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Evaluating the forecasting accuracy of the closed- and open economy New Keynesian DSGE models*

Phuong Van Nguyen †

Abstract

The primary purpose of this paper is to compare the forecasting performance of a small open economy New Keynesian Dynamic Stochastic General Equilibrium (SOE-NK-DSGE) model with its closed-economy counterpart. Based on the quarterly Australian data, these two competing models are recursively estimated, and point forecasts for seven domestic variables are compared. Since Australia is a small open economy, global economic integration and financial linkage play an essential role in this country. However, the empirical findings indicate that the open economy model yields predictions that are less accurate than those from its closed economy counterpart. Two possible reasons could cause this failure of the SOE-NK-DSGE model: *(1) misspecification of the foreign sector*, and *(2) a higher degree of estimation uncertainty*. Thus, this research paper examines further how these two issues are associated with this practical problem. To this end, we perform two additional exercises in a new variant of the SOE-NK-DSGE and Bayesian VAR models. Consequently, the findings from these two exercises reveal that a combination of misspecification of the foreign sector and a higher degree of estimation uncertainty causes the failure of the open economy DSGE model in forecasting. Thus, one uses the SOE-NK-DSGE model for prediction with caution.

Keywords: Small open economy New Keynesian DSGE model, Bayesian estimation, forecasting accuracy, RMSEs.

JEL Classification: B22, C11, E37, E47

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1 Introduction

The main goal of this research paper is to address the fundamental question of whether a small open economy New Keynesian Dynamic Stochastic General Equilibrium (SOE-NK-DSGE) model can generate more accurate point forecasts for seven key domestic macroeconomic variables, such as interest rate, inflation, consumption, investment, wage, employment and output, than its closed- economy counterpart. Furthermore, this research paper examines whether the misspecification and estimation uncertainty matter to the forecasting performance of the SOE-NK-DSGE model.

Over last two decades, the SOE-NK-DSGE model has become a workhorse for policy analysis and forecasting. To advance the explanation for business cycle fluctuations and forecasting performances, DSGE models have been enriched by incorporating a wide range of features (Christiano et al. (2005), Smets and Wouters (2005) for nominal rigidities; Gerali et al. (2010), Kollmann et al. (2011) for financial friction; Gertler et al. (2008), Christiano et al. (2016) for labor friction etc). More notably, adding foreign sector into a DSGE model has more attractive applications than its closed-economy counterpart. Accordingly, it can capture higher dimensions, such as world demand, exchange rate, tariffs or global spillover, etc. Thus, variants of small open economy NK-DSGE model, SOE-NK-DSGE for short, have been widely applied at central banks around the world (see Table 10 in Appendix A).

Beyond the higher dimension, there are two remaining explanations for the popularity of the SOE-NK-DSGE models. First, several empirical studies by Erceg et al. (2007), Adolfson et al. (2008b), and Cwik et al. (2011) reveal a considerable implication of openness for the transmission of domestic disturbances to inflation. Second, in regard to forecasting performance, the SOE-NK-DSGE models are competitive with other conventional time series models such as VAR and BVAR models (see Adolfson et al. (2007b), Coenen et al. (2010), Lees et al. (2010), Marcellino and Rychalovska (2014), Zorzi et al. (2017)). Therefore, a well-specified SOE-NK-DSGE model would, in principle, deliver a better explanation for variations in domestic variables, and make more accurate predictions for these variables.

However, it is worthy of consideration that a larger-sized model faces a higher risk of estimation uncertainty and misspecification as follows. The SOE-NK-DSGE model has a higher number of estimated parameters than that in its closed-economy counterpart. Thus, it suffers from a higher degree of estimation uncertainty. On the other hand, the existence of misspecification in the SOE-NK-DSGE model has been widely admitted in the current literature (Adolfson et al. (2007a, 2008a), Justiniano and Preston (2010a), Christiano et al. (2011) etc). In particular, this structural model fails to capture the notable effects of the external disturbance on a small open economy (Steinbach et al. (2009) for South Africa; Justiniano and Preston (2010a) for Canada; Choi and Hur (2015) for Korea; Daniel Rees and Hall (2016) for Australia, etc.). Two possible aspects in a small open economy DSGE model, such as the foreign sector and the transmission channel of international spillover to a small open economy, might suffer from this issue. The detailed discussions about these two aspects are given below.

Regarding the foreign sector, one might wrongly specify this area. For example, due to globalization, there exist international comovements across nations. However, a small open economy DSGE model does not incorporate these comovements, in particular, foreign and domestic disturbances (see Justiniano and Preston (2010a) and Bergholt (2015)). On the other hand, a country is a small open economy. International trade and financial linkage are essential to this nation. However, one might include the import and export sectors in a DSGE model but international linkage. Thus, this might also cause misspecification in a small open economy DSGE model.

Second, the transmission channel of international spillover to a small open economy might be wrongly specified, especially the exchange rate channel. Indeed, the structural model has the difficulty in replicating the volatilities and persistence of the exchange rate. Accordingly, many studies defined this issue, so-called: *the consumption-real exchange rate anomaly* or *the exchange rate disconnect puzzle* (see Maurice and Rogoff (2000), Devereux and Engel (2002), Chari et al. (2002), Rabanal and Tuesta (2010), and Engel (2014)). Among these studies, for example, Engel (2014) argued "*the correlation of the exchange rate with the economic fundamentals is low*". Because of this issue, one might have the difficulty to model the exchange rate channel correctly. Thus, a small open economy DSGE model suffers from misspecification.

To this end, this paper develops and estimates a small open economy medium-sized DSGE model. Indeed, our model specification closely follows two studies by Jääskelä and Nimark (2011) and Adolfson and Lindé (2011). Thus, this model can generate point forecasts for seven domestic macroeconomic variables: interest rate, inflation, consumption, investment, wage, employment, and output. Indeed, the evaluation of forecasting accuracy of this open economy model will be conducted in comparison with its related closed-economy counterpart. Accordingly, these two competing models are recursively estimated via the Bayesian technique and the quarterly Australian data from 1993Q1 to 2016Q1. Following the current literature on DSGE model forecasting, furthermore, the standard criteria such as root mean squared errors, and the Diebold-Mariano test, are used.

Before comparing the forecasting performance of two competing models, we re-examine the impact of the foreign sector on estimated parameters and the variations in domestic variables. We do this because these international influences of the international influences might provide initial identification for our underlying question of whether the presence of the foreign aspect delivers a better prediction. Indeed, the empirical result indicates two striking findings. The first one is the differences in estimated parameters between two competing models. The second one is a minimal effect of the international spillover on the variations in domestic macroeconomic variables. These findings may suggest two possible explanations if the initial guess that the forecasting performance of the open economy model does not dominate the one of the closed economy model. Accordingly, the first possible explanation is attributed to a higher degree of estimation uncertainty. If so, point forecast is worse in the SOE-NK-DSGE model. Meanwhile, the second possible explanation is due to the negligible effect of the international spillover on a small open economy or the misspecification of the international sector. If so, two competing models then generate point forecast equally.

To answer our research question, we move forward comparing the forecasting performance between two models. The finding indicates that an open economy DSGE model cannot beat its related closed-economy counterpart. This finding would be surprising since Australia is a small open economy, and international trade and financial linkage are vital to this country. Hence, we go further to seek the explanation for this failure of an open economy DSGE model. Accordingly, there are two potential explanations for this issue: the misspecification of the foreign sector and the degree of estimation uncertainty. To address the question of how these two possible reasons are related to less accurate prediction of an open economy DSGE model, we perform the two following exercises.

At first, the empirical evidence in favor of the minimal impact of the foreign sector on variations in domestic variables motivates us to perform an exercise on the effects of misspecification. This first exercise is carried out by creating a new variant of the open economy DSGE model. In this new variant of an open economy DSGE model, we eliminate the problem of estimation uncertainty. More specifically, we reduce the number of estimated parameters. Indeed, all parameters associated with the foreign sector are fixed by calibration. Hence, the new variant of the open economy model and its closed economy counterpart have an equal number of the parameters to be estimated. This implies that theoretically, we can use this exercise to reveal how the misspecification of the foreign sector influences the forecasting performance of the open economy DSGE model.

The second exercise is to use the variants of closed and open economy Bayesian VAR models. A Bayesian VAR model is purely estimated from actual data. Meanwhile, a DSGE model is strongly imposed by theory. As a result, to what exent misspecification does not exist in a Bayesian VAR model. In the literature, moreover, the Bayesian VAR model is typically used as a reference model of an estimated DSGE model (Smets and Wouters (2003), Nergro et al. (2007), Adolfson et al. (2007a)). Indeed, we estimate Bayesian VARs on the small set of observables from the closed economy model and the broad set of observables from the open economy model. The point forecasts are then computed from these two BVAR models. Therefore, to the extent that BVAR models do not suffer from the problem of misspecification, this exercise enables us to point out that to what extent the higher number of parameters to be estimated and the related issue of the increase in estimation uncertainty affect the forecasting performance.

Based on these two exercises above, we find that a combination of the misspecification of the foreign sector and a higher degree of estimation uncertainty take primary responsibility for worsening the forecasting performance of an open economy DSGE model. To what extent, thus, this finding would be relevant to literature in that the small open economy DSGE model-based forecasts should be used with caution. Meanwhile, one should build a DSGE model, which can reveal the notable effects of the international spillover on the small open economy.

The rest of this paper is organized as follows. Section 2 introduces the related literature. Section 3 presents the theoretical open economy DSGE model and its closed-economy counterpart. Data set and methodology are presented in section 4. Section 5 shows the estimation and result. Section 6 gives empirical evidence on the influence of the external sector on aggregate domestic activities. The forecasting evaluation procedure and explanation for the difference in prediction between two models are described in section 7. Finally, section 8 gives some conclusions.

2 Related Literature

To our knowledge, the current literature has a limited number of studies on this field research. For example, there are two previous studies as follows.

The first is a nearly 10-year-old study by Adolfson et al. (2008b) showing that closed- and open economy DSGE models perform equally in making the prediction for several key domestic macroeconomic variables. It is not clear, however, if the reported differences are statistically significant. Furthermore, these authors did not examine whether the problems of a higher degree of estimation uncertainty and misspecification matter the forecasting performance of the SOE-NK-DSGE model.

Second, Kolasa and Rubaszek (2018) showed that the SOE-NK-DSGE model cannot outperform its closed-economy counterpart in forecasting. These authors then attributed to the higher degree of estimation uncertainty. This empirical finding, however, is limited to only three domestic variables: interest rate, inflation, and output. In practice, one may want to know the prediction for a higher number of other critical domestic macroeconomic variables: employment, wage, investment, consumption. More importantly, the findings of Kolasa and Rubaszek (2018) might be still questionable as follows. Kolasa and Rubaszek (2018) examined the forecasting performance of the SOE-NK-DSGE model developed Justiniano and Preston (2010b). Accordingly, in this structural model, a reduced form VAR model was used to describe the foreign economy. This model specification implies a lack of comovement between foreign and domestic shocks. Thus, the DSGE model of Justiniano and Preston (2010b) suffers from misspecification concerning the foreign sector. To address this issue, Justiniano and Preston (2010a) developed another strategy for the DSGE model specification. For instance, these authors specified the comovement between foreign and domestic shocks in a two-country DSGE model[1]. However, this better specification still fails to coincide with the notable impact of the spillovers from the US economy on the Canadian one. This finding indicates that this two-country DSGE model still suffers from misspecification concerning either the foreign sector or transmission channel of the international spillovers to the domestic economy. However, Kolasa and Rubaszek (2018) argued the impact of the higher degree of estimation uncertainty but misspecification on the forecasting performance of the SOE-NK-DSGE model of Justiniano and Preston (2010b).

3 Theoretical model

3.1 The open economy medium-sized DSGE model

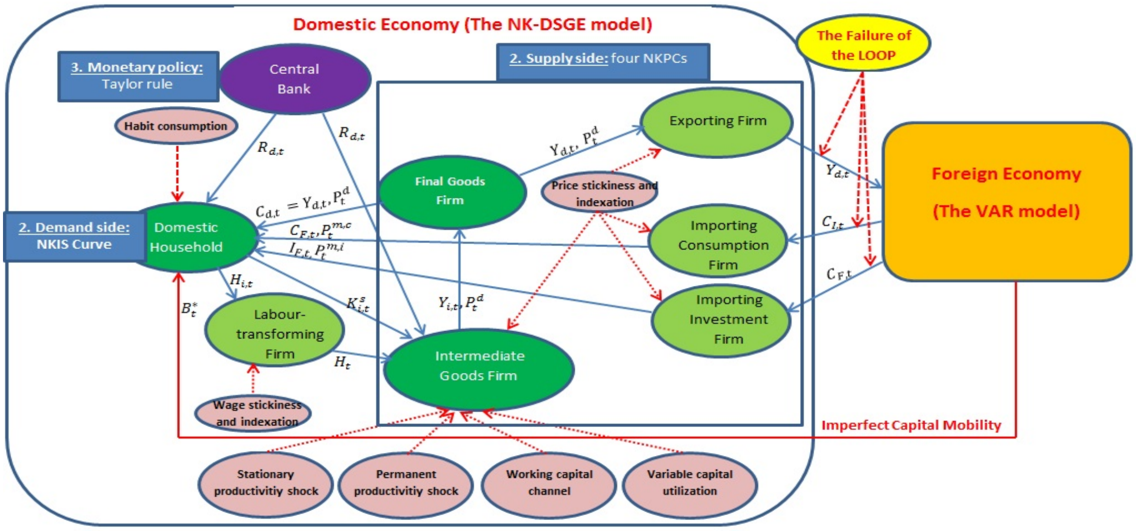
In this paper, we develop a small open-economy medium-sized DSGE model by modifying the model in the studies of Jääskelä and Nimark (2011) and Adolfson and Lindé (2011). Thus, this model includes various vital features, such as habit formation, price and wage stickiness, price indexation, capital utilization, working capital channel, the failure of the law of one price and interest rate parity, and incomplete exchange-rate pass-through. However, for simplicity, we exclude the government sector and tax rates. Therefore, the open-economy DSGE model has four main agents: firms, households, a central bank, and an exogenously foreign economy. Due to space constraints, we briefly introduce several striking features of the underlying theoretical model, as shown in Figure 1 below. The detailed model specification can be found in the supplemental document and the studies of Jääskelä and Nimark (2011) and Adolfson and Lindé (2011).

[1]More especially,Justiniano and Preston (2010a) specified the domestic shock, $\widehat{\varepsilon}_t$, as follows.

$$\widehat{\varepsilon}_t = \widehat{\varepsilon}_t^d + \widehat{\varepsilon}_t^f \tag{2.0.1}$$

where $\widehat{\varepsilon}_t^f$ and $\widehat{\varepsilon}_t^d$ are common and country-specific shocks, respectively. Moreover, these two disturbances follow the AR process. On the other hand, the common shock accounts for a proportion of variability in the domestic disturbance , $\mathrm{Var}(\widehat{\varepsilon}_t^f)/\mathrm{Var}(\widehat{\varepsilon}_t)$, and the correlation between foreign and domestic shocks is $corr(\widehat{\varepsilon}_t^f, \widehat{\varepsilon}_t)$.

Figure 1: Graphical illustration of a small open economy medium-sized model



Indeed, according to Figure 1 above, the underlying theoretical model has three striking features, which lead to a closed-economy in a global economic context. For example, on the demand-side, the first feature is to adopt the assumption of the domestic household's holding of both domestic and foreign bonds. This feature enables us to derive the Uncovered Interest Rate Parity, well known as the UIP. However, it is worth noting that because of the imperfect capital mobility, the UIP never holds in the real world. To address this issue, the underlying model includes the risk premium function. Because of the presence of this function, the UIP, then, fails to hold both theoretically and empirically. On the other hand, on the supply-side, the second feature is to introduce the export and import sectors. The primary role of these two sectors is to fulfill the domestic houshold's demand for imported consumption and investment goods and the foreign economy's demand for domestic goods. Moreover, the export and import sector's presence in the underlying theoretical model is to derive the law of one price gap since like the UIP, this price law never holds in the real world. Additionally, due to the inclusion of the Calvo price rigidity (Calvo (1983)) in the import and export sectors, the exchange-rate pass-through is incomplete. Indeed, the underlying model has four New Keynesian Phillip Curves (NKPC) describing the supply side. Finally, the last feature is to model the monetary policy rule, including the exchange rate.

3.1.1 Households

As shown in Figure 1, the model indicates that the domestic household consumes both domestic and imported goods as follows.

$$C_t = \left[(1-\omega_c)^{1/\eta_c}\left(C_t^d\right)^{\frac{\eta_c-1}{\eta_c}} + \omega_c^{1/\eta_c}\left(C_t^m\right)^{\frac{\eta_c-1}{\eta_c}}\right]^{\frac{\eta_c}{\eta_c-1}} \tag{3.1.1}$$

Furthermore, the model adopts the assumption that the domestic household holds both domestic and foreign bonds. This assumption enables us to derive the UIP. However, this parity never holds in the real world because of imperfect capital mobility. Therefore, the model includes the risk function to coincide with this failure of the UIP. This function has the form below.

$$\Phi\Big(\frac{A_t}{z_{t-1}}, \widetilde{\phi}_t\Big) = \exp\Big[-\widetilde{\phi}_a\frac{A_t-\bar{A}}{z_{t-1}} - \widetilde{\phi}_t\Big] \tag{3.1.2}$$

$$\text{where } A_t = \frac{S_t B^*_{t+1}}{P_t} \tag{3.1.3}$$

Because of the above function in (3.1.2), the log-linearization UIP will be.

$$\widehat{R}_t - \widehat{R}^*_t = E_t\Delta\widehat{s}_t - \widetilde{\phi}_a\widehat{a}_t + \widehat{\widetilde{\phi}}_t \tag{3.1.4}$$

The presence of the terms $\widehat{a}_t$ and $\widehat{\widetilde{\phi}}_t$ in the equation (3.1.4) above implies the failure of the UIP. This is because the difference between domestic and foreign interest rates $(\widehat{R}_t - \widehat{R}^*_t)$ is no longer equal to the changes in the nominal exchange rate $\Delta\widehat{s}_t$.

