits are approximately zero in the steady state.

Each intermediate goods firm chooses amount of k_{it} and l_{it}^d to rent, taking the input prices r_t and w_t as given. The standard static first-order conditions for cost minimization imply that real marginal cost is the same for all firms, i.e. does not have a subscript i associated with it, since all intermediate goods firms face the same aggregate technology shocks as well as the same input prices. Real marginal cost is given by

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\frac{w_t^{1-\alpha}r_t^{\alpha}}{A_t},$$

where

$$\begin{aligned} w_t &= \varrho\left(1-\alpha\right)A_t k_{it}^{\alpha}\left(l_{it}^d\right)^{-\alpha} \\ r_t &= \varrho\alpha A_t k_{it}^{\alpha-1}\left(l_{it}^d\right)^{1-\alpha}. \end{aligned}$$

I assume that the intermediate goods firms set their proces a lá Calvo (1983) and Yun (1996). That is, in each period, a fraction $\theta_p \in [0,1)$ of firms is not allowed to change their prices, and can only index them by the past inflation, which is controlled by the indexation parameter $\chi_p \in [0,1]$. The remaining $1-\theta_p$ firms that are allowed to reset their prices in period t, solve the following maximization problem:

$$\max_{p_{it}} \mathbb{E}_t \sum_{k=0}^{\infty}\left(\beta\theta_p\right)^k \frac{\lambda_{t+k}}{\lambda_t}\left\{\left(\prod_{s=1}^{k}\Pi_{t+s-1}^{\chi_p}\frac{p_{it}}{p_{t+k}} - mc_{t+k}\right)y_{it+k}\right\}$$

$$\text{s.t. } y_{it+k} = \left(\prod_{s=1}^{k}\Pi_{t+s-1}^{\chi_p}\frac{p_{it}}{p_{t+k}}\right)^{-\varepsilon} y_{t+k}^d.$$

If I define recursively:

$$g_t^1 = \lambda_t mc_t y_t^d + \beta\theta_p \mathbb{E}_t\left(\frac{\Pi_t^{\chi_p}}{\Pi_{t+1}}\right)^{-\varepsilon} g_{t+1}^1$$

$$g_t^2 = \lambda_t \Pi_{t,opt} y_t^d + \beta\theta_p \mathbb{E}_t\left(\frac{\Pi_t^{\chi_p}}{\Pi_{t+1}}\right)^{1-\varepsilon}\left(\frac{\Pi_{t,opt}}{\Pi_{t+1,opt}}\right) g_{t+1}^2,$$

where $\Pi_{t,opt} = \frac{p_{t,opt}}{p_t}$, the first-order condition to this problem can be written as $\varepsilon g_t^1 = (\varepsilon - 1)\, g_t^2$.

Finally, considering the price setting, the aggregate price index is:

$$p_t^{1-\varepsilon} = \theta_p\left(\Pi_{t-1}^{\chi_p}\right)^{1-\varepsilon} p_{t-1}^{1-\varepsilon} + \left(1-\theta_p\right) p_{t,opt}^{1-\varepsilon}.$$

3.2.3 Importing Firms

There is a continuum of importing firms indexed by i on the unit interval. The problem that these firms solve can be described as follows. First, importing firm i buys a homogenous good in the world market at the price p_t^* and turns it into a differentiated imported good through a differentiating technology and brand naming. Then, imported goods "packer" mixes these differentiated imported goods y_{it}^m, using the production technology:

$$y_t^m = \left[\int_0^1 \left(y_{it}^m \right)^{\frac{\varepsilon_m - 1}{\varepsilon_m}} di \right]^{\frac{\varepsilon_m}{\varepsilon_m - 1}}, \tag{11}$$

to produce the final imported good y_t^m. Finally, he sells the final imported good to the households, who decide to consume it or to invest it. The parameter ε_m is the elasticity of substitution across differentiated importing goods.

The imported goods packer chooses the bundle of goods that minimizes the cost of producing y_t^m, taking all imported goods prices p_{it}^m, final imported goods basket price p_t^m, and the quantity of imported goods y_{it}^m as given. The unit price of the output unit is equal to its unit cost p_t^m :

$$p_t^m = \left(\int_0^1 \left(p_{it}^m \right)^{1-\varepsilon_m} di \right)^{\frac{1}{1-\varepsilon_m}},$$

whereas the demand function for each differentiated imported good i is given by:

$$y_{it}^m = \left(\frac{p_{it}^m}{p_t^m} \right)^{-\varepsilon_m} y_t^m \quad \forall i.$$

Finally, total amount of imported goods is obtained by integrating over all differentiated imported goods:

$$Y_t^m = \int_0^1 y_{it}^m di.$$

In order to allow for the incomplete exchange rate pass-through to import prices, I assume that also these firms are subject to price stickiness a lá Calvo (1983) and Yun (1996). That is, in each period, a fraction $\theta_m \in [0, 1)$ of firms is not allowed to change their prices, and can only index them by the past inflation, which is controlled by the indexation parameter $\chi_m \in [0, 1]$. The remaining $1 - \theta_m$ that are allowed to reset their prices in period t, solve the following maximization problem:

$$\max_{p_{i,t}^m} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_m)^k \frac{\lambda_{t+k}}{\lambda_t} \left\{ \left(\prod_{s=1}^{k} \left(\Pi_{t+s-1}^m \right)^{\chi_m} \frac{p_{it}^m}{p_{t+k}^m} - \frac{s_{t+k} p_{t+k}^*}{p_{t+k}^m} \right) y_{it+k}^m \right\}$$

$$y_{it+k}^m = \left(\prod_{s=1}^{k} \left(\Pi_{t+s-1}^m \right)^{\chi_m} \frac{p_{it}^m}{p_{t+k}^m} \right)^{-\varepsilon_m} y_{t+k}^m,$$

where the marginal value of a dollar to the household is treated as exogenous by the firm, and where $\frac{s_t p_t^*}{p_t^m}$ represents the real marginal cost that is equal to the nominal marginal cost (the price of homogenous foreign good that they buy on the world market) devided by the imported goods price index.

Following the same strategy as in the problem of intermediate good firms, first order condition of importing firms can be written as $\varepsilon_m (g_t^m)^1 = (\varepsilon_m - 1)(g_t^m)^2$,with

$$(g_t^m)^1 = \lambda_t \frac{s_t p_t^*}{p_t^m} y_t^m + \beta\theta_m \mathbb{E}_t \left(\frac{(\Pi_t^m)^{\chi_m}}{\Pi_{t+1}^m} \right)^{-\varepsilon_m} (g_{t+1}^m)^1,$$

$$(g_t^m)^2 = \lambda_t \Pi_{t,opt}^m y_t^m + \beta\theta_m \mathbb{E}_t \left(\frac{(\Pi_t^m)^{\chi_m}}{\Pi_{t+1}^m} \right)^{1-\varepsilon_m} \left(\frac{\Pi_{t,opt}^m}{\Pi_{t+1,opt}^m} \right) (g_{t+1}^m)^2,$$

where $\Pi_{t,opt}^m = \frac{p_{t,opt}^m}{p_t^m}$. Given the price setup these firms face, the price index of import goods is:

$$(p_t^m)^{1-\epsilon_m} = \theta_m \left(\Pi_{t-1}^m \right)^{\chi_m(1-\varepsilon_m)} (p_{t-1}^m)^{1-\varepsilon_m} + (1-\theta_m) (p_{t,opt}^m)^{1-\epsilon_m}.$$

