Essays on Small Open Economy New Keynesian DSGE Models

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Dedicated to

My family is the most important thing in my life.

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List of Acronyms

BVAR	Bayesian Vector Autoregression
DSGE	Dynamic Stochastic General Equilibrium
NKPC	New Keynesian Phillips Curve
RBA	Reserve Bank of Australia
RMSE	Root Mean Square Error
SBV	The State Bank of Vietnam
SOE-NK-DSGE	Small Open Economy New Keynesian DSGE
VAR	Vector Autoregression
UIP	Uncovered Interest Parity

List of variable symbols in Chapter 2

A_t	The real aggregate net foreign asset position of the domestic economy
B_t^*	The foreign bond holding at the period t.
C_t	Aggregate consumption
C_t^d	Consumption of the domestic good
C_t^m	Consumption of the imported good
$C_{i,t}^m$	The demand for the differentiated imported consumption goods i
C_t^*	The aggregate foreign consumption.
C_t^x	The foreign demand for the (aggregate) domestic consumption good
D_t	The household's net cash income from participating in state contingent securities
$\mathbf{E}_t$	Expectation operator.
$F(I_t, I_{t-1})$	The function which turns investment into physical capital.
$H_{i,t}$	Homogeneous labour hired by the ith firm.
$h_{i,t}$	The ith household's level of work effort.
I_t	Total investment.
I_t^d	Domestic investment goods.
I_t^m	Imported investment goods.
$I_{i,t}^m$	The demand for the differentiated imported investment goods i
I_t^x	The foreign investment demand for the domestic goods.
$K_{i,t}$	The capital services stock.

$\bar{K}_{i,t}$	The physical capital stock.
M_t	The amount of nominal domestic assets.
$MC^x_{i,t}$	The nominal marginal cost of the exporting firm.
$MC^d_{i,t}$	The nominal marginal cost of domestic intermediate goods firm.
mc^d_t	The real marginal cost of domestic intermediate goods firm.
$mc^{m,j}_t$	The real marginal cost of importing firms.
mc^x_t	The real marginal cost of exporting firm.
N_t	Employment.
P^d_t	Output price.
$P^d_{i,t}$	Input price.
P^i_t	The price of investment goods.
P^c_t	The price of consumption goods.
$P^{m,c}_t$	The aggregate consumption price.
$P^{m,i}_t$	The aggregate investment price.
$P^{new}_{d,t}$	The reoptimized price in domestic firm.
$P^{new}_{m,j,t}$	The reoptimized price in importing firm.
$P^{new}_{x,t}$	The reoptimized price in exporting firm.
P^*_t	The foreign price level.
P^c_t	The aggregate consumption price.
P^i_t	The aggregate investment price.
$P^x_{i,t}$	The export price in the local currency of the export market.
$P_{k',t}$	The price of capital
Q_t	The amount of cash holdings.
R_{t-1}	The gross effective nominal rate.
R^f_{t-1}	The gross effective nominal rate paid by firm.
R^k_t	The gross nominal rental rate per unit of capital services.
S_t	The nominal exchange rate.
s	The time subscript runs from 0 to ∞.

$u_{i,t}$	The capital utilization rate
v_{t+s}	The marginal utility of the household's nominal income in period $t+s$
W_t	The nominal wage rate per unit of aggregate, homogeneous, labour $H_{i,t}$.
w_t	The real wage.
X_t	The real exchange rate.
$\tilde{X}_{i,t}$	The demand for the exporting firm's product i.
Y_t	Final good.
$Y_t(i)$	Intermediate good.
z_t	Permanent technology shock.
ν_t	The fraction of the intermediate firm's wage bill has to be financed in advance
z_t	A permanent technology shock.
ϵ_t	A covariance stationary technology shock
$\phi, \phi^{m,c}, \phi^{m,i}, \phi^x$	The fixed costs of the domestic intermediate, importing and exporting firms.
$\Phi\left(\frac{A_t}{z_t}, \widetilde{\phi}_t\right)$	The premium on foreign bond holdings.
$\widetilde{\phi}_t$	The time varying shock to the risk premium.
$\widetilde{\phi}_a$	The risk premium parameter concerning net foreign asset.
Υ_t	The stationary investment-specific technology shock.
Δ_t	Implies that households can join a market and buy new, installed capital, $\bar{K}_{i,t}$.
$\lambda_{d,t}$	The time-varying markup in the domestic firm.
$\lambda_t^{m,j}$	The time-varying markup in the importing firms $j=c,i$.
λ_t^x	The time-varying markup in the exporting firms.
Π_t	The profit.
π_t^d	The domestic inflation.
π_t^c	The CPI inflation.

$\pi_t^{m,j}$	The imported consumption and investment goods price inflation ($j = c, i$).
π_t^x	The export price inflation.
$\bar{\pi}_{t+1}^T$	The current inflation target or time-varying inflation target.
μ_t	The money growth.
$\widehat{\cdot}$	Log-linearized variables

List of variable symbols in Chapter 3

A_t	The real value of foreign bond.
B_t	The one-period foreign bond holding at the period t.
C_t	Aggregate consumption.
$C_{H,t}$	Aggregate domestic goods.
$C_{F,t}$	Aggregate imported goods.
$C_{H,t}(i)$, $C_{F,t}(i)$	The domestically-made and imported goods.
$C^*_{H,t}$	The foreign household demand for domestic goods
D_t	The one-period domestic bond holding at the period t.
e_t	The nominal exchange rate.
E_t	Expectation operator.
$\tilde{i}_t$, $\tilde{i}^*_t$	Domestic and international interest rates.
$\bar{i}$	The steady-state value of nominal interest rate (domestic).
$mc_{H,t}$	The domestic firm's real marginal cost.
$mc_{F,t}$	The importing firm's real marginal cost.
N_t	The household's worked labor.
P_t	The domestic CPI price.
$P_{H,t}$,$P_{F,t}$	The aggregate prices of the domestically-made and imported goods.
$P_{H,t}(i)$	The price of the domestically-made goods i.
$P_{F,t}(i)$	The price of the imported goods i.
$P^{new}_{H,t}(i)$	The reoptimized price of domestic firm i.
$P^{new}_{F,t}(i)$	The reoptimized price of importing firm i.
P^*_t	The foreign price.

j	The time subscript runs from 0 to ∞.
W_t	Nominal wage.
$Y_{H,t}(i)$	Home goods produced by firm i.
$\overline{Y}$	The steady-state value of domestic output.
Z_t	Stationary productivity shock.
$\Pi_{H,t}$, $\Pi_{F,t}$	The dividend from domestic and imported goods firms.
$\phi(.)$	The debt elastic interest rate premium.
$\tilde{\phi}_t$	The risk premium disturbance.
$\tilde{\varepsilon}_{m,t}$	The exogenous monetary policy shock.
$\tilde{\varepsilon}_{g,t}$	The preference shock.
Ψ_t	The law of one price gap.
$\widehat{.}$	Log-linearized variables

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Preface

This dissertation is a collection of two essays contributing to the field of small open economy New Keynesian DSGE models. The title of the first essay is "*Evaluating the forecasting accuracy of the closed- and open economy New Keynesian DSGE models*". This essay is published in the Dynare Working Papers Series and is available online at `https://www.dynare.org/wp-repo/dynarewp059.pdf`. The title of the second essay is "*The Vietnamese business cycle in an estimated small open economy New Keynesian DSGE model*". This essay is also published in the Dynare Working Papers Series and is available online at `https://www.dynare.org/wp-repo/dynarewp056.pdf`. Furthermore, this research was accepted for publication in the *Journal of Economic Studies (forthcomming)*. I believe the combination of these two essays makes a significant contribution to the literature on the field of small open economy New Keynesian DSGE models.

Chapter 1

Introduction

"*Frankly, we do not know which of these competing approaches, if any, will play a prominent role into the next generation of mainstream DSGE models. We do know that DSGE models will remain central to how macroeconomists think about aggregate phenomena and policy. There is simply no credible alternative to policy analysis in a world of competing economic forces.*"

Lawrence J. Christiano, Martin S. Eichenbaum, and Mathias Trabandt (2017). On DSGE Models[1].

[1] http://faculty.wcas.northwestern.edu/~yona/research/DSGE.pdf

The studies by Kydland and Prescott (1982) and Prescott (1986) argued that technology shocks are the most important driver of business cycles in the Real Business Cycle (RBC) model. On the other hand, in the RBC model the central bank has no power because of monetary neutrality. Conversely, money is not neutral in the New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model due to the presence of nominal rigidities. Indeed, a baseline NK-DSGE model has three main features, such as monopolistic competition, nominal rigidities (sticky-price or wage), and the short-run monetary non-neutrality. These features induce three fundamental equations as follows. First, the hybrid New Keynesian Phillips Curve presents the supply side. Second, the New Keynesian IS curve donates the demand side. Last, the model is closed by introducing monetary policy according to the Taylor rule. Furthermore, over the last decade, the DSGE models have been enriched by incorporating a wide range of features (Christiano et al. (2005), Smets and Wouters (2005) for nominal and real rigidities; Gerali et al. (2010), Kollmann et al. (2011) for financial friction; Gertler et al. (2008), Christiano et al. (2016) for labor friction etc). Thus, this micro-founded model has been widely using by academics and central banks. For example, Table 1.1 below lists examples of DSGE models used at selected central banks around the world.

Table 1.1: 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)
Norges Bank	NEMO	Brubakk and Gelain (2014)
Sveriges Riksbank	Ramses II	Adolfson et al. (2013)
Reserve Bank of Australia	Multi-sector Model	Rees et al. (2016)
Reserve Bank of New Zealand	NZSIM	Kamber et al. (2015)
International Monetary Fund	GIMF	Anderson et al. (2013)

More specifically, the inclusion of the foreign sector in the DSGE model is one of growing interests. This is because the small open economy New Keynesian DSGE model, or SOE-NK-DSGE for short, can give explanations for the impacts of international spillovers on the domestic economy. Thus, this model is particularly useful for small open economies where international trades and financial linkage are all essential to these nations.

An estimated SOE-NK-DSGE model is typically applied to the two following aspects. The first one is to make forecasts. The second one is to analyze the source of business cycle fluctuations. Therefore, this dissertation aims to focus on these two fields. Essay

1 focusses on the forecasting performance of SOE-NK-DSGE models. Essay 2 analyses the sources of business cycle fluctuations through the lense of an SOE-NK-DSGE model. The brief introductions to these two Essays are given below.

Regarding the 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), Ca'Zorzi et al. (2017)). Therefore, one would conjecture that a well-specified SOE-NK-DSGE model would, in principle, deliver a better explanation for the variations in domestic variables, and make more accurate predictions for these variables, than a closed economy NK-DSGE model counterpart. However, one should take into consideration that an SOE-NK-DSGE model might suffer from two potential problems as follows. First, in comparison with its closed economy counterpart, an SOE-NK-DSGE model has a higher degree of estimation uncertainty because of a higher number of estimated parameters. Second, aspects concerning the foreign sector and the international transmission channel might be wrongly specified. Moreover, the problem of the misspecification of an SOE-NK-DSGE model has been widely admitted in the current literature (Adolfson et al. (2007a, 2008b), Justiniano and Preston (2010a), Christiano et al. (2011), etc). On the other hand, the current literature has a limited number of studies on this field of research. For example, there are two related studies by Adolfson et al. (2008a) and Kolasa and Rubaszek (2018). However, the findings are still mixed as follows. Adolfson et al. (2008a) argued that closed- and open economy DSGE models perform equally in making the prediction for several key domestic macroeconomic variables. On the other hand, Kolasa and Rubaszek (2018) argued that the SOE-NK-DSGE model cannot outperform its closed-economy counterpart in forecasting. These authors then attributed the failure of the SOE-NK-DSGE models to the higher degree of estimation uncertainty. Therefore, Chapter 2 aims to address this issue in the current literature. Indeed, the main purpose of this Chapter is to compare the forecasting performances of an SOE-NK-DSGE model with its closed-economy counterpart. Furthermore, this chapter examines a question of whether the two above problems, such as estimation uncertainty and model misspecification, matter for the forecasting performance of an SOE-NK-DSGE model. To this end, we develop and estimate an SOE-NK-DSGE model. The model specification closely follows two studies by Jääskelä and Nimark (2011) and Adolfson and Lindé (2011). Thus, the theoretical model includes a number of important features, such as habit formation, price and wage stickiness, price indexation, the law of one price and interest rate parity, and incomplete exchange-rate pass-through, etc. On the other hand, the related closed-economy counterpart was developed by removing all aspects concerning the foreign economy from the SOE-NK-DSGE model. Empirically, these two competing models were recursively estimated by the Bayesian techniques and quarterly Australian data from 1993Q1 to

2016Q1. Moreover, point forecasts for interesting domestic variables were compared. The findings indicate that the forecasting accuracy is worse in the SOE-NK-DSGE model than its related closed economy counterpart. This finding is surprising. This is because Australia is a small open economy, both international trade and financial linkage strongly influence this country. This failure of the SOE-NK-DSGE model could be attributed to the two reasons above, such as misspecification of the foreign sector and a higher degree of estimation uncertainty. Thus, to seek the explanations for this failure of the SOE-NK-DSGE model, we performed two further exercises as follows. The first is to examine whether misspecification matter for this failure, we fix all parameters associated with the open econonmy aspect, so that estimation uncertainty is hold fixed between the closed and the open economy models. The second is to examine if the estimation uncertainty matters, we compare the forecast from the estimated Bayesian VAR models of the closed and the open economies. Consequently, we find 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. The main contribution of this research is as follows. It contributes to the growing interest in the current literature on the forecasting performance of the SOE-NK-DSGE model. In particular, this research paper examines the mixed findings in the current literature on the forecasting performance of the SOE-NK-DSGE models in comparison with its closed economy counterpart (Adolfson et al. (2008a) and Kolasa and Rubaszek (2018)). As a result, we argue that one should use the SOE-NK-DSGE model-based forecasting tools with caution.

In terms of analyzing the sources of business cycle fluctuations, Chapter 3 develops and estimates an SOE-NK-DSGE model for Vietnam. Indeed, the main purpose of this Chapter is to answer the question of what sources drive the Vietnamese business cycle fluctuations, especially the period of 1999Q1 and 2017Q1. This research question is particularly interesting one as follows.

First, Vietnam has witnessed a large fluctuation in the business cycle since the Revoluton, known as **Doi Moi**, took place in 1986. For example, the Vietnamese GDP growth had been rocketing and reached a peak of 9.54 % in 1995. However, due to the Asian financial crisis in 1997, this economy experienced a great fall. Afterward, Vietnam maintained a stable and high growth rate of output at approximately 6.52 % per year on average. Because of the 2008 financial global crisis, there was a fall in output growth. However, the Vietnamese economy had quickly recovered and caught up with the output growth of China since 2015.

Second, the degree of openness, which is defined as the ratio of import and export to GDP, is significantly high. Indeed, this country would be deemed as one of the most open economies in the world. As an example, in 2017 this indicator reached a considerably impressive level of 200 %, which was six times and four times as much as in China and the world, respectively. This implies that international trade plays an important role to this emerging country.

Thus, using a structural model, such as an SOE-NK-DSGE model, is especially useful to analyze the sources of business cycle fluctuations in Vietnam. Accordingly, we develop an SOE-NK-DSGE model for this country. In particular, the specification of this model closely follows the influential studies by Gali and Monacelli (2005), Monacelli (2005), and Justiniano and Preston (2010b) on the small open economy. Thus, the model includes various important features, such as habit formation, price stickiness, price indexation, the failure of the Uncovered Interest Rate Parity, the Law of One Price gap, and incomplete exchange-rate pass-through. However, the most striking difference between the SOE-NK-DSGE model in this paper and those in the three above studies is as follows. We model the foreign economy as a closed economy DSGE model rather than a reduced form VAR one. The model is then estimated using the Bayesian technique and Vietnamese data $1999Q1 - 2017Q1$. Based on the estimated model, this paper analyzes the sources of the business cycle fluctuations in this emerging economy as follows.

The estimated SOE-NK-DSGE model with the Bayesian technique fits data on the Vietnamese and foreign economies relatively well. As an example, in most of the variables, the fitted value insignificantly differs from its actual data, in particular, domestic interest rate and CPI inflation. Based on this estimated model, we find that the inflation dynamic in Vietnam is purely forward-looking behavior. It implies that expected inflation strongly influences the fluctuations in current inflation. On the other hand, no structural shock permanently affects the Vietnamese economy. Indeed, after the shock, the observed macroeconomic variables quickly go back to their steady-state level, except for domestic CPI inflation and interest rate.

We also find that there is a stronger response in domestic output growth than domestic CPI inflation to the monetary tightening. Thus, during the period of anti-inflation, the central bank of Vietnam, which is known as the State Bank of Vietnam (SBV), should implement a contractionary monetary policy with caution. Furthermore, the short-run incomplete exchange rate pass-through (ERPT) of around 27 % after three months implies a high and rapid ERPT in Vietnam. Therefore, the SBV's domestic currency devaluation policy, which is to promote exports, should be conducted with caution. Because of the 2008-global financial crisis, for example, this central bank devaluated the DONG currency relative to the US-Dollar. As a result, this policy caused the two-digit inflation in 2008 and 2011.

As one of the most open economies in the world, the fluctuations in interest rate and the real and nominal exchange rates in Vietnam are strongly influenced by the external-sector disturbances. However, the shock to the terms of trade accounts for a mild percentage in explaining the fluctuations in the output growth. On the other hand, the domestic disturbances, including stationary productivity and preference shocks account for a sizeable proportion in explaining the changes in domestic CPI inflation and the terms of trade. Last but not least, in most episodes over the whole sample period $1999Q1 - 2017Q1$, the variations in the Vietnamese output growth rate were highly associated with the demand-side disturbance (preference and risk premium shocks). Meanwhile, the fluctuations in the CPI inflation were mainly influenced by monetary policy shocks and import cost-push shocks.

There are two main contributions of this research as follows. First, there are a number of studies on developing and estimating both RBC and New Keynesian DSGE models for developing and emerging economies. However, the current literature on estimating the DSGE model for Vietnam is still limited. This research is the first attempt of developing and estimating this structural model for this country. Second, it contributes to the growing interest in the current literature on analyzing the sources of business cycle fluctuations in developing and emerging countries.

References

Adjemian, S., Bastani, H., Juillard, M., Karamé, F., Maih, J., Mihoubi, F., Perendia, G., Pfeifer, J., Ratto, M., and Villemot, S. (2011). DYNARE: Reference Manual Version 4. *Dynare Working Papers Series 1.*

Adolfson, M., Laséen, S., Christiano, L., Trabandt, M., and Walentin, K. (2013). RAMSES II-model description. *Sveriges Riksbank Occasional Paper Series 12.*

Adolfson, M., Laséen, S., Lindé, J., and MarcoRatto (2019). Identification versus misspecification in New Keynesian monetary policy models. *European Economic Review*, 113:225–246.

Adolfson, M., Laséen, S., Lindé, J., and Svensson, L. E. (2011). Optimal monetary policy in an operational medium-sized DSGE model. *Journal of Money, Credit and Banking*, 43(7):1287–1331.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2007a). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics*, 72(2):481–511.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2008a). Empirical properties of closed-and open-economy DSGE models of the Euro area. *Macroeconomic Dynamics*, 12(S1):2–19.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2008b). Evaluating an estimated New Keynesian small open economy model. *Journal of Economic Dynamics and Control*, 32(8):2690–2721.

Adolfson, M. and Lindé, J. (2011). Parameter identification in a estimated New Keynesian open economy model. *Sveriges Riksbank Working Paper Series 251.*

Adolfson, M., Lindé, J., and Villani, M. (2007b). Forecasting performance of an open economy DSGE model. *Econometric Reviews*, 26(2-4):289–328.

Altig, D., Christiano, L., Eichenbaum, M., and Lindé, J. (2003). The role of monetary policy in the propagation of technology shocks. *Manuscript, Northwestern University.*

Altig, D., Christiano, L., Eichenbaum, M., and Lindé, J. (2011). Firm-specific capital, nominal rigidities and the business cycle. *Review of Economic Dynamics*, 14(2):225–247.

An, S. and Schorfheide, F. (2007). Bayesian analysis of DSGE models. *Econometric reviews*, 26(2-4):113–172.

Anderson, D., Hunt, B., Kortelainen, M., Kumhof, M., Laxton, D., Muir, D., Mursula, S., and Snudden, S. (2013). Getting to know GIMF: The simulation properties of the global integrated monetary and fiscal model. *IMF Working Paper WP/13/55.*

Bańbura, M., Giannone, D., and Reichlin, L. (2010). Large Bayesian Vector Auto Regressions. *Journal of Applied Econometrics*, 25(1):71–92.

Bergholt, D. (2015). Foreign shocks. *Norges Bank Working Paper 15/2015.*

Brubakk, L. and Gelain, P. (2014). Financial factors and the macroeconomy - a policy model. *Norges Bank Staff Memos 10/2014.*

Buncic, D. and Melecky, M. (2008). An estimated New Keynesian policy model for Australia. *Economic Record*, 84(264):1–16.

Burgess, S., Fernandez-Corugedo, E., Groth, C., Harrison, R., Monti, F., Theodoridis, K., and Waldron, M. (2013). The Bank of England's forecasting platform: COMPASS, MAPS, EASE and the suite of models. *The Bank of England Working Paper No. 471.*

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3):383–398.

Canova, F. (2014). Bridging cyclical DSGE models and the raw data. *Journal of Monetary Economics*, 64:1–15.

Canova, F., Ferroni, F., and Matthes, C. (2014). Choosing the variables to estimate singular DSGE models. *Journal of Applied Econometrics*, 29(7):1099–1117.

Castro, G., Maria, J. R., Júlio, P., Félix, R. M., and Almeida, V. (2013). Inside PESSOA -a detailed description of the model. *Working Papers, Banco de Portugal.*

Ca'Zorzi, M., Kolasa, M., and Rubaszek, M. (2017). Exchange rate forecasting with DSGE models. *Journal of International Economics*, 107:127–146.

Chari, V. V., Kehoe, P. J., and McGrattan, E. R. (2002). Can sticky price models generate volatile and persistent real exchange rates? *Review of Economic Studies*, 69:533–6.

Choi, J. and Hur, J. (2015). An examination of macroeconomic fluctuations in Korea exploiting a Markov-switching DSGE approach. *Economic Modelling*, 51:183–199.

Christiano, L., Trabandt, M., and Walentin, K. (2011). Introducing financial frictions and unemployment into a small open economy model. *Journal of Economic Dynamics and Control*, 35(12):1999–2041.

Christiano, L. J. and Eichenbaum, M. (1992). Current Real-Business-Cycle Theories and Aggregate Labor-Market Fluctuations. *American Economic Review*, 82(3):430–450.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45.

Christiano, L. J., Eichenbaum, M. S., and Trabandt, M. (2016). Unemployment and business cycles. *Econometrica*, 84(4):1523–1569.

Clarida, R., Gali, J., and Gertler, M. (1999). The science of monetary policy: A New Keynesian perspective. *NBER Working Paper No. 7147*.

Coenen, G., Christoffel, K., and Warne, A. (2010). Forecasting with DSGE models. *ECB Working Paper No. 1185*.

Consolo, A., Favero, C. A., and Paccagnini, A. (2009). On the statistical identification of DSGE models. *Journal of Econometrics*, 98(2):203–223.