On the other hand, the domestic household offers its worked labor and capital service. The introduction of the labor-transforming firm is to incorporate the nominal friction of wage stickiness. Indeed, the domestic household solves the following optimization problem[2].

$$\begin{aligned}
&\underset{C_t,M_{t+1},\Delta_t,\bar{K}_{t+1},I_t,u_t,Q_t,B^*_{t+1},h_t}{\text{maximize}} && E_t\sum_{t=0}^{\infty}U(C_t,h_t,\frac{Q_t}{P_t})\\
&\text{subject to} && M_{t+1}+S_tB^*_{t+1}+P^c_tC_t+P^i_tI_t+P_t\Big[a(u_t)K_t+P_{k',t}\Delta_t\Big]\\
& && = R_{t-1}(M_t-Q_t)+Q_t+\Pi_t+W_tN_t+(R_{t-1}-1)R^k_tu_tK_t\\
& && + R^*_{t-1}\Phi\Big(\frac{A_{t-1}}{z_{t-1}},\widetilde{\phi}_{t-1}\Big)S_tB^*_{t-1}+D_t\\
&\text{and} && \bar{K}_{t+1}=(1-\delta)\bar{K}_t+\Upsilon_tF(I_t,I_{t-1})+\Delta_t\\
&\text{where} && U(C_t,N_t,\frac{M_t}{P_t}) = \zeta^c_t ln(C_t-bC_{t-1})-\zeta^h_tA_L\frac{H^{1+\sigma_L}_{i,t}}{1+\sigma_L}+A_q\frac{\Big(\frac{Q_t}{z_tP_t}\Big)^{1-\sigma_q}}{1-\sigma_q}
\end{aligned} \tag{3.1.5}$$

[2] Its first-order conditions are similar to the study of Adolfson et al. (2007a).

3.1.2 Final goods firm

As shown in Figure 1, the final goods firm buys the intermediate goods, $Y_t(i)$, from the domestic intermediate goods firm. This firm then aggregates these domestic intermediate goods and sells them to both domestic households, and exporting firms. Indeed, the final goods firm aggregates the domestic intermediate goods as follows:

$$Y_t = \Big[\int_0^1 Y_t(i)^{\frac{\lambda_{d,t}-1}{\lambda_{d,t}}} dj\Big]^{\frac{\lambda_{d,t}}{\lambda_{d,t}-1}}$$

where the variable, $\lambda_{d,t}$, denotes the time-varying markup in the domestic goods markets below.

$$\lambda_{d,t} = (1-\rho_{\lambda_d})\lambda_d + \rho_{\lambda_d}\lambda_{d,t-1} + \epsilon_{\lambda_d} \tag{3.1.6}$$

Given output price, P_t, and input price, $P_{i,t}$, the demand for the domestic intermediate goods, $Y_{i,t}$, is driven from the profit maximization problem such as

$$Y_{i,t} = Y_t\Big(\frac{P_{i,t}}{P_t}\Big)^{\frac{-\lambda_{d,t}}{\lambda_{d,t}-1}} \tag{3.1.7}$$

3.1.3 Domestic intermediate goods firm

To produce the domestic intermediate goods, the domestic intermediate goods firm combines labor ($H_{i,t}$), the effective utilization of the capital stock ($K_{i,t}$), and permanent and stationary productivity shocks ($z_{i,t}, \epsilon_{i,t}$). Furthermore, to induce the zero profit in steady-state, the fixed cost is subtracted from the production function. The domestic intermediate goods firm's production function is described below.

$$Y_{i,t} = \epsilon_t K_{i,t}^{\alpha}\Big(z_t H_{i,t}\Big)^{1-\alpha} - z_t\phi \tag{3.1.8}$$

It is worth noting that the effective utilization of the capital stock ($K_{i,t}$) in the production above is not necessarily the physical capital stock ($\bar{K}_{i,t}$). This implies that the model has variable capital utilization ($u_{i,t}$). The following equation presents the relation between these two capital stocks.

$$K_{i,t} = u_{i,t}\bar{K}_{i,t} \tag{3.1.9}$$

On the other hand, the feature of the working capital channel in the domestic intermediate goods firm is introduced as follows. We assume that the wage bill is partially financed in advance and the variable (ν_t) donates this fraction. Thus, the total wage cost of the domestic intermediate goods firm is

$$\nu_t W_t H_t R_{t-1} + (1-\nu_t)W_t H_t \tag{3.1.10}$$

It is worth noting that due to permanent productivity shocks in (3.1.8), and the capital working channel in (3.1.10) above, the closed-economy counterpart of this underlying open economy DSGE model will differ from the influential model of Smets and Wouters (2003).

Solving the domestic intermediate goods firm's cost minimization problem yields the two following results.

1. The domestic intermediate goods firm's demand for labor.

$$W_t R_t^f = (1-\alpha)\lambda_t P_{i,t} z_t \epsilon_t K_{i,t}^{\alpha}\Big(z_t H_{i,t}\Big)^{-\alpha} \tag{3.1.11}$$

2. The domestic intermediate goods firm's demand for capital service.

$$R_t^f = \alpha\lambda_t P_{i,t}\epsilon_t K_{i,t}^{\alpha-1}\Big(z_t H_{i,t}\Big)^{1-\alpha} \tag{3.1.12}$$

Combining the two above results (3.1.11) and (3.1.12) and taking the first-order condition of the total cost to output yields the domestic intermediate goods firm's real marginal cost.

$$mc_t^d = \Big(\frac{1}{1-\alpha}\Big)^{1-\alpha}\Big(\frac{1}{\alpha}\Big)^{\alpha}\big(r_t^k\big)^{\alpha}\Big[w_t\Big(\nu_t R_{t-1}+1-\nu_t\Big)\Big]^{1-\alpha}\frac{1}{\epsilon_t} \tag{3.1.13}$$

The above expression (3.1.13) indicates that the real marginal cost is identical to the cross domestic intermediate goods firm and independence of the domestic goods produced. More especially, because of the presence of the working capital term $\Big(\nu_t R_{t-1}+1-\nu_t\Big)$, it differs from the real marginal cost in the influential model of Smets and Wouters (2003)[3].

Moreover, the price indexation is introduced to obtain the hybrid New Keynesian Phillip curve. Indeed, a fraction of the domestic intermediate goods firm (ξ_d) that is not allowed to reset its price, will adjust its price according to the following rule.

$$P_{i,t+1}^d = \Big(\pi_t^d\Big)^{\kappa_d}\Big(\bar{\pi}_{t+1}^T\Big)^{1-\kappa_d}P_{i,t}^d \tag{3.1.15}$$

where $\pi_t^d = \frac{P_t^d}{P_{t-1}^d}$ is previous inflation. $\bar{\pi}_{t+1}^T$ is the current inflation target, and κ_d denotes an indexation parameter. On the other hand, a fraction $(1-\xi_d)$ can reset its price according to the mechanism of Calvo (1983). Because of this mechanism, the domestic intermediate goods firm's aggregate price will be

$$P_t^d = \Bigg[\xi_d\Big(P_{t-1}^d(\pi_{t-1}^d)^{\kappa_d}(\bar{\pi}_t^T)^{1-\kappa_d}\Big)^{\frac{1}{1-\lambda_{d,t}}} + (1-\xi_d)\Big(P_{d,t}^{new}\Big)^{\frac{1}{1-\lambda_{d,t}}}\Bigg]^{1-\lambda_{d,t}} \tag{3.1.16}$$

[3] Indeed, in the influential model of Smets and Wouters (2003), the domestic intermediate goods firm's real marginal cost is

$$mc_t^d = \Big(\frac{1}{1-\alpha}\Big)^{1-\alpha}\Big(\frac{1}{\alpha}\Big)^{\alpha}\big(r_t^k\big)^{\alpha}w_t^{1-\alpha}\frac{1}{\epsilon_t} \tag{3.1.14}$$

.

The domestic firm will seek the new price $P_{d,t}^{new}(i)$ to maximize its following expected present discounted profit subject to the final goods firm's demand curve in (3.1.7).

$$\max_{P_{d,t}^{new}(i)} E_t \sum_{j=0}^{\infty} (\beta\xi_d)^j \upsilon_{t+s} \Bigg[\left(\frac{P_{t+s-1}^d}{P_{t-1}^d}\right)^{\kappa_d} \left(\bar{\pi}_{t+1}^T \bar{\pi}_{t+2}^T ... \bar{\pi}_{t+s}^T\right)^{1-\kappa_d} P_{d,t}^{new} Y_{i,t+s} - MC_{i,t+s}^d \Big(Y_{i,t+s} + z_{t+s}\phi\Big)\Bigg] \tag{3.1.17}$$

Solving the above optimization problem yields the optimal price.

$$E_t \sum_{j=0}^{\infty} (\beta\xi_{m,j})^j \upsilon_{t+s} \left(\frac{\left(\frac{P_{t+s-1}^{m,j}}{P_{t-1}^{m,j}}\right)^{\kappa_{m,j}} \left(\bar{\pi}_{t+1}^T \bar{\pi}_{t+2}^T ... \bar{\pi}_{t+s}^T\right)^{1-\kappa_{m,j}}}{\frac{P_{t+s}^{m,j}}{P_t}} \right)^{\frac{-\lambda_{d,t+s}}{\lambda_{d,t+s}-1}} Y_{t+s} P_{t+s}^d \left[\frac{\left(\frac{P_{t+s-1}^d}{P_{t-1}^d}\right)^{\kappa_d} \left(\bar{\pi}_{t+1}^T \bar{\pi}_{t+2}^T ... \bar{\pi}_{t+s}^T\right)^{1-\kappa_d}}{\frac{P_{t+s}^d}{P_t^d}} \left(\frac{P_{d,t}^{new}}{P_t^d}\right) - \lambda_{d,t} \frac{MC_{i,t+s}^d}{P_{t+s}^d} \right] \tag{3.1.18}$$

Taking a log-linear approximation of the above expression (3.1.18) will lead to a hybrid New Keynesian Philip Curve for the domestic intermediate firm.

$$\begin{aligned}(\hat{\pi}_t^d - \hat{\pi}_t^T) =& \frac{\beta}{1+\kappa_d\beta}(E_t\hat{\pi}_{t+1}^d - \rho_\pi \hat{\pi}_t^T) + \frac{\kappa_d}{1+\kappa_d\beta}(\hat{\pi}_{t-1}^d - \hat{\pi}_t^T) \\ &- \frac{\kappa_d(1-\rho_\pi)}{1+\kappa_d\beta}\hat{\pi}_t^T + \frac{(1-\xi_d)(1-\beta\xi_d)}{\xi_d(1+\kappa_d\beta)}(\widehat{mc}_t^d + \hat{\lambda}_t^d)\end{aligned} \tag{3.1.19}$$

3.1.4 Importing firms

As shown in Figure 1, there are two types of importing firms. Unlike the domestic intermediate goods firm, these two importing firms do not produce goods. Instead, they buy a homogenous good in the foreign economy. They then sell to fulfill the domestic household's demand for imported consumption and investment goods. These two demands are given below.

$$C_{i,t}^m = C_t^m \left(\frac{P_{i,t}^{m,c}}{P_t^{m,c}}\right)^{\frac{-\lambda_t^{m,c}}{\lambda_t^{m,c}-1}} \text{ and } I_{i,t}^m = I_t^m \left(\frac{P_{i,t}^{m,i}}{P_t^{m,i}}\right)^{\frac{-\lambda_t^{m,c}}{\lambda_t^{m,c}-1}} \tag{3.1.20}$$

where the variables, $\lambda_t^{m,c}$ and $\lambda_t^{m,c}$, denote the time-varying markup on the imported consumption and investment goods, respectively. Indeed, these two disturbances follow the process below.

$$\lambda_t^{m,j} = (1-\rho_{\lambda^{m,j}})\lambda^{m,j} + \rho_{\lambda^{m,j}}\lambda_{t-1}^{m,j} + \epsilon_{\lambda^{m,j}} \text{ where } j = c, i \tag{3.1.21}$$

It is worth noting that the importing firms buy goods in the foreign economy at the world price P_t^* and sell to the domestic household at the local-currency prices, $P_t^{m,c}$ and $P_t^{m,i}$. Thus, we take the first-order condition of the importing firm's total cost to its output to yield its real marginal cost below.

$$mc_t^{m,j} = \frac{S_t P_t^*}{P_t^{m,j}} \text{ where } j = c, i \tag{3.1.22}$$

The expression above implies that the real marginal costs are identical to cross importing firms. On the other hand, it is worth noting that the real exchange rate is defined as follows.

$$X_t = \frac{S_t P_t^*}{P_t^c} \tag{3.1.23}$$

$$\text{where } P_t^c = \left[(1-\omega_c)(P_t^d)^{1-\eta_c} + \omega_c (P_t^{m,c})^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} \tag{3.1.24}$$

Thus, the importing firm's real marginal cost in expression (3.1.22) can be interpreted as the law of one price gap as in two well-known studies by Gali and Monacelli (2005) and Monacelli (2005).

Similar to the domestic intermediate goods firms, the importing firms have the feature of both price stickiness and indexation. The following rules demonstrate the price indexation.

$$P_{i,t+1}^{m,j} = \left(\pi_t^{m,j}\right)^{\kappa_{m,j}} \left(\bar{\pi}_{t+1}^T\right)^{1-\kappa_{m,j}} P_{i,t}^{m,j} \text{ where } \pi_t^{m,j} = \frac{P_t^{m,j}}{P_{t-1}^{m,j}} \tag{3.1.25}$$

On the other hand, a fraction of the importing firm, $(1-\xi_{m,j})$ and $j = c, i$, can reset its price according to the mechanism of Calvo (1983). Because of this mechanism, the importing firm's aggregate price will be

$$P_t^{m,j} = \left[\xi_{m,j}\left(P_{t-1}^{m,j}(\pi_{t-1}^{m,j})^{\kappa_{m,j}}(\bar{\pi}_t^T)^{1-\kappa_{m,j}}\right)^{\frac{1}{1-\lambda_{m,j,t}}} + (1-\xi_{m,j})\left(P_{m,j,t}^{new}\right)^{\frac{1}{1-\lambda_{m,j,t}}}\right]^{1-\lambda_{m,j,t}} \tag{3.1.26}$$

The importing firms will seek the new price $P_{m,j,t}^{new}(i)$ to maximize its following expected present discounted profit subject to the domestic household's demand curve in (3.1.20).

$$
\max_{P^{new}_{m,j,t}(i)} E_t \sum_{j=0}^{\infty} (\beta\xi_{m,j})^j v_{t+s} \Bigg[\left(\frac{P^{m,j}_{t+s-1}}{P^{m,j}_{t-1}}\right)^{\kappa_{m,j}} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_{m,j}} P^{new}_{m,j,t} C^{m,j}_{i,t+s} \\ - MC^{m,j}_{i,t+s}\left(C^{m,j}_{i,t+s} + z_{t+s}\phi^{m,j}\right)\Bigg] \tag{3.1.27}
$$

Solving the above optimization problem yields the optimal price.

$$
E_t \sum_{j=0}^{\infty} (\beta\xi_{m,j})^j v_{t+s} \left(\frac{\left(\frac{P^{m,j}_{t+s-1}}{P^{m,j}_{t-1}}\right)^{\kappa_{m,j}} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_{m,j}}}{\frac{P^{m,j}_{t+s}}{P_t}{}^{m,j}} \right)^{\frac{-\lambda_{m,j,t+s}}{\lambda_{m,j,t+s}-1}} C^{m,j}_{t+s} P^{m,j}_{t+s} \\ \left[\frac{\left(\frac{P^{m,j}_{t+s-1}}{P^{m,j}_{t-1}}\right)^{\kappa_{m,j}} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_d}}{\frac{P^{m,j}_{t+s}}{P^{m,j}_t}} \left(\frac{P^{new}_{m,j,t}}{P^{m,j}_t}\right) - \lambda_{m,j,t} \frac{MC^{m,j}_{i,t+s}}{P^{m,j}_{t+s}} \right] \tag{3.1.28}
$$

Taking a log-linear approximation of the above expression (3.1.28) will lead to a hybrid New Keynesian Philip Curve for the importing firms.

$$
(\hat{\pi}^{m,j}_t - \hat{\pi}^T_t) = \frac{\beta}{1+\kappa_{m,j}\beta}(E_t\hat{\pi}^{m,j}_{t+1} - \rho_\pi \hat{\pi}^T_t) + \frac{\kappa_d}{1+\kappa_{m,j}\beta}(\hat{\pi}^{m,j}_{t-1} - \hat{\pi}^T_t) \\ - \frac{\kappa_{m,j}(1-\rho_\pi)}{1+\kappa_{m,j}\beta}\hat{\pi}^T_t + \frac{(1-\xi_{m,j})(1-\beta\xi_{m,j})}{\xi_{m,j}(1+\kappa_{m,j}\beta)}(\widehat{mc}^{m,j}_t + \widehat{\lambda}^{m,j}_t) \tag{3.1.29}
$$

It is worth noting that hybrid New Keynesian Philip Curve for the importing firms in (3.1.29) implies that the exchange rate pass-through is incomplete due to the presence of the nominal friction, such as the sticky price. Indeed, the log-linear approximation of the law of one price gap in (3.1.22) is below.

$$
\widehat{mc}^{m,j}_t = \widehat{p}^*_t + \widehat{s}_t - \widehat{p}^{m,j}_t \text{ where } j = c, i \tag{3.1.30}
$$

3.1.5 Exporting firm

Similar to the importing firm, the exporting firm does not produce goods. As shown in Figure 1, it buys goods from the final goods firm and sells to the foreign economy. The demand for domestic goods in the foreign economy is given below.

$$
C^x_{i,t} = C^*_t \left(\frac{P^*_{i,t}}{P^*_t}\right)^{\frac{-\lambda^x_t}{\lambda^x_t - 1}} \text{ where } P^*_{i,t} = \frac{P^d_{i,t}}{S_t} \tag{3.1.31}
$$