3.2.4 Exporting Firms

There is a continuum of exporting firms indexed by i on the unit interval. Each firm i buys a homogenous final domestic good in the domestic market and differentiates it by differentiating technology or brand naming. Then, they sell these differentiated goods to the rest of the world. The demand for each variety of these goods comes from the households in the foreign economy, who decide to consume it or invest to it, and can be written as follows:

$$e_{i,t} = \left(\frac{p_{it}^e}{p_t^e} \right)^{-\varepsilon_e} e_t,$$

where ε_e is the elasticity of substitution between differentiated exporting goods. Total amount of exported goods, E_t, is thus obtained by integrating over all differentiated exporting goods:

$$E_t = \int_0^1 e_{it} di,$$

with the exported goods price index:

$$p_t^e = \left(\int_0^1 (p_{it}^e)^{1-\varepsilon_e} di \right)^{\frac{1}{1-\varepsilon_e}}.$$

Assuming that the domestic economy is small relative to the foreign economy, and thus plays a negligible part in the aggregate foreign consumption, the demand for the final export good in the foreign economy is:

$$e_t = \left(\frac{p_t^e}{p_t^*} \right)^{-\eta_f} y_t^*,$$

where η_f is the elasticity of substitution between domestic and foreign goods in the foreign economy, and y_t^* is the output of the rest of the world.

I assume that exporters exhibit local-currency pricing, i.e. they take into account the conditions of the foreign market when setting prices. In order to allow for incomplete exchange rate pass-through in the export market, I assume that export prices are sticky al á Calvo (1983) and Yun (1996). In particular, each period, fraction $1-\theta_e$ of the firms is allowed to change the price, while the outstanding θ_e firms can only index their prices by the past inflation $\left(\Pi_t^* = \frac{p_t^*}{p_{t-1}^*}\right)$. Indexation parameter is denoted by $\chi_e \in [0,1]$. The nominal marginal cost of exporting firms is the price of domestic final good expressed in the foreign currency $\left(\frac{p_t}{s_t}\right)$, which divided by the export price index gives real marginal cost $\left(\frac{p_t}{s_t p_t^e}\right)$. Hence, exporting firm i that is allowed to reset its price solves:

$$\max_{p_{i,t}^e} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_e)^k \frac{\lambda_{t+k}}{\lambda_t} \left\{ \left(\prod_{s=1}^{k} \left(\Pi_{t+s-1}^*\right)^{\chi_{e,c}} \frac{p_{it}^e}{p_{t+k}^e} - \frac{p_{t+k}}{s_{t+k} p_{t+k}^e} \right) e_{it+k} \right\}$$

$$\text{s.t } e_{i,t+k} = \left(\prod_{s=1}^{k} \left(\Pi_{t+s-1}^*\right)^{\chi_e} \frac{p_{it}^e}{p_{t+k}^e} \right)^{-\varepsilon_e} e_{t+k}.$$

Similar to the importing goods case, the recursive representation of the problem is $\varepsilon_e (g_t^e)^1 = (1-\varepsilon_e)(g_t^e)^2$, where

$$(g_t^e)^1 = \lambda_t mc_t^e e_t + \beta\theta_e \mathbb{E}_t \left(\frac{(\Pi_t^*)^{\chi_e}}{\Pi_{t+1}^e} \right)^{-\varepsilon_e} (g_{t+1}^e)^1$$

$$(g_t^e)^2 = \lambda_t \Pi_{opt,t}^e e_t + \beta\theta_e \mathbb{E}_t \left(\frac{(\Pi_t^*)^{\chi_e}}{\Pi_{t+1}^e} \right)^{1-\varepsilon_e} \left(\frac{\Pi_{opt,t}^e}{\Pi_{opt,t+1}^e} \right) (g_{t+1}^e)^2.$$

Finally, given Calvo pricing,

$$1 = \theta_e \left(\frac{(\Pi_{t-1}^*)^{\chi_e}}{\Pi_t^e} \right)^{1-\varepsilon_e} + (1-\theta_e)(\Pi_{opt,t}^e)^{1-\varepsilon_e}.$$

3.3 Government

The monetary authority uses the following interest rate rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\gamma_R} \left(\left(\frac{\Pi_t^c}{\Pi^c} \right)^{\gamma_\Pi} \left(\frac{s_t}{s} \right)^{\gamma_s} \left(\frac{ \frac{ \frac{y_t^d}{z_t} }{ \frac{y_{t-1}^d}{z_{t-1}} } \frac{z_t}{z_{t-1}} }{ \Upsilon_{y^d} } \right)^{\gamma_y} \right)^{1-\gamma_R} \exp(m_t),$$

where Π^c is the target level of inflation, R is the steady state nominal gross return to capital, Υ_{y^d} is the steady state gross growth rate of y_t^d, m_t is a random shock to monetary policy given as $m_t = \sigma_m \varepsilon_{mt}$, where $\varepsilon_{mt} \sim \mathcal{N}(0,1)$. Finally, s_t denotes the nominal interest rate.[5] The role of

[5] Lubik and Schorfheide (2005, 2006) show that in the case of Canada and UK Central Banks systematically take into account level of the nominal exchange rates in setting the interest rate, while the Central Bank of Australia does not. This implies that Central Banks of Canada and UK recognize nominal exchange rate as the part of the Taylor rule, whereas this variable is not in the Taylor rule that Australian Central Bank follows. However, I will allow for the exchange rate to be part of the Taylor rule in all three cases.

the Government is to set up lump sum transfers in each period so that the Government budget constraint given by,

$$T_t = \frac{\int_0^1 m_{jt} dj}{p_t} - \frac{\int_0^1 m_{jt-1} dj}{p_t} + \frac{\int_0^1 b_{jt+1} dj}{p_t} - R_{t-1} \frac{\int_0^1 b_{jt} dj}{p_t}$$

holds in each period.

3.4 Foreign Assets

As described above, I define net foreign assets as $a_t^f = \frac{s_t b_{t+1}^*}{p_t}$. The evolution of net foreign assets is:

$$\frac{s_t b_{t+1}^*}{p_t} - \frac{R_{t-1}^* \Phi\left(\frac{s_{t-1} b_t^*}{p_{t-1}}\right) s_t b_t^*}{p_t} = \frac{s_t p_t^e}{p_t} E_t - \frac{s_t p_t^*}{p_t} Y_t^m,$$

which could be, after substituting the previously mentioned definition of the foreign assets, written as follows:

$$a_t^f - \frac{R_{t-1}^* \Phi\left(a_{t-1}^f\right) s_t b_t^*}{p_t} = \frac{s_t p_t^e}{p_t} E_t - \frac{s_t p_t^*}{p_t} Y_t^m.$$

3.5 Aggregation

The aggregate demand for the final domestic good is

$$y_t^d = c_t^d + i_t^d + e_t + \mu^{-1} a[u_t] k_t.$$

After plugging in the expressions for c_t^d, i_t^d, e_t, the demand of intermediate good i, and the final good producer production function, and integrating over all firms, the aggregate demand for the final domestic good becomes:

$$(1-\alpha_c)\left(\frac{p_t}{p_t^c}\right)^{-\eta_c} c_t + (1-\alpha_i)\left(\frac{p_t}{p_t^i}\right)^{-\eta_i} i_t + e_t + \mu^{-1} a[u_t] k_t = \frac{A_t \left(u_t k_{t-1}\right)^{\alpha} \left(l_t^d\right)^{1-\alpha} - \phi z_t}{v_t^p},$$

where $v_t^p = \int_0^1 \left(\frac{p_{it}}{p_t}\right)^{-\varepsilon} di$ is the price dispersion term that is, considering the Calvo price setting, given by

$$v_t^p = \theta_p \left(\frac{\Pi_{t-1}^{\chi}}{\Pi_t}\right)^{-\varepsilon} v_{t-1}^p + (1-\theta_p) \Pi_{t,opt}^{-\varepsilon}.$$