Cooley, T. F. and Hansen, G. D. (1989). The inflation tax in a real business cycle model. *American Economic Review*, pages 733–748.

Cwik, T., Müller, G. J., and Wolters, M. H. (2011). Does trade integration alter monetary policy transmission? *Journal of Economic Dynamics and Control*, 35(4):545–564.

Del Negro, M., Eusepi, S., Giannoni, M. P., Sbordone, A. M., Tambalotti, A., Cocci, M., Hasegawa, R., and Linder, M. H. (2013). The FRBNY-DSGE model. *Federal Reserve Bank of New York Staff Reports*.

Del Negro, M. and Schorfheide, F. (2006). How good is what you've got? DGSE-VAR as a Toolkit for Evaluating DSGE models. *Federal Reserve Bank of Atlanta Economic Review*.

Del Nergro, M., Schorfheide, F., Smets, F., and Wouters, R. (2007). On the fit of New Keynesian models. *Journal of Business Economic Statistics*, 25(2):123–143.

Devereux, M. B. and Engel, C. (2002). Exchange rate pass-through, exchange rate volatility, and exchange rate disconnect. *Journal of Monetary Economics*, 49:913–940.

Diebold, F. X. and Mariano, R. (1995). Comparing forecast accuracy. *Journal of Business and*.

Doan, T., Litterman, R., and Sims, C. (1984). Forecasting and conditional projection using realistic prior distributions. *Econometric reviews*, 3(1):1–100.

Dorich, J., Johnston, M., Mendes, R., Murchison, S., and Zhang, Y. (2013). ToTEM II: An Updated Version of the Bank of Canada's Quarterly Projection Model. *Bank of Canada Technical Report No. 100.*

Dotsey, M. and King, R. G. (2005). Implications of state-dependent pricing for dynamic macroeconomic models. *Journal of Monetary Economics*, 52(1):213–242.

Edge, R. M. and Gurkaynak, R. S. (2010). How useful are estimated DSGE model forecasts for central bankers? *Brookings Papers on Economic Activity.*

Edge, R. M., Kiley, M. T., and Laforte, J. (2010). A comparison of forecast performance between federal reserve staff forecasts, simple reduced-form models, and a DSGE model. *Journal of Applied Econometrics*, 25(4):720–754.

Engel, C. (2014). *Exchange rates and Interest Parity*, volume 4, pages 453–522.

Erceg, C. J., Gust, C., and L´opez-Salido, D. (2007). The transmission of domestic shocks in the open economy. *International Finance Discussion Papers,Board of Governors of the Federal Reserve System.*

Forni, M., Hallin, M., Lippi, M., and Reichlin, L. (2003). Do financial variables help forecasting inflation and real activity in the euro area? *Journal of Monetary Economics*, 50(6):1243–1255.

Fujiwara, I., Hara, N., Hirose, Y., and Teranishi, Y. (2005). The Japanese economic model. *Monetary and Economic Studies*, 23(2):61–142.

Gadatsch, N., Hauzenberger, K., and Stähler, N. (2015). German and the rest of Euro area fiscal policy during the crisis. *Deutsche Bundesbank Discussion Paper No 05/2015.*

Gadatsch, N., Hauzenberger, K., and Stähler, N. (2016). Fiscal policy during the crisis: A look on Germany and the Euro area with GEAR. *Economic Modelling*, 52:997–1016.

Galí, J. (2015). *Monetary policy, inflation, and the business cycle: an introduction to the New Keynesian framework and its applications.* Princeton University Press.

Gali, J. and Monacelli, T. (2005). Monetary policy and exchange rate volatility in a small open economy. *The Review of Economic Studies*, 72 (3):707–734.

Gerali, A., Neri, S., Sessa, L., and Signoretti, F. (2010). Credit and Banking in a DSGE model of the Euro area. *Journal of Money, Credit and Banking*, 42(S1):107–141.

Gertler, M., Sala, L., and Trigari, A. (2008). An estimated monetary DSGE model with unemployment and staggered nominal wage bargaining. *Journal of Money, Credit and Banking*, 40(8):1713–1764.

Geweke, J. (1991). *Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments*, volume 196. Federal Reserve Bank of Minneapolis, Research Department Minneapolis, MN, USA.

Gourinchas, P.-O. and Rey, H. (2014). *External adjustment, global imbalances, valuation effects*, volume 4 of *Handbook of International Economics*, pages 585–645. Elsevier.

Guerrieri, L., Gust, C., and López-Salido, J. D. (2010). International competition and inflation: A New Keynesian perspective. *American Economic Journal: Macroeconomics*, 2(4):247–280.

Gupta, R. and Kabundi, A. (2008). A dynamic factor model for forecasting macroeconomic variables in South Africa. *Forthcoming International Journal of Forecasting.*

Gupta, R. and Kabundi, A. (2010). Forecasting macroeconomic variables in a small open economy: a comparison between small-and large-scale models. *Journal of Forecasting*, 29(1-2):168–185.

Gust, C., Leduc, S., and Vigfusson, R. (2010). Trade integration, competition, and the decline in exchange-rate pass-through. *Journal of Monetary Economics*, 57(3):309–324.

Hamilton, J. D. (1994). *Time series analysis*, volume 2. Princeton university press Princeton, NJ.

Hansen, N. and Kern, S. (2004). Evaluating the CMA evolution strategy on multimodal test functions. In *PPSN*, volume 8, pages 282–291. Springer.

Harvey, D., Leybourne, S., and Newbold, P. (1997). Testing the equality of prediction mean squared errors. *International Journal of Forecasting*, 13(2):281–291.

Hastings, W. K. (1970). Monte Carlo sampling methods using Markov Chains and their applications. *Biometrika*, 57(1):97–109.

Herbst, E. and Schorfheide, F. (2012). Evaluating DSGE model forecasts of comovements. *Journal of Econometrics*, 171(2):152–166.

Hodge, A., Robinson, T., and Stuart, R. (2008). *A small BVAR-DSGE model for forecasting the Australian economy.* Economic Research Department, Reserve Bank of Australia.

Ireland, P. N. (2006). Technology shocks in the New Keynesian model. *Review of Economics and Statistics*, 86(4).

Ireland, P. N. (2011). A New Keynesian perspective on the Great Recession. *Journal of Money, Credit and Banking*, 43(1):31–54.

Iskrev, N. (2010a). Evaluating the strength of identification in DSGE models. A priori approach. In *Society for Economic Dynamics, 2010 Meeting Papers*.

Iskrev, N. (2010b). Local identification in DSGE models. *Journal of Monetary Economics*, 57(2):189–202.

Iskrev, N. (2018). Calibration and the estimation of macroeconomic models. *Banco de Portugal Working Papers*.

Iskrev, N. and Ratto, M. (2011). Algorithms for identification analysis under the DYNARE environment: final version of the software. *Joint Research Center European Commission*.

Jaimovich, N. and Rebelo, S. (2009). Can News about the future drive the business cycle? *American Economic Review*, 99(4):1097–1118.

Jääskelä, J. P. and Nimark, K. (2011). A medium-scale New Keynesian open economy model of Australia. *Economic Record*, 87(276):11–36.

Justiniano, A. and Preston, B. (2010a). Can structural small open-economy models account for the influence of foreign disturbances? *Journal of International Economics*, 81(1):61–74.

Justiniano, A. and Preston, B. (2010b). Monetary policy and uncertainty in an empirical small open-economy model. *Journal of Applied Econometrics*, 25(1):93–128.

Kalman, R. E. (1960). A new approach to linear filtering and prediction problems. *Journal of basic Engineering*, 82(1):35–45.

Kamber, G., McDonald, C., Sander, N., and Theodoridis, K. (2015). A structural model for policy analysis and forecasting: NZSIM. *RBNZ Discussion Paper Series DP2015/05*.

Kim, J. (2000). Constructing and estimating a realistic optimizing model of monetary policy. *Journal of Monetary Economics*, 45(2):329–359.

King, R. G., Plosser, C. I., and Rebelo, S. T. (1988). Production, growth and business cycles: I. The basic neoclassical model. *Journal of Monetary Economics*, 21(2-3):195–232.

Kolasa, M. and Rubaszek, M. (2018). Does foreign sector help forecast domestic variables in DSGE models? *International Journal of Forecasting*, 34(4):809–821.

Kollmann, R., Enders, Z., and Müller, G. J. (2011). Global banking and international business cycles. *European Economic Review*, 55(3):407–426.

Koop, G., Poirier, D. J., and Tobias, J. L. (2007). *Bayesian econometric methods*. Cambridge University Press.

Kydland, F. E. and Prescott, E. C. (1982). Time to build and aggregate fluctuations. *Econometrica*, 50(6):1345–1370.

Langcake, S. and Robinson, T. (2018). Forecasting the Australian economy with DSGE and BVAR models. *Applied Economics*, 50(3):251–267.

Leeper, E. M. and Sims, C. A. (1994). Toward a modern macroeconomic model usable for policy analysis. *NBER macroeconomics annual*, 9:81–118.

Lees, K., Matheson, T., and Smith, C. (2010). Open economy forecasting with a DSGE-VAR: Head to head with the RBNZ published forecasts. *International Journal of Forecasting*, 27(2):512–528.

Litterman, R. B. (1986). Forecasting with Bayesian Vector Autoregressions—five years of experience. *Journal of Business Economic Statistics*, 4(1):25–38.

Lombardo, G. and McAdam, P. (2012). Financial market frictions in a model of the Euro area. *Economic Modelling*, 29(6):2460–2485.

Long, J. B., Jr, and Plosser, C. I. (1983). Real business cycles. *Journal of Political Economy*, 91(1):39–69.

Lubik, T. A. and Schorfheide, F. (2007). Do central banks respond to exchange rate movements? A structural investigation. *Journal of Monetary Economics*, 54(4):1069–1087.

Marcellino, M. and Rychalovska, Y. (2014). Forecasting with a DSGE model of a small open economy within the monetary union. *Journal of Forecasting*, 33(5):315–338.

Marcellino, M., Stock, J. H., and Watson, M. W. (2003). Macroeconomic forecasting in the Euro area: Country specific versus area-wide information. *European Economic Review*, 47(1):1–18.

Maurice, O. and Rogoff, K. (2000). The six major puzzles in international macroeconomics. Is there a common cause? *NBER Macroeconomics Annual 2000*, pages 339–390.

McGrattan, E. R. (1994). The macroeconomic effects of distortionary taxation. *Journal of Monetary Economics*, 33(3):573–601.

Metropolis, N., Rosenbluth, A. W., Rosenbluth, M. N., Teller, A. H., and Teller, E. (1953). Equation of state calculations by fast computing machines. *The Journal of chemical physics*, 21(6):1087–1092.

Müller, U. K. (2012). Measuring prior sensitivity and prior informativeness in large Bayesian models. *Journal of Monetary Economics*, 59:581–597.

Monacelli, T. (2005). Monetary policy in a low pass-through environment. *Journal of Money, Credit and Banking*, 37:1047–1066.

Nimark, K. P. (2009). A structural model of Australia as a small open economy. *Australian Economic Review*, 42(1):24–41.

Pfeifer, J. (2017). An introduction to grahps in DYNARE. *Working Paper, The University of Cologne.*

Prescott, E. (1986). Theory Ahead of Business Cycle Measurement. *Carnegie-Rochester Conference Series on Public Policy*, 25:11–44.

Rabanal, P. and Tuesta, V. (2010). Euro-Dollar real exchange rate dynamics in an estimated two-country model: An assessment. *Journal of Economic Dynamics and Control*, 34(4):780–797.

Rees, D. M., Smith, P., and Hall, J. (2016). A Multi-sector Model of the Australian economy. *Economic Record*, 92(298):374–408.

Rotemberg, J. J. and Woodford, M. (1997). An optimization-based econometric framework for the evaluation of monetary policy. *NBER macroeconomics annual*, 12:297–346.

Rubaszek, M. and Skrzypczyński, P. (2008). On the forecasting performance of a small-scale DSGE model. *International Journal of Forecasting*, 24(3):498–512.

Schmitt-Grohé, S. and Uribe, M. (2012). What's News in business cycles. *Econometrica*, 80(6):2733–2764.

Schmitt-Grohé, S. and Uribe, M. (2018). How important are Terms-Of-Trade shocks? *International Economic Review*, 59(1):85–111.

Schumacher, C. (2007). Forecasting German GDP using alternative factor models based on large datasets. *Journal of Forecasting*, 26(4):271–302.

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica: Journal of the Econometric Society*, pages 1–48.

Smets, F. and Wouters, R. (2003). An estimated Dynamic Stochastic General Equilibrium model of the Euro area. *Journal of the European economic association*, 1(5):1123–1175.

Smets, F. and Wouters, R. (2004). Forecasting with a Bayesian DSGE model: An application to the Euro area. *JCMS: Journal of Common Market Studies*, 42(4):841–867.

Smets, F. and Wouters, R. (2005). Comparing shocks and frictions in US and Euro area business cycles: a Bayesian DSGE approach. *Journal of Applied Econometrics*, 20(2):161–183.

Steinbach, M., Mathuloe, P., and Smit, B. (2009). An open economy New Keynesian DSGE model of the South African economy. *South African Journal of Economics*, 77(2):207–225.

Steinsson, J. (2003). Optimal monetary policy in an economy with inflation persistence. *Journal of Monetary Economics*, 50(7):1425–1456.

Stähler, N. and Thomas, C. (2012). FiMod — a DSGE model for fiscal policy simulations. *Economic Modelling*, 29(2):239–261.

Stock, J. H. and Watson, M. W. (2002a). Forecasting using principal components from a large number of predictors. *Journal of the American statistical association*, 97(460):1167–1179.

Stock, J. H. and Watson, M. W. (2002b). Macroeconomic forecasting using diffusion indexes. *Journal of Business Economic Statistics*, 20(2):147–162.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, volume 39, pages 195–214. Elsevier.

Wang, M. (2009). Comparing the DSGE model with the factor model: an out-of-sample forecasting experiment. *Journal of Forecasting*, 28(2):167–182.

Wolters, M. H. (2015). Evaluating point and density forecasts of DSGE models. *Journal of Applied Econometrics*, 30(1):74–96.

Chapter 2

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

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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 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 linkages 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 misspecication and estimation uncertainty causes the failure of the open economy DSGE model in forecasting.

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

JEL Classification: B22, C11, E37, E47

2.1 Introduction

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 1.1 in Chapter 1).

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. (2008a), and Cwik et al. (2011) revealed 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), Christoffel et al. (2010), Lees et al. (2010), Marcellino and Rychalovska (2014), Ca'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, 2008b), 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.). Accordingly, there are two possible explanations for this issue. The first explanation is that the structural model has difficulty in replicating the volatilities and persistence of the exchange rate, and other issues, the so-called *"consumption-real exchange rate anomaly"* and *"exchange rate disconnect puzzle"* (Maurice and Rogoff (2000), Devereux and Engel (2002), Chari et al. (2002), Rabanal and Tuesta (2010), and Engel (2014)). In particular, Chari et al. (2002) mentioned *"If prices are held fixed for at least one year, risk aversion is high, and preferences are separable in* *leisure, then real exchange rates generated by the model are as volatile as in the data and quite persistent, but less so than in the data."* The two-country NK-DSGE model of Rabanal and Tuesta (2010) also has difficulty in revealing the negative correlation between relative consumption and real exchange rate. In addition, Engel (2014) argued *"Although this survey has suggested many different models, it is questionable that the models allow us to explain, even after the fact, the movements in major currency rates."* On the other hand, the second explanation is attributed to a lack of international co-movement across countries in a SOE-NK-DSGE model because of asymmetric shocks (Justiniano and Preston (2010a), Bergholt (2015)). Even though Justiniano and Preston (2010a) specified the correlated cross-country disturbances, this specification partially coincided with the effects of the international spillover on small economies like Canada. As a result, misspecification and estimation uncertainty may decrease the practical application of open economy DSGE models.

Therefore, 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.

This paper is related to two previous studies. The first is a more than 10-year-old study by Adolfson et al. (2008a) 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 for 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 this result 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.

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 using 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 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, the forecasting accuracy of the open economy DSGE model becomes worse.

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 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. 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. However, it is worth noting that there is a limit of this exercise as follows. The results will only be valid to the extent, that the calibration does not increase the misspecification of the 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, there is no misspecification problem when using Bayesian VAR models. In the literature, moreover, the Bayesian VAR model is typically used as a reference model of an estimated DSGE model (Smets and Wouters (2003), Del Negro 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 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. These findings imply that the SOE-NK-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.

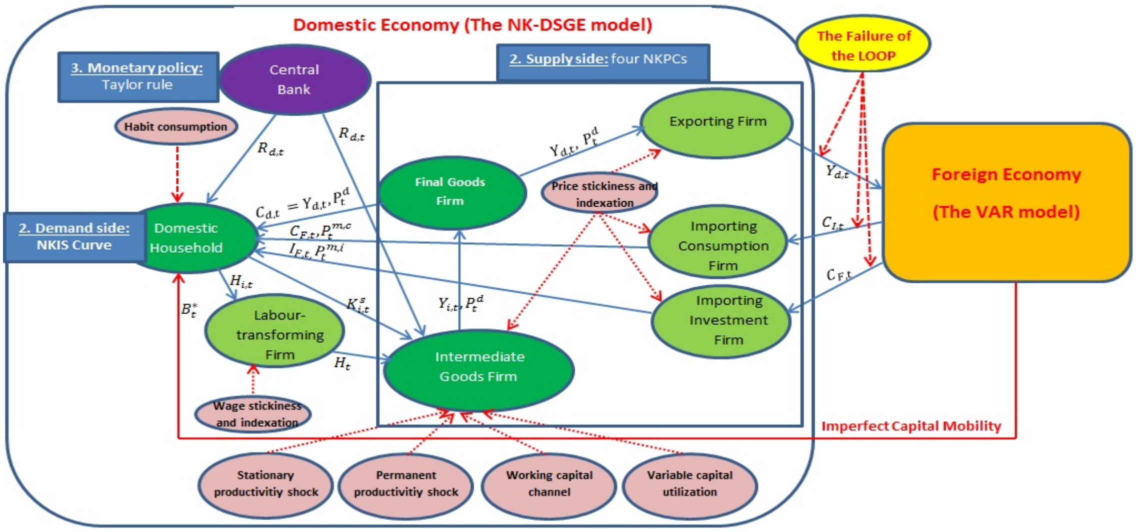
The rest of this paper is organized as follows. Section 2.2 presents the theoretical open economy DSGE model and its closed-economy counterpart. Section 2.3 introduces the data set and estimation methodology. Section 2.4 shows the estimation and result. Section 2.5 gives empirical evidence on the influence of the external sector on aggregate domestic activities. Section 2.6 shows the forecasting evaluation procedure and explanation for the difference in prediction between two competing models. Section 2.7 gives some conclusions.

2.2 Theoretical model

2.2.1 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 2.1 below. The detailed model specification is almost identical to the one in the studies of Jääskelä and Nimark (2011) and Adolfson and Lindé (2011).

Figure 2.1: Graphical illustration of a small open economy medium-sized model



Indeed, according to Figure 2.1 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 Phillips Curves (NKPC) describing the supply side. Finally, the last feature is to model the monetary policy rule, including the exchange rate.

Households

As shown in Figure 2.1, the model indicates that the domestic household consumes both domestic and imported goods in period t as follows.

$$C_t = \Big[(1-\omega_c)^{1/\eta_c}\Big(C_t^d\Big)^{\frac{\eta_c-1}{\eta_c}} + \omega_c^{1/\eta_c}\Big(C_t^m\Big)^{\frac{\eta_c-1}{\eta_c}}\Big]^{\frac{\eta_c}{\eta_c-1}}. \tag{2.2.1.1}$$

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 in period t below:

$$\Phi\Big(\frac{A_t}{z_t}, \widetilde{\phi}_t\Big) = \exp\Big[-\widetilde{\phi}_a \frac{A_t - \bar{A}}{z_t} + \widetilde{\phi}_t\Big], \tag{2.2.1.2}$$

$$\text{where } A_t = \frac{S_t \mathbf{E}_t B_{t+1}^*}{P_t^d}. \tag{2.2.1.3}$$

Because of the above function in (2.2.1.2), the log-linearization UIP in period t will be.

$$\widehat{R}_t - \widehat{R}_t^* = \mathbf{E}_t \Delta \widehat{S}_{t+1} - \widetilde{\phi}_a \widehat{a}_t + \widehat{\widetilde{\phi}}_t. \tag{2.2.1.4}$$

The presence of the terms $\widehat{a}_t$ and $\widehat{\widetilde{\phi}}_t$ in the equation (2.2.1.4) 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 $\mathbf{E}_t \Delta \widehat{S}_{t+1}$.

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[1].

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

$$
\begin{aligned}
\text{maximize} \quad & \mathbf{E}_t \sum_{s=0}^{\infty} \beta^s U(C_{t+s}, h_{t+s}, \frac{Q_{t+s}}{P^d_{t+s}}), \\
\text{subject to} \quad & \mathbf{E}_t \sum_{s=0}^{\infty} \beta^s \Bigg[M_{t+s+1} + S_{t+s} B^*_{t+s+1} + P^c_{t+s} C_{t+s} + P^i_{t+s} I_{t+s} + \\
& + P^d_{t+s} \Big[a(u_{t+s}) \bar{K}_{t+s} + P_{k',t+s} \Delta_{t+s} \Big] \Bigg] \\
& = \mathbf{E}_t \sum_{s=0}^{\infty} \beta^s \Bigg[R_{t+s-1}(M_{t+s} - Q_{t+s}) + Q_{t+s} + \Pi_{t+s} + W_{t+s} h_{t+s} + \\
& + R^k_{t+s} u_{t+s} \bar{K}_{t+s} + R^*_{t+s-1} \Phi\Big(\frac{A_{t+s-1}}{z_{t+s-1}}, \widetilde{\phi}_{t+s-1} \Big) S_{t+s} B^*_{t+s} + D_{t+s} \Bigg], \qquad (2.2.1.5) \\
\text{and} \quad & \mathbf{E}_t \sum_{s=0}^{\infty} \beta^s \Big[\bar{K}_{t+s+1} \Big] \\
& = \mathbf{E}_t \sum_{s=0}^{\infty} \beta^s \Big[(1-\delta) \bar{K}_{t+s} + \Upsilon_{t+s} F(I_{t+s}, I_{t+s-1}) + \Delta_{t+s} \Big], \\
\text{where} \quad & U(C_{t+s}, h_{t+s}, \frac{M_{t+s}}{P^d_{t+s}}) = \zeta^c_{t+s} ln(C_{t+s} - bC_{t+s-1}) - \\
& - \zeta^h_{t+s} A_L \frac{h^{1+\sigma_L}_{t+s}}{1+\sigma_L} + A_q \frac{\left(\frac{Q_{t+s}}{z_{t+s} P_{t+s}} \right)^{1-\sigma_q}}{1-\sigma_q}.
\end{aligned}
$$

Final goods firm

As shown in Figure 2.1, 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 in period t as follows:

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

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

$$
\lambda_{d,t} = (1 - \rho_{\lambda_d}) \lambda_d + \rho_{\lambda_d} \lambda_{d,t-1} + \epsilon_{\lambda_{d,t}}. \qquad (2.2.1.6)
$$

Given output price, P^d_t, and input price, $P^d_{i,t}$, the demand for the domestic intermediate goods, $Y_{i,t}$, is driven from the profit maximization problem in period t such as

$$
Y_{i,t} = Y_t \Big(\frac{P^d_t}{P^d_{i,t}} \Big)^{\frac{\lambda_{d,t}}{\lambda_{d,t}-1}}. \qquad (2.2.1.7)
$$

Domestic intermediate goods firm

To produce the domestic intermediate goods in period t, the domestic intermediate goods firm combines homogeneous labor ($H_{i,t}$), the capital services 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 in period t is described below.

$$Y_{i,t} = z_t^{1-\alpha} \epsilon_t K_{i,t}^{\alpha} H_{i,t}^{1-\alpha} - z_t \phi. \tag{2.2.1.8}$$

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 the capital utilization rate ($u_{i,t}$). The following equation presents the relation between these two capital stocks in period t.

$$K_{i,t} = u_{i,t} \bar{K}_{i,t}. \tag{2.2.1.9}$$

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) denotes this fraction. Thus, the total wage cost of the domestic intermediate goods firm in period t is

$$W_t H_{i,t} R_t^f = W_t H_{i,t} \Big[\nu_t R_{t-1} + (1 - \nu_t) \Big]. \tag{2.2.1.10}$$

It is worth noting that due to permanent productivity shocks in (2.2.1.8), and the capital working channel in (2.2.1.10) 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 in period t.