The variables, λ^*_t and λ^x_t, denote the time-varying markup on the exported goods, which follows the process below.

$$\lambda_t^x = (1-\rho_{\lambda^x})\lambda^x + \rho_{\lambda^x}\lambda_{t-1}^x + \epsilon_{\lambda^x,t} \tag{3.1.32}$$

It is worth noting that the exporting firm buys the final goods in the domestic economy at the domestic price $P_{i,t}^d$, and sells them in the international market at the foreign prices, $P_{i,t}^*$. We take the first-order condition of the exporting firm's total cost to its output to yield its real marginal cost below.

$$mc_t^x = \frac{P_t^d}{S_t P_t^x} \tag{3.1.33}$$

The expression above implies that the real marginal cost is identical to cross exporting firms. Thus, we dropt the index i. On the other hand, it is worth remembering the definition of the real exchange rate in the expression (3.1.23). Thus, the exporting firm's real marginal costs in the expression (3.1.33) can also be interpreted as the law of one price gap as in the two well-known studies by Gali and Monacelli (2005) and Monacelli (2005). On the other hand, similar to the domestic intermediate goods firms, the exporting firm has the feature of both price stickiness and indexation. The following rules demonstrate the price indexation.

$$P_{i,t+1}^x = \left(\pi_t^x\right)^{\kappa_x}\left(\bar{\pi}_{t+1}^T\right)^{1-\kappa_x} P_{i,t}^x \text{ where } \pi_t^x = \frac{P_t^x}{P_{t-1}^x} \tag{3.1.34}$$

On the other hand, a fraction of the exporting firm $(1-\xi_x)$ can reset its price according to the mechanism of Calvo (1983). Because of this mechanism, the exporting firm's aggregate price will be

$$P_t^x = \left[\xi_x\left(P_{t-1}^x(\pi_{t-1}^x)^{\kappa_x}(\bar{\pi}_t^T)^{1-\kappa_{m,j}}\right)^{\frac{1}{1-\lambda_{m,j,t}}} + (1-\xi_x)\left(P_{x,t}^{new}\right)^{\frac{1}{1-\lambda_{x,t}}}\right]^{1-\lambda_{x,t}} \tag{3.1.35}$$

The exporting firms will seek the new price $P_{x,t}^{new}(i)$ to maximize its following expected present discounted profit subject to the foreign economy's demand curve in (3.1.31).

$$\max_{P^{new}_{x,t}(i)} E_t \sum_{j=0}^{\infty} (\beta\xi_x)^j v_{t+s} \Bigg[\left(\frac{P^x_{t+s-1}}{P^x_{t-1}}\right)^{\kappa_x} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_{m,j}} P^{new}_{x,t} C^x_{i,t+s} \\ - MC^x_{i,t+s}\left(C^x_{i,t+s} + z_{t+s}\phi^x\right)\Bigg] \tag{3.1.36}$$

Solving the above optimization problem yields the optimal price.

$$E_t \sum_{j=0}^{\infty} (\beta\xi_x)^j v_{t+s} \left(\frac{\left(\frac{P^x_{t+s-1}}{P^x_{t-1}}\right)^{\kappa_x} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_x}}{\frac{P^x_{t+s}{}^x}{P_t}} \right)^{\frac{-\lambda_{x,t+s}}{\lambda_{x,t+s}-1}} C^x_{t+s} P^x_{t+s} \\ \left[\frac{\left(\frac{P^x_{t+s-1}}{P^x_{t-1}}\right)^{\kappa_x} \left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_d}}{\frac{P^x_{t+s}}{P^x_t}} \left(\frac{P^{new}_{x,t}}{P^x_t}\right) - \lambda_{x,t} \frac{MC^x_{i,t+s}}{P^x_{t+s}} \right] \tag{3.1.37}$$

Taking a log-linear approximation of the above expression (3.1.37) will lead to a hybrid New Keynesian Philip Curve for the exporting firms.

$$(\hat{\pi}^x_t - \hat{\pi}^T_t) = \frac{\beta}{1+\kappa_x\beta}(E_t\hat{\pi}^x_{t+1} - \rho_\pi\hat{\pi}^T_t) + \frac{\kappa_d}{1+\kappa_x\beta}(\hat{\pi}^x_{t-1} - \hat{\pi}^T_t) \\ - \frac{\kappa_x(1-\rho_\pi)}{1+\kappa_x\beta}\hat{\pi}^T_t + \frac{(1-\xi_x)(1-\beta\xi_x)}{\xi_x(1+\kappa_x\beta)}(\widehat{mc}^x_t + \widehat{\lambda}^x_t) \tag{3.1.38}$$

It is worth noting that hybrid New Keynesian Philip Curve for the exporting firms in (3.1.38) implies that the exchange rate pass-through is incomplete due to the presence of the nominal rigidity such as the sticky price. Indeed, its log-linear approximation of the law of one price gap in (3.1.33) is

$$\widehat{mc}^x_t = \widehat{p}^d_t - \widehat{p}^x_t - \widehat{s}_t \tag{3.1.39}$$

3.1.6 Central bank

The central bank of Australia, which is known as the Reserve Bank of Australia (RBA), has implemented an inflation target policy since the 1990s. To capture this policy, following an estimated DSGE model for Australia, Jääskelä and Nimark (2011), we assume the RBA adjusts its policy interest rate in responding to the deviation of inflation from inflation target, the output gap, and the real exchange rate as follows.

$$\hat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left[\hat{\bar{\pi}}^T_t + r_\pi(\hat{\bar{\pi}}^T_{t-1} - \hat{\bar{\pi}}^T_t) + r_y\hat{y}_{t-1} + r_x\hat{x}_{t-1}\right] \\ + r_{\Delta\pi}\Delta\hat{\pi}^T_{t-1} + r_{\Delta y}\Delta\hat{y}_t + \epsilon_{R,t} \tag{3.1.40}$$

3.1.7 Market clearing conditions

The three following markets must clear in equilibrium.

The first one is the domestic final goods market.

$$C_t^d + I_t^d + C_t^x + I_t^x = Y_t - a(u_t)\bar{K}_t \tag{3.1.41}$$

The second one is the international balance of payment.

$$S_t P_t^x - S_t P_t^x (C_t^m + I_t^m) = S_t B_{t+1}^* - R_{t-1}^* \Phi\Big(\frac{A_t}{z_{t-1}}, \widetilde{\phi}_t\Big) S_t B_t^* \tag{3.1.42}$$

It is worth noting that the left-hand side of the above expression (3.1.42) is the trade balance, whereas its right-hand side is the capital account.

The third one is the loan market since it is the working capital channel in the intermediate goods firm.

$$\nu_t W_t H_t = \mu_t M_t - Q_t \tag{3.1.43}$$

3.2 The impact of the foreign sector on domestic variables

The inclusion of the foreign sector in a New Keynesian DSGE model will influence the transmission of domestic shock. As an example, Adolfson et al. (2008b) showed that domestic inflation responds more to a monetary policy disturbance in the open economy DSGE model. Similarly, Cwik et al. (2011) indicated that openness considerably alters the transmission of domestic monetary disturbance. In response to a contractionary monetary policy shock, in particular, CPI inflation and domestic inflation fall more significantly in more open economies. Therefore, a well-specified open economy DSGE model and a small degree of estimation uncertainty would better, in principle, explain the variations in domestic variables and make more accurate predictions for these variables.

This section shows theoretically how variations in seven key domestic macroeconomic variables are influenced by the following foreign factors: exchange rate, foreign output, foreign interest rate, foreign inflation and five foreign disturbances: risk premium (σ_ϕ), asymmetric technology (σ_{z*}), imported consumption markup ($\sigma_{\lambda^{mc}}$), imported investment markup ($\sigma_{\lambda^{mi}}$), and exporting markup (σ_{λ^x}) shocks.

In this model, as shown in Figure 1, the following fundamental channels will connect and transmit the external shocks to the domestic economy.

The deviation of the UIP.

$$\widehat{R}_t - \widehat{R}_t^* = E_t \Delta \widehat{S}_t - \widetilde{\phi}_a \widehat{a}_t + \widehat{\widetilde{\phi}}_t \tag{3.2.1}$$

Three laws of one price gaps:

$$
\begin{aligned}
\text{The imported consumption firm} \quad & \Delta\widehat{mc}_t^{m,c} = \widehat{\pi}_t^* + \Delta\widehat{s}_t - \widehat{\pi}_t^{m,c} \\
\text{The imported investment firm} \quad & \Delta\widehat{mc}_t^{m,i} = \widehat{\pi}_t^* + \Delta\widehat{s}_t - \widehat{\pi}_t^{m,i} \\
\text{The exporting firm} \quad & \Delta\widehat{mc}_t^{x} = \widehat{\pi}_t^d - \hat{\pi}_t^x - \Delta\hat{s}_t
\end{aligned}
\tag{3.2.2}
$$

The following section shows the direct or indirect impact of the foreign sector on seven endogenous variables.

First, the domestic inflation dynamic ($\widehat{\pi}_t^d$) is described as the hybrid New Keynesian Phillip Curve in the equation (3.1.19). Its fluctuation is influenced by the external sectors via the exporting firm's the law of one price gap in (3.2.2). Thus, a rise in domestic inflation is associated with the depreciation of exchange rate $\hat{s}_t$, the exporting firm's hybrid New Keynesian Phillip curve $\hat{\pi}_t^x$.

Second, log-linear domestic consumption is depicted below

$$
\begin{aligned}
\hat{c}_t = & \frac{1}{\mu_z^2 + b^2\beta}\Bigg\{ b\beta\mu_z\hat{c}_{t+1} + b\mu_z\hat{c}_{t-1} - b\mu_z(\hat{\mu}_{z,t} + \beta\hat{\mu}_{z,t+1}) \\
& - (\mu_z - b\beta)(\mu_z - b)\hat{\psi}_{z,t} - (\mu_z - b\beta)(\mu_z - b)\omega_c[\gamma^{c,mc}]^{-(1-\eta_c)} \\
& \left[\widehat{\gamma}_{t-1}^{mc,d} + \widehat{\pi}_t^{m,c} - \widehat{\pi}_t^d\right] + (\mu_z - b)(\mu_z\hat{\zeta}_t^c - b\beta\zeta_{t+1}^c)\Bigg\}
\end{aligned}
\tag{3.2.3}
$$

Based on the above expression (3.2.3), the changes in domestic consumption are related to external factors, such as the domestic consumption term of trade $\widehat{\gamma}_{t-1}^{mc,d}$ and imported consumption inflation $\widehat{\pi}_t^{m,c}$. Therefore, there will be a drop in domestic consumption due to positive imported consumption markup shock ($\sigma_{\lambda^{mc}}$) and a rise in imported consumption inflation ($\widehat{\pi}_t^{m,c}$).

Third, the equation (3.2.4) below presents log-linear domestic investment. Accordingly, the changes in investment are influenced by several external factors, such as the domestic investment term of trade ($\hat{\gamma}_{t-1}^{mi,d}$) and imported investment inflation $\hat{\pi}_t^{m,i}$. Thus, a positive imported investment markup shock ($\sigma_{\lambda^{mi}}$), for example, increases domestic investment.

$$
\begin{aligned}
\hat{i}_t = & \frac{1}{\mu_z^2 S''(\mu_z)(1+\beta)}\Bigg\{ \mu_z^2 S''(\mu_z)(\hat{i}_{t-1} + \beta\hat{i}_{t+1} - \hat{\mu}) + \hat{P}_{k',t} \\
& + \hat{\Upsilon}_t - \omega_i(\gamma^{i,mi})^{-(1-\eta_i)}\left[\hat{\gamma}_{t-1}^{mi,d} + \hat{\pi}_t^{m,i} - \hat{\pi}_t^d\right]\Bigg\}
\end{aligned}
\tag{3.2.4}
$$

Fourth, the equation (3.2.5) below depicts the log-linear form of the domestic goods market-clearing condition in (3.1.41). Therefore, the foreign factors, such as the foreign output ($\hat{y}_t^*$), the foreign terms of trade ($\hat{\gamma}_t^{x,*}$), and asymmetric technology shock ($\hat{\tilde{z}}_t^*$), influence the domestic output ($\hat{y}_t$). For example, an increase in the world's output and positive world technology shock cause a rise in domestic output growth. Moreover, other external factors can also indirectly influence domestic output via domestic consumption and investment.

$$\hat{y}_t = \frac{1}{\lambda_d(1-\alpha)}\Bigg\{(1-\omega_c)(\gamma^{c,d})^{\eta_c}(\frac{\bar{c}}{\bar{y}})[\hat{c}_t + \eta_c\hat{\gamma}_t^{c,d}] + (1-\omega_i)(\gamma^{i,d})^{\eta_i}(\frac{\bar{i}}{\bar{y}})[\hat{i}_t + \eta_i\hat{\gamma}_t^{i,d}] + \frac{\bar{y}^*}{\bar{y}}[\hat{y}_t^* - \eta_f\hat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^*]\Bigg\} \tag{3.2.5}$$

Fifth, the indirect impacts of external factors (foreign output $\hat{y}_t^*$, the foreign terms of trade $\hat{\gamma}_t^{x,*}$ and asymmetric technology shocks $\hat{\tilde{z}}_t^*$) on employment via its effect on working hours are depicted as the two following equations. The link between employment and working hours is described in the equation (3.2.6) below.

$$\hat{E}_t = \frac{\beta}{1+\beta}\hat{E}_{t+1} + \frac{1}{1+\beta}\hat{E}_{t-1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{\xi_e}(\hat{h}_t - \hat{E}_t) \tag{3.2.6}$$

On the other hand, variations in working hours are impacted by external blocks as described in the equation (3.2.7) below.

$$\begin{aligned}\lambda_d(1-\alpha)\hat{h}_t =&(1-\omega_c)(\gamma^{c,d})^{\eta_c}(\frac{\bar{c}}{\bar{y}})(\hat{c}_t + \eta_c\hat{\gamma}_t^{c,d})\\ &(1-\omega_i)(\gamma^{i,d})^{\eta_i}(\frac{\bar{i}}{\bar{y}})(\hat{i}_t + \eta_i\hat{\gamma}_t^{i,d}) + \frac{\bar{y}^*}{\bar{y}}(\hat{y}_t^* - \eta_f\hat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^*)\\ &+ r^k(\frac{\bar{k}}{\bar{y}})\frac{1}{\mu_z}(\hat{k}_t - \hat{\bar{k}}_t) - \lambda_d\hat{\varepsilon}_t - \alpha(\hat{k}_t - \hat{\mu}_{z,t})\end{aligned} \tag{3.2.7}$$

Sixth, the equation (3.2.8) shows the indirect impacts of the foreign sector on change in wage via its effect on domestic inflation $\hat{\pi}_t^d$, imported goods consumption inflation $\hat{\pi}_t^c$ and working hours $\hat{h}_t$.

$$\begin{aligned}\hat{w}_t =& -\frac{1}{\sigma_L\lambda_w - b_w(1+\beta\xi_w^2)}\Bigg[b_w\xi_w\hat{w}_{t-1} + b_w\beta\xi_w\hat{w}_{t+1} + b_w\beta\xi_w(\hat{\pi}_{t+1}^d - \hat{\pi}_t^T)\\ &- b_w\xi_w(\hat{\pi}_t^d - \rho_{\hat{\bar{\pi}}^T}\hat{\pi}_t^T) + b_w\xi_w\kappa_w(\hat{\pi}_{t-1}^d - \hat{\pi}_t^T) + b_w\beta\xi_w\kappa_w(\hat{\pi}_t^c - \rho_{\hat{\bar{\pi}}^T}\hat{\pi}_t^T)\\ &- (1-\lambda_w)\sigma_L\hat{h}_t + (1-\lambda_w)\hat{\psi}_{z,t} - (1-\lambda_w)\hat{\zeta}_t^h\Bigg]\end{aligned} \tag{3.2.8}$$

Last, the foreign impacts on variations in domestic interest are clearly explained via two channels: the uncovered interest rate parity and policy rule. For example, the effect of risk premium ($\hat{\tilde{\phi}}_t$) on the domestic interest rate is analytically described by the uncovered interest rate parity in the equation (3.2.1). On the other hand, the effect of the real exchange rate ($\hat{x}_{t-1}$) on the domestic interest rate is clearly shown by policy rule in the equation (3.2.9)

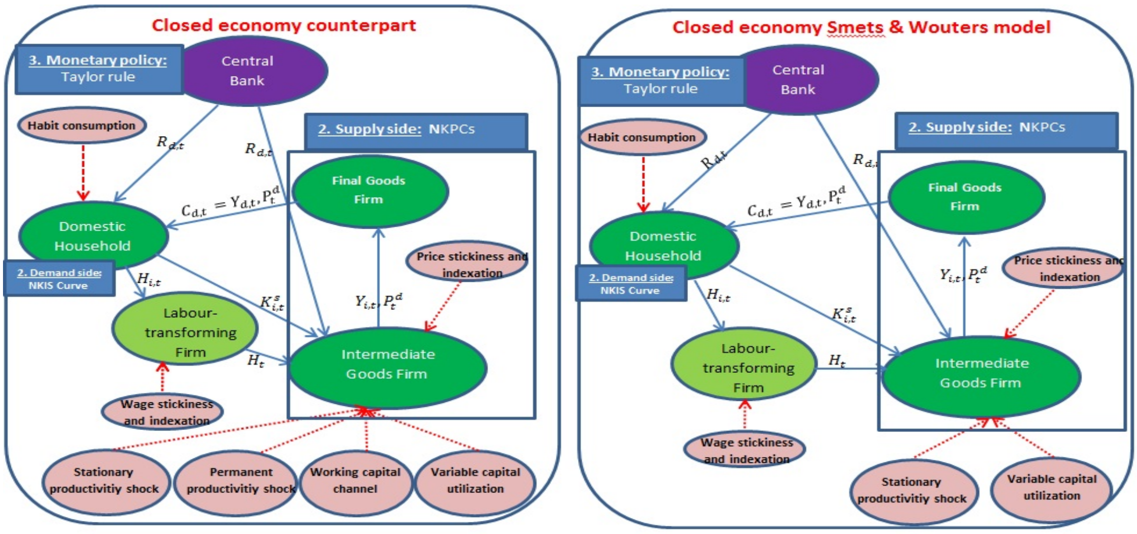
$$\begin{aligned}\hat{R}_t =& \rho_R \widehat{R_{t-1}} + (1-\rho_R)\big[\hat{\bar{\pi}}_t^T + r_\pi(\hat{\pi}_{t-1}^T - \hat{\bar{\pi}}_t^T) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\big] \\ &+ r_{\Delta\pi}\Delta\hat{\pi}_{t-1}^T + r_{\Delta y}\Delta\hat{y}_t + \epsilon_{R,t}\end{aligned} \tag{3.2.9}$$

3.3 Closed-economy DSGE model

There are 67 log-linearized equations in the underlying open economy DSGE model. To build its closed- economy DSGE counterpart, 34 linearized equations and 22 parameters related to the foreign sector will be removed. On the supply side, for example, there are no importing and exporting firms at all. On the demand side, on the other hand, there are no the imported consumption and investment goods in aggregate consumption and investment. Regarding policy rule, the central bank is no longer to adjust its interest rate in response to the real exchange rate. Finally, the closed-economy DSGE model uses seven domestic macroeconomics observed variables to estimate model parameters. The detailed procedure for turning open economy DSGE model into its closed-economy counterpart can be found in the enclosed document.