The labor market clearing condition is obtained by integrating (9) over all households j:

$$l_t^d = \frac{1}{v_t^w} l_t,$$

where $v_t^w = \int_0^1 \left(\frac{w_{jt}}{w_t}\right)^{-\eta} dj$ is the wage dispersion term, that, because of the presence of sticky wages, is given by,

$$v_t^w = \theta_w \left(\frac{w_{t-1}}{w_t}\frac{\Pi_{t-1}^{\chi_w}}{\Pi_t}\right)^{-\eta} v_{t-1}^w + (1-\theta_w)\left(\Pi_t^{w*}\right)^{-\eta}.$$

Using the definition of total imports, the market clearing condition at the imported goods market can be written as:

$$Y_t^m = \int_0^1 y_{i,t}^m di = y_t^m v_t^m = \left(c_t^m + i_t^m\right) v_t^m,$$

where $v^m = \int_0^1 \left(\frac{p_{i,t}^m}{p_t^m}\right)^{-\varepsilon_m} di$, given Calvo price setting the evolution of this term is

$$v_t^m = \theta_m \left(\frac{\left(\Pi_{t-1}^m\right)^{\chi_m}}{\Pi_t^m}\right)^{-\varepsilon_m} v_{t-1}^m + (1-\theta_m)\left(\Pi_{t,opt}^m\right)^{-\varepsilon_m}.$$

Analogously, using the definition of the total exports, market clearing of the exports market can be written as:

$$E_t = \int_0^1 e_{i,t} di = e_t \int_0^1 \left(\frac{p_{i,t}^e}{p_t^e}\right)^{-\varepsilon_e} di = v_t^e \left(\frac{p_t^e}{p_t^*}\right)^{-\eta_f} y_t^*,$$

where $v_t^e = \int_0^1 \left(\frac{p_{i,t}^e}{p_t^e}\right)^{-\varepsilon_e} di$, with the evolution:

$$v_t^e = \theta_e \left(\frac{\left(\Pi_{t-1}^*\right)^{\chi_e}}{\Pi_t^e}\right)^{-\varepsilon_e} v_{t-1}^e + (1-\theta_m)\left(\Pi_{t,opt}^e\right)^{-\varepsilon_e}.$$

3.6 Relative Prices and Marginal Costs

Since I introduce foreign sector to the closed economy setting of the model, it is convenient to define the following relative price expressions:

$$\begin{aligned} \kappa_t^{c,d} &= \frac{p_t^c}{p_t}, \quad \kappa_t^{c,m} = \frac{p_t^c}{p_t^m}, \quad \kappa_t^{m,d} = \frac{p_t^m}{p_t} \\ \kappa_t^{i,d} &= \frac{p_t^i}{p_t}, \quad \kappa_t^{i,m} = \frac{p_t^i}{p_t^m}, \quad \kappa_t^{e,*} = \frac{p_t^e}{p_t^*}. \end{aligned}$$

Furthermore, since nominal and real marginal costs of the exporting and importing firms are given in terms of relative prices, it is convenient to define them as follows:

$$mc_t^{m.c} = \frac{s_t p_t^*}{p_t^m} = \frac{s_t p_t^*}{p_t^{m,c}} \frac{p_t^e}{p_t^e} \frac{p_t}{p_t} = \frac{1}{mc_t^e} \frac{1}{\kappa_t^{m,d}} \frac{1}{\kappa_t^{e,*}},$$

and

$$mc_t^e = \frac{p_t}{s_t p_t^e} \frac{p_{t-1}}{p_{t-1}} \frac{p_{t-1}^e}{p_{t-1}^e} \frac{s_{t-1}}{s_{t-1}} = mc_{t-1}^e \frac{\Pi_t}{\Pi_t^e} \frac{s_{t-1}}{s_t}.$$

3.7 The Foreign Economy

The foreign economy is considered as exogenously given. That is, I consider foreign inflation, foreign interest rate, and foreign output to be exogenous. Following Adolfson et al. (2005) and Justiniano and Preston (2005), I model the foreign economy as the vector autoregressive (VAR) model. Denote a vector of foreign variables as $F^* = [\Pi_t^*, R_t^*, y_t^*]$. Then, the data generating process is assumed to take the following form:

$$F_t^* = A * F_{t-1}^* + \varepsilon_t^*.$$

Parameters of the matrix A are then introduced into the model and estimated.

4 Estimation

A subset of the deep structural parameters of the model is estimated uding Bayesian techniques, whereas the other subset of the parameters are calibrated in a standard fashion.

4.1 Estimation Procedure

The structural parameters of the model are denoted by $\theta \in \Theta$, and are estimated using Bayesian techniques. After writing the competitive equilibrium conditions of the model in the log-linearized form, the state space representation of the model can be written as:

$$S_t = AS_{t-1} + B\varepsilon_t \quad (12)$$

$$obs_t = CS_{t-1} + D\varepsilon_t, \quad (13)$$

where (12) represents a state equation, and (13) represents a measurement equation that connects model variables to the vector of observables, obs_t. Since it is not possible to write the likelihood function of this model in the closed form, I use the Kalman filter to evaluate the likelihood of the model, under the assumption that all structural shocks are normally distributed. Let us denote the data as $Y^T = \{y_t\}_{t=1}^T$, and the likelihood of the model given the set of structural parameters as $\mathcal{L}\left(Y^T|\theta\right)$. The likelihood function is then combined with the prior density $\pi(\theta)$ to form the posterior density $\pi(\theta|Y)$ as

$$\pi(\theta|Y) \propto \mathcal{L}\left(Y^T|\theta\right)\pi\left(\theta\right). \tag{14}$$

I use a random walk Metropolis-Hastings algorithm to sample from the proposal posterior distribution, which is a multivariate normal $\mathrm{N}(0,c)$, where c is chosen to guarantee the acceptance rate between 35 and 45 percent. I generate 1 million draws and use first 30 percent of the draws as so-called burn-up period. Once I obtain Markov chains, I use their means as point estimates of the paramters.