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

$$W_t R_t^f = (1 - \alpha) \lambda_t P_{i,t}^d z_t^{1-\alpha} \epsilon_t K_{i,t}^{\alpha} H_{i,t}^{-\alpha}. \tag{2.2.1.11}$$

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

$$R_t^k = \alpha \lambda_t P_{i,t}^d z_t^{1-\alpha} \epsilon_t K_{i,t}^{\alpha-1} H_{i,t}^{1-\alpha}. \tag{2.2.1.12}$$

Combining the two above results (2.2.1.11) and (2.2.1.12) and taking the first-order condition of the total cost to output yields the domestic intermediate goods firm's real marginal cost in period t.

$$mc_t^d = \Big(\frac{1}{1-\alpha}\Big)^{1-\alpha}\Big(\frac{1}{\alpha}\Big)^{\alpha}\big(r_t^k\big)^{\alpha}\Big[w_t\Big(\nu_t R_{t-1} + 1 - \nu_t\Big)\Big]^{1-\alpha}\frac{1}{\epsilon_t}. \qquad (2.2.1.13)$$

The above expression (2.2.1.13) indicates that the real marginal cost is identical 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)[2].

Moreover, the price indexation is introduced to obtain the hybrid New Keynesian Phillips curve. Indeed, a fraction of the domestic intermediate goods firm (ξ_d) that is not allowed to reset its price in period $t+s+1$ where the time subscript $s = 0 : \infty$, will adjust its price according to the following rule.

$$\mathbf{E}_t P_{i,t+s+1}^d = \mathbf{E}_t \Big(\pi_{t+s}^d\Big)^{\kappa_d}\Big(\bar{\pi}_{t+s+1}^T\Big)^{1-\kappa_d} P_{i,t+s}^d. \qquad (2.2.1.15)$$

where $\mathbf{E}_t \pi_{t+s}^d = \frac{P_{t+s}^d}{P_{t+s-1}^d}$ is inflation in period $t+s$. $\mathbf{E}_t \bar{\pi}_{t+s+1}^T$ is the inflation target or time-varying inflation target in period $t+s$, 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 in period $t+s$ will be

$$\mathbf{E}_t P_{t+s}^d = \mathbf{E}_t \Bigg[\xi_d\Big(P_{t+s-1}^d(\pi_{t+s-1}^d)^{\kappa_d}(\bar{\pi}_{t+s}^T)^{1-\kappa_d}\Big)^{\frac{1}{1-\lambda_{d,t+s}}} + (1-\xi_d)\Big(P_{d,t}^{new}\Big)^{\frac{1}{1-\lambda_{d,t+s}}}\Bigg]^{1-\lambda_{d,t+s}}. \qquad (2.2.1.16)$$

The domestic firm will seek the new price $P_{d,t}^{new}$ to maximize its following expected present discounted profit subject to the final goods firm's demand curve in (2.2.1.7).

$$\max_{P_{d,t}^{new}} \mathbf{E}_t \sum_{s=0}^{\infty}(\beta\xi_d)^s v_{t+s}\Bigg[\Big(\frac{P_{t+s-1}^d}{P_{t-1}^d}\Big)^{\kappa_d}\Big(\bar{\pi}_{t+1}^T\bar{\pi}_{t+2}^T ... \bar{\pi}_{t+s}^T\Big)^{1-\kappa_d} P_{d,t}^{new} Y_{i,t+s} - MC_{i,t+s}^d\Big(Y_{i,t+s} + z_{t+s}\phi\Big)\Bigg]. \qquad (2.2.1.17)$$

The first order condition of the above optimization problem is shown below.

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

$$mc_t^d = \Big(\frac{1}{1-\alpha}\Big)^{1-\alpha}\Big(\frac{1}{\alpha}\Big)^{\alpha}\big(r_t^k\big)^{\alpha} w_t^{1-\alpha}\frac{1}{\epsilon_t}. \qquad (2.2.1.14)$$

.

$$\mathbf{E}_t\sum_{s=0}^{\infty}(\beta\xi_d)^s v_{t+s}\left(\frac{\left(\frac{P^d_{t+s-1}}{P^d_{t-1}}\right)^{\kappa_d}\left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_d}}{\frac{P^d_{t+s}}{P_t}}\right)^{\frac{-\lambda_{d,t+s}}{\lambda_{d,t+s}-1}} Y_{t+s}P^d_{t+s}*$$
$$\left[\frac{\left(\frac{P^d_{t+s-1}}{P^d_{t-1}}\right)^{\kappa_d}\left(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\right)^{1-\kappa_d}}{\frac{P^d_{t+s}}{P^d_t}}\left(\frac{P^{new}_{d,t}}{P^d_t}\right)-\lambda_{d,t}\frac{MC^d_{i,t+s}}{P^d_{t+s}}\right]=0. \tag{2.2.1.18}$$

Taking a log-linear approximation of the above expression (2.2.1.18) will lead to a hybrid New Keynesian Phillips Curve for the domestic intermediate firm.

$$\begin{aligned}(\hat{\pi}^d_t-\hat{\bar{\pi}}^T_t)=&\frac{\beta}{1+\kappa_d\beta}(\mathbf{E}_t\hat{\pi}^d_{t+1}-\rho_\pi\hat{\bar{\pi}}^T_t)+\frac{\kappa_d}{1+\kappa_d\beta}(\hat{\pi}^d_{t-1}-\hat{\bar{\pi}}^T_t)\\&-\frac{\kappa_d(1-\rho_\pi)}{1+\kappa_d\beta}\hat{\bar{\pi}}^T_t+\frac{(1-\xi_d)(1-\beta\xi_d)}{\xi_d(1+\kappa_d\beta)}(\widehat{mc}^d_t+\widehat{\lambda}^d_t).\end{aligned} \tag{2.2.1.19}$$

Importing firms

As shown in Figure 2.1, 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 in period t are given below.

$$C^m_{i,t}=C^m_t\left(\frac{P^{m,c}_{i,t}}{P^{m,c}_t}\right)^{\frac{-\lambda^{m,c}_t}{\lambda^{m,c}_t-1}} \text{ and } I^m_{i,t}=I^m_t\left(\frac{P^{m,i}_{i,t}}{P^{m,i}_t}\right)^{\frac{-\lambda^{m,c}_t}{\lambda^{m,c}_t-1}}. \tag{2.2.1.20}$$

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

$$\lambda^{m,j}_t=(1-\rho_{\lambda^{m,j}})\lambda^{m,j}+\rho_{\lambda^{m,j}}\lambda^{m,j}_{t-1}+\epsilon_{\lambda^{m,j},t},\ \text{where } j=c,i. \tag{2.2.1.21}$$

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, $P^{m,c}_t$ and $P^{m,i}_t$. Thus, we take the first-order condition of the importing firm's total cost to its output to yield its real marginal cost in period t below.

$$mc^{m,j}_t=\frac{S_tP^*_t}{P^{m,j}_t},\ \text{where } j=c,i. \tag{2.2.1.22}$$

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 in period t is defined as follows.

$$X_t = \frac{S_t P_t^*}{P_t^c}, \tag{2.2.1.23}$$

$$\text{where } P_t^c = \left[(1-\omega_c)(P_t^d)^{1-\eta_c} + \omega_c (P_t^{m,c})^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}}. \tag{2.2.1.24}$$

Thus, the importing firm's real marginal cost in expression (2.2.1.22) 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 in period $t+s+1$.

$$\mathbf{E}_t P_{i,t+s+1}^{m,j} = \mathbf{E}_t \left(\pi_{t+s}^{m,j}\right)^{\kappa_{m,j}} \left(\bar{\pi}_{t+s+1}^T\right)^{1-\kappa_{m,j}} P_{i,t+s}^{m,j}, \text{ where } \pi_{t+s}^{m,j} = \frac{P_{t+s}^{m,j}}{P_{t+s-1}^{m,j}}. \tag{2.2.1.25}$$

On the other hand, fraction of the importing firms, $(1-\xi_{m,j})$ 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 in period $t+s$ will be

$$\mathbf{E}_t P_{t+s}^{m,j} = \mathbf{E}_t \left[\xi_{m,j}\left(P_{t+s-1}^{m,j}(\pi_{t+s-1}^{m,j})^{\kappa_{m,j}}(\bar{\pi}_{t+s}^T)^{1-\kappa_{m,j}}\right)^{\frac{1}{1-\lambda_t^{m,j}}} + (1-\xi_{m,j})\left(P_{m,j,t}^{new}\right)^{\frac{1}{1-\lambda_{t+s}^{m,j}}}\right]^{1-\lambda_{t+s}^{m,j}}. \tag{2.2.1.26}$$

The importing firms will seek the new prices $P_{m,c,t}^{new}$ and $P_{m,i,t}^{new}$ to maximize the following expected present discounted profits subject to the domestic household's demand curve in (2.2.1.20).

$$\max_{P_{m,c,t}^{new}} \mathbf{E}_t \sum_{s=0}^{\infty} (\beta\xi_{m,c})^s \upsilon_{t+s} \left[\left(\frac{P_{t+s-1}^{m,c}}{P_{t-1}^{m,c}}\right)^{\kappa_{m,c}} \left(\bar{\pi}_{t+1}^T \bar{\pi}_{t+2}^T \ldots \bar{\pi}_{t+s}^T\right)^{1-\kappa_{m,c}} P_{m,c,t}^{new} C_{i,t+s}^m \right.$$
$$\left. - S_{t+s} P_{t+s}^* \left(C_{i,t+s}^m + z_{t+s}\phi^{m,c}\right)\right]. \tag{2.2.1.27}$$

$$\max_{P^{new}_{m,i,t}} \mathbf{E}_t \sum_{s=0}^{\infty} (\beta \xi_{m,i})^s v_{t+s} \Bigg[\Big(\frac{P^{m,i}_{t+s-1}}{P^{m,i}_{t-1}}\Big)^{\kappa_{m,i}} \Big(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\Big)^{1-\kappa_{m,i}} P^{new}_{m,i,t} I^m_{i,t+s} \\ - S_{t+s}P^*_{t+s}\Big(I^m_{i,t+s} + z_{t+s}\phi^{m,i}\Big)\Bigg]. \tag{2.2.1.28}$$

The first order conditions of the above optimization problems are given below.

$$\mathbf{E}_t \sum_{s=0}^{\infty} (\beta \xi_{m,c})^s v_{t+s} \left(\frac{\Big(\frac{P^{m,c}_{t+s-1}}{P^{m,c}_{t-1}}\Big)^{\kappa_{m,c}} \Big(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\Big)^{1-\kappa_{m,c}}}{\frac{P^{m,c}_{t+s}}{P_t}{}^{m,c}} \right)^{\frac{-\lambda^{m,c}_{t+s}}{\lambda^{m,c}_{t+s}-1}} C^m_{t+s} P^{m,c}_{t+s} * \\ \left[\frac{\Big(\frac{P^{m,c}_{t+s-1}}{P^{m,c}_{t-1}}\Big)^{\kappa_{m,c}} \Big(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\Big)^{1-\kappa_d}}{\frac{P^{m,c}_{t+s}}{P^{m,c}_t}} \Big(\frac{P^{new}_{m,c,t}}{P^{m,c}_t}\Big) - \lambda^{m,c}_{t+s} \frac{S_{t+s}P^*_{t+s}}{P^{m,c}_{t+s}} \right] = 0. \tag{2.2.1.29}$$

$$\mathbf{E}_t \sum_{s=0}^{\infty} (\beta \xi_{m,i})^s v_{t+s} \left(\frac{\Big(\frac{P^{m,i}_{t+s-1}}{P^{m,i}_{t-1}}\Big)^{\kappa_{m,i}} \Big(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\Big)^{1-\kappa_{m,i}}}{\frac{P^{m,i}_{t+s}}{P_t}{}^{m,i}} \right)^{\frac{-\lambda^{m,i}_{t+s}}{\lambda^{m,i}_{t+s}-1}} I^m_{t+s} P^{m,i}_{t+s} * \\ \left[\frac{\Big(\frac{P^{m,i}_{t+s-1}}{P^{m,i}_{t-1}}\Big)^{\kappa_{m,i}} \Big(\bar{\pi}^T_{t+1}\bar{\pi}^T_{t+2}...\bar{\pi}^T_{t+s}\Big)^{1-\kappa_d}}{\frac{P^{m,i}_{t+s}}{P^{m,i}_t}} \Big(\frac{P^{new}_{m,i,t}}{P^{m,i}_t}\Big) - \lambda^{m,i}_{t+s} \frac{S_{t+s}P^*_{t+s}}{P^{m,i}_{t+s}} \right] = 0. \tag{2.2.1.30}$$

Taking a log-linear approximation of the two above expressions (2.2.1.29) and (2.2.1.30) will lead to the hybrid New Keynesian Philips Curve for the importing firms.

$$(\hat{\pi}^{m,j}_t - \hat{\bar{\pi}}^T_t) = \frac{\beta}{1+\kappa_{m,j}\beta}(\mathbf{E}_t\hat{\pi}^{m,j}_{t+1} - \rho_\pi \hat{\bar{\pi}}^T_t) + \frac{\kappa_d}{1+\kappa_{m,j}\beta}(\hat{\pi}^{m,j}_{t-1} - \hat{\bar{\pi}}^T_t) \\ - \frac{\kappa_{m,j}(1-\rho_\pi)}{1+\kappa_{m,j}\beta}\hat{\bar{\pi}}^T_t + \frac{(1-\xi_{m,j})(1-\beta\xi_{m,j})}{\xi_{m,j}(1+\kappa_{m,j}\beta)}(\widehat{mc}^{m,j}_t + \widehat{\lambda}^{m,j}_t). \tag{2.2.1.31}$$

It is worth noting that hybrid New Keynesian Philips Curve for the importing firms in (2.2.1.31) 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 (2.2.1.22) is below.

$$\widehat{mc}^{m,j}_t = \widehat{p}^*_t + \widehat{s}_t - \widehat{p}^{m,j}_t, \text{ where } j = c, i. \tag{2.2.1.32}$$

Exporting firm

Similar to the importing firm, the exporting firm does not produce goods. As shown in Figure 2.1, it buys the final domestic goods from the final goods firm and sells in the foreign economy. The demand for the exporting firm's goods i in period t is given below.

$$\tilde{X}_{i,t} = \tilde{X}_t \Big(\frac{P^x_{i,t}}{P^*_t} \Big)^{\frac{-\lambda^x_t}{\lambda^x_t - 1}}. \tag{2.2.1.33}$$

The variables, λ^x_t, denotes the stochastic markup on the exported goods in period t, which follows the process below.

$$\lambda^x_t = (1 - \rho_{\lambda^x})\lambda^x + \rho_{\lambda^x}\lambda^x_{t-1} + \epsilon_{\lambda^x,t}. \tag{2.2.1.34}$$

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

$$mc^x_t = \frac{P^d_t}{S_t P^x_t}. \tag{2.2.1.35}$$

The expression above implies that the real marginal cost is identical to across exporting firms. Thus, we drop the index i. On the other hand, it is worth remembering the definition of the real exchange rate in the expression (2.2.1.23). Thus, the exporting firm's real marginal costs in the expression (2.2.1.35) 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 in period $t + s + 1$.

$$\mathbf{E}_t P^x_{t+s+1} = \mathbf{E}_t \Big(\pi^x_t\Big)^{\kappa_x} \Big(\bar{\pi}^T_{t+s+1}\Big)^{1-\kappa_x} P^x_{t+s}, \text{ where } \mathbf{E}_t \pi^x_{t+s} = \frac{P^x_{t+s}}{P^x_{t+s-1}}. \tag{2.2.1.36}$$

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 in period t will be

$$\mathbf{E}_t P^x_{t+s} = \mathbf{E}_t \left[\xi_x \left(P^x_{t+s-1} (\pi^x_{t+s-1})^{\kappa_x} (\bar{\pi}^T_{t+s})^{1-\kappa_x} \right)^{\frac{1}{1-\lambda_{m,j,t+s}}} + (1-\xi_x) \left(P^{new}_{x,t} \right)^{\frac{1}{1-\lambda_{x,t+s}}} \right]^{1-\lambda_{x,t+s}}. \tag{2.2.1.37}$$

The exporting firms will seek the new price $P^{new}_{x,t}$ to maximize its following expected present discounted profit subject to the foreign economy's demand curve in (2.2.1.33).

$$\max_{P^{new}_{x,t}} \mathbf{E}_t \sum_{s=0}^{\infty} (\beta\xi_x)^s \upsilon_{t+s} \left[\left(\frac{P^x_{t+s-1}}{P^x_{t-1}} \right)^{\kappa_x} \left(\bar{\pi}^T_{t+1} \bar{\pi}^T_{t+2} ... \bar{\pi}^T_{t+s} \right)^{1-\kappa_x} P^{new}_{x,t} \tilde{X}_{i,t+s} - \frac{P_{t+s}}{S_{t+s}} \left(\tilde{X}_{i,t+s} + z_{t+s}\phi^x \right) \right]. \tag{2.2.1.38}$$

The first order condition of the above optimization problem is given below.

$$\mathbf{E}_t \sum_{s=0}^{\infty} (\beta\xi_x)^s \upsilon_{t+s} \left(\frac{\left(\frac{P^x_{t+s-1}}{P^x_{t-1}} \right)^{\kappa_x} \left(\bar{\pi}^T_{t+1} \bar{\pi}^T_{t+2} ... \bar{\pi}^T_{t+s} \right)^{1-\kappa_x}}{\frac{P^x_{t+s}}{P_t}^{x}} \right)^{\frac{-\lambda^x_{t+s}}{\lambda^x_{t+s}-1}} \tilde{X}^x_{t+s} P^x_{t+s} * \left[\frac{\left(\frac{P^x_{t+s-1}}{P^x_{t-1}} \right)^{\kappa_x} \left(\bar{\pi}^T_{t+1} \bar{\pi}^T_{t+2} ... \bar{\pi}^T_{t+s} \right)^{1-\kappa_d}}{\frac{P^x_{t+s}}{P^x_t}} \left(\frac{P^{new}_{x,t}}{P^x_t} \right) - \lambda^x_{t+s} \frac{MC^x_{i,t+s}}{P^x_{t+s}} \right] = 0. \tag{2.2.1.39}$$

Taking a log-linear approximation of the above expression (2.2.1.39) will lead to a hybrid New Keynesian Philips Curve for the exporting firms.

$$(\hat{\pi}^x_t - \hat{\bar{\pi}}^T_t) = \frac{\beta}{1+\kappa_x\beta} (\mathbf{E}_t \hat{\pi}^x_{t+1} - \hat{\bar{\pi}}^T_t) + \frac{\kappa_d}{1+\kappa_x\beta} (\hat{\pi}^x_{t-1} - \hat{\bar{\pi}}^T_t) - \frac{\kappa_x(1-\rho_\pi)}{1+\kappa_x\beta} \hat{\bar{\pi}}^T_t + \frac{(1-\xi_x)(1-\beta\xi_x)}{\xi_x(1+\kappa_x\beta)} (\widehat{mc}^x_t + \hat{\lambda}^x_t). \tag{2.2.1.40}$$

It is worth noting that hybrid New Keynesian Philips Curve for the exporting firms in (2.2.1.40) 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 (2.2.1.35) is

$$\widehat{mc}^x_t = \hat{p}^d_t - \hat{p}^x_t - \hat{s}_t. \tag{2.2.1.41}$$

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 lagged interest rates $\widehat{R}_{t-1}$, the deviation of CPI inflation from the time-varying inflation target $(\hat{\pi}^c_{t-1} - \hat{\bar{\pi}}^T_t)$, the lagged output gap $\hat{y}_{t-1}$, and the lagged real exchange rate $\hat{x}_{t-1}$, and changes in CPI inflation $\Delta\hat{\pi}^c_t$ and output $\Delta\hat{y}_t$ as follows (log-linear form).

$$\begin{aligned}\hat{R}_t =& \rho_R \widehat{R}_{t-1} + (1-\rho_R)\big[\hat{\bar{\pi}}^T_t + r_\pi(\hat{\pi}^c_{t-1} - \hat{\bar{\pi}}^T_t) + r_y\hat{y}_{t-1} + r_x\hat{x}_{t-1}\big] \\ &+ r_{\Delta\pi}\Delta\hat{\pi}^c_t + r_{\Delta y}\Delta\hat{y}_t + \epsilon_{R,t}.\end{aligned} \tag{2.2.1.42}$$

Market clearing conditions

The three following markets must clear in equilibrium in period t.

The first one is the domestic final goods market.

$$C^d_t + I^d_t + C^x_t + I^x_t = Y_t - a(u_t)\bar{K}_t. \tag{2.2.1.43}$$

The second one is the international balance of payment.

$$S_tP^x_t(C^x_t + I^x_t) - S_tP^*_t(C^m_t + I^m_t) = S_t\mathbf{E}_tB^*_{t+1} - R^*_{t-1}\Phi\Big(\frac{A_{t-1}}{z_{t-1}}, \widetilde{\phi}_{t-1}\Big)S_tB^*_t. \tag{2.2.1.44}$$

It is worth noting that the left-hand side of the above expression (2.2.1.44) 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.

$$\nu_tW_tH_t = \mu_tM_t - Q_t. \tag{2.2.1.45}$$

2.2.2 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 shocks. As an example, Adolfson et al. (2008a) 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 2.1, the following fundamental channels will connect and transmit the external shocks to the domestic economy.