It is worthy noting that the underlying open economy DSGE model is a modified version of the models of Christiano et al. (2005) and Altig et al. (2011). Thus, its closed economy DSGE counterpart is almost identical to the model of Christiano et al. (2005) and Altig et al. (2011). More specifically, it also slightly differs from the well-known closed-economy DSGE model of Smets and Wouters (2003). Accordingly, Figure 2 shows two notable differences between the closed-economy counterpart and the influential model of Smets and Wouters (2003). As shown in section (3.1.3), first, the closed-economy DSGE counterpart has a working capital channel, whereas Smets and Wouters (2003) did not. Second, the domestic intermediate goods firm's production function includes a stochastic unit-root technology shock, which there does not exist in the model of Smets and Wouters (2003). This specification is identical to Altig et al. (2011). Therefore, it enables the use of trending data about Australia.

Figure 2: Graphical illustration of a closed-economy medium-sized model



4 Data and methodology

4.1 Data

The theoretical model mentioned above incorporates the inflation targeting policy. The central bank of Australia has implemented this policy since 1990s. Thus, to be consistent with theoretical model, the quarterly Australian data for the period of 1993Q1 to 2016Q1 is used to estimate our model. Particularly, there are fourteen macroeconomic variables. They are the GDP deflator (π_t^d), real wage (W_t/P_t), consumption (C_t), investment (I_t), real effective exchange rate ($\tilde{x}_t$), interest rate (R_t), hours worked (H_t), output GDP (Y_t), export ($\tilde{X}_t$), import ($\tilde{M}_t$), consumption price (π_t^{cpi}), foreign (trade-weighted) output (Y_t^*), foreign inflation (π_t^*), and foreign interest rate (R_t^*). The detail of data source is presented in Appendix B. On the other hand, the procedure to handle raw data is described in the following steps. Firstly, real value is generated. All real variables are measured in per-capita units. Then the growth rates are calculated as the first log-difference. Only real exchange rate ($\tilde{x}_t$), and hours worked (H_t) are computed as deviation around the mean and the trend. Finally, data is shown in Figure 3.

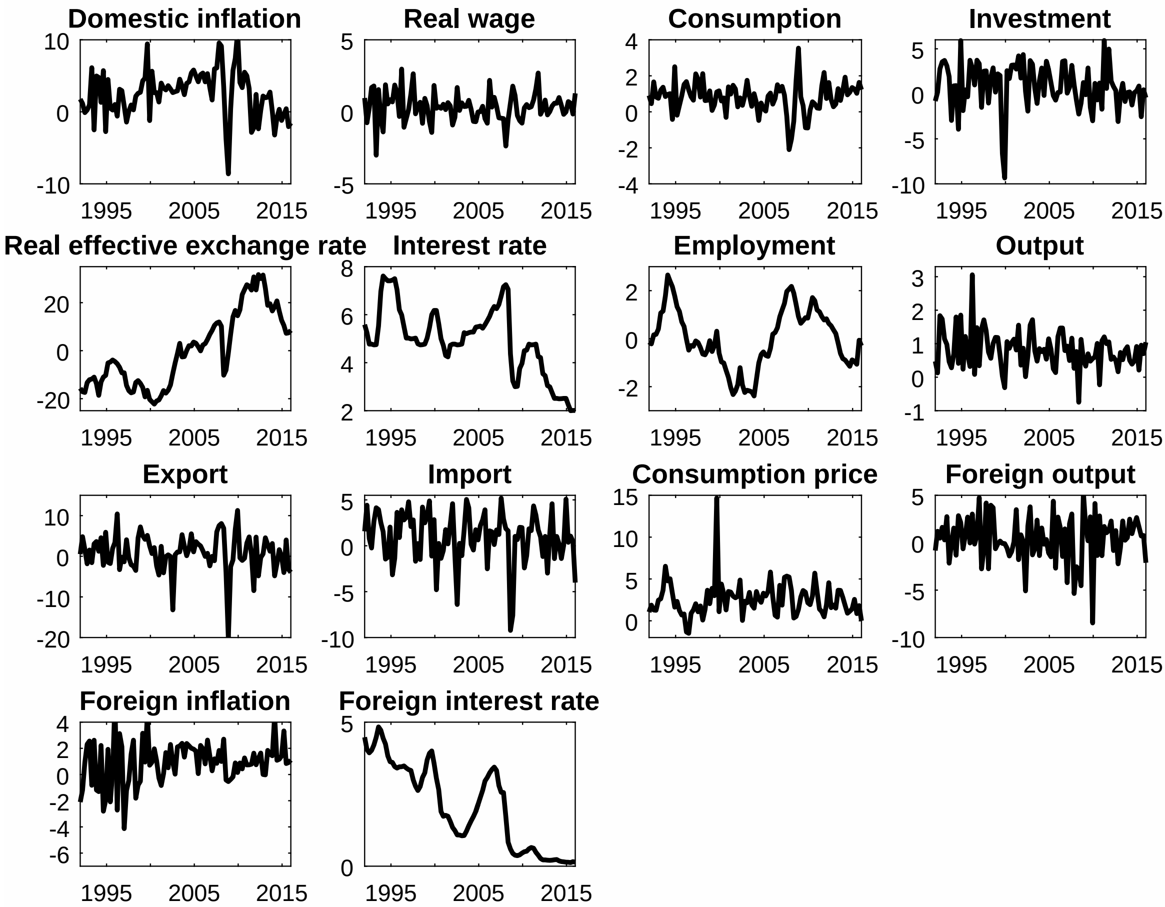


Figure 3: Australian data

4.2 Forming the posterior density and maximum a posterior estimation

The log-linearized DSGE model can be expressed as a state-space framework.

The state equation	$\Omega_t = A\Omega_{t-1} + B\varepsilon_t$	(4.2.1)
The observed equation	$\Phi_t = C\Phi_{t-1} + D\Omega_t + F\epsilon_t$	(4.2.2)
The shocks and measurement errors	$\varepsilon_t \sim N(0, I_q)$ and $\epsilon_t \sim N(0, I_r)$	(4.2.3)

where Ω_t is the m-dimensional vector of model variables or state vector and Φ_t is an n-dimensional vector of observed variables. Based on the state space system, the log-likelihood, $\ln L = \ln p(\Phi_t|\Theta)$, can be computed with the Kalman filter[4] and Θ represents the matrix of parameters, including $A, B, C, D,\ F,\ I_q$ and I_r.

The Bayes theorem enables us to combine prior and likelihood distributions. In particular, the posterior density, $p(\Theta|\Phi_t)$, is proportional, $\propto$, to the product of prior distribution, $p(\Theta)$, and likelihood function, $p(\Phi_t|\Theta)$, as in the following formula.

[4] For further detail, see Hamilton (1994).

$$p(\Theta|\Phi_t) \propto p(\Theta)p(\Phi_t|\Theta) \tag{4.2.4}$$

In terms of the log form, the posterior density in (4.2.4) will be

$$\begin{aligned} \ln p(\Theta|\Phi_t) &\propto \ln p(\Theta) + \ln p(\Phi_t|\Theta) \\ &\propto \ln p(\Theta) + \ln L \end{aligned} \tag{4.2.5}$$

It is worth noting that the conditional posterior density $p(\Theta|\Phi_t)$ is typically a complex form. Thus, we can not directly sample from this density. To address this issue, we use the Metropolis-Hastings sampling algorithm. Accordingly, we will generate the number of random values (ϑ) from a proposal density. Indeed, this proposal distribution is a multivariate normal density as follows.

$$q(\vartheta \mid \Theta^{i-1}) \sim \mathbf{N}(\Theta^{i-1}, c^2\Sigma) \tag{4.2.6}$$

where the covariance matrix Σ is typically the negative of the inverse Hessian at the mode of the conditional posterior density $p(\Theta|\Phi_t)$ in (4.2.4). A candidate ϑ, which is randomly generated from the above density, leads to an increase in the conditional posterior density of $p(\vartheta|\Phi_t)p(\Theta^{i-1}|\Phi_t)$. It is then accepted $\Theta^i = \vartheta$. Otherwise, it is rejected and $\vartheta = \Theta^{i-1}$. Thus, we typically control the parameter c to get a designated acceptance ratio. This acceptance ratio is computed below.

$$\text{The acceptance ratio} = \frac{\text{A number of accepted draws}}{\text{A total number of proposal draws}} \tag{4.2.7}$$

5 Estimation and results

To compare the quality of the forecast, first, we estimate closed- and open economy DSGE models separately by moving windows. The forecasting horizon runs from 1 to 12 quarter horizons for each window. Furthermore, there are 92 observations in a full sample size, and each subsample accounts for 60 observations. As a result, there are 21 windows in total, which are re-estimated quarterly. Then the out-of-sample forecast is generated.

Calibration

In this paper, fifteen parameters were calibrated (see Table 11 in Appendix C). Discount rate (β) is 0.999 to match sample average real interest rate. This value is almost the same as some studies on DSGE models in Australia by Jääskelä and Nimark (2011) and Rees et al. (2016). Labor supply elasticity (σ_L), real cash holding elasticity (σ_q) and capital utilization cost parameter (σ_a) are calibrated as 1, 10.62 and 0.049, respectively.

These three values are in line with Adolfson et al. (2007a) and Jääskelä and Nimark (2011). Following Jääskelä and Nimark (2011), a fraction of imported consumption goods and investment goods in a bundle are an average share of import in the consumption and investment basket ($\omega_c = 0.2, \omega_i = 0.5$). Following Adolfson et al. (2007a), labor disutility (A_L), cash in utility function (A_q), and wage markup (λ_w) are 7.5, 0.38 and 1.05, respectively. These values are also in line with Jääskelä and Nimark (2011). Capital share (α) is 0.25, which is average compensation to capital as a share of GDP. This value is the same as Rees et al. (2016) and slightly lower than Jääskelä and Nimark (2011). Following Adolfson et al. (2007a), we do not estimate elasticity of substitution between domestic goods and foreign consumption goods (η_c). It is calibrated as 0.885, which is almost the same as Justiniano and Preston (2010b). Finally, both Smets and Wouters (2003) and Adolfson et al. (2007a) did not estimate the persistent parameter for inflation target process. In this paper, it was calibrated as 0.975.

Prior distributions

In general, researchers use previous studies for prior information. In this paper, there are three distributions to be used as prior densities of estimated parameters, such as beta, normal, and inverse gamma. More specifically, the beta distribution is applied to parameters which are located between 0 and 1, while the normal distribution is used for parameters ranging from $-\infty$ to $+\infty$. On the other hand, inverse gamma describes parameters of positive value.

Accordingly, the Calvo parameters, indexation parameters, consumption habits, and persistence parameters of the shock process use beta distribution as their priors. The Calvo parameters are assigned as 0.675. This implies that firms are expected to adjust their price every three quarters. This prior is also in line with Adolfson et al. (2007a) and Jääskelä and Nimark (2011). The uncertainty of this mean prior is set as 0.05. In a study on estimating DSGE for Australia, Jääskelä and Nimark (2011) use the truncate uniform as the prior density for indexation parameters. However, in this paper beta distribution is applied. Prior means are specified as 0.5, and their uncertainty is 0.15. This setting is identical to Adolfson et al. (2007a). Following Jääskelä and Nimark (2011), consumption habit is set with a prior mean of 0.65, and its variance is 0.1. Parameters in the shock process are highly persistent. Their prior means are 0.85, and variances are 0.1. On the other hand, Jääskelä and Nimark (2011) set prior means as 0.5, but they are higher uncertainty.

Since all variances of shock are positive values, Jääskelä and Nimark (2011) use the truncate uniform $[0, \infty)$. However, in this paper, the inverse gamma distributions are applied. Following Altig et al. (2011), for example, the standard deviations of the non-stationary technology and monetary shocks are 0.2 and 0.15 percent, respectively. On the other hand, based on Cooley and Hansen (1995), the size of the stationary technology is 0.7. The sizes of 10 remaining shocks, such as investment-specific technology shock, asymmetric technology shock, etc, are in line with Adolfson et al. (2007a). Similarly, prior means of two parameters for elasticity of substitution, such as η_i and η_f, are 1.5.

Normal distributions are used mostly for parameters in the monetary policy rule. For example, the coefficient of inflation is 1.8. Prior mean on output is 0.125 which is identical to Adolfson et al. (2007a) and Jääskelä and Nimark (2011). Finally, prior mean on exchange rate response is very low at 0.01. Meanwhile, Adolfson et al. (2007a) set it at zero. Three parameters of markup in domestic and imported consumption and investment firms use the normal distribution as prior densities. This strategy is identical to Adolfson et al. (2007a).

Estimation and results

The theoretical model parameters will be estimated via the Bayesian technique. Based on the state-space form, the log-likelihood function ($\ln L$) is evaluated via the Kalman filter[5]. Afterward, several optimization algorithms are used to find the mode of the posterior density $p(\Theta|\Phi_t)$ in (4.2.5). Using this mode, we propose a multivariate normal distribution $q(\vartheta \mid \Theta^{i-1})$ in (4.2.6). Then, we generate $250,000$ draws from this proposal density. On the other hand, we specify the parameter c to target the acceptance rate of around 30 %, which is typically used in the literature. Meanwhile, we determine 45 % of draws in discards. Convergence diagnostic test, such as the method of Geweke (1991), is then applied. Accordingly, no convergence problem is found. Indeed, this estimation procedure of the Markov Chain Monte Carlo (MCMC) method with the Metropolis-Hastings algorithm is conducted via the DYNARE Toolbox of Adjemian et al. (2011).

[5] Our theoretical model takes the linear form. Thus, the Kalman filter algorithm can evaluate the likelihood function.

Table 1: Prior and posterior densities

Order	Parameters		Full sample						
			Prior distribution			**posterior distribution**			
						open economy		closed economy	
			type	mean	std.dev	mean	std.dev	mean	std.dev
1	Calvo wage	ξ_w	beta	0.675	0.050	**0.7323**	0.0300	**0.5550**	0.0280
2	Calvo domestic price	ξ_d	beta	0.675	0.050	**0.7500**	0.0240	**0.8790**	0.0240
3	Calvo import cons.price	ξ_{mc}	beta	0.675	0.050	0.5330	0.0400		
4	Calvo import invs.price	ξ_{mi}	beta	0.675	0.0500	0.5660	0.0440		
5	Calvo export .price	ξ_x	beta	0.675	0.050	0.7140	0.0480		
6	Calvo employment	ξ_e	beta	0.675	0.050	**0.9000**	0.0080	**0.9170**	0.0000
7	Indexation wages	κ_w	beta	0.500	0.150	**0.5050**	0.1210	**0.1570**	0.0620
8	Indexation domestic price	κ_d	beta	0.500	0.150	**0.5030**	0.1180	**0.1630**	0.0790
9	Indexation import cons. price	κ_{mc}	beta	0.500	0.150	0.1120	0.0500		
10	Indexation import invs. price	κ_{mi}	beta	0.500	0.150	0.1550	0.0650		
11	Indexation export price	κ_x	beta	0.500	0.150	0.1880	0.0790		
12	Markup domestic	λ^d	normal	1.200	0.050	**1.1970**	0.0460	**1.2350**	0.0440
13	Markup import cons.	λ^{mc}	normal	1.200	0.050	1.2660	0.0470		
14	Markup import invs.	λ^{mi}	normal	1.200	0.050	1.2250	0.0360		
15	Investment adiustment cost	S”	normal	7.694	1.5	**1.3330**	0.2880	**12.135**	1.5000
16	Habit formation	b	beta	0.650	0.100	**0.9890**	0.0000	**0.9700**	0.0100
17	Subst. elasticity invest	η_i	inv.gamma	1.500	inf	7.3510	1.1480		
18	Subst. elasticity foreign	η_f	inv.gamma	1.500	inf	1.8560	0.3160		
19	Technology growth	μ_z	normal	1.0060	0.0005	**1.0080**	0.0000	**1.0060**	0.0000
20	Risk premium	ϕ	inv.gamma	0.010	inf	0.0540	0.0280		
21	Stationary tech.shock	ρ_Υ	beta	0.850	0.100	**0.7540**	0.0790	**0.9170**	0.0160
22	Unit root tech.shock	ρ_{μ_z}	beta	0.850	0.100	**0.9840**	0.0040	**0.4480**	0.0750
23	Investment specific tech.shock	ρ_ε	beta	0.850	0.100	**0.9990**	0.0000	**0.6220**	0.0690
24	Asymmetric tech.shock	ρ_{z*}	beta	0.850	0.100	0.8550	0.1000		