To perform the variance decomposition, I start from the state space representation and obtain $MA\left(\infty\right)$ form of the model, to evaluate the relevance of the shocks in different time horizons. In particular, I can rewrite (12) as

$$\begin{aligned} \left(I-AL\right)S_t &= B\varepsilon_t \\ S_t &= \left(I-AL\right)^{-1}B\varepsilon_t. \end{aligned} \tag{15}$$

Plugging (15) into (13) to obtain the form that connects observables to the shocks, gives:

$$\begin{aligned} obs_t &= C\left(I-AL\right)^{-1}B\varepsilon_{t-1}+D\varepsilon_t \\ &= \sum_{i=0}^{\infty}C\left(AL\right)^{i}B\varepsilon_{t-1-i}+D\varepsilon_t. \end{aligned}$$

Using this $MA\left(\infty\right)$ form I can perform the variance decomposition and evaluate the contribution of each shock to the variance of the macroeconomic variables.[6]

4.2 Data

I estimate the model using quarterly data for Australia, Canada, and UK, commonly used as examples of developed small open economies in the literature. The rest of the world is approximated by the US economy. I use post Bretton-Woods data, in that during this period exchange rates were held roughly constant. This leads to the sample period 1972:I-2006:IV. The vector of the observables is the following:

$$Y^T = \left(\log\Pi_t, \log R_t, \triangle\log y_t, \triangle\log c_t, \triangle\log E_t, \log s_t^r,\ \ \log\Pi_t^*, \log R_t^*, \Delta\log y_t^*\right)',$$

where the first six series are associated with the domestic economy, and the remaining three with the US economy. Specifically, Π_t denotes percentage change in the CPI, R_t is the real interest rate measured by T-bills, y_t is real per capita gross domestic product (GDP), c_t is real per capita aggregate consumption, E_t is real per capita total exports denominated in domestic currency, and

[6] The complete procedure is somewhat cumbersome, and the details are provided in the Technical Appendix.

s_t^r is the real exchange rate.[7] Exchange rate series are obtained from the International Financial Statistics.[8] Data on consumption and all other components of the Canadian GDP are recovered from the Canada's National Statistical Agency.[9] The rest of the data are downloaded from the Data Stream International.[10]

Variables with superscript $*$ indicate rest of the world variables, approximated by the US data. In particular, Π_t^* is a percentage change in the US CPI, R_t^* is the US Treasury Bill Rate, and y_t^* is real per capita US GDP. Output and CPI data are obtained from the National Income and Product Accounts, whereas Treasury Bill Rate data are from the Federal Reserve Board.

4.3 Calibration and Priors

I calibrate a subset of the structural parameters of the model. This procedure is prefered to estimating all parameters for several reasons. For example, the likelihood cannot provide additional information for some parameters; some parameters are better identified using micro data. Therefore, I choose to calibrate these parameters in a standard fashion. In particular, the discount factor β, which is difficult to identify, is set to 0.99 in order to match the annual interest rate of 4 percent. Following Altig et al. (2005) I calibrate the depreciation rate to be 0.025, and the share of capital to be 0.36. I choose a value of 7.5 for the preference parameter ψ, which implies that in the steady state households work one third of their time. Following Christiano et al. (2005) and Adolfson et al. (2005),the labor supply elasticity is set to 1, so that markup in wage setting is 1.05. I set the elasticity of labor supply parameter to 21. Finally, I choose the same calibration as well as prior distributions for all three countries.

All remaining structural parameters of the model are estimated. I first assign prior distributions to these parameters, summarized in Table 2. The choice of the distribution families is as follows. First, as fairly standard in the literature, I impose beta distribution on all parameters with feasible values in the unit interval.[11] These parameters include the autoregressive coefficients of the shocks, Calvo parameters, indexation parameters, habit persistence parameter, interest rate smoothing parameter, and the home bias in consumption and investment parameters. Second, for the parameters with positive values I impose a gamma distribution since it is defined on the $[0, \infty)$ space. These parameters include the standard deviations of the shocks, and the investment adjust-

[7] Real exchange rate is the CPI measured exchange rate. That is $\log s_t^r = \log s_t + \log(CPI^{US}) - \log(CPI^{DomesticCountry})$.

[8] Available at http://ifs.apdi.net/imf.

[9] Available at http://www.statcan.gc.ca.

[10] In case of Canada, to be consistent with the model, I construct nominal consumption excluding the consumption for durable goods. For the same reason I also exclude government spending from the output series. Furthermore, CPI is constructed using the consumption deflators for nondurable goods and services. However, in case of UK and Australia, since detailed data is not available, I use consumption of all goods, gross output that includes also government spending, and consumer price index that includes prices of all goods.

[11] See An and Schorfheide (2007) for general discussion about the Bayesian techniques, including the choice of the priors, and Del Negro and Schorfheide (2006) for the discussion about forming priors.

ment cost. Third, I impose a normal distribution on the unrestricted parameters, i.e. parameters that can take any value, such as parameters in the Taylor rule.[12]

The choice of the moments of the prior distributions is as follows. For the habit persistence parameter I impose a beta distribution with the mean 0.65, which is equal to the estimate of this parameter obtained by Altig et al. (2005) for the US economy, whereas the standard deviation of this parameter is set to 0.1 percent. For the domestic Calvo parameter I use a beta distribution with the mean 0.675, which implies average price and wage stickiness of 3 quarters. Following Adolfson et al. (2005), I use smaller value for the foreign sector, in order to account for observed lower exchange-rate pass through. However, I use a higher standard deviation, 0.15 percent, to allow for higher uncertainty. I choose rather uninformative priors for the parameters that determine the elasticity of substitution between different types of goods. I use a gamma distribution with mean 2 and standard deviation 0.5, except for the elasticity of substitution between domestic and foreign goods, which I choose to be 1.5 following the results of Chari et al. (2002). I set a normal distribution with mean 2.76 and standard deviation 0.75 as the prior distribution for the investment adjustment cost, considering the estimate of Altig et al. (2005).

I choose a gamma distribution with mean 0.3 and standard deviation 0.2 percent as the prior distribution for all the shocks in the model. Following Adolfson et al. (2005), I impose a beta distribution with mean 0.85 and standard deviation 0.1 percent for all autoregressive coefficients. Finally, i impose normal distributions on the coefficients in the foreign VAR, following Justiniano and Preston (2005).

4.4 Estimation Results

In Table 3 I report mean and standard deviations of the posterior distributions for all three countries in the benchmark model, i.e. a model that features all aforementioned rigidities. I choose the mean of the Markov chain of the estimated parameter as a point estimate. In Figures 7 and 8 I present prior and posterior distributions of the parameters whose implications on the real exchange dynamics will be discussed in the next section. The posterior distributions are obtained as the approximation of the distribution from the same family as the prior distributions, with mean and standard deviation equal to the mean and standard deviation of the Markov chain. In fact, in most of the cases the posterior distributions do differ from the prior distribution, suggesting that the data are very informative about the posterior distribution of the parameters.

I now turn to the discussion of the point estimates of the parameters and their comparison among the three countries. The habit formation parameter is very high in Canada and UK, whereas it is twice smaller in case of Australia. This result is in line with the estimates of Justiniano and Preston (2005), who estimate simpler model using the data for Canada, Australia and New

[12] This is consistent with the existing literature. I use the same priors as Rabanal and Rubio-Ramirez (2005), who take the same original estimates of Taylor adjusted for the annual data.

Zealand.[13] The parameter that controls the share of imports in consumption, α_c, is approximately 0.1 for Canada and Australia, whereas for the UK it is higher, 0.3. Domestic price stickiness in Canada is rather high (0.751), which would imply that domestic producers can change their prices every four quarters. In case of the UK this parameter is slightly lower (0.726), whereas it is the lowest for Australia (0.632), which implies that the producers can change their prices on average every 2.7 quarters. This estimate is similar to the one of Justiniano and Preston (2005) who estimate this parameter to be 0.61. Also Adolfson et al. (2005) estimate that in the Euro area producers can change prices every 3.5 quarters. However, this result is not directly comparable with my estimation for the UK, even though the UK economy is one of the four biggest economies, output wise, in the Euro area. The estimates of other stickiness parameters (exporting goods and importing goods stickiness parameters) in all three economies are lower than the domestic one, which implies that producers in other sectors can change their prices more frequently. However, there are no existing estimates that can be used to compare my results, since the models that have been estimated are much simpler and do not include these parameters. The elasticity of substitution between domestic and imported goods is very high in all three countries. The lowest among EOS parameters is the one among the differentiated exported goods. This is true for all three countries.