The deviation of the UIP.

$$\widehat{R}_t - \widehat{R}_t^* = \mathbf{E}_t \Delta \widehat{S}_{t+1} - \widetilde{\phi}_a \widehat{a}_t + \widehat{\widetilde{\phi}}_t. \tag{2.2.2.1}$$

Three laws of one price gaps:

$$\begin{aligned} &\text{The imported consumption firm} \quad \Delta \widehat{mc}_t^{m,c} = \widehat{\pi}_t^* + \Delta \widehat{s}_t - \widehat{\pi}_t^{m,c}, \\ &\text{The imported investment firm} \quad \Delta \widehat{mc}_t^{m,i} = \widehat{\pi}_t^* + \Delta \widehat{s}_t - \widehat{\pi}_t^{m,i}, \\ &\text{The exporting firm} \quad \Delta \widehat{mc}_t^{x} = \widehat{\pi}_t^d - \hat{\pi}_t^x - \Delta \hat{s}_t. \end{aligned} \tag{2.2.2.2}$$

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

First, the domestic inflation dynamics ($\widehat{\pi}_t^d$) is described as the hybrid New Keynesian Phillips Curve in the equation (2.2.1.19). Its fluctuation is influenced by the external sectors via the exporting firm's the law of one price gap in (2.2.2.2). Thus, a rise in domestic inflation is associated with the depreciation of exchange rate $\hat{s}_t$, the exporting firm's hybrid New Keynesian Phillips curve $\hat{\pi}_t^x$.

Second, log-linear domestic consumption is depicted below

$$\begin{aligned} \hat{c}_t = & \frac{1}{\mu_z^2 + b^2\beta} \Bigg\{ b\beta\mu_z \mathbf{E}_t \hat{c}_{t+1} + b\mu_z \hat{c}_{t-1} - b\mu_z(\hat{\mu}_{z,t} + \beta \mathbf{E}_t \hat{\mu}_{z,t+1}) \\ & - (\mu_z - b\beta)(\mu_z - b)\hat{\psi}_{z,t} - (\mu_z - b\beta)(\mu_z - b)\omega_c [\gamma^{c,mc}]^{-(1-\eta_c)} \\ & [\widehat{\gamma}_{t-1}^{mc,d} + \widehat{\pi}_t^{m,c} - \hat{\pi}_t^d] + (\mu_z - b)(\mu_z \hat{\zeta}_t^c - b\beta \mathbf{E}_t \zeta_{t+1}^c) \Bigg\}. \end{aligned} \tag{2.2.2.3}$$

Based on the above expression (2.2.2.3), the changes in domestic consumption are related to external factors, such as the domestic consumption terms 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 (2.2.2.4) below presents log-linear domestic investment. Accordingly, the changes in investment are influenced by several external factors, such as the domestic investment terms 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.

$$\hat{i}_t = \frac{1}{\mu_z^2 S''(\mu_z)(1+\beta)} \Bigg\{ \mu_z^2 S''(\mu_z)(\hat{i}_{t-1} + \beta \mathbf{E}_t \hat{i}_{t+1} - \hat{\mu}_t) + \hat{P}_{k',t} + \hat{\Upsilon}_t - \omega_i (\gamma^{i,mi})^{-(1-\eta_i)} \left[\hat{\gamma}_{t-1}^{mi,d} + \hat{\pi}_t^{m,i} - \hat{\pi}_t^d \right] \Bigg\}. \tag{2.2.2.4}$$

Fourth, the equation (2.2.2.5) below depicts the log-linear form of the domestic goods market-clearing condition in (2.2.1.43). 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.

$$\hat{y}_t = \frac{1}{\lambda_d} \Bigg\{ (1-\omega_c)(\gamma^{c,d})^{\eta_c} (\frac{\bar{c}}{\bar{y}})[\hat{c}_t + \eta_c \hat{\gamma}_t^{c,d}] + (1-\omega_i)(\gamma^{i,d})^{\eta_i} (\frac{\bar{i}}{\bar{y}})[\hat{i}_t + \eta_i \hat{\gamma}_t^{i,d}] + \frac{\bar{y}^*}{\bar{y}} [\hat{y}_t^* - \eta_f \hat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^*] - r^k (\frac{\bar{k}}{\bar{y}}) \frac{1}{\mu_z} (\hat{k}_t - \hat{\bar{k}}_t) \Bigg\}. \tag{2.2.2.5}$$

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 in the two following equations. The link between employment $\hat{N}_t$ and working hours is described in the equation (2.2.2.6) below.

$$\hat{N}_t = \frac{\beta}{1+\beta} \mathbf{E}_t \hat{N}_{t+1} + \frac{1}{1+\beta} \hat{N}_{t-1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{\xi_e(1+\beta)} (\hat{H}_t - \hat{N}_t). \tag{2.2.2.6}$$

On the other hand, variations in working hours are impacted by external blocks as described in the equation (2.2.2.7) below.

$$\lambda_d(1-\alpha)\hat{H}_t = (1-\omega_c)(\gamma^{c,d})^{\eta_c} (\frac{\bar{c}}{\bar{y}})(\hat{c}_t + \eta_c \hat{\gamma}_t^{c,d}) \quad (1-\omega_i)(\gamma^{i,d})^{\eta_i} (\frac{\bar{i}}{\bar{y}})(\hat{i}_t + \eta_i \hat{\gamma}_t^{i,d}) + \frac{\bar{y}^*}{\bar{y}} (\hat{y}_t^* - \eta_f \hat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^*) + r^k (\frac{\bar{k}}{\bar{y}}) \frac{1}{\mu_z} (\hat{k}_t - \hat{\bar{k}}_t) - \lambda_d \hat{\varepsilon}_t - \alpha(\hat{k}_t - \hat{\mu}_{z,t}). \tag{2.2.2.7}$$

Sixth, the equation (2.2.2.8) 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 $\hat{h}_t$.

$$
\begin{aligned}
\hat{w}_t = & -\frac{1}{\sigma_L \lambda_w - b_w(1+\beta\xi_w^2)} \Bigg[b_w \xi_w \hat{w}_{t-1} + b_w \beta \xi_w \mathbf{E}_t \hat{w}_{t+1} + b_w \beta \xi_w (\mathbf{E}_t \hat{\pi}_{t+1}^d - \hat{\bar{\pi}}_t^T) \\
& - b_w \xi_w (\hat{\pi}_t^d - \rho_{\hat{\bar{\pi}}^T} \hat{\bar{\pi}}_t^T) + b_w \xi_w \kappa_w (\hat{\pi}_{t-1}^c - \hat{\bar{\pi}}_t^T) + b_w \beta \xi_w \kappa_w (\hat{\pi}_t^c - \rho_{\hat{\bar{\pi}}^T} \hat{\bar{\pi}}_t^T) \\
& - (1-\lambda_w)\sigma_L \hat{H}_t + (1-\lambda_w)\hat{\psi}_{z,t} - (1-\lambda_w)\hat{\zeta}_t^h \Bigg].
\end{aligned} \tag{2.2.2.8}
$$

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 (2.2.2.1). 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 (2.2.2.9)

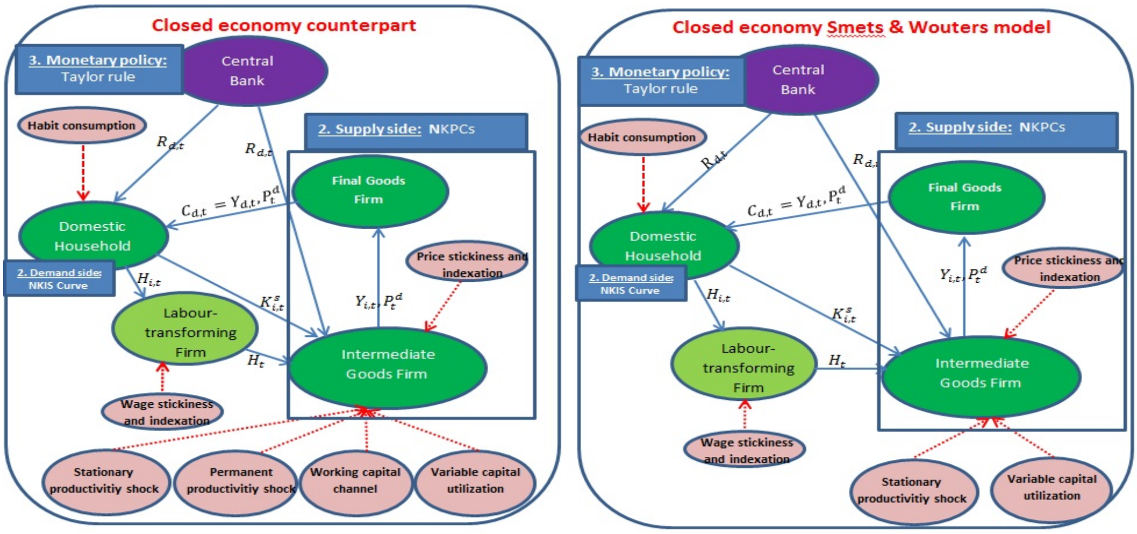
$$
\begin{aligned}
\hat{R}_t = & \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left[\hat{\bar{\pi}}_t^T + r_\pi(\hat{\pi}_{t-1}^c - \hat{\bar{\pi}}_t^T) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\right] \\
& + r_{\Delta\pi}\Delta\hat{\pi}_t^c + r_{\Delta y}\Delta\hat{y}_t + \epsilon_{R,t}.
\end{aligned} \tag{2.2.2.9}
$$

2.2.3 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 imported consumption and investment goods in aggregate consumption and investment. Regarding the 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 macroeconomic observed variables to estimate the model parameters.

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, interestingly 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 2.2 shows two notable differences between the closed-economy counterpart and the influential model of Smets and Wouters (2003). As shown in section (2.2.1), 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 2.2: Graphical illustration of a closed-economy medium-sized model



2.3 Data and methodology

2.3.1 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 the theoretical model, 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), employment (N_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 2.8.1. 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 2.3.

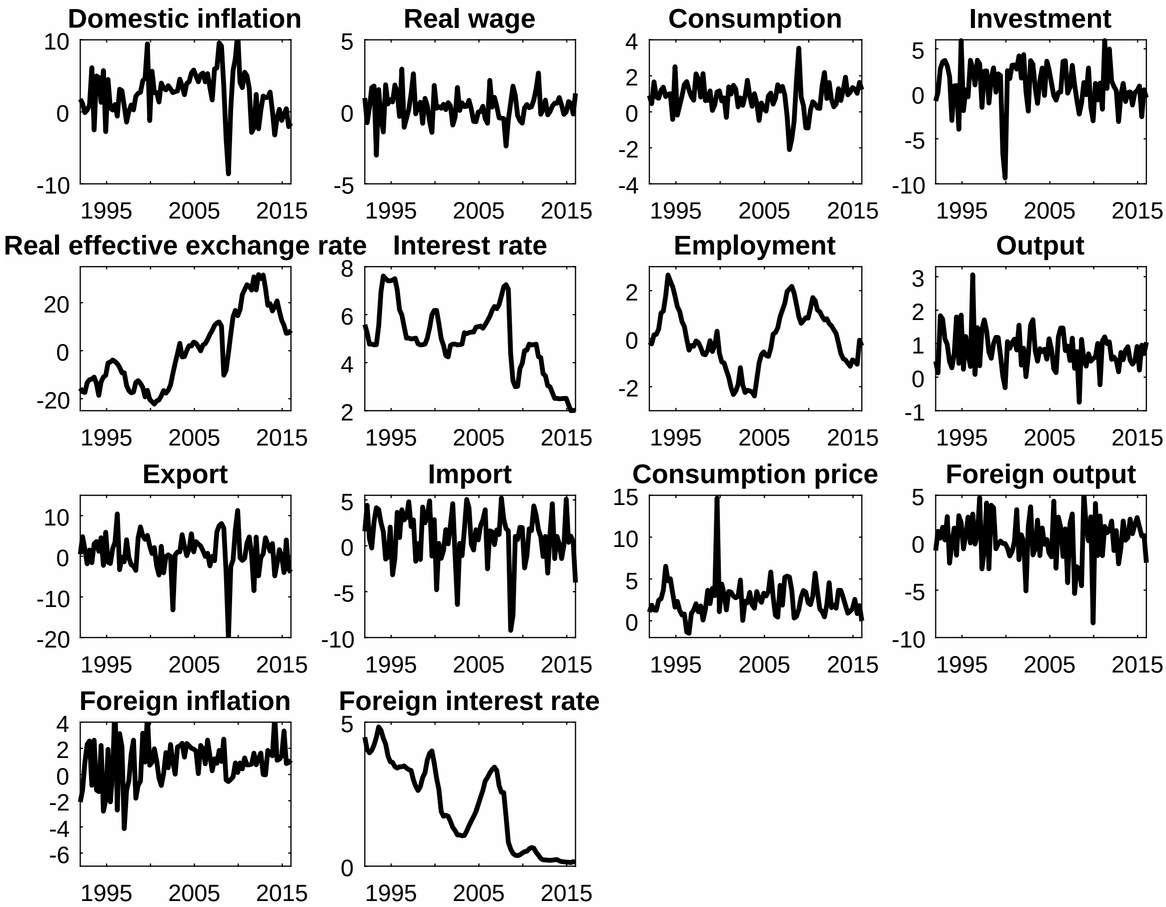


Figure 2.3: Australian data

2.3.2 Estimation Methodology

The log-linearized DSGE model can be expressed as a state-space framework below. This is because the state space system represents the backward looking solution of the forward looking model under the assumption of rational expectations.

The state equation	$\Omega_t = A\Omega_{t-1} + B\varepsilon_t$	(2.3.2.1)
The observed equation	$\Phi_t = C\Phi_{t-1} + D\Omega_t + F\epsilon_t$	(2.3.2.2)
The shocks and measurement errors	$\varepsilon_t \sim N(0, I_q)$ and $\epsilon_t \sim N(0, I_r)$	(2.3.2.3)

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[3] 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,

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

$p(\Theta)$, and likelihood function, $p(\Phi_t|\Theta)$, as in the following formula.

$$p(\Theta|\Phi_t) \propto p(\Theta)p(\Phi_t|\Theta) \tag{2.3.2.4}$$

In terms of the log form, the posterior density in (3.4.3.4) will be

$$\begin{aligned} \ln p(\Theta|\Phi_t) &\propto \ln p(\Theta) + \ln p(\Phi_t|\Theta) \\ &\propto \ln p(\Theta) + \ln L \end{aligned} \tag{2.3.2.5}$$

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.

$$q(\vartheta \mid \Theta^{i-1}) \sim \mathbf{N}(\Theta^{i-1}, c^2\Sigma) \tag{2.3.2.6}$$

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 (2.3.2.4). 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.

$$\text{The acceptance ratio} = \frac{\text{A number of accepted draws}}{\text{A total number of proposal draws}} \tag{2.3.2.7}$$

2.4 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 2.10 in Appendix 2.8.2). 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[4] (ρ_{π^T}). In this paper, it was calibrated as 0.975, which is identical to Adolfson et al. (2007a).

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

[4] According to Adolfson et al. (2007a), it is the AR(1) process.

truncate uniform [0, ∞). 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 Adolfson et al. (2007a), 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 (2.3.2.4). Using this mode, we propose a multivariate normal distribution $q(\vartheta \mid \Theta^{i-1})$ in (2.3.2.6). 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 2.1: 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 adjustment 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	$\tilde{\phi}_a$	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 2.2: 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 2.1 and 2.2 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 except for the non-stationary and investment-specific technology shocks. Meanwhile, the estimated standard deviations of shocks are smaller in the closed economy model except for the non-stationary, stationary technology and consumption preference shocks.

Finally, regarding the estimated parameters in the policy rule, inflation and inflation growth response $(r_\pi, r_{\Delta\pi})$ are bigger in the 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.

2.5 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 2.2.2, 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 functions and a variance decomposition. The findings may then give some initial guesses for the forecasting performance of the underlying open economy DSGE model.

2.5.1 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 2.2.2.

First, Figure 2.4 shows the responses of macroeconomic variables to a positive risk premium shock (σ_{ϕ}). Based on the uncovered interest rate parity in the equation (2.2.1.4), it is worth noting that the 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. An increase in the 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 (2.2.2.2). 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 the 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.

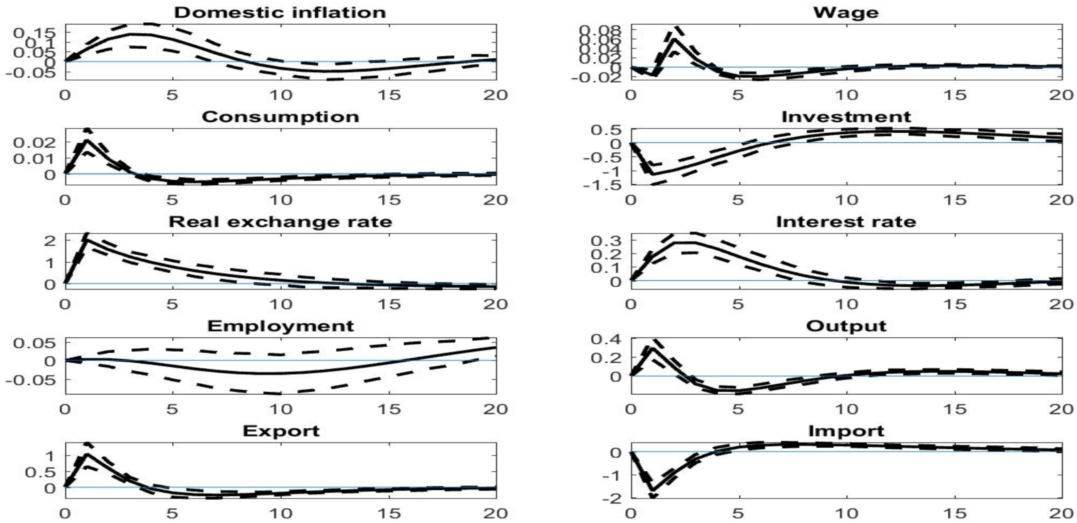


Figure 2.4: Responses to risk premium shock (σ_ϕ)

Second, Figure 2.5 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 (2.2.2.5). 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 hardly respond to the foreign supply-side shock.

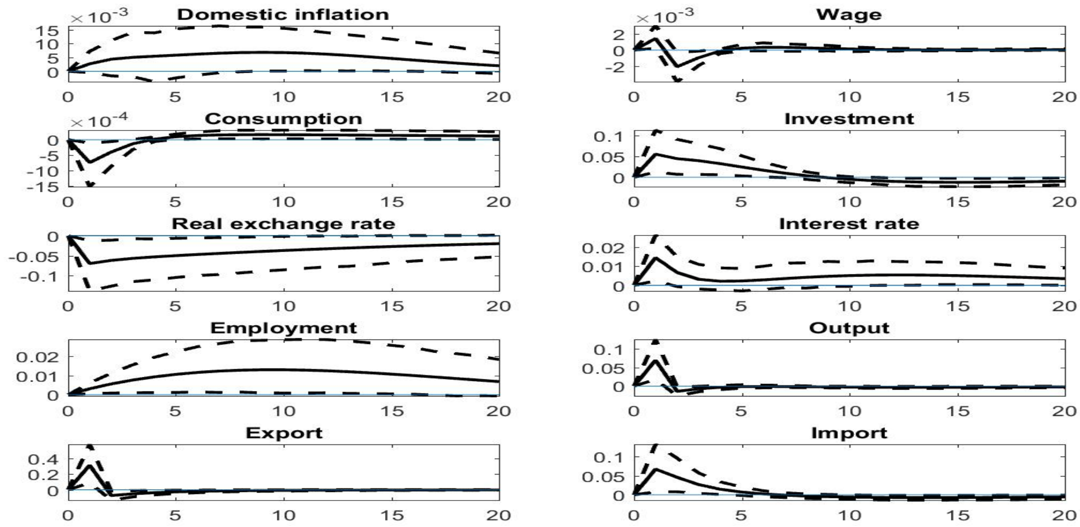


Figure 2.5: Responses to asymmetric technology shock (σ_{z*})

Third, Figure 2.6 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 (2.2.2.2). 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.

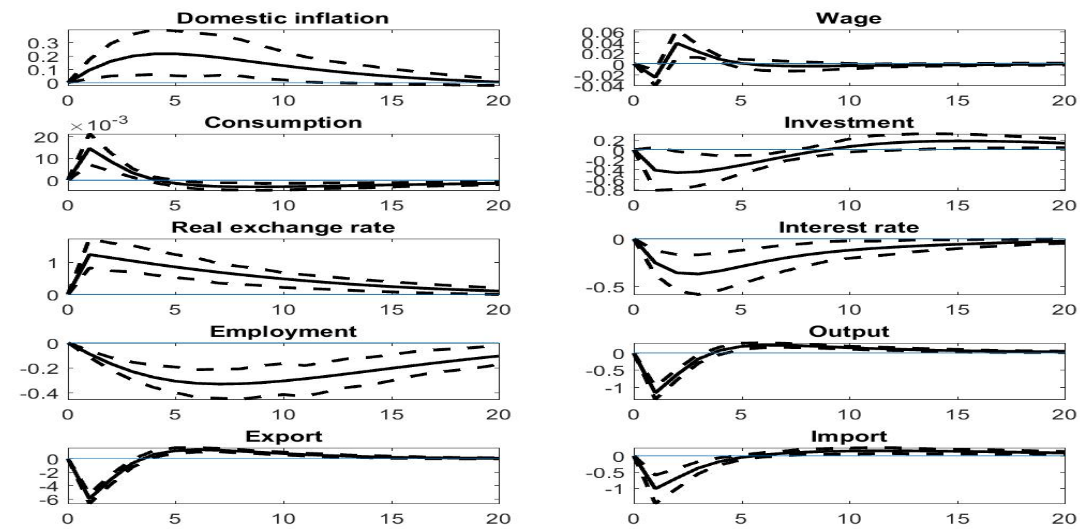


Figure 2.6: Responses to exporting markup shock (σ_{λ^x})

Last, Figure 2.7 and 2.8 show the effects of two remaining external-sector 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).