Table 2: Prior and posterior densities

Order	**Parameters**		**Full sample**						
			Prior distribution			**posterior distribution**			
						open economy		closed economy	
			type	mean	std.dev	mean	std.dev	mean	std.dev
25	Consumption preference shock	ρ_{ζ_c}	beta	0.850	0.100	**0.5360**	0.0850	**0.5890**	0.0610
26	Labor supply shock	ρ_{ζ_h}	beta	0.850	0.100	**0.5600**	0.0600	**0.9990**	0.0000
27	Risk premium shock	ρ_{ϕ}	beta	0.850	0.100	0.9610	0.0310		
28	Domestic markup shock	ρ_{λ^d}	beta	0.850	0.100	**0.4790**	0.0750	**0.7590**	0.0660
29	Imp. cons. markup shock	$\rho_{\lambda^{mc}}$	beta	0.850	0.100	0.9820	0.0110		
30	Imp. invs. markup shock	$\rho_{\lambda^{mi}}$	beta	0.850	0.100	0.9350	0.0300		
31	Export markup shock	ρ_{λ^x}	beta	0.850	0.100	0.5890	0.1210		
32	Unit root tech.shock	σ_{μ}	inv.gamma	0.200	inf	**0.2550**	0.0560	**0.9930**	0.0820
33	Stationary tech.shock	σ_{ϵ}	inv.gamma	0.700	inf	**2.9790**	0.2280	**4.3230**	0.3450
34	Invest.spec.tech.shock	σ_{Υ}	inv.gamma	0.200	inf	**6.9460**	1.0580	**0.9250**	0.1440
35	Asymmetric tech.shock	σ_{z*}	inv.gamma	0.400	inf	0.2820	0.1390		
36	Consumption preference shock	σ_{ζ^c}	inv.gamma	0.200	inf	**0.1720**	0.0310	**0.2200**	0.0340
37	Labor supply shock	σ_{ζ^h}	inv.gamma	1.000	inf	**0.3340**	0.0350	**0.1940**	0.0300
38	Risk premium shock	σ_{ϕ}	inv.gamma	0.050	inf	0.3710	0.0880		
39	Domestic markup shock	σ_{λ^d}	inv.gamma	1.000	inf	**0.4970**	0.0540	**0.2830**	0.0370
40	Imp. cons.markup shock	$\sigma_{\lambda^{mc}}$	inv.gamma	1.000	inf	2.6610	0.4640		
41	Invs. cons.markup shock	$\sigma_{\lambda^{mi}}$	inv.gamma	1.000	inf	2.3140	0.4820		
42	Export markup shock	σ_{λ^x}	inv.gamma	1.000	inf	2.4850	0.5170		
43	Monetary shock	σ_R	inv.gamma	0.150	inf	**0.1110**	0.0100	**0.0830**	0.0080
44	Inflation target shock	σ_{π^c}	inv.gamma	0.050	inf	**0.2010**	0.0390	**0.0730**	0.0470
45	Interest rate smoothing	ρ_R	beta	0.800	0.050	**0.8950**	0.0130	**0.9320**	0.0100
46	Inflation response	r_{π}	normal	1.800	0.100	**1.8550**	0.0920	**1.7050**	0.1040
47	Diff.inflation response	$r_{\Delta\pi}$	normal	0.300	0.050	**0.1560**	0.0220	**0.0830**	0.0140
48	Real exch. rate response	r_x	normal	0.010	0.050	0.0070	0.0110		
49	Output respond	r_y	normal	0.125	0.050	**-0.0020**	0.0120	**0.0050**	0.0080
50	Diff. output respond	$r_{\Delta y}$	normal	0.0625	0.050	**0.0570**	0.0130	**-0.0330**	0.0090

Tables 1 and 2 report the posterior mean estimations for the closed- and open economy DSGE models. In general, adding foreign block yields some fundamental differences in the estimated parameters between these two competing models. Afterwards, these fundamental differences may influence the forecasting ability of these two models.

First, nominal friction in terms of Calvo wage (ξ_w) is smaller in the closed economy model. On the other hand, Calvo domestic price (ξ_d) and Calvo employment (ξ_e) are bigger in the closed economy model. Regarding nominal frictions such as wage and domestic price, indexations are significantly smaller in the closed economy model.

Second, real frictions in terms of investment adjustment cost are considerably bigger in the closed economy model. They are 1.3330 and 12.135 for the open and closed economy models, respectively. Meanwhile, the estimated habit formation is 0.97 in closed economy framework, which is slightly smaller than that of 0.989 in the open economy one.

Third, the estimated persistent parameters in structural shocks are bigger in the closed economy model exception for non-stationary and investment-specific technology shocks. Meanwhile, the estimated standard deviations of shocks are smaller in the closed economy model exception for non-stationary, stationary, and consumption preference shocks.

Final, regarding the estimated parameters in policy rule, inflation and inflation growth response ($r_\pi, r_{\Delta\pi}$) are bigger in open economy settings. On the other hand, interest rate smoothing ρ_R is smaller in the open economy model. More especially, the estimated parameters for output responses are very notable. As an example, parameters for output response are estimated to be a negative value of -0.002 in the open economy and a positive value of 0.005 in the closed economy model. Conversely, parameters for output growth response are estimated to be a positive value of 0.057 in the open economy and a negative value of -0.033 in the closed economy setting.

6 The empirical evidences on the effects of the external sector

Before evaluating the forecasting performance, it would be interesting to know how the foreign sector influences the variations in domestic macroeconomic variables. In Section 3.2, we theoretically analyzed the effects of the foreign sector on seven domestic variables. in this Section, we then provide the empirical evidence concerning these impacts. This empirical evidence will be revealed through two channels: impulse response function and variance decomposition. The findings may then give some initial guesses for the forecasting performance of the underlying open economy DSGE model.

6.1 The response of domestic variables to external-sector shocks

This section presents empirical evidence of how seven domestic macroeconomic variables react to five estimated foreign shocks. In this paper, accordingly, there are five estimated foreign shocks: risk premium (σ_{ϕ}), asymmetric technology (σ_{z*}), imported consumption markup ($\sigma_{\lambda^{mc}}$), imported investment markup ($\sigma_{\lambda^{mi}}$), and exporting markup ($\sigma_{\lambda^{x}}$) disturbances. In general, the responses of macroeconomic variables are in line with our theoretical analysis in Section 3.2.

First, Figure 4 shows the responses of macroeconomic variables to a positive risk premium shock (σ_{ϕ}). Based on the uncovered interest rate parity in the equation (3.1.4), it is worth noting that risk premium shock can also be interpreted as the uncovered interest rate parity shock or an autonomous change in the expectations about the future exchange rate. Increasing value in real exchange rate implies a real deprecation of the home currency. Therefore, a positive premium depreciates both the nominal and real exchange rate. It then increases the price of imported consumption and investment goods, whereas it lowers the price of exporting goods. Therefore, import decreases but export rises. Moreover, through the uncovered interest rate parity, a positive premium shock increases the domestic interest rate. On the other hand, the effect of premium shock on domestic inflation can be explained via the LOOP gap in the exporting firm in (3.2.2). Accordingly, the depreciation of local currency leads domestic inflation to rise. Furthermore, the premium shock is treated as a demand-sided disturbance. Thus, it also increases domestic output. A positive risk premium keeps employment unchanged for the initial stage but decreases it for later periods. However, this response is statistically insignificant. It is important to note that the level of the exchange-rate pass-through can be examined via risk premium shock (σ_{ϕ}). We see that this shock leads real exchange rates to rise by 2 %, whereas domestic inflation increases by around a minimal magnitude of around 0.15 %. This implies a low exchange-rate pass-through.

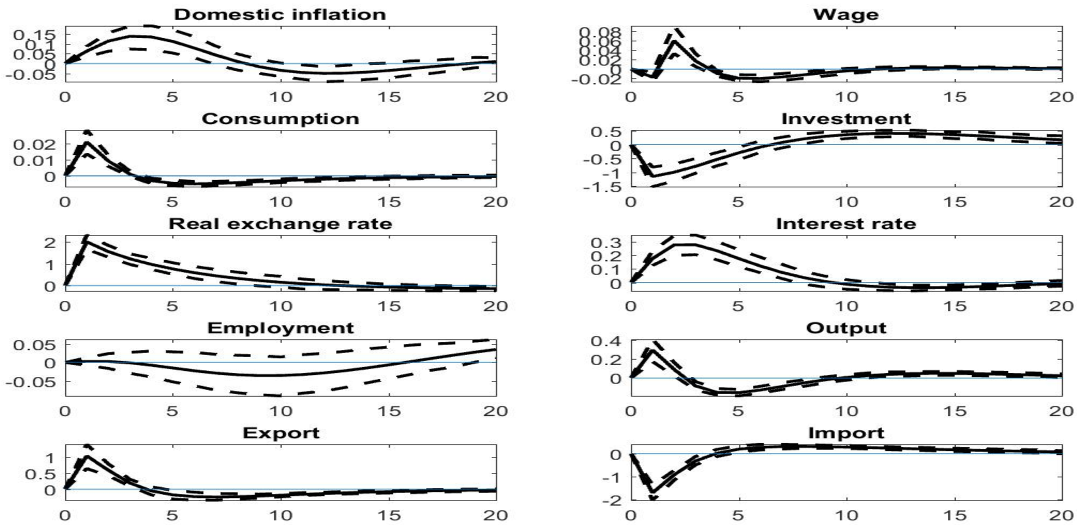


Figure 4: Responses to risk premium shock (σ_ϕ)

Second, Figure 5 presents the responses of macroeconomic variables to the asymmetric technology (σ_{z*}). Asymmetric technology is defined as the relative technology process of domestic to foreign economy . Thus, it is interpreted as an external supply-side shock. A positive realization of this shock increases domestic output due to the market-clearing condition in the equation (3.2.5). Then, there is a very mild negative domestic response. However, this response immediately returns to the steady-state. Due to the price stickiness, this shock leads to a persistent increase in domestic inflation. However, this response is statistically insignificant, and the magnitude is very negligible. A positive asymmetric shock forces interest rate to rise, but it is statistically insignificant as well. This find slightly differs from the study by Buncic and Melecky (2008) in that all three variables in Australia almost do not respond to the foreign supply-side shock.

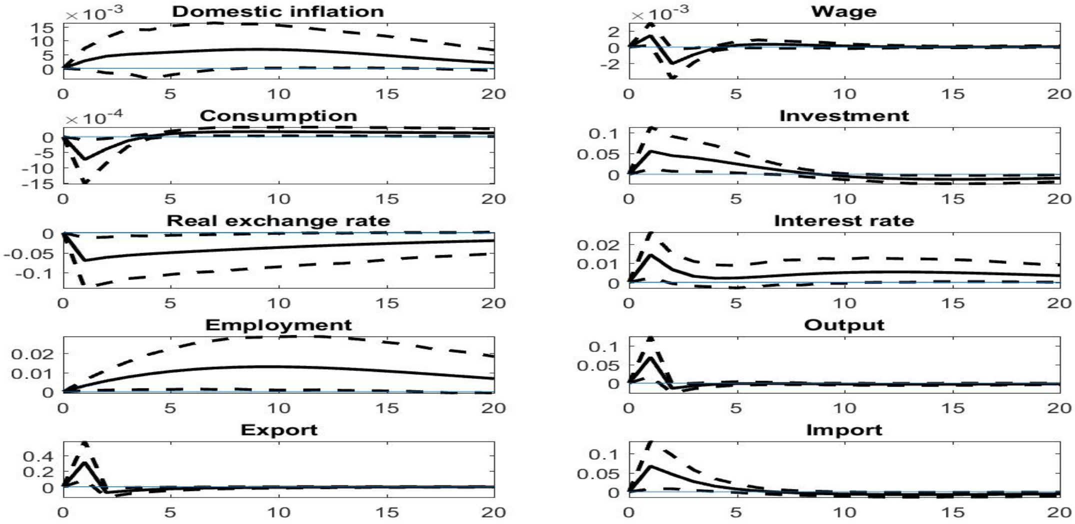


Figure 5: Responses to asymmetric technology shock (σ_{z*})

Third, Figure 6 presents the effects of foreign exporting markup shock, σ_{λ^x}. It also represents a supply-side shock. The indirect effect of this shock on domestic inflation is transformed via its impact on the exporting firm inflation ($\hat{\pi}_t^x$). It is then transformed through the LOOP gap in the equation (3.2.2). On the other hand, this positive supply-sided shock decreases domestic output. The central bank would then recover output growth by lowering the domestic interest rate. On the other hand, this shock depreciates the real exchange rate, which increases the price of imported consumption and investment goods. Thus, home country imports decrease.

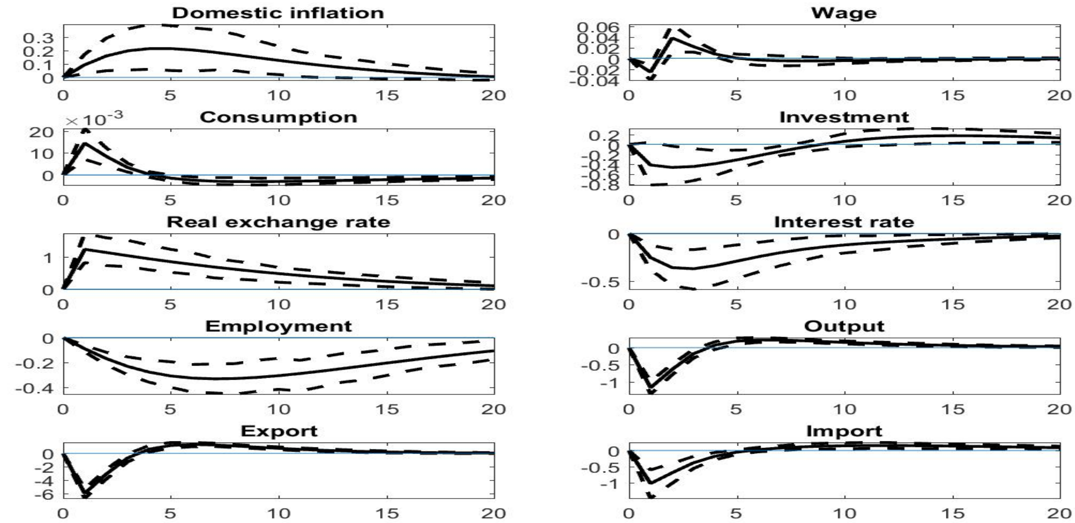


Figure 6: Responses to exporting markup shock (σ_{λ^x})

Last, Figure 7 and 8 show the effects of two remaining external-sector supply-sided shocks. They are imported consumption markup, $\sigma_{\lambda^{mc}}$, and imported investment markup, $\sigma_{\lambda^{mi}}$, disturbances. All expected responses of variables take place. For example, these two shocks force domestic inflation and output into opposite directions. Due to these disturbances, the real exchange rate appreciates. Other responses are almost identical to the study by Adolfson et al. (2007a).

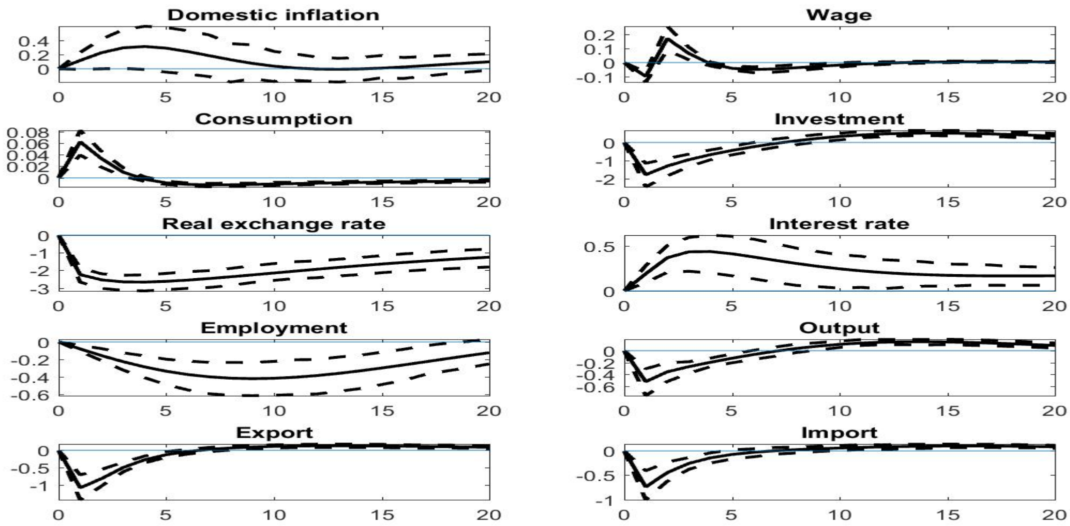


Figure 7: Responses to importing consumption markup shock ($\sigma_{\lambda^{mc}}$)

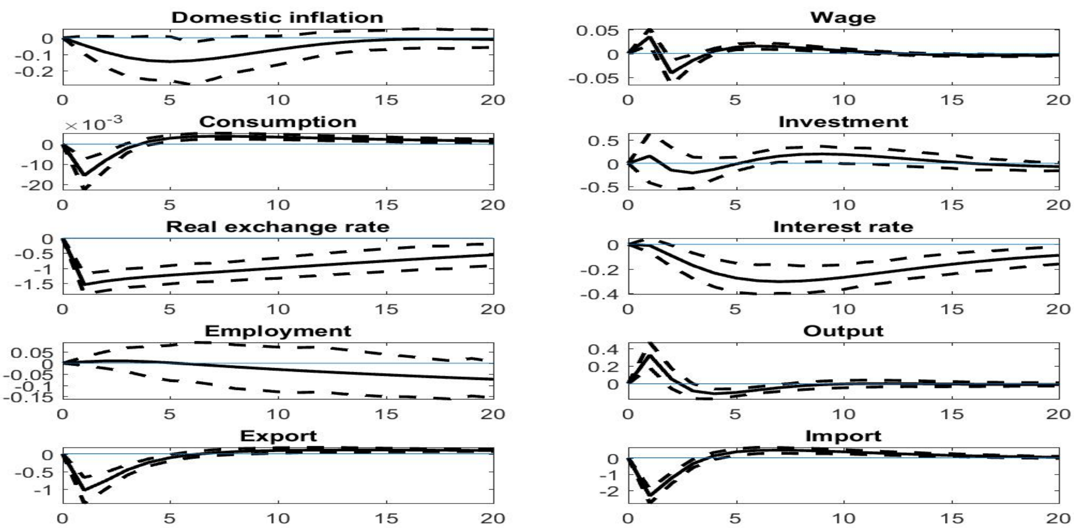


Figure 8: Responses to importing investment markup shock ($\sigma_{\lambda^{mi}}$)

To sum up, it would appear that the responses of domestic variables to five estimated foreign-sector shocks are either mild in magnitude or statistically insignificant. Conversely, these responses of external-related variables, such as exchange rate, export, and import are strong in magnitude and statistically significant. This finding is in line with some previous studies in Australia (Buncic and Melecky (2008), Daniel Rees and Hall (2016)). To reveal the magnitude of the contribution of these external shocks on aggregate domestic activities, we go next step to computing the variance decomposition.