The point estimates of the indexation parameters are quite low. The highest among indexation parameters is the wage indexation parameter, which is approximately 0.5. However, one should be careful in the interpretation of this result, since in the posterior distributions of these parameters are very close to their prior distributions. This result implies that the prior distributions for these parameters are very informative. One possible explanation is that in the estimation procedure I do not use the data on employment, i.e. I do not use series of hours worked, that would possibly provide more information for the estimation of this parameter.

The point estimates of the coefficients in the Taylor rule are rather similar among the three countries. In particular, all Central Banks aggresively target inflation, since the inflation parameters in Canada, Australia, and UK are 1.523, 1.725 and 1.836 respectively. The coefficients that determine the responsiveness of the Central Bank to the exchange rate movements are very low in case of all three countries, being the lowest in the case of Canada. In Australia this coefficient is 0.102, whereas in case of UK it is 0.127.

The autoregressive coefficients is very high for the technology shock and asymmetric technology shock. The preference shock and labor supply shock are less persistent, especially for Canada.

In order to evaluate the importance of particular frictions in the explanation of the exchange rate dynamics, I estimate different versions of the model. In fact, I will shut down one by one different frictions, which naturally changes the point estimates from the benchmark model.

[13] Thier framework is very similar to the framework of Gali and Monacelli (2005).

5 Exchange Rate Dynamics

After calibrating and estimating all the structural parameters of the model, I analyze the performance of an estimated model in terms of replicating the real exchange rate dynamics. I perform several exercises. First, I calculate the real exchange rate standard deviation and autocorrelation implied by the estimated model. Second, I assess the performance of the benchmark model, which includes number of nominal and real rigidities. Third, I evaluate the importance of each friction in the model for the replication of the real exchange rate dynamics. To do so, I exclude one friction at a time and reestimate the model. Fourth, I also evaluate the importance of particular type of frictions, such as price stickiness or indexation, by excluding all price stickiness parameters or all indexation parameters at a time and reestimating the model. The results are reported in Tables 4 and 5.

5.1 Benchmark Model

In this section I investigate the performance of the benchmark model in terms of its ability to explain the exchange rate dynamics. I use point estimates reported in Table 3 to simulate the model and calculate the implied model moments.[14]

The performance of the model in replicating the exchange rate persistance in all three countries is remarkably good. In case of Canada, the model implied persistance is 0.92 compared to the persistence of 0.98 observed in the data. The performance of the model is even better for Australia and UK: 0.94 compared to 0.96 in the data for Australia, and 0.92 compared to 0.915 in the data for UK.

The model volatility of the real exchange rate in case of Canada is very similar to the data (3.09 in the model compared to 3.12 in the data), and slighthly lower in case of Australia (3.03 in the model compared to 3.22 in the data). The model can reproduce a high real exchange rate volatility for UK (3.80), but it is approximately 1 percent lower than in the data.

Overall, the performance of the model along both these dimensions is pretty satisfying. However, the primary purpose of my analysis is to understand which of the channels are crucial for this sucessful replication of the exchange rate dynamics. I turn to this investigation in what follows.

5.2 Sensitivity Analysis

5.2.1 Persistence

To evaluate the importance of various rigidities of the model in explaining the exchange rate persistence, I compare the real exchange rate persistence of a model that excludes a particular

[14] I simulate the process 10000 times and report the mean values.

rigidity or rigidities with the one of the benchmark model. The smaller is the difference, the less important the particular rigidity is.

My results suggest that the most important parameters for the replication of exchange rate persistence are the price and wage stickiness parameters. Specifically, the performance of the model significantly worsens when the domestic price stickiness parameter, θ_p, is excluded from the model. This pattern is observed across all three countries. In fact, the real exchange rate persistence decreases from 0.92 to 0.73 in Canada, from 0.93 to 0.78 in Australia, and from 0.92 to 0.81 in the UK. This result suggests that the domestic price stickiness largely contributes to the high persistence of the real exchange rate in the model. A possible explanation for this result is as follows. As described in my model, the real exchange rate is defined as the nominal exchange rate corrected by the relative price of the domestic and world economy. Since my model is a small open economy model, the world price cannot be altered by the economic decisions of the agents in a small domestic economy and can be considered constant. Therefore, all movements in the relative price come from the movements in the domestic CPI level. A higher degree of domestic price stickiness implies that on average domestic firms are allowed to change prices less often, suggesting higher persistence of inflation (measured by the change in domestic CPI). This higher inflation persistence implies higher persistence of the real exchange rate.

A similar intuition follows when I consider the price stickiness parameter of the importing goods producers, θ_m, which is a part of the domestic economy CPI. Since I allow for the local currency pricing, i.e. domestic importers set prices of imported goods in their own currency, the frequency with which they change their prices will undoubtedly influence the real exchange rate persistence through its effect on the persistence of domestic inflation. As Table 4 shows, if importers faced flexible prices the persistence of the real exchange rate would decrease, but less than in the case when domestic price stickiness is excluded from the model. The decrease in the persistence is the highest in the UK. This result can be explained by the fact that the share of imports in the consumption basket is the highest in the UK, thus implying the biggest relative importance of this channel. Furthermore, my results suggest that the price stickiness in the exporting sector, θ_e, is not very important in case of Canada and Australia (implied exchange rate persistence does not significantly change), whereas in UK it is as important as the price stickiness in the importing sector.

Finally, the wage stickiness parameter is also shown to play an important role in the replication of the exchange rate persistence. In fact, when I exclude this parameter, the model persistence falls by more than 0.12. A possible explanation is that, following results of Chari et al. (2002) who suggest that the stickier are the wages the less likely producers are to change their prices, and therefore inflation and real exchange rate will be more persistent. However, Chari et al. (2002) claim that importance of this parameter is not very big, somwhat contrary to my results.

I also show that the indexation parameters also have an important effect on the persistence of the real exchange rate. In particular, the domestic price indexation, χ_p, and wage indexation, χ_w, seem to be the most important among the indexation parameters. The presence of the indexation implies a higher persistence of the inflation, since prices will be indexed by the prices in the previous period. Therefore, the intuition described above follows also in this case. Again, the indexation parameter in the exporting sector is, as expected, less important than its counterpart in the importing sector.

I conclude this discussion by evaluating the effect of the elasticity of substitution parameters on the persistence of the real exchange rate. The procedure here is slightly different than in the previous cases. Specifically, if any of these parameters is set to zero the solution of the model will be undetermined. Therefore, for the solution of the model to be determined, the EOS parameters need to be positive. Therefore, I calibrate elasticity parameters to be equal to 0.9, which is a very small value compared to the benchmark estimates, and then reestimate other parameters of the model. However, I conclude that imposing high values of these parameters is not crucial for the high exchange rate persistence. The most imporant among EOS parameters is ε, which defines the EOS among differentiated intermediate goods.

Therefore, the rigidities that have the highest effect on the high exchange rate persistence are the price stickiness, domestic price stickiness being the most important one, and the indexation, with the domestic goods indexation parameter as the most significant among them.