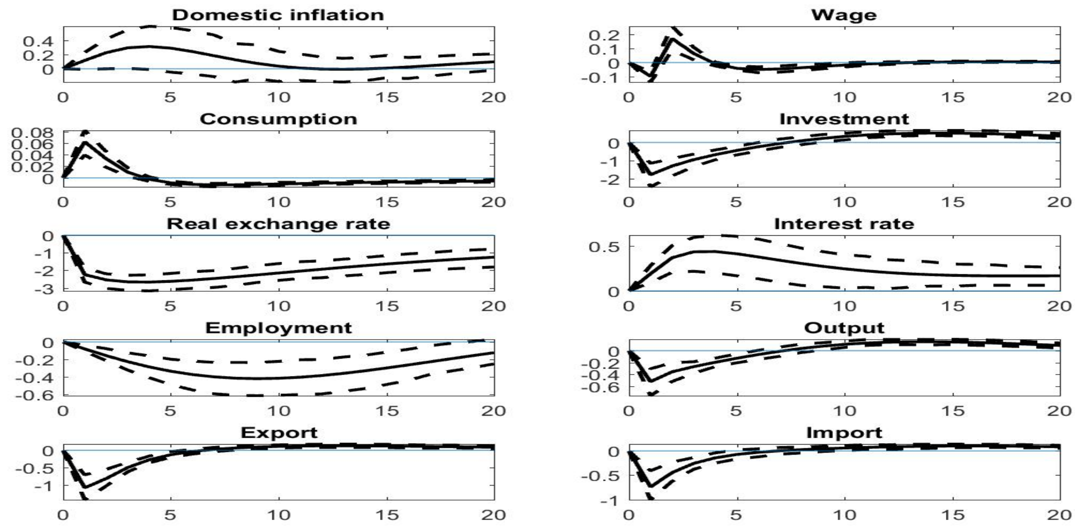


Figure 2.7: Responses to importing consumption markup shock ($\sigma_{\lambda^{mc}}$)

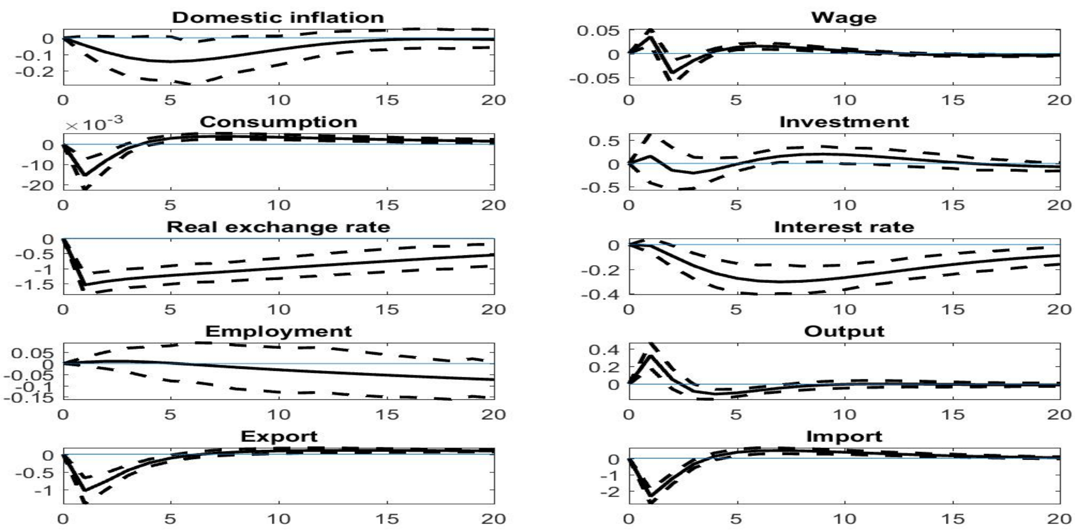


Figure 2.8: Responses to importing investment markup shock ($\sigma_{\lambda^{mi}}$)

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 for 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.

2.5.2 How strongly do external shocks influence the domestic economy?

Tables 2.3 and 2.4 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 shocks (σ_{λ^x}). This impact is clearly explained through the LOOP gap in the exporting firm in (2.2.2.2). On the other hand, exports are mainly driven by asymmetric technology shock (σ_{z*}). This fact is not surprising. Intuitively, changes in technology in the foreign economy would strongly influence its economic growth. Thus, if technology in a foreign economy develops faster than in 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 2.3: 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 2.4: 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 2.1. Thus, we move next to comparing the forecasting performance between closed – and open economy DSGE models.

2.6 Forecasting evaluation procedure

2.6.1 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, if the values are close to unity, this indicates that forecasts from both closed- and open-economy DSGE models are equally accurate. However, in order to test whether the ratio of RMSEs is statistically significantly different from unity, the two-tailed Diebold-Mariano test is then conducted.

Table 2.5 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 all forecasting errors tend 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 produces more accurate forecasts 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.

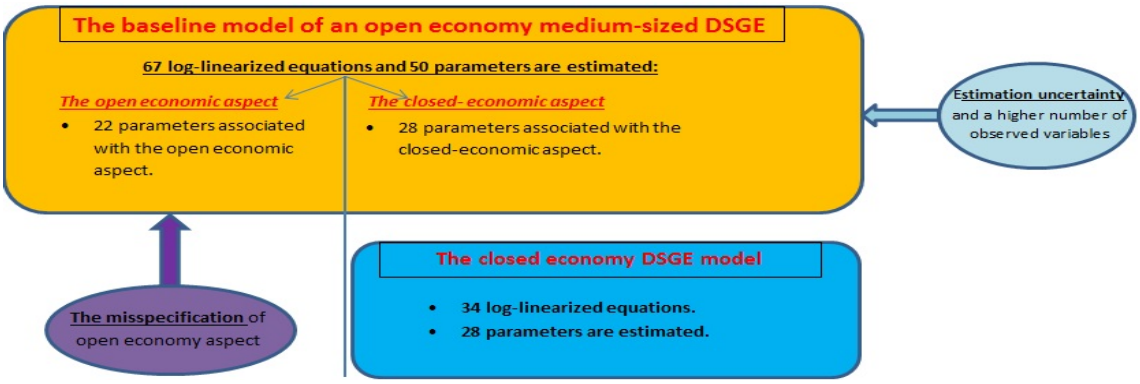
Table 2.5: The relative RMSE of open-economy to closed-economy DSGE model

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 2.9, 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 2.9: Graphical illustration of the open and closed economy models



2.6.2 The new variant of open and closed economy models

Based on the full sample size of the Australian data, in Section 2.5, 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 2.1 and 2.2). 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 (3.4.3.2). 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 2.6: 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 2.7: 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 2.8: 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 2.10, 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 2.6 and 2.7 show the posterior estimates of this open economy model through the full sample size.

Figure 2.10: Graphical illustration of a variant of open and closed economy models

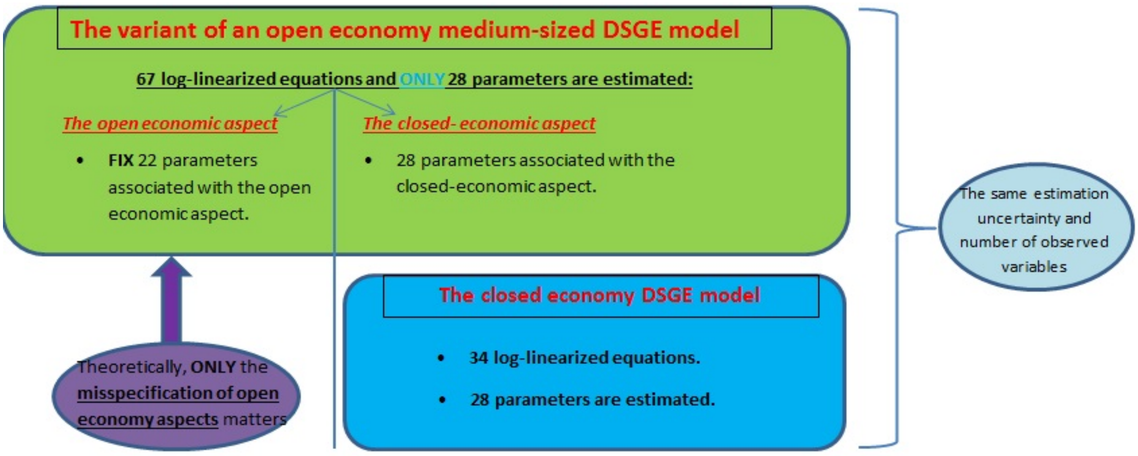


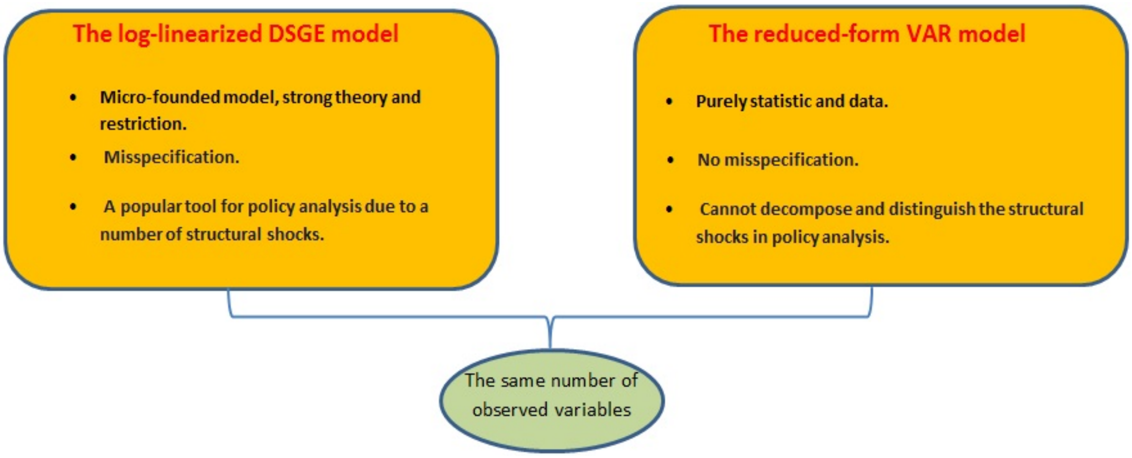
Table 2.8 shows the relative RMSEs of the modification of open to closed economy DSGE models. Accordingly, the forecasting error tends to increase for higher periods. Furthermore, almost all relative RMSE values are above unity and statistically significant. For example, some RMSE values in the cases 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.

2.6.3 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 2.11 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 (Del 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), Del Negro 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 2.11: 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 2.9 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 . It 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, 2008b), 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 2.9: The relative RMSE of open-economy to closed-economy BVAR model

Horizon quaters	**Relative root mean squared errors**						
	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.

2.7 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.

2.8 Appendices

2.8.1 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.

2.8.2 Calibrated parameters

Table 2.10: 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 dom. goods	Justiniano and Preston (2010b)
15	ρ_{π^c}	0.975	Persistent param. inflation target	Adolfson et al. (2007a)

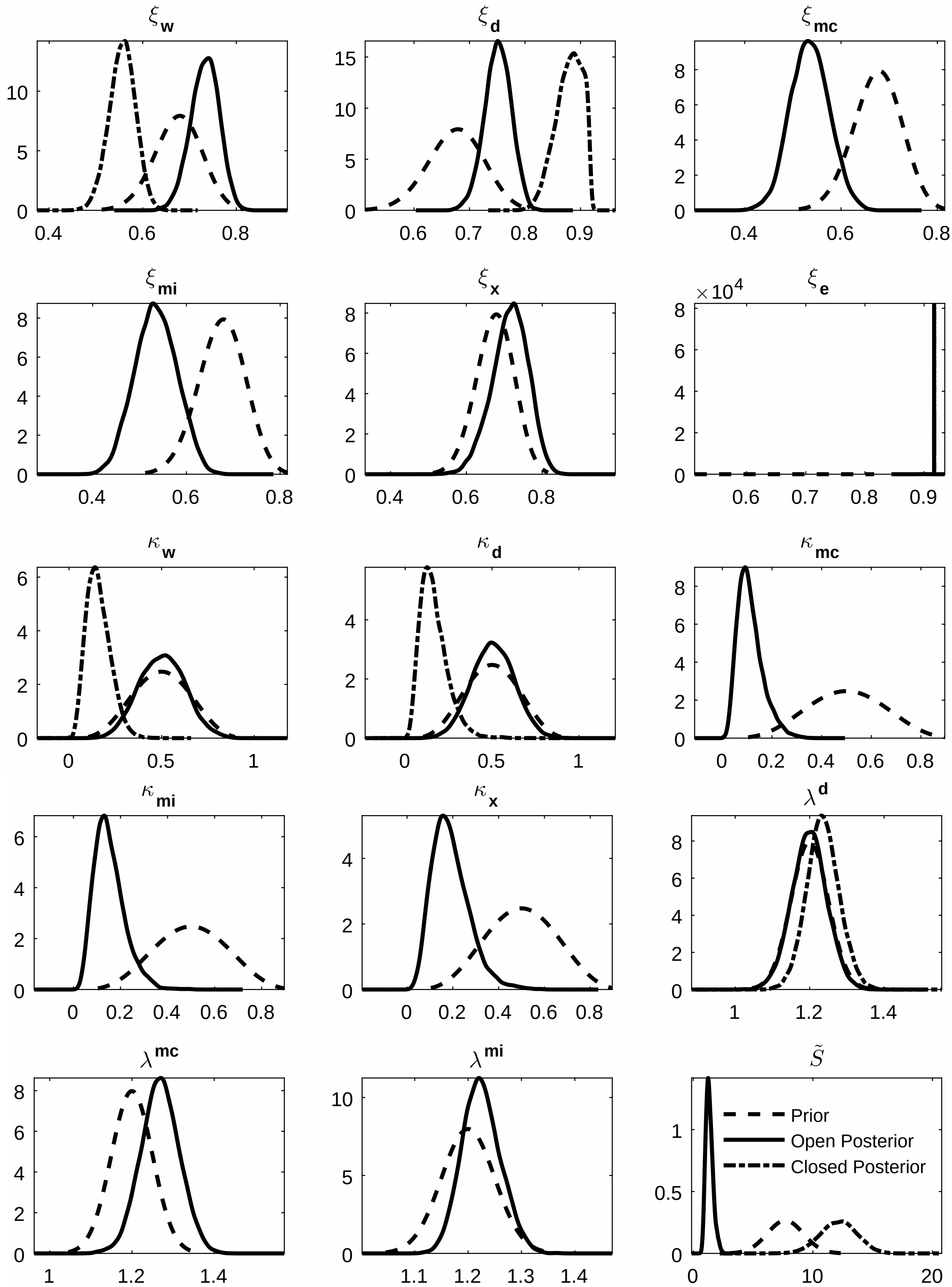


Figure 2.12: Prior and Posterior densities in the closed-and open economy DSGE model

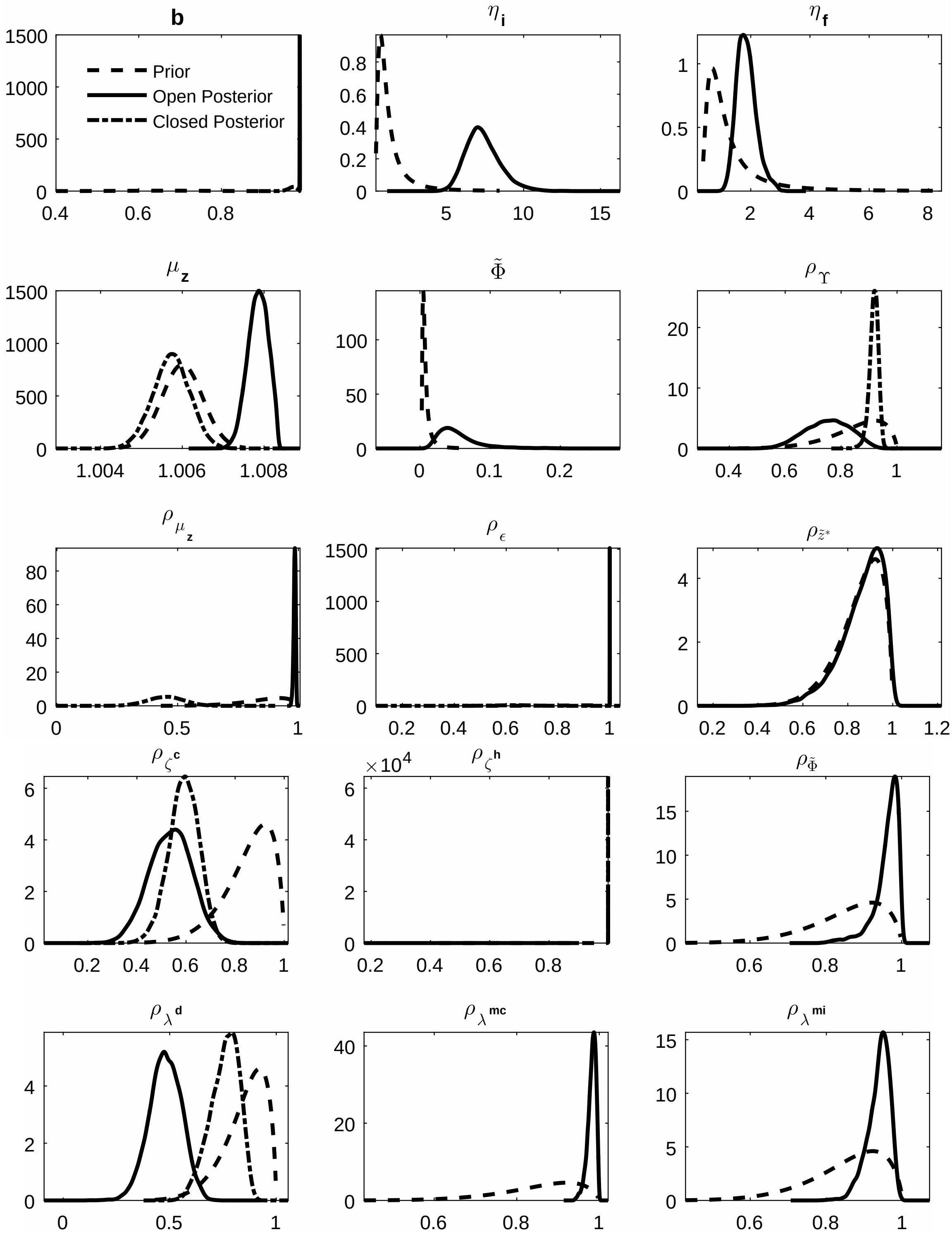


Figure 2.13: Prior and Posterior densities in the closed-and open-economy DSGE model

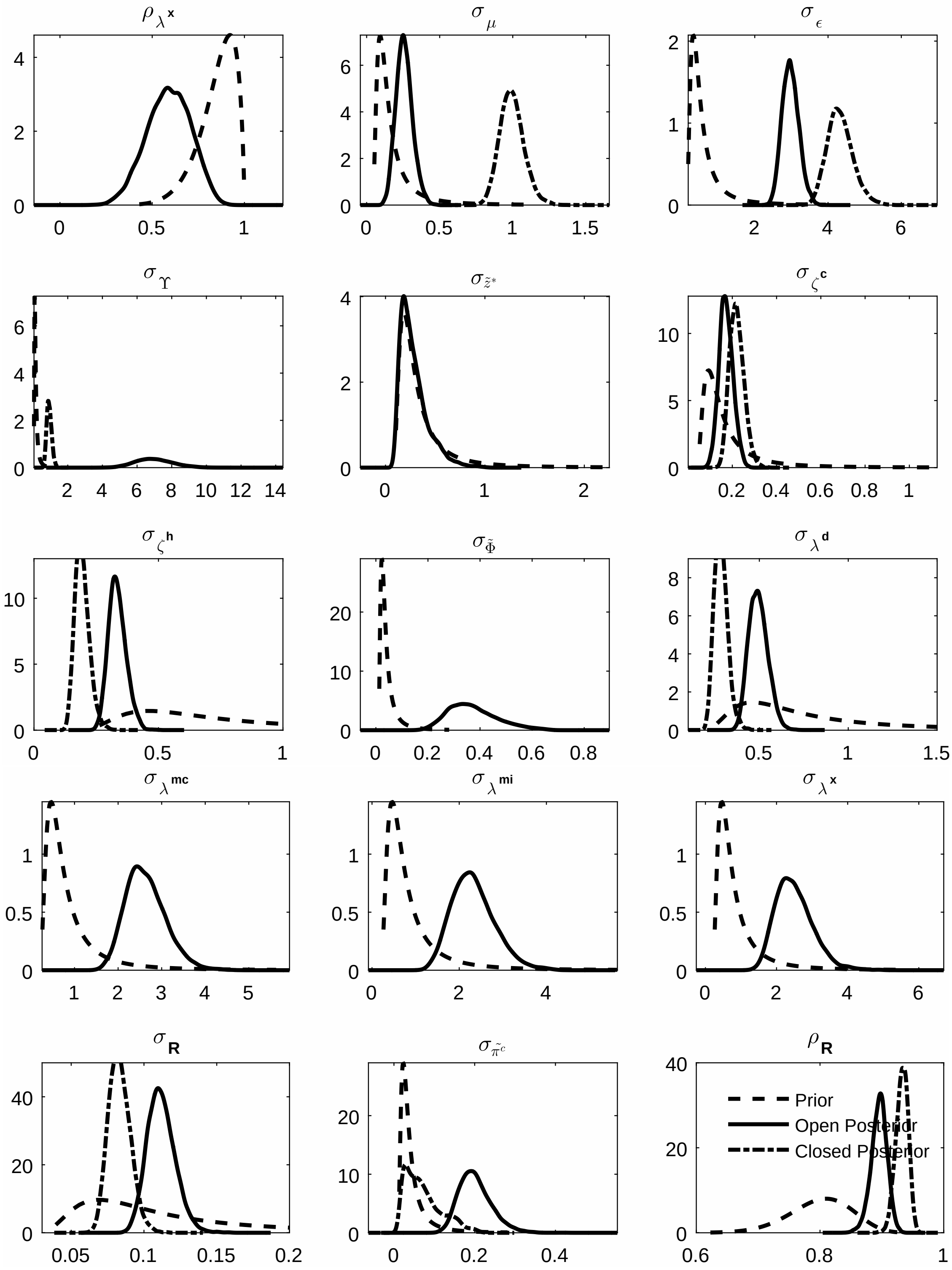


Figure 2.14: Prior and Posterior densities in the closed-and open-economy DSGE model

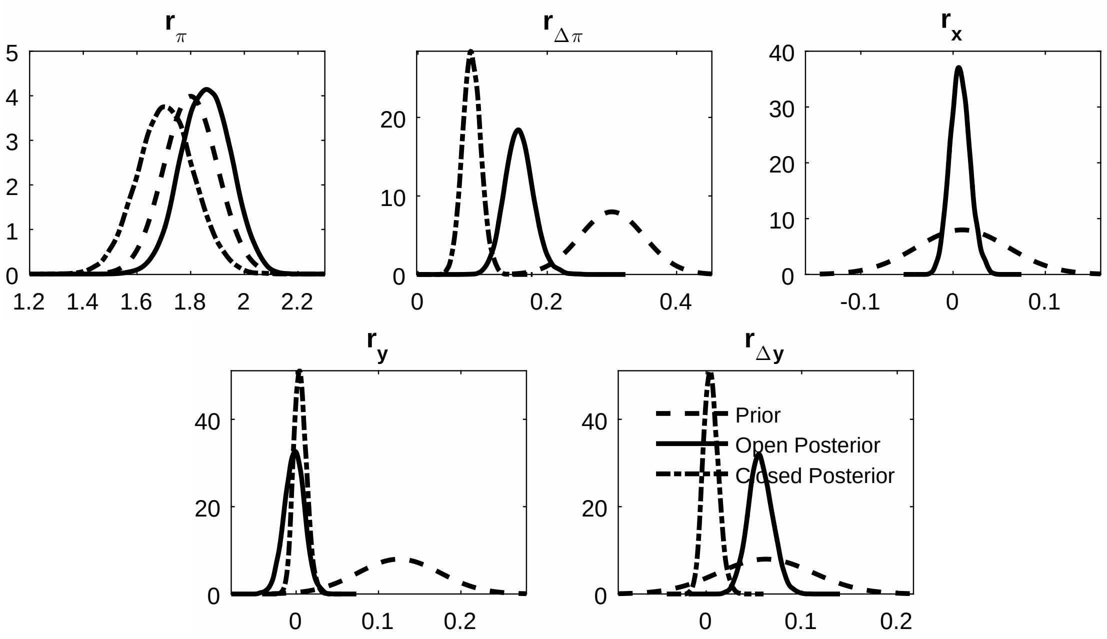


Figure 2.15: Prior and Posterior densities in the closed-and open-economy DSGE model

References

Adjemian, S., Bastani, H., Juillard, M., Karamé, F., Maih, J., Mihoubi, F., Perendia, G., Pfeifer, J., Ratto, M., and Villemot, S. (2011). DYNARE: Reference Manual Version 4. *Dynare Working Papers Series 1.*

Adolfson, M., Laséen, S., Christiano, L., Trabandt, M., and Walentin, K. (2013). RAMSES II-model description. *Sveriges Riksbank Occasional Paper Series 12.*

Adolfson, M., Laséen, S., Lindé, J., and Ratto, M. (2019). Identification versus misspecification in New Keynesian monetary policy models. *European Economic Review*, 113:225–246.