6.2 How largely do external shocks influence the domestic economy

Tables 3 and 4 show how each individual external shock contributes to domestic variable fluctuations.

In general, the contribution of each foreign shock on aggregate domestic activities is very mild, whereas these external disturbances significantly influence changes in the foreign variables. For example, variations in macroeconomic variables, including external variables such as the real exchange rate, do not account for the risk premium or interest rate parity shock (σ_{ϕ}). The real exchange rate is significantly driven by exporting markup shock (σ_{λ^x}). This impact is clearly explained through the LOOP gap in the exporting firm in (3.2.2). On the other hand, export is mainly driven by asymmetric technology shock (σ_{z*}). This fact is not be surprising. Intuitively, change in technology in the foreign economy would strongly influence its economic growth. Thus, if technology in a foreign economy develops faster than the home country, the growth rate of the foreign economy tends to be higher. The foreign economy then tends to import more. Thus, in the first quarter, the shock to asymmetric technology also accounts for a notable fraction of the changes in the domestic output growth. However, this contribution is negligible in higher horizons. On the other hand, fluctuations in import are mainly advocated by imported consumption and investment markup disturbances, $\sigma_{\lambda^{mc}}$ and $\sigma_{\lambda^{mi}}$.

Table 3: Conditional variance decomposition

Variables	Foreign shocks					Domestic shocks
	σ_{ϕ}	σ_{z*}	σ_{λ^x}	$\sigma_{\lambda^{mc}}$	$\sigma_{\lambda^{mi}}$	
Quarter 1						
Domestic inflation	0.00	0.06	0.11	0.02	0.33	99.79
Real wage	0.00	0.04	0.47	0.06	0.01	99.42
Consumption	0.00	0.04	0.70	0.04	0.07	99.14
Investment	0.01	0.69	9.22	0.08	3.49	86.51
Exchange rate	0.03	11.65	34.00	16.81	26.81	10.70
Interest rate	0.06	16.58	9.76	0.03	7.84	65.74
Employment	0.00	2.63	2.02	0.02	0.01	95.32
Output	0.09	27.62	5.06	2.06	1.68	63.49
Export	0.23	82.40	2.65	2.44	2.32	9.94
Import	0.03	10.67	4.91	51.02	23.87	6.53
Quarter 4						
Domestic inflation	0.00	0.32	0.76	0.15	0.16	97.91
Real wage	0.00	0.11	1.69	0.13	0.16	97.91
Consumption	0.00	0.04	0.57	0.04	0.06	99.30
Investment	0.01	0.84	5.47	0.09	2.51	91.09
Exchange rate	0.02	9.46	45.24	14.33	15.23	15.72
Interest rate	0.01	13.25	17.45	3.04	7.20	59.06
Employment	0.00	1.88	1.77	0.00	0.00	96.35
Output	0.04	15.59	4.10	1.06	1.01	78.19
Export	0.18	77.15	3.59	3.21	2.32	13.55
Import	0.04	12.33	5.31	47.42	22.33	12.58
Quarter 8						
Domestic inflation	0.00	0.47	0.87	0.24	0.15	93.34
Real wage	0.00	0.10	1.75	0.14	0.18	97.82
Consumption	0.00	0.03	0.52	0.03	0.06	99.36
Investment	0.00	0.63	3.46	0.09	1.59	94.23
Exchange rate	0.02	7.03	45.83	12.28	8.79	26.06
Interest rate	0.00	7.64	13.53	5.68	3.53	69.61
Employment	0.00	1.05	1.29	0.00	0.00	97.66
Output	0.03	12.49	3.12	0.88	1.02	82.46
Export	0.16	76.68	3.16	2.82	2.33	14.85
Import	0.03	10.93	4.69	46.06	21.36	16.93

Table 4: Conditional variance decomposition

Variables	Foreign shocks					Domestic shocks
	σ_{ϕ}	σ_{z*}	σ_{λ^x}	$\sigma_{\lambda^{mc}}$	$\sigma_{\lambda^{mi}}$	
Quarter 16						
Domestic inflation	0.00	0.46	0.69	0.22	0.13	98.50
Real wage	0.00	0.10	1.62	0.13	0.17	97.98
Consumption	0.00	0.03	0.45	0.03	0.05	99.44
Investment	0.00	0.51	2.99	0.11	1.52	94.87
Exchange rate	0.01	4.07	35.96	8.87	4.45	46.65
Interest rate	0.00	0.61	7.80	4.60	1.56	82.44
Employment	0.00	0.36	0.56	0.00	0.00	99.08
Output	0.03	10.70	3.23	0.71	0.88	84.46
Export	0.15	75.29	3.14	2.79	2.42	16.21
Import	0.03	10.70	4.45	44.08	21.08	19.65
Period 28						
Domestic inflation	0.00	0.42	0.90	0.21	0.13	93.34
Real wage	0.00	0.03	0.39	0.03	0.04	99.52
Consumption	0.00	0.03	0.39	0.03	0.04	99.52
Investment	0.00	0.53	3.11	0.13	1.49	94.73
Exchange rate	0.01	2.17	22.57	5.24	2.44	67.57
Interest rate	0.00	1.97	5.27	2.69	0.85	89.22
Employment	0.00	0.13	0.20	0.01	0.00	99.66
Output	0.02	10.05	3.32	0.67	0.85	85.09
Export	0.15	74.52	3.21	2.89	2.40	16.40
Import	0.03	10.69	4.59	42.62	20.54	21.54
Period 40						
Domestic inflation	0.00	0.41	1.12	0.21	0.13	98.14
Real wage	0.00	0.08	1.40	0.12	0.15	98.25
Consumption	0.00	0.02	0.35	0.02	0.03	99.87
Investment	0.00	0.53	3.08	0.13	1.48	94.78
Export	0.15	74.18	3.21	2.90	2.39	17.17
Import	0.03	10.53	4.52	41.98	20.25	22.69

Shortly, based on three aspects (parameter estimation, the responses of domestic variables and the contributions of foreign shocks), we find the minimal impact of the external sector on the home economy. This finding is identical to previous studies on the SOE-NK-DSGE models in Australia (Buncic and Melecky (2008), Daniel Rees and Hall (2016)) and other small open economies (Steinbach et al. (2009) for South Africa; Justiniano and Preston (2010a) for Canada; Choi and Hur (2015) for Korea etc). This failure of the SOE-NK-DSGE model in explaining the effect of the foreign sector on domestic business cycle fluctuations may point out the potential episodes as shown in Section 1. Thus, we move toward step to comparing the forecasting performance between closed – and open economy DSGE models.

7 Forecasting evaluation procedure

7.1 The open and closed-economy DSGE models

The procedure for forecasting evaluation includes the two following steps. At first, this paper uses the moving window technique. Accordingly, each window has a sample size of 60 observations and forecasts up to the 12-quarter horizons. Thus, 21 windows in total are needed to re-estimate quarterly. Second, the root mean square error (RMSE) is computed as RMSE = $\sqrt{\frac{\sum_1^T e_i^2}{T}}$ for two competing models. Then, its relative values of open economy DSGE model to closed-economy DSGE model are calculated. These values below unity suggest that point forecasts from an open economy DSGE model are more accurate than those from the closed-economy DSGE model. On the other hand, these values above unity imply that point forecasts from an open economy DSGE model are worse than those from the closed-economy DSGE model. Meanwhile, these values are slightly different from unity. This indicates that forecasts from both closed- and open-economy DSGE models are equally accurate; however, in order to know if these values are statistically significant difference from unity. The two-tailed Diebold-Mariano test is then conducted.

Table 5 shows the relative RSME values of open-economy to closed-economy DSGE models. Accordingly, almost the relative RMSE values are higher than unity. On the other hand, it would be fair to say that it is difficult to compare these relative RSME values among different SOE-NK-DSGE models. This is because of different model specifications, observed variables, and the length of forecast periods. For example, Adolfson et al. (2007b) used the small open economy medium-sized NK-DSGE model. However, these authors never compute relative RMSE values. Furthermore, the forecast horizons include 1 and 8 quarters. On the other hand, Kolasa and Rubaszek (2018) used the small-sized DSGE model of Justiniano and Preston (2010b). Thus, this implies that the prediction from this small-scaled model has a lower degree of estimation uncertainty.

However, in principle, like the prediction from other SOE-NK-DSGE models, almost forecasting error tends to increase in the higher forecast horizons. As an example, in the case of real wage, these values slightly differ from unity for the first three quarters. However, they increase for later periods. Meanwhile, in the case of domestic inflation, the relative RMSE is around 1.37 for the first quarter. In contrast, these values rise at the higher forecasting horizons. Similar patterns take place in the remaining variables. Moreover, the two-tailed Diebold-Mario test confirms that almost all these RMSE values are statistically significant at 10 %, in particular, in the case of domestic inflation, consumption, investment, and output. As an example, in the case of domestic output, except for the first quarter, the difference from unity is not statistically significant in two later periods. However, the remaining forecasting horizons are statistically significant differences from unity. Meanwhile, in the case of real wage and interest rate, some episodes are not statistically significantly different from unity. In contrast, almost all remaining episodes are statistically significantly different from unity at either 1 % or 5 %. Thus, it would be fair to say that the closed economy DSGE model does forecasting better than the open economy model. This finding is surprising since Australia is a small open economy, and international trade and financial linkage are vital to this country. Hence, we go further to seek the explanation for this failure of an open economy DSGE model.

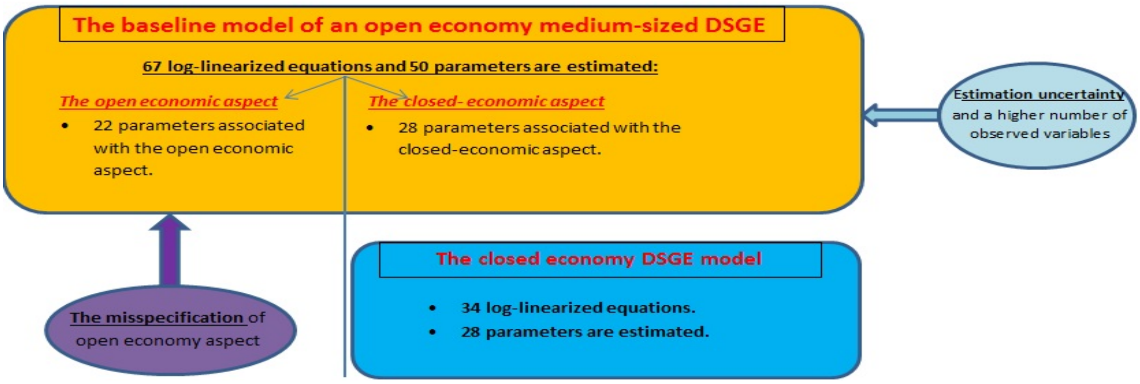
Table 5: The relative RMSE of open-economy to closed-economy DSGE model

Horizon	**Relative root mean squared errors**						
quaters	Domestic inflation	Real wage	Consumption	Investment	Interest rate	Employment	Output
1	1.3744*	1.0631	1.4330*	1.1392**	1.3097*	1.1854**	0.7207**
2	1.5808*	1.1079	1.6545*	1.4811*	1.2431*	1.2681*	0.9345
3	1.8014*	1.0988	1.7698*	1.7821*	1.1614**	1.3164*	1.1031
4	1.8219*	1.1142***	1.8419*	2.0811*	1.0757	1.3344*	1.2380*
5	1.7929*	1.1820**	1.8550*	2.3619*	1.0440	1.3502*	1.3351*
6	1.8482*	1.1610**	2.1541*	2.6195*	1.0416	1.3709*	1.4148*
7	1.6669*	1.1291***	2.0160*	2.8021*	1.0781	1.3950*	1.4879*
8	1.5102*	1.0701	1.8953*	2.9431*	1.1335**	1.4185*	1.5382*
9	1.6844*	1.1138***	1.9780*	2.9711*	1.2107*	1.4440*	1.5699*
10	1.9722*	1.1247**	2.0818*	3.0738*	1.2859*	1.4688*	1.5644*
11	2.0511*	1.0293	1.9630*	3.0744*	1.3257*	1.4805*	1.5305*
12	2.3388*	1.1487**	1.8653*	3.1218*	1.3458*	1.4839*	1.5287*

Notes: The values in the table reveal the relative RMSE of the open economy DSGE model to the closed-economy DSGE one. These values below unity suggests that forecasts from an open economy DSGE framework are more accurate than from a closed-economy DSGE one. On the other hand, these values above unity imply that forecasts from an open economy DSGE framework are worse than from a closed-economy DSGE one. Meanwhile, these values are slightly different from unity, it concludes that forecast from both closed and open economy DSGE models are equally accurate. Asterisks ***,**, and * represent the 1%, 5 %, and 10 % significance levels of the two-tailed Diebold-Mariano test, respectively.

As shown in Figure 9, an estimated open economy DSGE model might face two potential problems: misspecification and estimation uncertainty. For example, there are 50 structural parameters to be estimated in the open economy DSGE model, whereas its closed economy counterpart has 28 structural parameters. This implies there is a higher degree of estimation uncertainty in an estimated SOE-NK-DSGE model. On the other hand, the foreign sector makes the SOE-NK-DSGE model significantly differ from its closed economy counterpart. Then, this foreign sector might be misspecified in the open economy DSGE model. Thus, we go further to address the question of how these two potential reasons are associated with the disappointing performance of the open economy DSGE model on forecasting. Indeed, we conduct two further exercises in a variant of open economy DSGE and Bayesian VAR models in the following sections.

Figure 9: Graphical illustration of the open and closed economy models



7.2 The new variant of open and closed economy models

Based on the full sample size of the Australian data, in Section 6.2, we show the minimal effect of the foreign sector on aggregate domestic activities. This then motivates us to examine the question of whether the misspecification of the foreign sector leads to the less accurate point forecasts of the SOE-NK-DSGE model. To do that, we perform the exercise which eliminates the impact of estimation uncertainty on the forecasting performance of both competing models. Indeed, the degree of estimation uncertainty is fixed for both competing models. To do that, in the baseline SOE-NK-DSGE model above, we reduce a number of parameters to be estimated and create a new variant of the SOE-NK-DSGE model. More specifically, in this variant of the SOE-NK-DSGE model, all external-sector related parameters are calibrated according to the estimated values in the estimated baseline SOE-NK-DSGE model above (see Table 1 and 2). Thus, two competing models in this exercise have an equal number of the parameters to be estimated. Moreover, the variant of the SOE-NK-DSGE model is estimated with seven observed domestic variables, which are identical to its related closed economy counterpart.

It is worth noting that we do not use observed variables associated with the foreign sector to estimate the variant of the SOE-NK-DSGE model. A main explanation for doing that is given as follows. The inclusion of these observed variables implies that the new variant of the SOE-NK-DSGE model suffers from a higher degree of estimation uncertainty. This is because we have to include and estimate a number of the additional measurement errors in the non-structural parameter matrix of I_r in the measurement equation (4.2.2). These additional measurement errors correspond to the foreign-sector observed variables. Moreover, a recent striking study by Canova et al. (2014) on choosing the variables to estimate the DSGE models argued, "*Approaches that tag on measurement errors or non-existent structural shocks in order to use a larger number of observables in estimation may distort parameter estimates and jeopardize inference.*" Thus, the inclusion of observed variables associated with the foreign sector violates the primary purpose of the underlying exercise of eliminating the potential effects of the estimation uncertainty.