5.2.2 Volatility

Table 5 displays the implied real exchange rate volatilities when the rigidities are excluded from the model. Price and wage stickiness parameters turn out to play an important role in the replication of the real exchange rate volatility as well. The intuition is as follows. The model features local currency pricing, which implies that importing and exporting firms set their prices in local currency. Therefore, if a shock hits the economy and some producers are not allowed to adjust their prices, large fluctuations in the exchange rate will be needed for the model to return to the equilibrium.

The importance of the domestic price stickiness, as well as the price stickiness in the importing sector, is crucial in the replication of the exchange rate volatility. When these parameters are excluded from the model, the volatility of the real exchange rate series declines significantly. In particular, if I exclude the domestic price stickiness parameter, the volatility falls by approximately 1 percentage point in Canada, 0.6 percentage points in Australia and 0.7 percentage points in the UK.

The importance of indexation parameters is large also in this case. Once all indexation parameters are excluded, the volatility of the real exchange rate decreases by approximately more than 1 percentage point in all three countries. In this case, the wage indexation seems to be relatively most important among all indexation parameters.

Finally, the performance of the model in this dimension is relatively better in case of Australia and Canada. A possible explanation might be thet using a small open economy model is not suited for the analysis of the UK economy. Using a two-country model would induce the interaction between the domestic and world economy, and therefore, most likely have different implications on the dynamics of the real exchange rate.

5.3 Variance decomposition

The model features nine shocks: intratemporal preference shock ($\varepsilon_{\xi,t}$), labor supply shock ($\varepsilon_{\varphi,t}$), aggregate technology shock ($\varepsilon_{A,t}$), investment specific shock ($\varepsilon_{\mu,t}$), monetary policy shock ($\varepsilon_{\mu,t}$), asymmetric technology shock ($\varepsilon_{z^*,t}$) and three foreign economy shocks ($\varepsilon_{\pi^*,t}$, $\varepsilon_{R^*,t}$, $\varepsilon_{y^*,t}$) . Therefore, this model represents a desirable setting for the investigation of the main driving forces of the exchange rate volatility.

The model has the same number of shocks as observables, ruling out stochastic singularity. In Tables 6, 7 and 8 I report the contribution of each shock to the variance of the observables in the model at four different horizons: 4 quarters, 8 quarters, 12 quarters and 20 quarters, for three different countries. The result is derived using the point estimates of the parameters in the benchmark model. Among domestic shocks, the most important shocks are the monetary policy shock, labor supply shock, and investment specific shock. Monetary policy shock can explain the biggest part of the volatility of the real exchange rate in all three countries, and is about 45 percent.

Among the world shocks only the effect of the shock to the interest rate is important, and is about 8 percent in Canada, while in Australia and UK it contributes in explaining approximately 7 percent of the total volatility of the exchange rate.

6 Conclusions

In this paper I estimate a small open economy DSGE model using the data for three countries: Australia, Canada, and the UK. The model builds on a closed economy DSGE model of Christiano et al. (2005) and Smets and Wouters (2003), by incorporating an open economy component into it. In particular, I add two sectors: importing and exporting sector; in both sectors producers face price stickiness. I estimate the model using Bayesian estimation techniques.

One of the purposes of this paper was to assess how good is this model in replicating the real exchange rate dynamics, its persistence and volatility. I show that the benchmark model performs rather well along both dimensions in all of the three countries. Furthermore, I evaluate the importance of various rigidities of the model for the replication of exchange rate persistence and volatility. I find that the most important frictions for the replication of the real exchange rate persistence are the domestic price stickiness parameter, domestic indexation, wage stickiness and wage indexation. This result is because higher price or wage stickiness implies higher persistence of inflation, and therefore higher persistance of the real exchange rate. All of these parameters are also important in explaining the real exchange rate volatility as well.

Finally, I investigate the importance of the nine shocks of the model in explaining the volatility of the real exchange rate. I show that among the domestic shocks, the most important are the investment specific technology shock, monetary policy shock, and labor supply shock, whereas the shock to the foreign interest rate dominates among the world shocks.

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7 Tables and Figures

Table 1: Dynamics of the nominal and real exchange rate in the data

	Canada		Australia		UK	
	St.dev	AR.	St. dev	AR	St.dev	AR
Nominal exchange rate	2.97	0.97	2.97	0.97	5.03	0.93
Real exchange rate	3.09	0.97	3.22	0.96	5.10	0.92

Table 2: Prior distributions

Parameter	*Form*	*Mean*	*Standard Deviation %*
Habit persistence (h)	beta	0.65	0.1
Share of imports in consumption (α_c)	beta	0.4	0.2
Share of imports in investment (α_i)	beta	0.4	0.2
EOS - (η_c)	gamma	2	0.5
EOS - (η_m)	gamma	2	0.5
EOS - (η_e)	gamma	2	0.5
EOS - (η_w)	gamma	3	0.5
EOS - (ε)	gamma	1.5	0.267
EOS - (η_f)	gamma	1.5	0.267
Calvo - domestic goods (θ_p)	beta	0.675	0.1
Calvo - imported goods ($\theta_{m,c}$)	beta	0.5	0.25
Calvo - exported goods (θ_e)	beta	0.5	0.25
Calvo - wages (θ_w)	beta	0.675	0.1
Investment adjustment cost (κ)	normal	2.76	0.75
Indexation - domestic prices (χ_p)	beta	0.5	0.1
Indexation - imported goods (χ_m)	beta	0.5	0.1
Indexation - export goods (χ_e)	beta	0.5	0.1
Indexation - wages (χ_w)	beta	0.5	0.1
Taylor rule: response to output	normal	1.5	0.25
Taylor rule: response to inflation	normal	0.125	0.125
Taylor rule: response to interest rate	beta	0.8	0.05
Taylor rule: response to the real interest rate	normal	0	0.05
AR(1) Technology shock	beta	0.85	0.1
AR(1) Preference shock	beta	0.85	0.1
AR(1) Labor supply shock	beta	0.85	0.1
AR(1) Asymmetric technology shock	beta	0.85	0.1
Std of the preference shock	gamma	0.3	0.2
Std of the labor supply shock	gamma	0.3	0.2
Std of the technology shock	gamma	0.3	0.2
Std of the investment specific shock	gamma	0.3	0.2
Std of the monetary policy shock	gamma	0.3	0.2
Std of the asymmetric technology shock	gamma	0.3	0.2
Std of the foreign output shock	gamma	0.3	0.2
Std of the foreign inflation shock	gamma	0.3	0.2
Std of the foreign interest rate shock	gamma	0.3	0.2