Adolfson, M., Laséen, S., Lindé, J., and Svensson, L. E. (2011). Optimal monetary policy in an operational medium-sized DSGE model. *Journal of Money, Credit and Banking*, 43(7):1287–1331.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2007a). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics*, 72(2):481–511.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2008a). Empirical properties of closed-and open-economy DSGE models of the Euro area. *Macroeconomic Dynamics*, 12(S1):2–19.

Adolfson, M., Laséen, S., Lindé, J., and Villani, M. (2008b). Evaluating an estimated New Keynesian small open economy model. *Journal of Economic Dynamics and Control*, 32(8):2690–2721.

Adolfson, M. and Lindé, J. (2011). Parameter identification in a estimated New Keynesian open economy model. *Sveriges Riksbank Working Paper Series 251.*

Adolfson, M., Lindé, J., and Villani, M. (2007b). Forecasting performance of an open economy DSGE model. *Econometric Reviews*, 26(2-4):289–328.

Altig, D., Christiano, L., Eichenbaum, M., and Lindé, J. (2003). The role of monetary policy in the propagation of technology shocks. *Manuscript, Northwestern University.*

Altig, D., Christiano, L., Eichenbaum, M., and Lindé, J. (2011). Firm-specific capital, nominal rigidities and the business cycle. *Review of Economic Dynamics*, 14(2):225–247.

Altug, S. (1989). Time-to-build and aggregate fluctuations: some new evidence. *International Economic Review*, 30(4):889–920.

An, S. and Schorfheide, F. (2007). Bayesian analysis of DSGE models. *Econometric Reviews*, 26(2-4):113–172.

Anderson, D., Hunt, B., Kortelainen, M., Kumhof, M., Laxton, D., Muir, D., Mursula, S., and Snudden, S. (2013). Getting to know GIMF: The simulation properties of the global integrated monetary and fiscal model. *IMF Working Paper WP/13/55.*

Bańbura, M., Giannone, D., and Reichlin, L. (2010). Large Bayesian Vector Auto Regressions. *Journal of Applied Econometrics*, 25(1):71–92.

Bergholt, D. (2015). Foreign shocks. *Working Paper 15/2015, Norges Bank.*

Brubakk, L. and Gelain, P. (2014). Financial factors and the macroeconomy - a policy model. *Staff Memos 10/2014, Norges Bank.*

Buncic, D. and Melecky, M. (2008). An estimated New Keynesian policy model for Australia. *Economic Record*, 84(264):1–16.

Burgess, S., Fernandez-Corugedo, E., Groth, C., Harrison, R., Monti, F., Theodoridis, K., and Waldron, M. (2013). The Bank of England's forecasting platform: COMPASS, MAPS, EASE and the suite of models. *The Bank of England Working Paper No. 471.*

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3):383–398.

Canova, F. (2014). Bridging cyclical DSGE models and the raw data. *Journal of Monetary Economics*, 64:1–15.

Canova, F., Ferroni, F., and Matthes, C. (2014). Choosing the variables to estimate singular DSGE models. *Journal of Applied Econometrics*, 29(7):1099–1117.

Ca'Zorzi, M., Kolasa, M., and Rubaszek, M. (2017). Exchange rate forecasting with DSGE models. *Journal of International Economics*, 107:127–146.

Chari, V. V., Kehoe, P. J., and McGrattan, E. R. (2002). Can sticky price models generate volatile and persistent real exchange rates? *Review of Economic Studies*, 69:533–6.

Choi, J. and Hur, J. (2015). An examination of macroeconomic fluctuations in Korea exploiting a Markov-switching DSGE approach. *Economic Modelling*, 51:183–199.

Christiano, L., Trabandt, M., and Walentin, K. (2011). Introducing financial frictions and unemployment into a small open economy model. *Journal of Economic Dynamics and Control*, 35(12):1999–2041.

Christiano, L. J. and Eichenbaum, M. (1992). Current Real-Business-Cycle Theories and Aggregate Labor-Market Fluctuations. *American Economic Review*, 82(3):430–450.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45.

Christiano, L. J., Eichenbaum, M. S., and Trabandt, M. (2016). Unemployment and business cycles. *Econometrica*, 84(4):1523–1569.

Christoffel, K., Coenen, G., and Warne, A. (2010). Forecasting with DSGE models. *ECB Working Paper Series No 1185*.

Clarida, R., Gali, J., and Gertler, M. (1999). The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature*, 34(7):1661–1707.

Consolo, A., Favero, C. A., and Paccagnini, A. (2009). On the statistical identification of DSGE models. *Journal of Econometrics*, 98(2):203–223.

Cooley, T. F. and Hansen, G. D. (1989). The inflation tax in a real business cycle model. *The American Economic Review*, 79(4):733–748.

Cwik, T., Müller, G. J., and Wolters, M. (2011). Does trade integration alter monetary policy transmission? *Journal of Economic Dynamics and Control*, 35(4):545–564.

Daniel Rees, P. S. and Hall, J. (2016). A Multi-sector model of the Australian economy. *Economic Record*, 92(298):374–408.

Del Negro, M., Eusepi, S., Giannoni, M. P., Sbordone, A. M., Tambalotti, A., Cocci, M., Hasegawa, R., and Linder, M. H. (2013). The FRBNY-DSGE model. *Staff Reports No. 647, Federal Reserve Bank of New York*.

Del Negro, M. and Schorfheide, F. (2006). How good is what you've got? DGSE-VAR as a Toolkit for Evaluating DSGE models. *Economic Review*, 91(2):21–37.

Del Negro, M., Schorfheide, F., Smets, F., and Wouters, R. (2007). On the fit of New Keynesian models. *Journal of Business Economic Statistics*, 25(2):123–143.

Devereux, M. B. and Engel, C. (2002). Exchange rate pass-through, exchange rate volatility, and exchange rate disconnect. *Journal of Monetary Economics*, 49:913–940.

Diebold, F. X. and Mariano, R. S. (1995). Comparing Predictive Accuracy. *Journal of Business and Economic Statistics*, 13(3):253–263.

Doan, T., Litterman, R., and Sims, C. (1984). Forecasting and conditional projection using realistic prior distributions. *Econometric Reviews*, 3(1):1–100.

Dorich, J., Johnston, M., Mendes, R., Murchison, S., and Zhang, Y. (2013). ToTEM II: An Updated Version of the Bank of Canada's Quarterly Projection Model. *Technical Report No. 100, Bank of Canada.*

Dotsey, M. and King, R. G. (2005). Implications of state-dependent pricing for dynamic macroeconomic models. *Journal of Monetary Economics*, 52(1):213–242.

Edge, R. M. and Gurkaynak, R. S. (2010). How useful are estimated DSGE model forecasts for central bankers? *Brookings Papers on Economic Activity*, 41(2):209–259.

Edge, R. M., Kiley, M. T., and Laforte, J. (2010). A comparison of forecast performance between federal reserve staff forecasts, simple reduced-form models, and a DSGE model. *Journal of Applied Econometrics*, 25(4):720–754.

Engel, C. (2014). *Exchange Rates and Interest Parity*, volume 4 of *Handbook of International Economics*, pages 453–522. Elsevier.

Erceg, C. J., Gust, C., and López-Salido, D. (2007). The transmission of domestic shocks in the open economy. *NBER Working Paper No. 13613.*

Forni, M., Hallin, M., Lippi, M., and Reichlin, L. (2003). Do financial variables help forecasting inflation and real activity in the Euro area? *Journal of Monetary Economics*, 50(6):1243–1255.

Fujiwara, I., Hara, N., Hirose, Y., and Teranishi, Y. (2005). The Japanese economic model. *Monetary and Economic Studies*, 23(2):61–142.

Gadatsch, N., Hauzenberger, K., and Stähler, N. (2015). German and the rest of Euro area fiscal policy during the crisis. *Deutsche Bundesbank Discussion Paper No 05/2015.*

Gadatsch, N., Hauzenberger, K., and Stähler, N. (2016). Fiscal policy during the crisis: A look on Germany and the Euro area with GEAR. *Economic Modelling*, 52:997–1016.

Galí, J. (2015). *Monetary policy, inflation, and the business cycle: an introduction to the New Keynesian framework and its applications.* Princeton University Press.

Gali, J. and Monacelli, T. (2005). Monetary policy and exchange rate volatility in a small open economy. *The Review of Economic Studies*, 72 (3):707–734.

Gerali, A., Neri, S., Sessa, L., and Signoretti, F. (2010). Credit and Banking in a DSGE model of the Euro area. *Journal of Money, Credit and Banking*, 42(S1):107–141.

Gertler, M., Sala, L., and Trigari, A. (2008). An estimated monetary DSGE model with unemployment and staggered nominal wage bargaining. *Journal of Money, Credit and Banking*, 40(8):1713–1764.

Geweke, J. (1991). Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. *Research Department Staff Report 148, Federal Reserve Bank of Minneapolis*.

Gourinchas, P.-O. and Rey, H. (2014). *External adjustment, global imbalances, valuation effects*, volume 4 of *Handbook of International Economics*, pages 585–645. Elsevier.

Guerrieri, L., Gust, C., and López-Salido, J. D. (2010). International competition and inflation: A New Keynesian perspective. *American Economic Journal: Macroeconomics*, 2(4):247–280.

Gupta, R. and Kabundi, A. (2010). Forecasting macroeconomic variables in a small open economy: a comparison between small-and large-scale models. *Journal of Forecasting*, 29(1-2):168–185.

Gupta, R. and Kabundi, A. (2011). A large factor model for forecasting macroeconomic variables in South Africa. *International Journal of Forecasting*, 27(4):1076–1088.

Gust, C., Leduc, S., and Vigfusson, R. (2010). Trade integration, competition, and the decline in exchange-rate pass-through. *Journal of Monetary Economics*, 57(3):309–324.

Hamilton, J. D. (1994). *Time series analysis*, volume 2. Princeton university press Princeton, NJ.

Hansen, N. and Kern, S. (2004). Evaluating the CMA evolution strategy on multimodal test functions. In *Parallel Problem Solving from Nature - PPSN VIII. PPSN 2004*, volume 3242. Springer, Berlin, Heidelberg.

Harvey, D., Leybourne, S., and Newbold, P. (1997). Testing the equality of prediction mean squared errors. *International Journal of Forecasting*, 13(2):281–291.

Hastings, W. K. (1970). Monte Carlo sampling methods using Markov Chains and their applications. *Biometrika*, 57(1):97–109.

Herbst, E. and Schorfheide, F. (2012). Evaluating DSGE model forecasts of comovements. *Journal of Econometrics*, 171(2):152–166.

Hodge, A., Robinson, T., and Stuart, R. (2008). A small BVAR-DSGE model for forecasting the Australian economy. *Research Discussion Paper RDP 2008-04, Reserve Bank of Australia.*

Ireland, P. N. (2006). Technology shocks in the New Keynesian model. *Review of Economics and Statistics*, 86(4):923–936.

Ireland, P. N. (2011). A New Keynesian perspective on the Great Recession. *Journal of Money, Credit and Banking*, 43(1):31–54.

Iskrev, N. (2010a). Evaluating the strength of identification in DSGE models. A priori approach. *2010 Meeting Papers 1117, Society for Economic Dynamics.*

Iskrev, N. (2010b). Local identification in DSGE models. *Journal of Monetary Economics*, 57(2):189–202.

Iskrev, N. (2018). Calibration and the estimation of macroeconomic models. *Working Papers 1/2018, Banco de Portugal.*

Iskrev, N. and Ratto, M. (2011). Algorithms for identification analysis under the DYNARE environment: final version of the software. *EUR - Scientific and Technical Research Reports JRC67624, Joint Research Center.*

Jaimovich, N. and Rebelo, S. (2009). Can News about the future drive the business cycle? *American Economic Review*, 99(4):1097–1118.

Jääskelä, J. P. and Nimark, K. (2011). A medium-scale New Keynesian open economy model of Australia. *Economic Record*, 87(276):11–36.

Justiniano, A. and Preston, B. (2010a). Can structural small open-economy models account for the influence of foreign disturbances? *Journal of International Economics*, 81(1):61–74.

Justiniano, A. and Preston, B. (2010b). Monetary policy and uncertainty in an empirical small open-economy model. *Journal of Applied Econometrics*, 25(1):93–128.

Kalman, R. E. (1960). A new approach to linear filtering and prediction problems. *Journal of basic Engineering*, 82(1):35–45.

Kamber, G., McDonald, C., Sander, N., and Theodoridis, K. (2015). A structural model for policy analysis and forecasting: NZSIM. *RBNZ Discussion Paper Series*, DP2015/05.

Kim, J. (2000). Constructing and estimating a realistic optimizing model of monetary policy. *Journal of Monetary Economics*, 45(2):329–359.

King, R. G., Plosser, C. I., and Rebelo, S. T. (1988). Production, growth and business cycles: I. The basic neoclassical model. *Journal of Monetary Economics*, 21(2-3):195–232.

Kolasa, M. and Rubaszek, M. (2018). Does foreign sector help forecast domestic variables in DSGE models? *International Journal of Forecasting*, 34(2-3):809–821.

Kollmann, R., Enders, A., and Müller, G. (2011). Global banking and international business cycles. *European Economic Review*, 55:407–426.

Koop, G., Poirier, D. J., and Tobias, J. L. (2007). *Bayesian econometric methods.* Cambridge University Press.

Kydland, F. E. and Prescott, E. C. (1982). Time to build and aggregate fluctuations. *Econometrica*, 50(6):1345–1370.

Langcake, S. and Robinson, T. (2018). Forecasting the Australian economy with DSGE and BVAR models. *Applied Economics*, 50(3):251–267.

Leeper, E. M. and Sims, C. A. (1994). Toward a modern macroeconomic model usable for policy analysis. *NBER Macroeconomics Annual*, 9:81–140.

Lees, K., Matheson, T., and Smith, C. (2010). Open economy forecasting with a DSGE-VAR: Head to head with the RBNZ published forecasts. *International Journal of Forecasting*, 27(2):512–528.

Litterman, R. B. (1986). Forecasting with Bayesian Vector Autoregressions—five years of experience. *Journal of Business and Economic Statistics*, 4(1):25–38.

Lombardo, G. and McAdam, P. (2012). Financial market frictions in a model of the Euro area. *Economic Modelling*, 29(6):2460–2485.

Long, J. B., Jr, and Plosser, C. I. (1983). Real Business Cycles. *Journal of Political Economy*, 91(1):39–69.

Lubik, T. A. and Schorfheide, F. (2007). Do central banks respond to exchange rate movements? A structural investigation. *Journal of Monetary Economics*, 54(4):1069–1087.

Marcellino, M. and Rychalovska, Y. (2014). Forecasting with a DSGE model of a small open economy within the monetary union. *Journal of Forecasting*, 33(5):315–338.

Marcellino, M., Stock, J. H., and Watson, M. W. (2003). Macroeconomic forecasting in the Euro area: Country specific versus area-wide information. *European Economic Review*, 47(1):1–18.

Maurice, O. and Rogoff, K. (2000). The six major puzzles in international macroeconomics. Is there a common cause? *NBER Macroeconomics Annual*, 15(1):339–390.

McGrattan, E. R. (1994). The macroeconomic effects of distortionary taxation. *Journal of Monetary Economics*, 33(3):573–601.

Metropolis, N., Rosenbluth, A. W., Rosenbluth, M. N., Teller, A. H., and Teller, E. (1953). Equation of state calculations by fast computing machines. *The Journal of chemical physics*, 21(6):1087–1092.

Müller, U. K. (2012). Measuring prior sensitivity and prior informativeness in large Bayesian models. *Journal of Monetary Economics*, 59:581–597.

Monacelli, T. (2005). Monetary policy in a low pass-through environment. *Journal of Money, Credit and Banking*, 37:1047–1066.

Nimark, K. P. (2009). A structural model of Australia as a small open economy. *Australian Economic Review*, 42(1):24–41.

Pfeifer, J. (2017). An introduction to graphs in DYNARE. *Working Paper March 2013, The University of Cologne.*

Rabanal, P. and Tuesta, V. (2010). Euro-Dollar real exchange rate dynamics in an estimated two-country model: An assessment. *Journal of Economic Dynamics and Control*, 34(4):780–797.

Rees, D. M., Smith, P., and Hall, J. (2016). A Multi-sector Model of the Australian economy. *Economic Record*, 92(298):374–408.

Rotemberg, J. J. and Woodford, M. (1997). An optimization-based econometric framework for the evaluation of monetary policy. *NBER Macroeconomics Annual*, 12(1997):297–346.

Rubaszek, M. and Skrzypczyński, P. (2008). On the forecasting performance of a small-scale DSGE model. *International Journal of Forecasting*, 24(3):498–512.

Schmitt-Grohé, S. and Uribe, M. (2012). What's News in business cycles. *Econometrica*, 80(6):2733–2764.

Schumacher, C. (2007). Forecasting German GDP using alternative factor models based on large datasets. *Journal of Forecasting*, 26(4):271–302.

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica*, 48(1):1–48.

Smets, F. and Wouters, R. (2003). An estimated Dynamic Stochastic General Equilibrium model of the Euro area. *Journal of the European Economic Association*, 1(5):1123–1175.

Smets, F. and Wouters, R. (2004). Forecasting with a Bayesian DSGE model: an application to the Euro area. *Journal of Common Market Studies*, 42(4):841–867.

Smets, F. and Wouters, R. (2005). Comparing shocks and frictions in US and Euro area business cycles: a Bayesian DSGE approach. *Journal of Applied Econometrics*, 20(2):161–183.

Steinbach, M., Mathuloe, P., and Smit, B. (2009). An open economy New Keynesian DSGE model of the South African economy. *South African Journal of Economics*, 77(2):207–225.

Steinsson, J. (2003). Optimal monetary policy in an economy with inflation persistence. *Journal of Monetary Economics*, 50(7):1425–1456.

Stähler, N. and Thomas, C. (2012). FiMod — a DSGE model for fiscal policy simulations. *Economic Modelling*, 29:239–261.

Stock, J. H. and Watson, M. W. (2002a). Forecasting using principal components from a large number of predictors. *Journal of the American Statistical Association*, 97(460):1167–1179.

Stock, J. H. and Watson, M. W. (2002b). Macroeconomic forecasting using diffusion indexes. *Journal of Business and Economic Statistics*, 20(2):147–162.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester conference series on public policy*, 39:195–214.

Wang, M. (2009). Comparing the DSGE model with the factor model: an out-of-sample forecasting experiment. *Journal of Forecasting*, 28(2):167–182.

Wolters, M. H. (2015). Evaluating point and density forecasts of DSGE models. *Journal of Applied Econometrics*, 30(1):74–96.

Chapter 3

The Vietnamese business cycle in an estimated small open economy New Keynesian DSGE model

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Abstract

The primary purpose of this paper is to investigate the sources of the business cycle fluctuations in Vietnam. To this end, we develop a small open economy New Keynesian Dynamic Stochastic General Equilibrium (SOE-NK-DSGE) model. Accordingly, this model includes various features, such as habit consumption, staggered price, price indexation, incomplete exchange-rate pass-through, the failures of the law of one price and the uncovered interest rate parity. It is then estimated by using the Bayesian technique and Vietnamese data $1999Q1 - 2017Q1$. Based on the estimated model, this paper analyses the sources of the business cycle fluctuations in this emerging economy. Indeed, this research paper is the first attempt of developing and estimating the SOE-NK-DSGE model with the Bayesian technique for Vietnam.

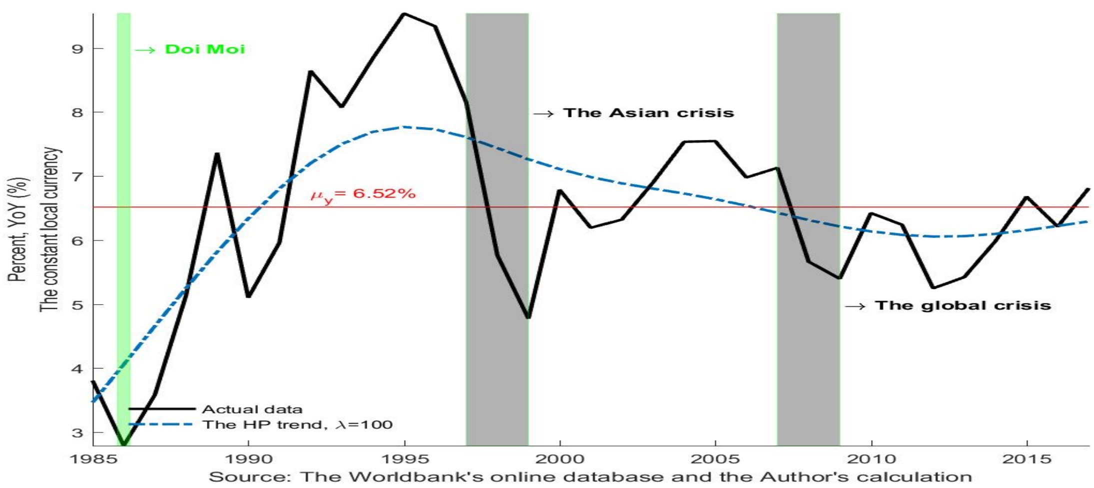
JEL classification: E12, E31, E32, E47, E52, F41, F43.

Keywords: International macroeconomics; the international spillover; the Vietnamese economy; the New Keynesian DSGE model; the Bayesian estimation.

3.1 Introduction

The primary purpose of this research paper is to address the question of what sources drive the business cycle fluctuations in Vietnam, in particular over the period of 1999Q1 to 2017Q1? To this end, we develop and estimate a small open economy New Keynesian Dynamic Stochastic General Equilibrium (SOE-NK-DSGE) model. This question is particularly interesting because Vietnam has witnessed large fluctuations in the business cycle for over 30 years. For example, Figure 3.1 presents that after launching the Revolution in 1986, known as **Doi Moi**, the Vietnamese GDP growth has been rocketing and reaches a peak of 9.54 % in 1995. However, due to the Asian financial crisis in 1997, this economy experiences a great fall. Afterward, Vietnam maintains a stable and high growth rate of output at approximately 6.52 % per year on average. Moreover, based on the World Bank report, this growth rate is always notably higher than the world. Because of the 2008 financial global crisis, there is a fall in output growth. However, the Vietnamese economy has quickly recovered and caught up with the output growth of China since 2015.