Table 6: Prior and posterior densities

Order	Parameters		Full sample				
			Prior distribution			**Posterior distribution** a variant of open economy	
			type	mean	std.dev	mean	std.dev
1	Calvo wage	ξ_w	beta	0.675	0.050	0.6309	0.0018
2	Calvo domestic price	ξ_d	beta	0.675	0.050	0.7498	0.0006
3	Calvo import cons.price	ξ_{mc}	beta	0.675	0.050	calibrate to 0.5330	
4	Calvo import invs.price	ξ_{mi}	beta	0.675	0.0500	calibrate to 0.5660	
5	Calvo export .price	ξ_x	beta	0.675	0.050	calibrate to 0.7140	
6	Calvo employment	ξ_e	beta	0.675	0.050	0.7328	0.0004
7	Indexation wages	κ_w	beta	0.500	0.150	0.2989	0.0110
8	Indexation domestic price	κ_d	beta	0.500	0.150	0.2815	0.0073
9	Indexation import cons. price	κ_{mc}	beta	0.500	0.150	calibrate to 0.1120	
10	Indexation import invs. price	κ_{mi}	beta	0.500	0.150	calibrate to 0.1550	
11	Indexation export price	κ_x	beta	0.500	0.150	calibrate to 0.1880	
12	Markup domestic	λ^d	normal	1.200	0.050	1.4172	0.0012
13	Markup import cons.	λ^{mc}	normal	1.200	0.050	calibrate to 1.2660	
14	Markup import invs.	λ^{mi}	normal	1.200	0.050	calibrate to 1.2250	
15	Investment adiustment cost	S”	normal	7.694	1.5	7.8469	1.8449
16	Habit formation	b	beta	0.650	0.100	0.8616	0.0003
17	Subst. elasticity invest	η_i	inv.gamma	1.500	inf	calibrate to 7.3510	
18	Subst. elasticity foreign	η_f	inv.gamma	1.500	inf	calibrate to 1.8560	
19	Technology growth	μ_z	normal	1.0060	0.0005	1.0054	0.0000
20	Risk premium	ϕ	inv.gamma	0.010	inf	calibrate to 0.0540	
21	Stationary tech.shock	ρ_Υ	beta	0.850	0.100	0.9983	0.0000
22	Unit root tech.shock	ρ_{μ_z}	beta	0.850	0.100	0.8884	0.0010
23	Investment specific tech.shock	ρ_ε	beta	0.850	0.100	0.6905	0.0079
24	Asymmetric tech.shock	ρ_{z*}	beta	0.850	0.100	calibrate to 0.8550	

Table 7: Prior and posterior densities

Order	Parameters		Full sample				
			Prior distribution			Posterior distribution a variant of open economy	
			type	mean	std.dev	mean	std.dev
25	Consumption preference shock	ρ_{ζ_c}	beta	0.850	0.100	0.9992	0.0000
26	Labor supply shock	ρ_{ζ_h}	beta	0.850	0.100	0.3820	0.0065
27	Risk premium shock	ρ_{ϕ}	beta	0.850	0.100	calibrate to 0.9610	
28	Domestic markup shock	ρ_{λ^d}	beta	0.850	0.100	0.7056	0.0532
29	Imp. cons. markup shock	$\rho_{\lambda^{mc}}$	beta	0.850	0.100	calibrate to 0.9820	
30	Imp. invs. markup shock	$\rho_{\lambda^{mi}}$	beta	0.850	0.100	calibrate to 0.9350	
31	Export markup shock	ρ_{λ^x}	beta	0.850	0.100	calibrate to 0.5890	
32	Unit root tech.shock	σ_{μ}	inv.gamma	0.200	inf	0.3329	0.0072
33	Stationary tech.shock	σ_{ϵ}	inv.gamma	0.700	inf	2.1082	0.0636
34	Invest.spec.tech.shock	σ_{Υ}	inv.gamma	0.200	inf	8.7949	0.2021
35	Asymmetric tech.shock	σ_{z*}	inv.gamma	0.400	inf	calibrate to 0.2820	
36	Consumption preference shock	σ_{ζ^c}	inv.gamma	0.200	inf	0.0923	0.0002
37	Labor supply shock	σ_{ζ^h}	inv.gamma	1.000	inf	0.3444	0.0015
38	Risk premium shock	σ_{ϕ}	inv.gamma	0.050	inf	calibrate to 0.3710	
39	Domestic markup shock	σ_{λ^d}	inv.gamma	1.000	inf	0.4641	0.0019
40	Imp. cons.markup shock	$\sigma_{\lambda^{mc}}$	inv.gamma	1.000	inf	calibrate to 2.6610	
41	Invs. cons.markup shock	$\sigma_{\lambda^{mi}}$	inv.gamma	1.000	inf	calibrate to 2.3140	
42	Export markup shock	σ_{λ^x}	inv.gamma	1.000	inf	calibrate to 2.4850	
43	Monetary shock	σ_R	inv.gamma	0.150	inf	0.0807	0.0000
44	Inflation target shock	σ_{π^c}	inv.gamma	0.050	inf	0.1381	0.0013
45	Interest rate smoothing	ρ_R	beta	0.800	0.050	0.8997	0.0002
46	Inflation response	r_{π}	normal	1.800	0.100	1.7824	0.0095
47	Diff.inflation response	$\mathrm{r}_{\Delta\pi}$	normal	0.300	0.050	0.1301	0.0003
48	Real exch. rate response	r_x	normal	0.010	0.050	calibrate to 0.0070	
49	Output respond	r_y	normal	0.125	0.050	0.0057	1.6935
50	Diff. output respond	$\mathrm{r}_{\Delta y}$	normal	0.0625	0.050	0.0217	0.0000

Table 8: The relative RMSE of variant to closed-economy DSGE model

Horizon quaters	**Relative root mean squared errors**						
	Domestic inflation	Real wage	Consumption	Investment	Interest rate	Employment	Output
1	1.1631**	1.0778	1.0439	1.0150	1.1152***	1.0886	0.9044
2	1.2455**	0.9959	1.2143**	1.1345**	1.1241**	1.0734	0.9649
3	1.4270***	1.0619	1.3729**	1.1969*	1.1904**	1.1668**	1.1235*
4	1.5192***	1.1629**	1.4191**	1.1820*	1.2082**	1.1762**	1.1893*
5	1.5477***	1.1579**	1.3013**	1.2896**	1.3335**	1.1893**	1.2234**
6	1.6459***	1.0825	1.1934**	1.2976**	1.3936***	1.2095**	1.2068**
7	1.6495***	1.0670	1.1279**	1.3023**	1.4087***	1.2391**	1.2412**
8	1.6988***	1.0842	1.1592**	1.3282***	1.4139**	1.2672**	1.2661**
9	1.7121***	1.1260**	1.2513**	1.3533**	1.4594**	1.2913	1.3033***
10	1.9924***	1.1597**	1.3244**	1.3923***	1.4902***	1.3215**	1.3601***
11	2.2051***	1.1170**	1.2814**	1.4984***	1.5071***	1.3909**	1.4098***
12	2.2146***	1.2489**	1.2800**	1.5313***	1.5162***	1.4206**	1.4632***

Notes: The values in the table reveal the relative RMSE of the open economy DSGE model to the closed-economy DSGE one. These values below unity suggests that forecasts from an open economy DSGE framework are more accurate than from a closed-economy DSGE one. On the other hand, these values above unity imply that forecasts from an open economy DSGE framework are worse than from a closed-economy DSGE one. Meanwhile, these values are slightly different from unity, it concludes that forecast from both closed and open economy DSGE models are equally accurate. Asterisks ***,**, and * represent the 1%, 5 %, and 10 % significance levels of the two-tailed Diebold-Mariano test, respectively.

As shown in Figure 10, there are 28 parameters to be estimated in both competing models. Accordingly, in this exercise, the degree of estimation uncertainty is fixed. Thus, only the misspecification of the foreign sector in the new variant of the SOE-NK-DSGE model matters. Tables 6 and 7 show the posterior estimates of this open economy model through the full sample size.

Figure 10: Graphical illustration of a variant of open and closed economy models

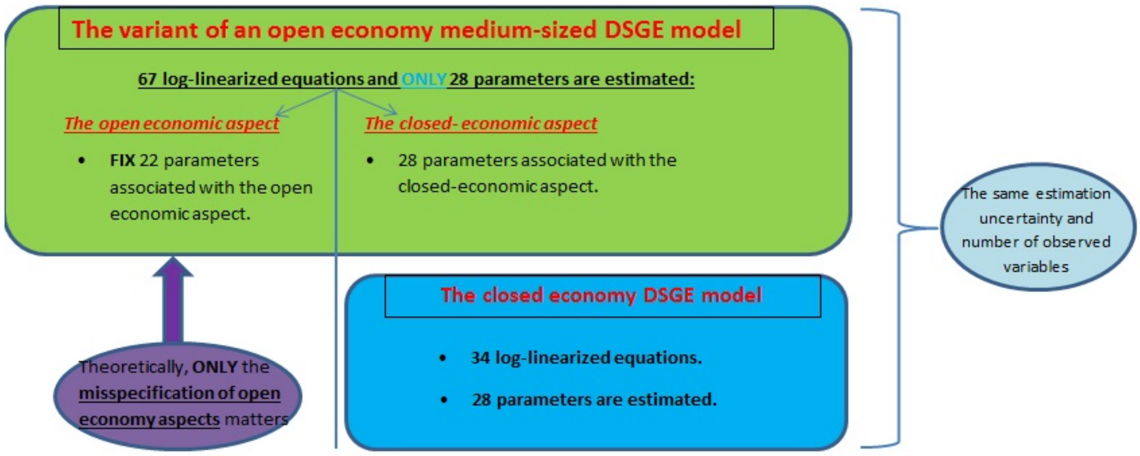
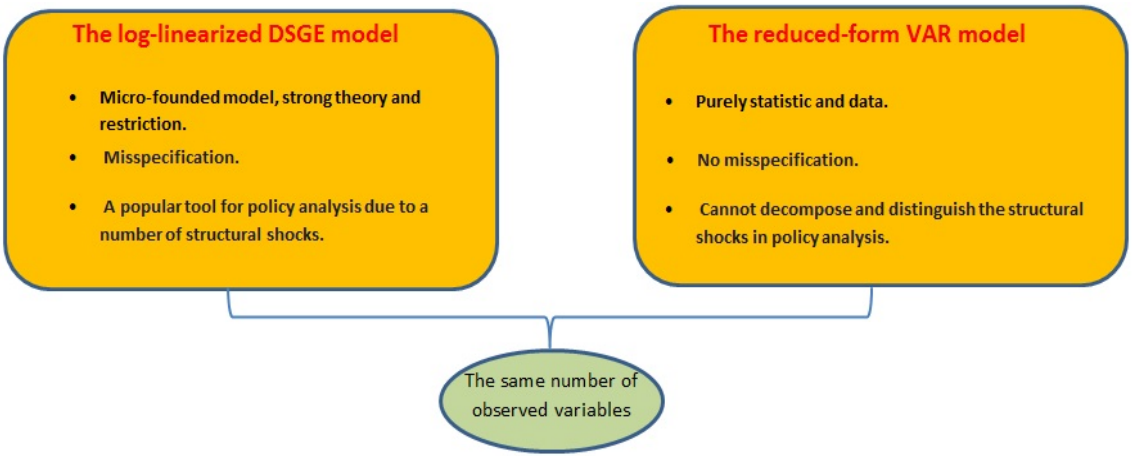


Table 8 shows the relative RMSEs of the modification of open to closed economy DSGE models. Accordingly, the forecasting error tends to increase for higher periods. Furthermore, almost relative RMSE values are above unity and statistically significant. For example, some RMSE values in the cases of real wage, consumption, investment, employment, and output, slightly differ from unity. However, the remaining episodes show higher-unity values. In particular, almost all RMSE indicators in the case of domestic inflation are above 1.2. A similar pattern takes place in the case of consumption. This finding implies that the variant of the SOE-NK-DSGE model cannot beat its closed-economy counterpart in prediction. This fact implies that misspecification takes primary responsibility for the failure of the variant of the SOE-NK-DSGE model.

7.3 The Bayesian VAR models

It is worthy to note that log-linearized DSGE and reduced-form VAR models share two features in common. First, a log-linearized DSGE model can be represented as a reduced-form VAR model. Second, parameters in these two models are estimated using the Bayesian techniques. However, Figure 11 shows a striking difference between these two models. More specifically, a DSGE model is too stylized and restricts its model parameter, which strongly depend on theory (Negro and Schorfheide (2006), Consolo et al. (2009), Canova (2014)). On the other hand, restrictions on parameters in a VAR model purely depend on data and statistical aspects. This implies that to what extent a Bayesian VAR model does not typically have the problem of misspecification. Hence, a Bayesian VAR (BVAR) model can be used as a reference model of a DSGE model (Smets and Wouters (2003), Nergro et al. (2007), Adolfson et al. (2007a)). In this paper, we use variants of the Bayesian VAR model to seek explanations for the failure of the open economy DSGE model in forecasting.

Figure 11: The DSGE and Bayesian VAR models



Using the same dataset in the DSGE model, in particular, we estimate both closed and open economy Bayesian VAR models with independent Normal-Wishart prior. Similar to the closed-economy DSGE counterpart, for example, the closed-economy BVAR is estimated through a subset of data of seven observed domestic variables. On the other hand, full observed variables in the SOE-NK-DSGE model are used to estimate the open economy Bayesian VAR model.

The forecasting evaluation procedure for closed and open economy BVAR models is identical to the process for the DSGE model. For example, 21 windows are re-estimated quarterly, and these BVAR models generate the point forecasts for seven key domestic variables. The result of forecasting comparison is drawn based on standard criteria. Finally, two potential consequences are yielded as follows. The first possible outcome is that the finding is identical to the case of the DSGE model. In particular, the open economy BVAR model cannot beat its closed-economy counterpart. This implies that the degree of estimation uncertainty is mainly associated with the failure of an open economy DSGE model in forecasting. On the other hand, the second potential outcome is that a result is the complete opposite to the case of the DSGE model. In other words, the open economy BVAR model outperforms its closed-economy counterpart. This implies that misspecification is mainly associated with the failure of an open economy DSGE model in forecasting.

Table 9 shows the relative RMSE values of the open economy BVAR model to its closed economy counterpart. Accordingly, most of these relative values are higher than unity, such as in the cases of real wage, consumption, and investment, etc. Furthermore, the Diebold-Mariano test confirms that these differences are statistically significant, except for some episodes of consumption for the first four quarters and the interest rate for the first two quarters. Thus, it would be fair to say that the open economy BVAR model cannot generate more accurate point forecasts than its closed-economy counterpart. This similar result with the case of the DSGE model implies a higher degree of estimation uncertainty is associated with the failure of open economy DSGE in prediction.

To sum up, based on the two above exercises, it would fair to say that a combination of the misspecification of the foreign sector and a higher degree of estimation uncertainty worsen the forecasting accuracy of the open economy DSGE model. This conclusion is not so surprising . This is because, as mentioned before, the misspecification of the foreign sector in the SOE-NK-DSGE model has been widely admitted in the current literature (Adolfson et al. (2007a, 2008a), Justiniano and Preston (2010a), Christiano et al. (2011) etc). On the other hand, there is typically a higher number of parameters to be estimated in the SOE-NK-DSGE model. This implies that this model suffers from a higher degree of estimation uncertainty. To what extent, thus, this finding would be relevant to literature in that the SOE-NK-DSGE model-based forecasts should be used with caution. Meanwhile, one should build a SOE-NK-DSGE model, which can reveal the notable effects of the international spillover on the small open economy.

Table 9: The relative RMSE of open-economy to closed-economy BVAR model

Horizon	**Relative root mean squared errors**						
quaters	Domestic inflation	Real wage	Consumption	Investment	Interest rate	Employment	Output
1	0.7840**	1.1488***	1.0687	1.4552*	0.8617	1.8263*	1.2719**
2	0.9192	1.2563**	1.0047	1.4130*	1.0686	1.9673*	1.5871*
3	1.1271***	1.1612***	0.9778	1.2488**	1.1295***	2.1757*	1.2481***
4	1.1326**	1.1848**	1.1094	1.2360**	1.1566***	2.3376*	1.4320*
5	1.1384**	1.0762	1.3114**	1.3261**	1.1343***	2.3207*	1.3518**
6	1.1839**	1.0881	1.3021**	1.2400**	1.1357***	2.1904*	1.2525* *
7	1.1437**	1.1734***	1.1991***	1.1783***	1.2071**	2.0769*	1.1027
8	1.0078	1.1871***	1.1479**	1.1409***	1.2936**	1.9557**	0.9048
9	1.0516	1.2642**	1.3050**	0.9243	1.3290**	1.8691*	1.2796**
10	1.1823**	1.4807*	1.3816**	1.3580**	1.3096**	1.8171*	1.3161**
11	1.1327***	1.3926**	1.4888*	1.1086	1.2569**	1.8196*	1.0053
12	1.1165***	1.0472	1.2376**	1.1024	1.2113**	1.8768*	1.0814

Notes: The values in the table reveal the relative RMSE of the open economy DSGE model to the closed-economy DSGE one. These values below unity suggests that forecasts from an open economy DSGE framework are more accurate than from a closed-economy DSGE one. On the other hand, these values above unity imply that forecasts from an open economy DSGE framework are worse than from a closed-economy DSGE one. Meanwhile, these values are slightly different from unity, it concludes that forecast from both closed and open economy DSGE models are equally accurate. Asterisks ***,**, and * represent the 1%, 5 %, and 10 % significance levels of the two-tailed Diebold-Mariano test, respectively.

8 Conclusion

The dynamic stochastic general equilibrium model has been widely used in both academia and actual practice in the world. Notably, over the last two decades, the DSGE model has been enriched with various features. This makes the DSGE model explain business cycle fluctuations and performing predictions for aggregate variables well. Notably, the SOE-NK-DSGE model has a particular interest in policy analysis and forecasting. In this paper, we answer a fundamental question of whether the SOE-NK-DSGE model can generate a more accurate point forecast than its closed economy counterpart. Based on the Australian data, we find that the small open economy medium-sized DSGE model can not beat its closed economy counterpart. This finding is surprising since Australia is a small open economy, global economic integration, and financial linkages are essential to this nation. This motivates us to seek explanations for the failure of this SOE-NK-DSGE model. Accordingly, we performed two further exercises to reveal a question of how misspecification and estimation uncertainty are associated with this unexpected consequence. Based on these two exercises, this research paper finds that a combination of the misspecification of the foreign sector and a higher degree of estimation uncertainty worsens the forecasting accuracy of the SOE-NK-DSGE model. To what extent, thus, this finding would be relevant to literature in that the small open economy DSGE model-based forecasts should be used with caution. Meanwhile, one should build a DSGE model, which can reveal the notable effects of international spillover on the small open economy.

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Appendices

A DSGE models at the selected Central Banks

Table 10: The open economy DSGE models at some selected central banks

Central bank	Model	References
Bank of Canada	ToTEM II	Dorich et al. (2013)
Bank of England	COMPASS	Burgess et al. (2013)
Bank of Japan	JEM	Fujiwara et al. (2005)
European Central Bank	NAWM	Lombardo and McAdam (2012)
Bundesbank	GEAR	Gadatsch et al. (2015)
Banco de Espana	FiMod	Stähler and Thomas (2012)
Banco de Portugal	PESSOA	Castro et al. (2013)
Norges Bank	NEMO	Brubakk and Gelain (2014)
Sveriges Riksbank	Ramses II	Adolfson et al. (2013)
Reserve Bank of Australia	Multi-sector Model	Daniel Rees and Hall (2016)
Reserve Bank of New Zealand	NZSIM	Kamber et al. (2015)
International Monetary Fund	GIMF	Anderson et al. (2013)

B Data sources

In this paper, I use the following quarterly Australian data for the period 1993-2016.