Table 3: Posterior distributions: benchmark model

	Canada		Australia		UK	
Parameter	*Mean*	*.St dev*	*Mean*	*St. dev*	*Mean*	*St. dev*
Habit persistence (h)	0.74	0.07	0.32	0.02	0.79	0.12
Share of imports in consumption (α_c)	0.16	0.13	0.10	0.12	0.33	0.09
Share of imports in investment (α_i)	0.31	0.10	0.15	0.11	0.32	0.08
EOS - (η_c)	7.69	0.13	6.02	0.09	6.53	0.19
EOS - (η_m)	4.32	0.14	2.34	0.14	5.32	0.03
EOS - (η_e)	1.21	0.07	1.98	0.10	2.74	0.11
EOS - (ε)	4.53	0.17	3.90	0.19	5.22	0.02
EOS - $\left(\eta_f\right)$	2.32	0.16	1.97	0.08	3.20	0.18
Calvo - domestic goods (θ_p)	0.75	0.01	0.63	0.17	0.73	0.10
Calvo - imported goods (θ_m)	0.44	0.12	0.33	0.04	0.64	0.09
Calvo - exported goods (θ_e)	0.54	0.09	0.61	0.13	0.37	0.11
Calvo - wages (θ_w)	0.81	0.08	0.65	0.03	0.87	0.18
Indexation - domestic prices $\left(\chi_p\right)$	0.23	0.08	0.34	0.13	0.12	0.14
Indexation - imported goods (χ_m)	0.25	0.11	0.32	0.10	0.33	0.07
Indexation - exported goods (χ_e)	0.13	0.09	0.21	0.14	0.28	0.10
Indexation - wages (χ_w)	0.47	0.13	0.39	0.07	0.52	0.03
Taylor rule: γ_y	0.18	0.18	0.23	0.03	0.39	0.19
Taylor rule: γ_π	1.52	0.14	1.72	0.15	1.84	0.10
Taylor rule: γ_R	0.87	0.03	0.68	0.15	0.83	0.13
Taylor rule: γ_s	0.09	0.01	0.10	0.03	0.13	0.10
AR(1) Technology shock	0.94	0.14	0.95	0.01	0.85	0.03
AR(1) Preference shock	0.54	0.13	0.76	0.02	0.73	0.00
AR(1) Labor supply shock	0.69	0.13	0.82	0.13	0.84	0.03
AR(1) Asymmetric technology shock	0.89	0.08	0.94	0.13	0.96	0.09
Std of the preference shock	0.02	0.14	0.10	0.03	0.09	0.15
Std of the labor supply shock	0.71	0.08	0.38	0.02	0.19	0.10
Std of the technology shock	0.06	0.01	0.12	0.09	0.22	0.09
Std of the investment specific shock	0.39	0.03	0.20	0.03	0.17	0.08
Std of the monetary policy shock	0.29	0.06	0.24	0.01	0.21	0.17
Std of the asymmetric technology shock	0.22	0.12	0.21	0.15	0.32	0.11
Std of the foreign output shock	0.32	0.11	0.47	0.14	0.20	0.10
Std of the foreign inflation shock	0.33	0.01	0.31	0.12	0.22	0.01
Std of the foreign interest rate shock	0.45	0.04	0.29	0.09	0.26	0.01

Table 4: Real exchange rate persistence under different model specifications

	Canada	Australia	UK
	AR	AR	AR
Benchmark Model	0.92	0.94	0.92
No θ_p	0.73	0.78	0.81
No θ_m	0.86	0.89	0.82
No θ_e	0.88	0.89	0.85
No θ_w	0.81	0.82	0.83
Flexible prices	0.72	0.77	0.80
No h	0.88	0.88	0.79
No χ_p	0.82	0.83	0.80
No χ_m	0.89	0.89	0.83
No χ_e	0.88	0.88	0.85
No χ_w	0.82	0.85	0.85
No indexation	0.85	0.83	0.80
EOS: η_c	0.92	0.93	0.91
EOS: η_m	0.89	0.89	0.89
EOS: η_e	0.88	0.87	0.89
EOS: ε	0.84	0.88	0.88
EOS: η_f	0.88	0.88	0.87

Table 5: Real exchange rate volatility under different model specifications

	Canada	Australia	UK
	AR	AR	AR
Benchmark Model	3.12	3.03	3.80
No θ_p	2.13	2.45	3.03
No θ_m	2.87	2.89	2.64
No θ_e	2.92	2.81	2.76
No θ_w	2.12	2.87	2.34
Flexible prices	2.32	2.27	2.42
No h	2.16	2.56	2.12
No χ_p	2.38	2.32	2.43
No χ_m	2.46	2.87	2.11
No χ_e	2.59	2.43	2.72
No χ_w	2.22	2.32	2.31
No indexation	2.23	2.40	2.09
EOS: η_c	2.30	2.31	2.39
EOS:η_m	3.01	2.72	2.34
EOS:η_e	2.97	2.84	2.76
EOS:ε	2.92	3.02	3.13
EOS:η_f	2.40	2.51	2.09

Table 6: Variance decomposition: Canada

Shock/Horizon	*4 quarters*	*8 quarters*	*12 quarters*	*20 quarters*
Preference shock	10.11	10.13	10.14	10.19
Labor supply shock	16.10	15.34	16.79	17.85
Technology shock	4.02	4.39	4.40	4.43
Investment specific shock	12.44	12.65	12.92	13.09
Monetary policy shock	43.27	42.76	41.09	40.03
Asymmetric technology shock	2.03	2.89	2.98	2.99
Foreign interest rate shock	8.90	8.75	8.63	8.39
Foreign inflation shock	3.09	3.05	3.00	2.97
Foreign output shock	0.02	0.02	0.04	0.05

Table 7: Variance decomposition: Australia

Shock/Horizon	*4 quarters*	*8 quarters*	*12 quarters*	*20 quarters*
Preference shock	12.07	12.09	12.67	12.70
Labor supply shock	16.82	16.05	15.45	16.36
Technology shock	5.10	5.39	5.401	5.44
Investment specific shock	10.90	10.98	11.01	11.10
Monetary policy shock	41.30	41.21	41.18	40.07
Asymmetric technology shock	1.90	1.99	2.08	2.10
Foreign interest rate shock	7.00	7.38	7.38	7.43
Foreign inflation shock	4.78	4.76	4.67	4.64
Foreign output shock	0.12	0.14	0.15	0.15

Table 8: Variance decomposition: UK

Shock/Horizon	*4 quarters*	*8 quarters*	*12 quarters*	*20 quarters*
Preference shock	9.03	9.02	9.04	8.99
Labor supply shock	14.08	14.47	14.53	14.75
Technology shock	7.98	7.78	7.63	7.51
Investment specific shock	10.90	10.98	11.01	11.10
Monetary policy shock	45.78	45.37	45.20	44.90
Asymmetric technology shock	2.90	2.12	2.33	2.34
Foreign interest rate shock	6.90	6.99	7.00	7.04
Foreign inflation shock	3.24	3.24	3.25	3.31
Foreign output shock	0.00	0.03	0.05	0.05

Figure 1: Log level of the nominal and real exchange rate for Canada period 1972:I - 2006:IV

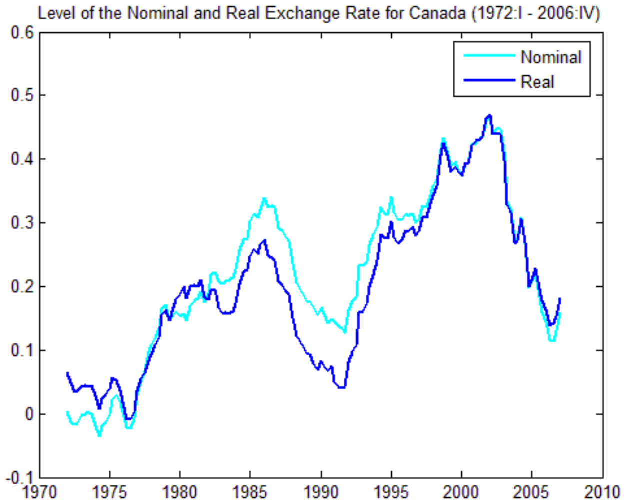

Figure 2: Log level of the nominal and real exchange rate for Australia period 1972:I - 2006:IV