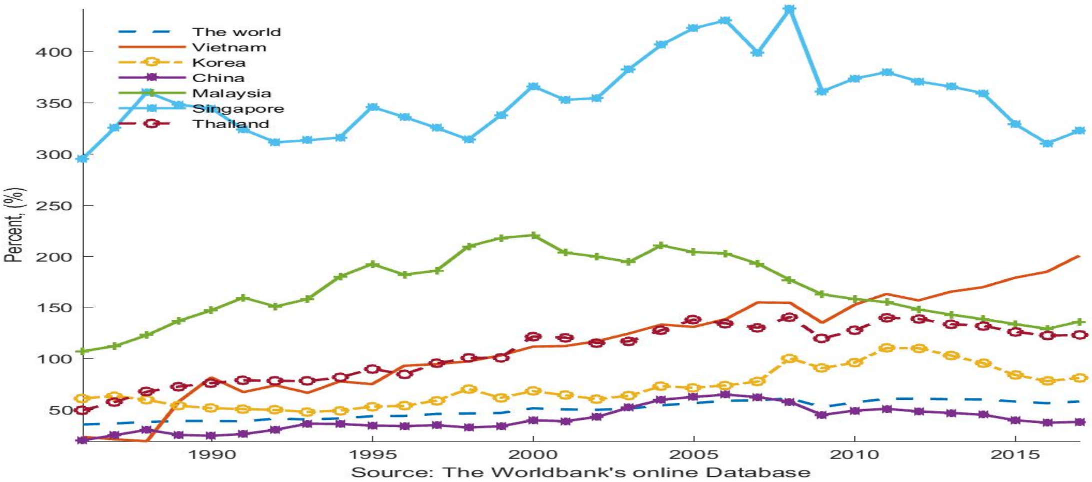
Figure 3.1: The annual output growth of Vietnam and its trend, 1985-2017



On the other hand, the New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model has been widely used for macroeconomic policy analysis. Thus, over the last decade, an increasing number of attempts have developed and estimated both Real Business Cycle (RBC) and DSGE models for other developing and emerging countries (Oviedo and Yue (2009),García-Cicco et al. (2010), Elisa and Padilla (2011), Mendoza (2010), García-Cicco et al. (2010), Boz et al. (2011), Mendoza and Yue (2012), etc). However, the literature on estimating a DSGE model for Vietnam is still limited. Thus, this paper is the first attempt of developing and estimating the SOE-NK-DSGE model with a wide range of important features for Vietnam.

One of the most striking features of the Vietnamese economy is that this emerging country strongly depends on international trade. International trade and financial linkage are particularly essential to this country. Based on the World Bank Database, for example, the Vietnamese degree of openness[1] (red line) has significantly increased since 2000 (see Figure 3.2). Thus, Vietnam became one of the most open economies in the world. As an example, this Figure presents Singapore as the most open economy in the ASEAN region, followed by Vietnam. Moreover, in 2017 this indicator reaches a considerably impressive level of 200 %, which is six times and four times as much as in China and the world, respectively. Thus, a structural model including the foreign sector, such as the SOE-NK-DSGE model, is important to explain the business cycle fluctuation in this country.

Figure 3.2: The annual openness of some selected emerging Asian nations, 1986-2017



To this end, we develop a small open economy New Keynesian Dynamic Stochastic General Equilibrium (SOE-NK-DSGE) model. In particular, the specification of this model closely follows the influential studies by Gali and Monacelli (2005), Monacelli (2005), and Justiniano and Preston (2010b) on the small open economy. Thus, our model includes various important features, such as habit formation, price stickiness, price indexation, the failure of the Uncovered Interest Rate Parity, the Law of One Price gap, and incomplete exchange-rate pass-through. However, the most striking difference between the SOE-NK-DSGE model in this paper and those in the three above studies is as follows. We model the foreign economy as a closed economy DSGE model rather than a reduced VAR one.

Empirically, our model estimation closely follows the vast literature on estimating the NK-DSGE model with the Bayesian technique (Smets and Wouters (2003, 2007), An and Schorfheide (2007), Adolfson et al. (2007), Del Negro and Schorfheide (2008), etc). Thus,

[1] The degree of openness is measured as the ratio of import and export to GDP.

to the best of our knowledge, this project is the first attempt of developing and estimating a SOE-NK-DSGE model for Vietnam.

The estimated SOE-NK-DSGE model with the Bayesian technique fits data on the Vietnamese and foreign economies relatively well. As an example, in most of the variables, the fitted value insignificantly differs from its actual data, in particular, domestic interest rate and CPI inflation. Based on this estimated model, we find that inflation dynamics in Vietnam are best described by a purely forward-looking behaviour. It implies that expected inflation strongly influences the fluctuations in current inflation. On the other hand, no structural shock affects the Vietnamese economy persistently. Indeed, after the shock, the observed macroeconomic variables quickly go back to their steady-state level, except for domestic CPI inflation and interest rate.

We also find that there is a stronger response in domestic output growth than domestic CPI inflation to the monetary tightening. Thus, during the period of anti-inflation, the SBV should implement a contractionary monetary policy with caution. Furthermore, the short-run incomplete exchange rate pass-through (ERPT) of around 27 % after three months implies a high and rapid ERPT in Vietnam. Therefore, the SBV's domestic currency devaluation policy, which is to promote exports, should be conducted with caution. Because of the 2008-global financial crisis, for example, this central bank devaluated the DONG currency relative to the US-Dollar. As a result, this policy caused the two-digit inflation in 2008 and 2011.

As one of the most open economies in the world, the fluctuations in interest rate and the real and nominal exchange rates in Vietnam are strongly influenced by the external-sector disturbances. However, the shock to the terms of trade accounts for a mild percentage in explaining the fluctuations in the output growth. This finding is identical to a recent striking study by Schmitt-Grohé and Uribe (2018) on the role of the terms-of-trade shock to the developing and emerging markets. On the other hand, the domestic disturbances, including stationary productivity and preference shocks account for a sizeable proportion in explaining the changes in domestic CPI inflation and the terms of trade.

Last but not least, in most episodes over the whole sample period $1999Q1-2017Q1$, the variations in the Vietnamese output growth rate were highly associated with the demand-side disturbance (preference and risk premium shocks). Meanwhile, the fluctuations in the CPI inflation were mainly influenced by monetary policy and import cost-push shocks.

The rest of this paper is organized as follows. Section 3.2 introduces the literature on estimating the Real Business Cycle and DSGE models for developing and emerging countries, including Vietnam. Section 3.3 presents the underlying theoretical SOE-NK-DSGE model. Section 3.4 shows model solution and data. Section 3.5 gives a detailed discussion about the estimation strategy and estimation procedure. Section 3.6 analyzes the sources of the business cycle fluctuations in Vietnam. Section 3.7 provides some conclusions.

3.2 The related Literature and Contributions

3.2.1 The Literature on the Emerging Market Universe

The sources of movements in the business cycle in the emerging countries are one of the growing interests over the last decade. Accordingly, both the real business cycle (RBC) and NK-DSGE models are widely applied to address this issue as follows.

First, in regard to using the RBC model, the role of interest rate to the variations in the aggregate activities in seven emerging markets, including Argentina, Brazil, Ecuador, Mexico, Peru, Philippines, and South Africa, are examined in the studies by Neumeyer and Perri (2005), Uribe and Yue (2006), Oviedo and Yue (2009). Meanwhile, the impacts of trend growth shock on the business cycle movements in the emerging countries are shown in studies by Aguiar and Gopinath (2007), García-Cicco et al. (2010), Boz et al. (2011). Furthermore, the contributions of both the total-factor productivity (TFP) and real interest rate to the business cycle movements are examined by Benjamin and Meza (2009), Elisa and Padilla (2011). Additionally, financial frictions are confirmed to be important in explaining the business cycle variations in the emerging economies (see García-Cicco et al. (2010), Mendoza (2010), Mendoza and Yue (2012)). On the other hand, the studies by Benjamin and Meza (2009), Kehoe and Ruhl (2009), and Boz et al. (2015) highlight the important role of labor market frictions in examining the South Korean and Mexican aggregate activities.

Second, regarding the NK-DSGE model, there are various papers estimating this model for policy analysis in the developing and emerging economies (Liu and Zhang (2010), Gu et al. (2014), Dai et al. (2015) for China; Elekdag et al. (2005), Choi and Hur (2015) for Korea; Sahminan et al. (2017), Gu et al. (2014) for Indonesia; Ramayandi (2011) for 4 ASEAN countries such as Malaysia, Thailand, Indonesia and Philippines; Saxegaard et al. (2010), Gabriel et al. (2016) for India; Silveira (2008), Palma and Portugal (2014) for Brazil, Castillo et al. (2013) for Peru, Medina and Soto (2007) for Chile and Steinbach et al. (2009) for South Africa).

3.2.2 The literature on Vietnam and Contributions

As mentioned above, over the last decade, an increasing number of attempts developed and estimated the DSGE model for other developing and emerging countries. However, the literature on estimating a DSGE model for Vietnam is still limited. On the other hand, several attempts investigated the Vietnamese business cycle fluctuations by using either non- or structural models as follows. For example, Le (2014) compared the variations in the business cycle between Vietnam and Indonesia in the context of a structural VAR model. Pham (2018) investigated the role of government expenditure in the lens of a closed-economy real business cycle model. Sala et al. (2019) examined the role of permanent productivity shock to five real aggregate variables in Vietnam. Accordingly, this shock delivered an insignificant contribution. However, it is worth noting that both Pham (2018) and Sala et al. (2019) used an estimated real business cycle model. Hence, the role of monetary policy and other nominal frictions, such as price rigidity and incomplete exchange-rate pass-through, were not included in these two research papers. Khieu (2014) evaluated the role of the Vietnamese monetary policy in an estimated three-equation closed economy NK-DSGE model. Indeed, this author used a model, which was developed by Ireland (2004). Huynh et al. (2017) used a calibrated DSGE model with the banking sector to investigate how policies stabilize the Vietnamese economy. However, both Khieu (2014) and Huynh et al. (2017) were limited to the aspect of a closed-economy. Hence, these two studies could not reveal the essential effects of the international spillovers on the Vietnamese economy. Given that Vietnam has one of the most open economies in the world, the presence of the foreign sector in the underlying model is especially relevant to explaining the business cycle fluctuations in this emerging country.

The research paper by Dizioli and Schmittmann (2015) is interesting since the foreign sector was included in this study. In particular, these authors described the Vietnamese economy in the framework of the Forecasting and Policy Analysis System (FPAS) model. Indeed, this model was developed by Berg and Laxton (2006a), Berg and Laxton (2006b), and used at the IMF. Accordingly, the FPAS model includes four fundamental equations: aggregate demand curve, price dynamic, uncovered interest rate, and monetary policy rule. However, Dizioli and Schmittmann (2015) aimed to seek the optimal monetary policy rather than the explanations for the business cycle fluctuations. For example, they argued that the optimal rule in Vietnam places more significant weight on output stabilization as the intermediate target to achieve inflation stability, while allowing greater exchange rate flexibility. Therefore, the source of the business cycle fluctuations in this country and the effects of international spillovers were never discussed. Indeed, there was no discussion about the forecast error variance decomposition and historical decomposition techniques in this research.

This study has two main contributions to the current literature. First, it is the first attempt of developing and estimating the SOE-NK-DSGE model with a wide range of important features for Vietnam. Second, it contributes to the growing literature on explaining the sources of business cycle fluctuations in emerging markets.

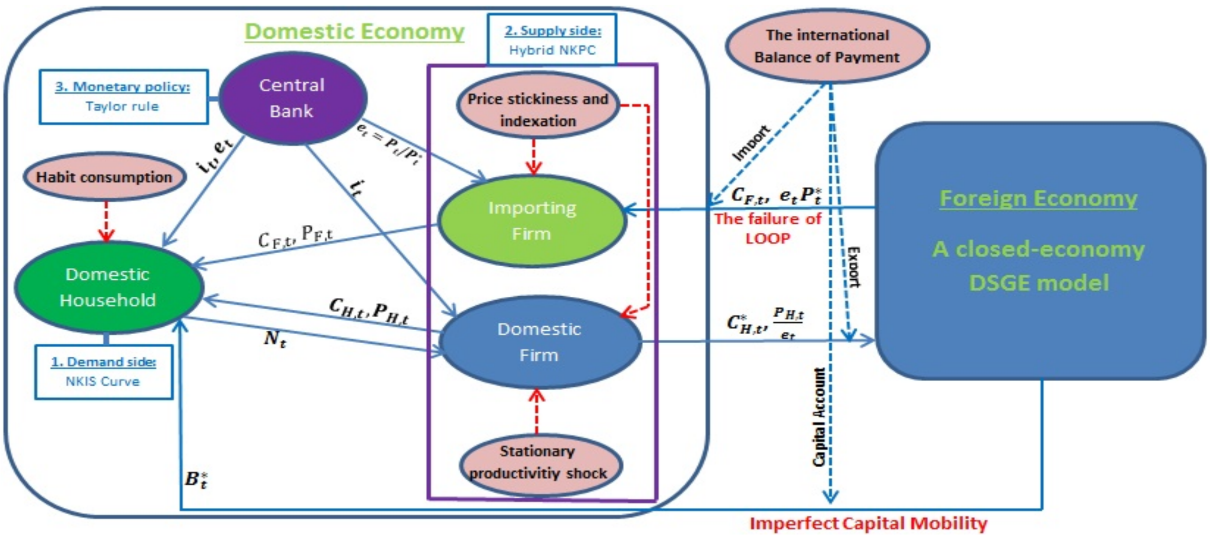
3.3 The theoretical model

3.3.1 An Overview of the theoretical model

It is worth noting that the small-sized model in this paper has three main agents in the domestic economy: households, firms, and central bank. Thus, there is no government sector. Furthermore, the quarterly data on investment is typically not available in the developing and emerging markets. Therefore, we do not incorporate the variable of investment into the underlying theoretical model.

Figure 3.3 below presents the agent's interaction. For example, in supply-side, the domestic firm produces its goods by combining stationary technology and the labor supply of the household. It also exports its goods to the foreign economy. Conversely, the importing firm does not produce its goods. Instead, it imports goods from the foreign economy and sells them to the domestic household. The presence of this importing firm enables us to derive the law of one price gap since the Law Of One Price (LOOP) fails to hold. Furthermore, the model includes nominal frictions such as sticky prices in the importing sector. Thus, the exchange-rate pass-through is incomplete. On the other hand, on the demand side, the assumption of the household's holding of domestic and foreign bonds enables us to derive the Uncovered Interest Rate Parity, well known as the UIP. However, the UIP never holds in Vietnam because of the imperfect capital mobility. To coincide with this issue, we introduce the risk premium function. Finally, we close the model by introducing the monetary policy. Indeed, the role of the central bank is described via the Taylor rule including the exchange rate.

Figure 3.3: Graphical illustration of a small open-economy New Keynesian DSGE model



The following sections shortly present several striking features of the theoretical model of SOE-NK-DSGE. Meanwhile, the detailed specification and solution for this conceptual model can be found in the over-60-page mathematical appendix that is available upon request.

3.3.2 Household

Each household maximizes its following intertemporal utility.

$$E_t \sum_{j=0}^{\infty} \beta^s \tilde{\varepsilon}_{g,t+j} \left[\frac{(C_{t+j} - hC_{t+j-1})^{1-\sigma}}{1-\sigma} - \frac{N_{t+j}^{1+\varphi}}{1+\varphi} \right].$$

where β and h are a discount factor and habit formation, respectively. For simplicity, we assume the case of the time script $j = 0$. Then, the variable N_t is the household's worked labor in period t. Two positive parameters (σ, φ) are the inverse elasticity of intertemporal substitution and labor disutility, respectively. $\tilde{\varepsilon}_{g,t}$ represents a preference shock in period t. Specifically, C_t is the aggregate consumption in period t.

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

where parameter α is the share of imported goods in the domestic aggregate consumption. Parameter, η, indicates the elasticity of substitution between domestic goods $C_{H,t}$ and imported goods $C_{F,t}$ in which they are the Dixit-Stiglitz aggregate type in period t such as below.

$$C_{H,t} = \left[\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \text{ and } C_{F,t} = \left[\int_0^1 C_{F,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

where the parameter (ε) is the elasticity of substitution between types of differentiated domestic and imported goods.

The procedure for the optimization of each household will take place subject to the following flow budget constraint in period t.

$$P_t C_t + D_t + e_t B_t = D_{t-1}[1 + \tilde{i}_{t-1}] + e_t B_{t-1}[1 + \tilde{i}^*_{t-1}]\phi(A_t) + W_t N_t + \Pi_{H,t} + \Pi_{F,t}. \quad (3.3.2.1)$$

D_t, B_t are one-period domestic and foreign bonds, respectively. Domestic and international interest rates are $\tilde{i}_t$, $\tilde{i}^*_t$. The nominal exchange rate is presented as e_t and domestic CPI price is P_t. The variable W_t is wage and $\Pi_{H,t}$, $\Pi_{F,t}$ represent the dividend from domestic and imported goods firms. Furthermore, the function $\phi(A_t)$ is referred to a debt elastic interest rate premium. It is mainly driven by two important foreign variables: the real value of foreign bond A_t and risk premium disturbance $\tilde{\phi}_t$ as

$$\phi(A_t) = \exp[-\chi(A_t + \tilde{\phi}_t)] \tag{3.3.2.2}$$

It is worth noting that A_t denotes the relative value of the real quantity of outstanding foreign bond in term of home currency to steady-state output $\overline{Y}$ in period t. It is measured as $A_t = \frac{\tilde{e}_{t-1}B_{t-1}}{\overline{Y}P_{t-1}}$. The specification of the risk premium function, $\phi(A_t)$, is identical to Schmitt-Grohé and Uribe (2003), Adolfson et al. (2007) and the strictly decreasing function in A_t. The presence of this function in the model causes the foreign debt level in a log-linear approximation to be stationary. For example, Schmitt-Grohé and Uribe (2003) explained "*To see why this device induces stationarity, let $p(d_t)$ denote the premium over the world interest rate paid by domestic residents, and d_t the stock of foreign debt. Then in the steady-state the Euler equation implies that $\beta[1 + r + p(d)] = 1$. This expression determines the steady-state net foreign asset position as a function of r and the parameters that define the premium function $p(.)$ only.*"

Furthermore, the presence of the risk premium function enables us to capture imperfect integration in the international financial market (Schmitt-Grohé and Uribe (2003), Adolfson et al. (2008), Justiniano and Preston (2010b)). Therefore, this specification is especially relevant to Vietnam, where capital mobility is still restricted and the UIP fails to hold.

Each household optimizes its utility by choosing the domestically-made and imported goods, $C_{H,t}(i)$, $C_{F,t}(i)$. It results in the following demand for each good in period t.

$$C_{H,t}(i) = \Big[\frac{P_{H,t}(i)}{C_{H,t}}\Big]^{-\theta} C_{H,t} \text{ and } C_{F,t}(i) = \Big[\frac{P_{F,t}(i)}{C_{F,t}}\Big]^{-\theta} C_{F,t}. \tag{3.3.2.3}$$

where $P_{H,t}(i)$ and $P_{F,t}(i)$ denote the prices of the domestically-made and imported goods i, respectively. On the other hand, a household's demand for aggregate domestic and foreign goods in period t are below.

$$\min_{C_{H,t},C_{F,t}} \quad P_t C_t = P_{H,t}C_{H,t} + P_{F,t}C_{F,t}, \tag{3.3.2.4}$$

$$\text{such that} \quad C_t = I_t^{\frac{\eta}{\eta-1}}, \tag{3.3.2.5}$$

$$\text{where} \quad I_t = (1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}. \tag{3.3.2.6}$$

The results are given below.

$$C_{H,t} = (1-\alpha)\Big(\frac{P_{H,t}}{P_t}\Big)^{-\eta} C_t \text{ and } C_{F,t} = \alpha\Big(\frac{P_{F,t}}{P_t}\Big)^{-\eta} C_t. \tag{3.3.2.7}$$

Furthermore, the consumer price index in period t is defined as the combination of these two prices as below.

$$P_t = \Big[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\Big]^{\frac{1}{1-\eta}}.$$

The combinations of the first-order conditions with respect to consumption C_t, labor N_t, and the one-period foreign and domestic bonds B_t and D_t yield the following standard non-linear equations.

1. The non-linear Euler equation:

$$(C_t - hC_{t-1})^{-\sigma} = \beta(1+\tilde{i}_t)E_t\Big(\frac{\tilde{\varepsilon}_{g,t+1}}{\tilde{\varepsilon}_{g,t}}\Big).\Big(\frac{P_t}{P_{t+1}}\Big)(C_{t+1} - hC_t)^{-\sigma}. \quad (3.3.2.8)$$

2. The non-linear labor supply:

$$\frac{N_t^{\varphi}}{(C_t - hC_{t-1})^{-\sigma}} = \frac{W_t}{P_t}. \quad (3.3.2.9)$$

3. The non-linear UIP:

$$[1+\tilde{i}_t] = E_t\Big(\frac{e_{t+1}}{e_t}\Big)[1+\tilde{i}_t^*]\phi(A_{t+1}). \quad (3.3.2.10)$$

3.3.3 Domestic firms

Given that there is a continuum of domestic firms, in period t, they produce home goods by combining labor and stationary productivity shock according to the following production function:

$$Y_{H,t}(i) = Z_t N_t(i). \quad (3.3.3.1)$$

Where stationary productivity shock in period t follows the AR (1) process

$$z_t = \rho_z z_{t-1} + \epsilon_{z,t} \text{ and } z_t = \log(Z_t). \quad (3.3.3.2)$$

We use this simple production function without capital since the quarterly data on the investment is typically not available in the developing and emerging economies. On the other hand, one would investigate both stationary and permanent productivity shocks. The specification of a production function, like in the study by García-Cicco et al. (2010), should be used. However, it is worth noting that the role of technology is no longer dominant in the model with nominal rigidity (see Gali (2002), Smets and Wouters (2003), Ireland (2004), Adolfson et al. (2007)).

The domestic firm produces to fulfill both home and foreign household demand for domestic goods. This demand in period t is given below.

$$Y_{H,t}(i) = \left[\frac{P_{H,t}(i)}{P_{H,t}} \right]^{-\varepsilon} \Big(C_{H,t} + C^*_{H,t} \Big). \tag{3.3.3.3}$$

On the other hand, nominal rigidities will be introduced as follows. In period $t + j$ and the time subcript $j = 0 : \infty$, the domestic firm resets its price $(E_t P_{H,t+j}(i))$ according to the Calvo-style setting and indexation $(0 < \gamma_H < 1)$ to the previous domestic-goods price inflation $(E_t \pi_{H,t+j-1})$. Accordingly, a percentage $(1 - \theta_H)$ of the firm can reset their price, whereas the reset θ_H adjust their price based on the following indexation rule

$$E_t P_{H,t+j}(i) = E_t P_{H,t+j-1}(i) \pi^{\gamma_H}_{H,t+j-1} \text{ and } E_t \pi_{H,t+j-1} = E_t \frac{P_{H,t+j-1}}{P_{H,t+j-2}}. \tag{3.3.3.4}$$

Since the inflation-targeting policy has not been adopted in Vietnam, the above rule of indexation does not incorporate target inflation. This specification of the above price indexation is identical to the studies of Christiano et al. (2005), Smets and Wouters (2003). However, other developing and emerging countries have adopted the inflation-targeting policy. The specification of price indexation, such as the study by Adolfson et al. (2007), should be used.