1. GDP deflator: Index = 2010, seasonally adiusted, economic data, Federal Reserve Bank of State Louis

https://fred.stlouisfed.org/series/AUSGDPDEFQISMEI.

2.Compensation of employees: Current price, million Australian Dollars, seasonally adiusted, Table 7: Income from Gross Domestic Product (GDP), The Australia Bureau of Statistic

http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5206.0Sep

3.Consumption: Final consumption on expenditure, current price, Million Australian Dollars, seasonally adiusted, Table 8: Household Final Consumption Expenditure,The Australia Bureau of Statistic

http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5206.0Sep

4.Invesment: Gross fixed Capital formation, current price, Billion Australian Dollar, seasonally adiusted, Internationl Financial Statstic, IMF, CD ROOM 2016.

5.Real effective exchange rate: March 1995 =100, the Australian dollar trade-weighted exchange rate index, adiusted for relative consumption price index, seasonally adiusted, the Reserve Bank of Australia

Real exchange rate measures-F15 at http://www.rba.gov.au/statistics/tables/.

6.Nominal interest rate: Central bank policy rate, Internationl Financial Statstic, IMF, CD ROOM 2016.

7.Employment: Number in thousands, period average, seasonally adiusted, Internationl Financial Statstic, IMF, CD ROOM 2016.

8.Population: Working age population, aged 15-64, Seasonally adiusted, economic data, Federal Reserve Bank of State Louis

https://fred.stlouisfed.org/series/LFWA64TTAUQ647S.

9.Gross domestic product(GDP): Current price in Million of Australian Dollars, seasonally adiusted. Table 1. Key National Accounts Aggregates, The Australia Bureau of Statistic.

http://abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5206.0Sep

10. Export: Current price, seasonally adiusted, million Australian Dollars, Internationl Financial Statstic, IMF, CD ROOM 2016.

11. Import: Current price, seasonally adiusted, million Australian Dollars, Internationl Financial Statstic, IMF, CD ROOM 2016.

12. Consumption price: seasonally adiusted, Internationl Financial Statstic, IMF, CD ROOM 2016.

In this papers, I proxy the G7+ Korean countries as foreign economy for Australia

1. Foreign gross domestic product: Million US Dollars, fixed PPP, seasonally adiusted, the OECD Statistics

http://stats.oecd.org/

2. Foreign GDP deflator: GDP expenditure index, 2010 index, seasonally adiusted, the OECD Statistics

http://stats.oecd.org/

3. Foreign interest rates: Average central bank policy interest rates (The United State, the European area, and iapan), Internationl Financial Statstic, IMF, CD ROOM 2016 and the European Statistic Data Warehouse.

C Calibrated parameters

Table 11: Calibrated parameters

Order	**Parameters**		**Description**	**Calibrated from**
1	β	0.999	Discount rate	Jääskelä and Nimark (2011)
2	σ_L	1	Labour supply elasticity	Adolfson et al. (2007a)
3	σ_q	10.62	Real cash holding elasticity	Adolfson et al. (2007a)
4	σ_a	0.049	Capital utilisation cost parameter	Adolfson et al. (2007a)
5	ν	1	Fraction of wage bill paid in advance	Adolfson et al. (2007a)
6	δ	0.013	Depreciation rate	Jääskelä and Nimark (2011)
7	α	0.25	Share of capital in production function	Rees et al. (2016)
8	λ_w	1.05	Wage mark up	Adolfson et al. (2007a)
9	ω_c	0.2	Fraction imported cons. goods in bundle	Jääskelä and Nimark (2011)
10	ω_i	0.5	Fraction imported inv. goods in bundle	Jääskelä and Nimark (2011)
11	μ	1.01	The money growth	Jääskelä and Nimark (2011)
12	A_L	7.5	Labour disutility parameter	Adolfson et al. (2007a)
13	A_q	0.380	Cash in utility function parameter	Adolfson et al. (2007a)
14	η_c	0.885	Elas. of subst. betw. for. and dos. goods	Justiniano and Preston (2010b)
15	ρ_{π^c}	0.975	Persistent param. inflation target	Adolfson et al. (2007a)

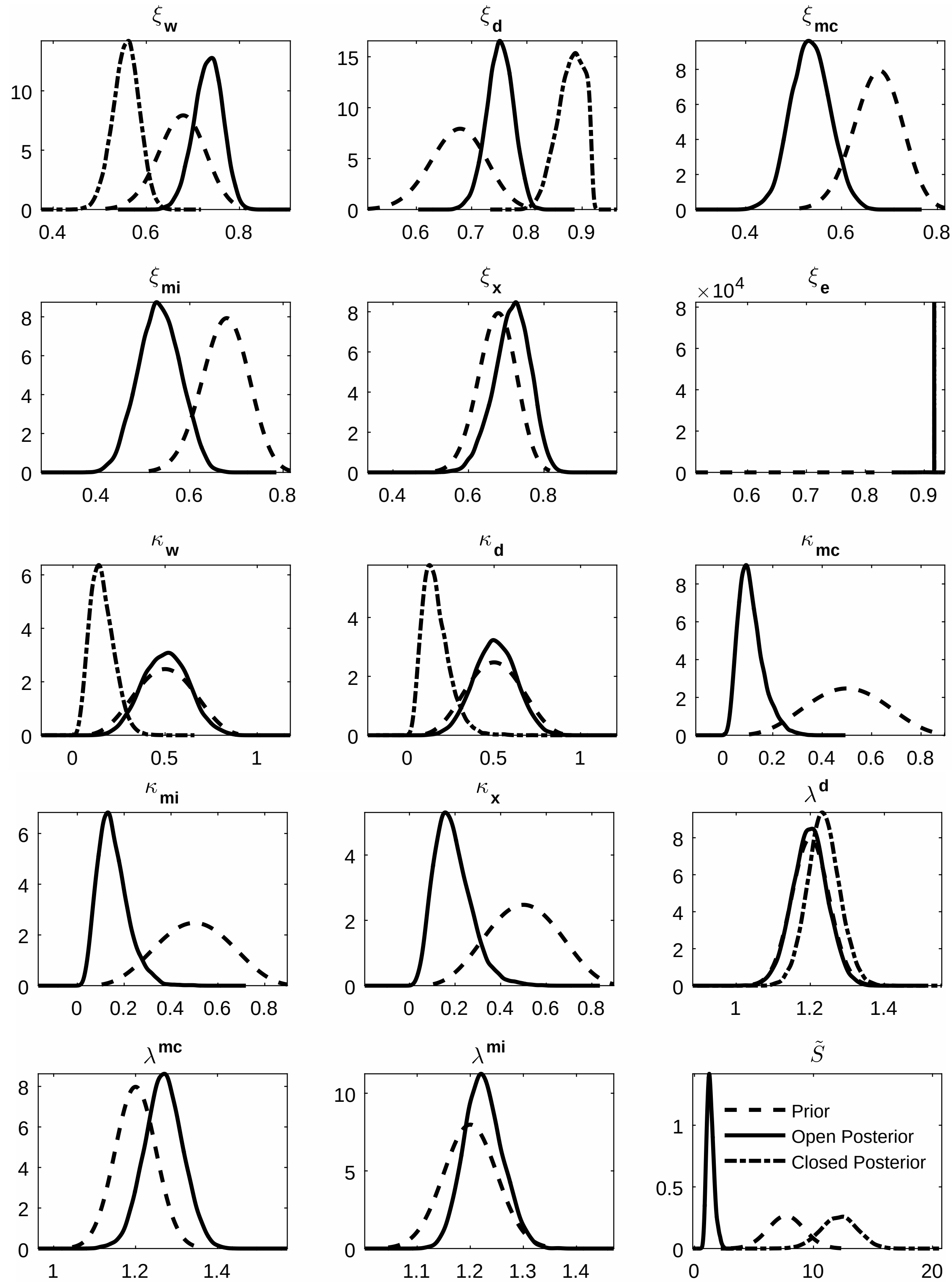

Figure 12: Prior and Posterior densities in the closed-and open economy DSGE model

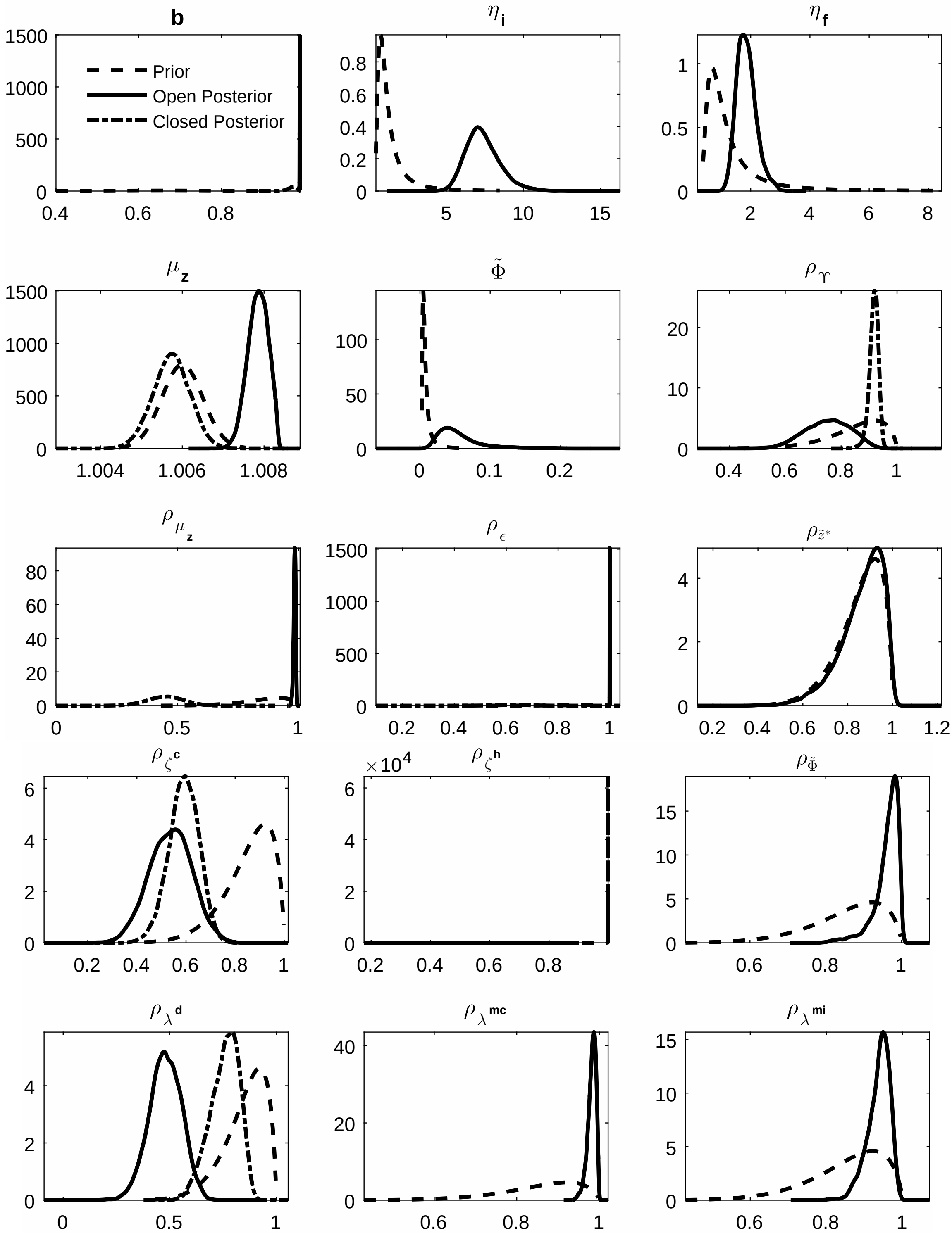

Figure 13: Prior and Posterior densities in the closed-and open-economy DSGE model

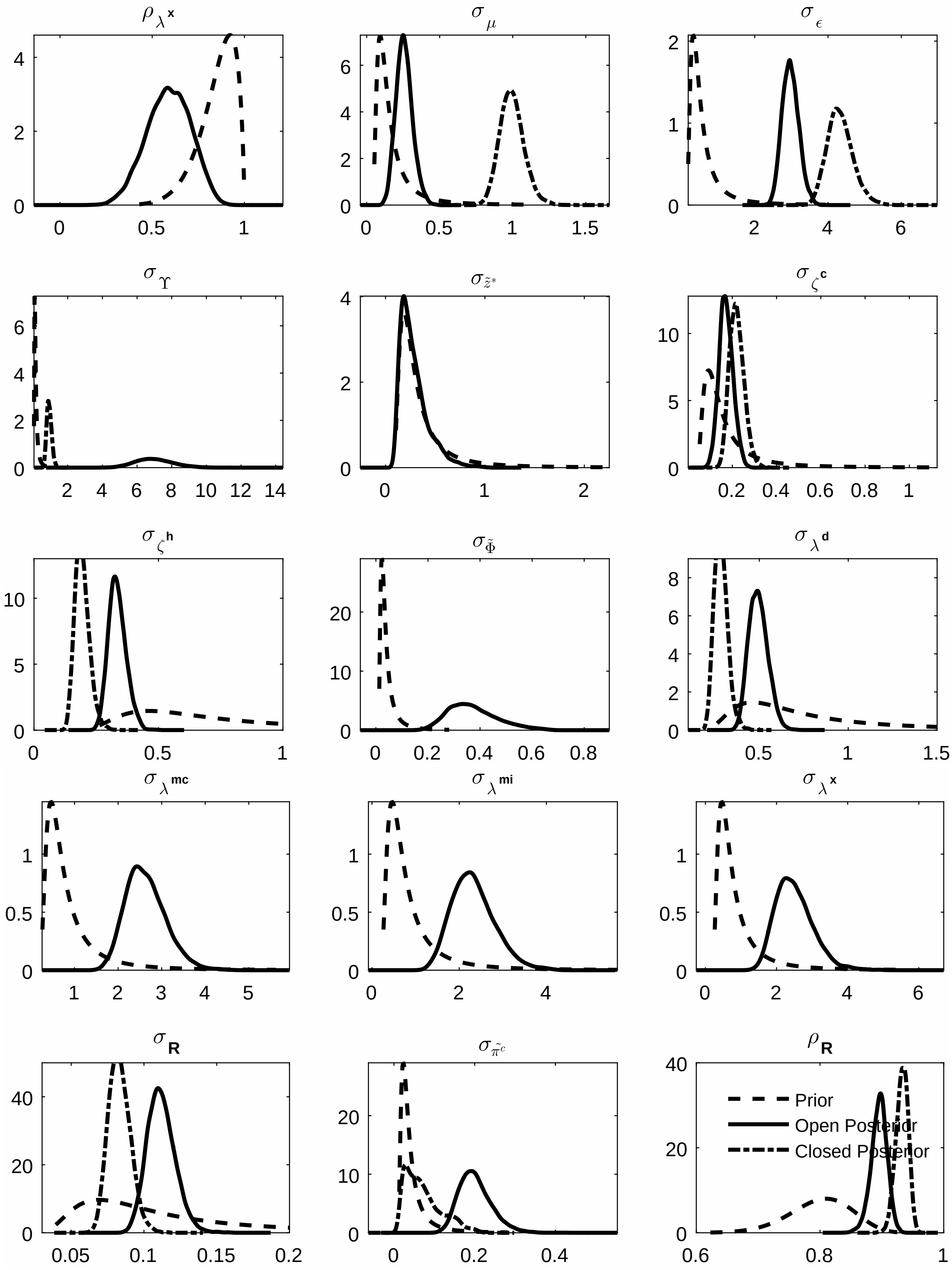

Figure 14: Prior and Posterior densities in the closed-and open-economy DSGE model

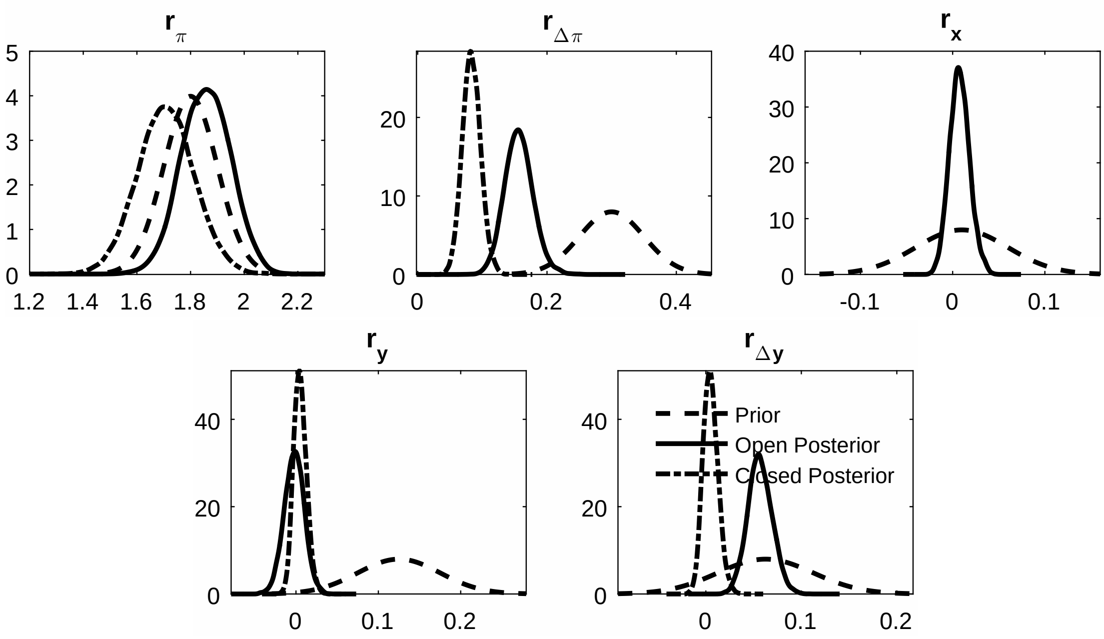

Figure 15: Prior and Posterior densities in the closed-and open-economy DSGE model