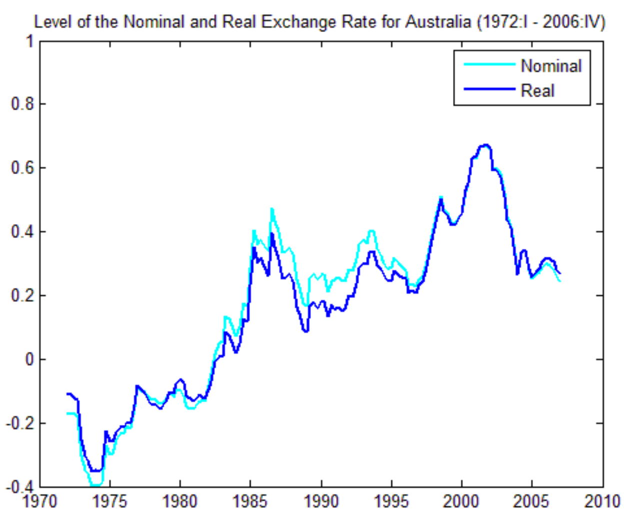

Figure 3: Log level of the nominal and real exchange rate for UK period 1972:I - 2006:IV

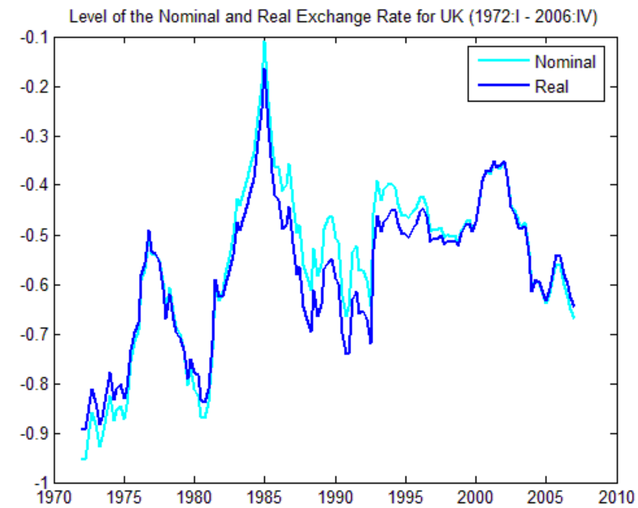

Figure 4: Growth rates of nominal and real exchange rates in Canada period 1972:I - 2006:IV

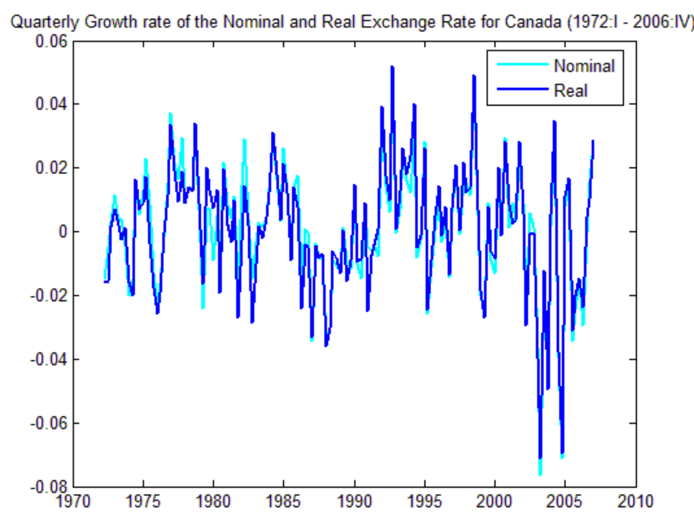

Figure 5: Growth rates of nominal and real exchange rates in Australia period 1972:I - 2006:IV

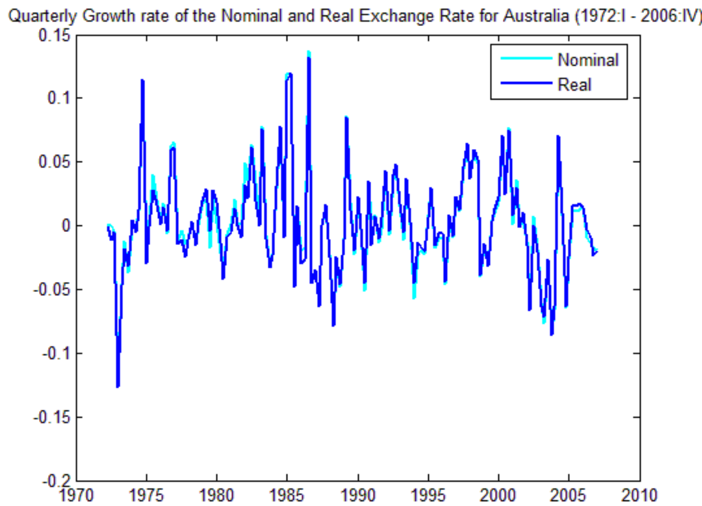

Figure 6: Growth rates of nominal and real exchange rates in UK period 1972:I - 2006:IV

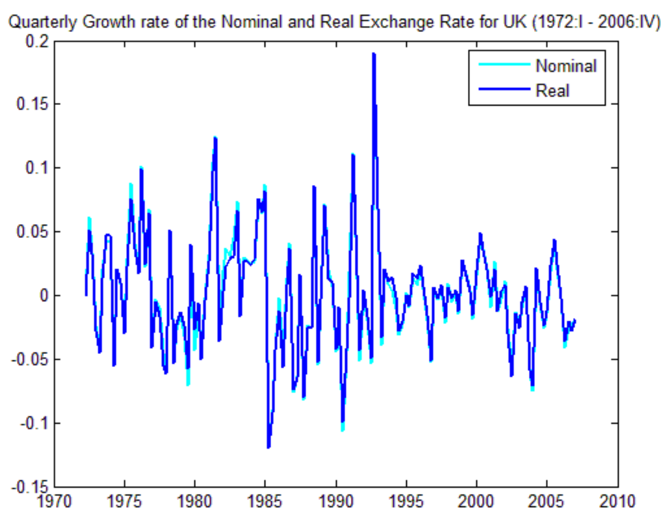

Figure 7: Prior and posterior distributions for some parameters for Canada

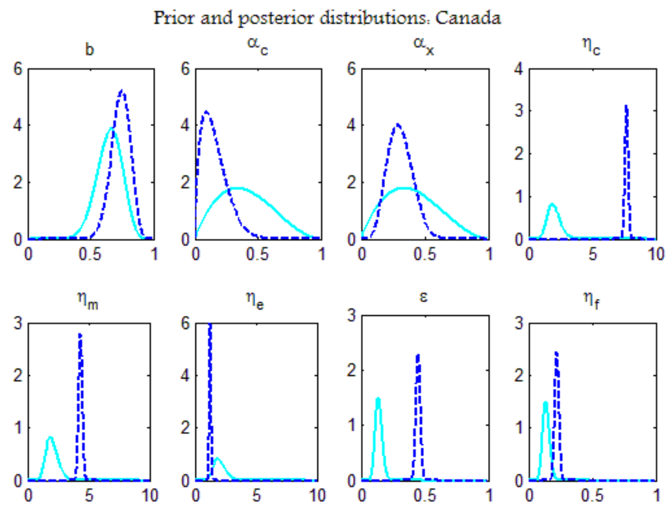

Figure 8: Prior and posterior distributions of stickiness parameters and EOS parameters for Canada