Given the demand for domestic goods (3.3.3.3), the optimization problem yields the following domestic firm's real marginal cost in period t.

$$mc_{H,t} = \frac{W_t}{P_{H,t} Z_t}. \tag{3.3.3.5}$$

The expression above (3.3.3.5) implies that the real marginal cost $(mc_{H,t})$ is identical across domestic firms and independent of the domestic goods made. On the other hand, because of the Calvo-setting price, the Dixit-Stiglitz aggregate price of the domestic firm in period t will be

$$P_{H,t} = \left[\int_0^1 P^{1-\varepsilon}_{H,t}(i) di \right]^{\frac{1}{1-\varepsilon}} = \left[\theta_H \Big(P_{H,t-1} \pi^{\delta_H}_{H,t-1} \Big)^{1-\varepsilon} + (1 - \theta_H) \Big(P^{new}_{H,t}(i) \Big)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{3.3.3.6}$$

Finally, each domestic firm will maximize its following expected present discounted profit subject to the demand curve in (3.3.3.3).

$$\max_{P_{H,t}^{new}(i)} \quad E_t \sum_{j=0}^{\infty} (\beta\theta_H)^j \left[\left(\frac{P_{H,t+j-1}(i)}{P_{H,t-2}(i)} \right)^{\delta_H} P_{H,t}^{new}(i) - P_{H,t+j} mc_{H,t+j}(i) \right] Y_{H,t+j}(i). \quad (3.3.3.7)$$

The procedure for the optimization results in the following expression

$$E_t \sum_{j=0}^{\infty} (\beta\theta_H)^j Y_{H,t+j}(i) \left[P_{H,t}^{new}(i) \left(\frac{P_{H,t+j-1}}{P_{H,t-1}} \right)^{\delta_H} - \frac{\varepsilon}{\varepsilon - 1} P_{H,t+j} mc_{H,t+j}(i) \right] = 0. \quad (3.3.3.8)$$

Taking a log-linear approximation of the above expression will lead to a Hybrid New Keynesian Phillips Curve for the domestic firm.

$$\widehat{\pi}_{H,t} = \frac{\beta}{1+\beta\delta_H} E_t \widehat{\pi}_{H,t+1} + \frac{\delta_H}{1+\beta\delta_H} \widehat{\pi}_{H,t-1} + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H(1+\beta\delta_H)} \widehat{mc}_{H,t}. \quad (3.3.3.9)$$

3.3.4 Importing firms

Since the domestic household's consumption packet includes both domestic and foreign goods, the purpose of the importing firm is to fulfill the household's demand for foreign goods. Furthermore, the presence of the importing firm enables the deriving of the law of one price gap as in the studies of Gali and Monacelli (2005), Monacelli (2005).

Differing from the domestic firm, the importing firm does not produce its goods. Instead, it imports goods from the foreign economy to fulfill the domestic demand for imported goods in period t below.

$$C_{F,t}(i) = \left[\frac{P_{F,t}(i)}{P_{F,t}} \right]^{-\varepsilon} C_{F,t}. \quad (3.3.4.1)$$

Similar to domestic firms, in period $t+j$ and $j = 0 : \infty$, the importing firm also resets their price ($E_t P_{F,t+j}(i)$) according to the Calvo-style setting and indexation ($0 < \gamma_F < 1$). Accordingly, a percentage $(1-\theta_F)$ of the firm can reset their price, whereas the rest θ_F adjust their price based on the following indexation rule

$$E_t P_{F,t+j}(i) = E_t P_{F,t+j-1}(i) \pi_{F,t+j-1}^{\gamma_H} \text{ and } E_t \pi_{F,t+j-1} = E_t \frac{P_{F,t+j-1}}{P_{F,t+j-2}}. (3.3.4.2)$$

Solving the importing firm's optimization problem yields its real marginal cost in period t such as

$$mc_{F,t}(i) = \frac{e_t P_{F,t}^{*}(i)}{P_{F,t}}. \quad (3.3.4.3)$$

The above expression (3.3.4.3) implies that the real marginal cost is identical across importing firms. Thus, we can drop the index i. On the other hand, it is worth noting that $P^*_{F,t} = P^*_t$ in the foreign economy. Furthermore, the definition of the real exchange rate in period t is

$$Q_t = \frac{e_t P_{F,t}}{P_t}. \tag{3.3.4.4}$$

Therefore, the importing firm's real marginal cost in (3.3.4.3) can be interpreted as the law of one price gap, such as $\Psi_t = MC_{F,t}(i)$. This intepretation is identical to Gali and Monacelli (2005), Monacelli (2005). On the other hand, because of the Calvo-setting price, the Dixit-Stiglitz aggregate price of the importing firm in period t will be.

$$P_{F,t} = \left[\int_0^1 P_{F,t}^{1-\varepsilon}(i)di\right]^{\frac{1}{1-\varepsilon}} = \left[\theta_F\left(P_{F,t-1}\pi_{F,t-1}^{\delta_F}\right)^{1-\varepsilon} + (1-\theta_F)\left(P_{F,t}^{new}\right)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}}. \tag{3.3.4.5}$$

Finally, each importing firm will maximize its following expected present discounted profit subject to the demand curve in (3.3.4.1).

$$\max_{P_{F,t}^{new}(i)} E_t \sum_{j=0}^{\infty} (\beta\theta_F)^j \left[\left(\frac{P_{F,t+j-1}(i)}{P_{F,t-2}(i)}\right)^{\delta_F} P_{F,t}^{new}(i) - P_{F,t+j} mc_{F,t+j}(i)\right] Y_{F,t+j}(i). \tag{3.3.4.6a}$$

The procedure for the optimization results in the following expression

$$E_t \sum_{j=0}^{\infty} (\beta\theta_F)^j Y_{F,t+j}(i) \left[P_{F,t}^{new}(i)\left(\frac{P_{F,t+j-1}}{P_{F,t-1}}\right)^{\delta_F} - \frac{\varepsilon}{\varepsilon-1} P_{F,t+j} mc_{F,t+j}(i)\right] = 0. \tag{3.3.4.7}$$

Taking a log-linear approximation of the above expression will lead to a hybrid New Keynesian Phillips Curve for the importing firm.

$$\widehat{\pi}_{F,t} = \frac{\beta}{1+\beta\delta_F} E_t \widehat{\pi}_{F,t+1} + \frac{\delta_F}{1+\beta\delta_F} \widehat{\pi}_{F,t-1} + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F(1+\beta\delta_F)} \widehat{mc}_{F,t} + \widehat{\epsilon}_{cp,t}. \tag{3.3.4.8}$$

It is worth noting that the hybrid New Keynesian Phillips Curve for the importing firm in (3.3.4.8) implies that due to the presence of the nominal friction such as the sticky price, the exchange rate pass-through is incomplete. Indeed, its log-linear approximation of the law of one price gap in (3.3.4.3) is

$$\widehat{mc}_{F,t} = \widehat{e}_t + \widehat{P}_t^* - \widehat{P}_{F,t}. \tag{3.3.4.9}$$

3.3.5 Foreign economy

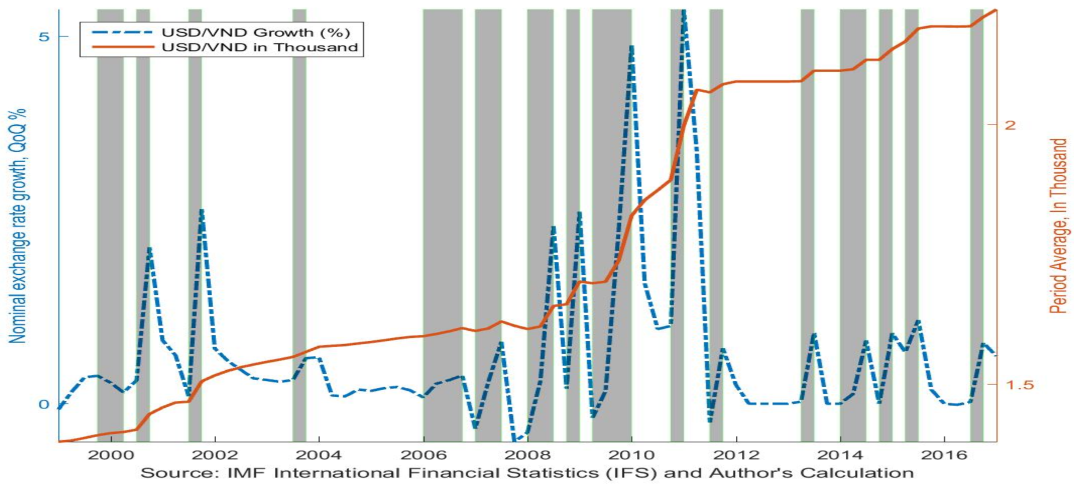
This paper uses a closed-economy DSGE model of Ireland (2011) to model the global economy. We do so because Vietnam is a small open economy. There is no significant spillover from this country to the foreign economy. This modelling strategy is identical to an influential study by Gali and Monacelli (2005), and other researches on the small open economy (see Buncic and Melecky (2008), Rees et al. (2016)).

There are four exogenous disturbances in the model of Ireland (2011). Two shocks to preference and cost-push follow the AR(1) process. Meanwhile, two remaining shocks to technology and policy follow the white noise. This modification gives three main advantages. The first one is to prevent the problem of singularity from the estimated model. This is because the total number of exogenous shocks is ten disturbances, whereas there are eight observed variables. The second advantage is to decompose the foreign structural shocks. In particular, the reduced-form BVAR model cannot reveal the structural disturbance. However, in the help of a DSGE model, the international structural shock is decomposed. The last advantage is to enhance the effects of the external shocks on the Vietnamese economy. This is because the number of shocks related to the external sector is seven, whereas there are three domestic disturbances (preference, technology, and monetary policy) in our structural model. This specification is especially relevant to Vietnam. This is because Vietnam has one of the highest degrees of openness in the world.

3.3.6 Central bank

To support the export sector, the central bank of Vietnam, known as the State Bank of Vietnam (SBV), has adopted a managed-float exchange rate regime. Accordingly, the fluctuations in the exchange rate of USD/VND are not highly volatile due to the interventions of this central bank (see Figure 3.4). Thus, modelling a monetary policy rule including the exchang rate is especially relevant to this emerging economy.

Figure 3.4: The Quarterly Nominal Exchange Rate (USD/VND), 1999Q1-2017Q1



Accordingly, to close the model, the monetary policy rule is introduced as follows.

$$\frac{\tilde{i}_t}{\bar{i}} = \Big(\frac{\tilde{i}_{t-1}}{\bar{i}}\Big)^{\psi_i}\Big[\Big(\frac{P_t}{P_{t-1}}\Big)^{\psi_\pi}\Big(\frac{Y_t}{\overline{Y}}\Big)^{\psi_y}\Big(\frac{Y_t}{Y_{t-1}}\Big)^{\psi_{\Delta y}}\Big(\frac{e_t}{e_{t-1}}\Big)^{\psi_s}\Big]^{(1-\psi_i)}\tilde{\varepsilon}_{m,t}. \qquad (3.3.6.1)$$

where $\bar{i}$ and $\overline{Y}$ are steady-state values of nominal interest rate and output. The variable $\tilde{\varepsilon}_{m,t}$ denotes an exogenous monetary policy shock. The interest rate rule in the expression (3.3.6.1) indicates that central bank adjusts its policy rate according to changes in inflation (P_t/P_{t-1}), output gap $(Y_t/\overline{Y})$, output growth (Y_t/Y_{t-1}) and the growth rate in the nominal exchange rate (e_t/e_{t-1}).

3.3.7 Exogenous shocks

This model has ten exogenous disturbances. Moreover, it includes a higher number of foreign shocks than that of domestic disturbances. The advantages of this specification are discussed before. Domestic technology, preference, risk premium and cost-push, terms-of-trade shocks ($\tilde{\varepsilon}_{z,t}$, $\tilde{\varepsilon}_{g,t}$, $\tilde{\varepsilon}_{\phi,t}$, $\tilde{\varepsilon}_{tot,t}$, $\tilde{\varepsilon}_{cp,t}$) and two shocks in the foreign economy block, such as foreign preference ($\tilde{\varepsilon}_{a^*,t}$) and cost-push ($\tilde{\varepsilon}_{cp^*,t}$), are modeled as the first-order autoregressive process. On the other hand, three remaining shocks, domestic monetary policy ($\tilde{\varepsilon}_{i,t}$), foreign technology ($\tilde{\varepsilon}_{cp^*,t}$) and foreign monetary policy ($\tilde{\varepsilon}_{i^*,t}$), follow the white noise process. It is worth noting that modelling the monetary policy shock as the white noise process is common in the standard literature (Smets and Wouters (2003), Adolfson et al. (2007), Justiniano and Preston (2010b), Ireland (2011)). Meanwhile, the strategy of modelling foreign technology shock closely follows Ireland (2011).

3.3.8 Market Clearing Condition

Beyond the domestic labor market, the three following markets must clear in equilibrium. First, the domestic bond market is cleared. Thus, $D_t = 0$ for all t. Second, goods market clearing in the domestic economy requires that domestic output is equal to the sum of domestic consumption and foreign consumption of home produced goods (exports). Accordingly, it is given below.

$$Y_t^d = C_{H,t} + C_{H,t}^*, \tag{3.3.8.1}$$

$$Y_t^* = C_t^*. \tag{3.3.8.2}$$

where the foreign demand for the domestically-made goods ($C_{H,t}^*$) is depicted as

$$C_{H,t}^* = \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\eta} Y_t^* = \left(\frac{P_{H,t}}{Q_t P_t}\right)^{-\eta} Y_t^* \text{ and } Q_t = \frac{e_t P_t^*}{P_t}.$$

It is worth noting that we adopt the assumption of symmetric preferences across countries; here is domestic and foreign economies. This strategy is identical to Gali and Monacelli (2005).

Finally, as shown in Figure 3.3, the last market-clearing condition is the home country's international balance of payment. Indeed, this international balance of payment can be obtained from the domestic household's budget constraint in (3.3.2.1). In particular, we plug the following expressions into the budget constraint in (3.3.2.1): the domestic household's total consumption expenditure $P_t C_t = P_{H,t} C_{H,t} + P_{F,t} C_{F,t}$ and the domestic and importing firm's profits $\Pi_{H,t} = P_{H,t} C_{H,t} - W_t N_t$, $\Pi_{F,t} = P_{F,t} C_{F,t} - e_t P_t^* C_{F,t}$. Moreover, since the domestic bond market clearing holds, $D_t = 0$ for all t. As a result, it is given below.

$$P_{H,t} C_{H,t}^* - e_t P_t^* C_{F,t} = e_t B_t - e_t B_{t-1}[1 + \tilde{i}_{t-1}^*]\phi(A_t), \tag{3.3.8.3}$$

$$\text{where: } \phi(A_t) = \exp[-\chi(A_t + \tilde{\phi}_t)] \text{ and } A_t = \frac{e_{t-1} B_{t-1}}{\bar{Y} P_{t-1}}. \tag{3.3.8.4}$$

It is worth noting that the left-hand side in the equation (3.3.8.3) is interpreted as the net trade balance, whereas the right-hand side is the net capital account in the international balance of payment.

3.3.9 How do structural shocks impact domestic variables?

Before taking data into this model, we theoretically analyze how ten structural shocks impact the domestic aggregate economic fluctuations. Thus, the log-linear approximation is used.

At first, the New Keynesian IS curve represents the demand side.

$$\widehat{c}_t - h\widehat{c}_{t-1} = E_t[\widehat{c}_{t+1} - h\widehat{c}_t] - \frac{1-h}{\sigma}(\widehat{i}_t - E_t\widehat{\pi}_{t+1}) + \frac{1-h}{\sigma}(\widehat{\varepsilon}_{g,t} - E_t\widehat{\varepsilon}_{g,t+1}). \qquad (3.3.9.1)$$

If we eliminate the habit formation parameter in the expression (3.3.9.1), the usual Euler equation is obtained. Moreover, it is clear that an increase in real interest rate, $(\widehat{i}_t - E_t\widehat{\pi}_{t+1})$, declines the current consumption, $(\widehat{c}_t)$, and this decline in consumption is governed by $(1-h)/\sigma(1+h)$. On the other hand, the preference shock $(\widehat{\varepsilon}_{g,t})$ positively influences the current consumption.

Second, the connection of domestic consumption and output, $(\widehat{c}_t,\ \widehat{y}_t)$, with foreign output, $(\widehat{y}_t^*)$, is established via the log-linear approximation of the goods market clearing condition as below

$$\widehat{y}_t = (1-\alpha)\widehat{c}_t + \alpha\eta(2-\alpha)\widehat{s}_t + \alpha\eta\widehat{\psi}_{F,t} + \alpha\widehat{y}_t^*. \qquad (3.3.9.2)$$

where the LOOP gap, $\widehat{\psi}_{F,t}$, is measured as the difference between foreign price and imported-goods price as below

$$\widehat{\psi}_{F,t} = (\widehat{e}_t + \widehat{p}_t^*) - \widehat{p}_{F,t}.$$

The expression (3.3.9.2) indicates that an increase in foreign output leads to a rise in domestic output, but a fall in consumption. This effect is identical to the impact of the LOOP gap, $\widehat{\psi}_{F,t}$. Therefore, an adverse foreign inflation shock and depreciation in the nominal exchange rate increase domestic output but decrease consumption. Moreover, the influences of the terms of trade, $(\widehat{s}_t)$, on domestic output and consumption are clearly shown in the expression (3.3.9.2). On the other hand, the change in the terms of trade has a log-linear form and presents the difference between imported-goods price inflation, $\widehat{\pi}_{F,t}$, and domestic-goods price inflation,$\widehat{\pi}_{H,t}$, as below.

$$\Delta\widehat{s}_t = \widehat{\pi}_{F,t} - \widehat{\pi}_{H,t} + \widehat{\varepsilon}_{tot,t}. \qquad (3.3.9.3)$$

It is worthwhile noting that in the specification of the terms of trade above, the term $(\widehat{\varepsilon}_{tot,t})$ is a shock to the terms of trade. Accordingly, it is modeled as an AR(1) process as such $\widehat{\varepsilon}_{tot,t} = \rho_{tot} * \widehat{\varepsilon}_{tot,t-1} + \widehat{\epsilon}_{tot,t}$. This simple specification would provide two advantages. The first advantage is, as mentioned before, that we would examine the issue of concern of how important the terms of trade is to the Vietnamese economy. This is because this impact would be one of the interesting issues in the current literature on the developing and emerging markets (Mendoza (1995), Kose (2002), Schmitt-Grohé and Uribe (2018)).

The second advantage is to prevent the problem of the singularity in our model.

Third, the volatilities of the real exchange rate, $\widehat{q}_t$, are impacted by the terms of trade and the LOOP gap as below

$$\widehat{q}_t = (\widehat{e}_t + \widehat{p}_t^*) - \widehat{p}_t = \widehat{\psi}_{F,t} + (1-\alpha)\widehat{s}_t. \tag{3.3.9.4}$$

Fourth, the domestic-goods price inflation, $\widehat{\pi}_{H,t}$, is depicted as a Hybrid New Keynesian Phillips Curve of the domestic firm as following.

$$\widehat{\pi}_{H,t} = \frac{\beta}{1+\beta\theta_H} E_t\widehat{\pi}_{H,t+1} + \frac{\delta_H}{1+\beta\theta_H}\widehat{\pi}_{H,t-1} + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H(1+\beta\theta_H)}\widehat{mc}_t. \tag{3.3.9.5}$$

As shown in the expression (3.3.9.5), the current domestic-goods price inflation depends on not only past but also future inflations. Moreover, change in the current domestically made-goods inflation is influenced by three foreign sources: foreign output, exchange rate and terms of trade. These sources have direct or indirect impacts via their effects on real marginal cost, $\widehat{mc}_t$, as such.

$$\widehat{mc}_t = \varphi\widehat{y}_t - (1+\varphi)\widehat{\varepsilon}_{a,t} + \alpha\widehat{s}_t + \frac{\sigma}{1-h}(\widehat{c}_t - h\widehat{c}_{t-1}). \tag{3.3.9.6}$$

Fifth, the imported-goods price inflation, $\widehat{\pi}_{F,t}$ is described as the Hybrid New Keynesian Phillips Curve of importing firm as follows.

$$\widehat{\pi}_{F,t} = \frac{\beta}{1+\beta\theta_F}\widehat{\pi}_{F,t-1} + \frac{\delta_F}{1+\beta\theta_F} E_t\widehat{\pi}_{F,t+1} + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F(1+\beta\theta_F)}\widehat{\psi}_t + \widehat{\varepsilon}_{cp,t}. \tag{3.3.9.7}$$

Similar to the domestic-goods price inflation, as in the expression (3.3.9.7), the imported-goods price inflation, $\widehat{\pi}_{F,t}$, depends on not only past but also future inflations. Moreover, it is impacted by the LOOP gap, $\widehat{\psi}_t$, and the cost-push shock, $\widehat{\varepsilon}_{cp,t}$.

Sixth, the domestic CPI inflation is associated with the domestic-goods price inflation and terms of trade as follows.

$$\widehat{\pi}_t = \widehat{\pi}_{H,t} + \alpha\Delta\widehat{s}_t. \tag{3.3.9.8}$$

Seventh, taking the log-linear approximation of the expression (3.3.2.10) to yield the following uncovered interest rate parity.

$$(\widehat{i}_t - E_t\widehat{\pi}_{t+1}) - (\widehat{i}_t^* - E_t\widehat{\pi}_{t+1}^*) = E_t\Delta\widehat{q}_{t+1} - \chi\widehat{a}_t - \widehat{\phi}_t. \tag{3.3.9.9}$$

Eighth, the log-linear approximation of the international balance of payment in the equation (3.3.8.3) is below.

$$\widehat{y}_t - \widehat{c}_t - \alpha(\widehat{s}_t + \widehat{\psi}_{F,t}) = \widehat{a}_t - \beta^{-1}\widehat{a}_{t-1}. \tag{3.3.9.10}$$

Finally, the policy rule in (3.3.6.1) is approximated as

$$\widehat{i}_t = \psi_i \widehat{i}_{t-1} + (1-\psi_i)\Big[\psi_\pi \widehat{\pi}_t + \psi_y \widehat{y}_t + \psi_{\Delta y}\widehat{\Delta y}_t + \psi_e \widehat{\Delta e}_t\Big] + \widehat{\varepsilon}_{m,t}. \tag{3.3.9.11}$$

As shown in (3.3.9.11), the central bank adjusts its policy interest rate in response to the past interest rate ($\widehat{i}_{t-1}$), CPI inflation (π_t), output gap ($\widehat{y}_t/\bar{y}$), output growth (Δy_t), and growth in nominal exchange rate ($\Delta\widehat{e}_t$). The disturbance ($\widehat{\varepsilon}_{m,t}$) denotes the monetary policy shock.

3.4 Model solution, data and estimation strategy

3.4.1 Model solution

This model has eleven endogenous variables: consumption ($\widehat{c}_t$), output ($\widehat{y}_t$), interest rate ($\widehat{i}_t$), real exchange rate ($\widehat{q}_t$), term of trade ($\widehat{s}_t$), CPI inflation ($\widehat{\pi}_t$), domestic-goods price inflation ($\widehat{\pi}_{H,t}$), imported-goods price inflation ($\widehat{\pi}_{F,t}$), the LOOP gap ($\widehat{\psi}_{F,t}$), the real quantity outstanding foreign bond ($\widehat{a}_t$), and domestic real marginal cost ($\widehat{mc}_t$). To solve for these eleven endogenous variables, eleven above log-linear approximation equations, from (3.3.9.1) to (3.3.9.11), are used. Furthermore, this model has five foreign economy variables corresponding to the foreign economy block (see Section 3.3.5).

It is worthwhile noting that the number of external-related shocks accounts for the dominant proportion. In particular, there are ten structural shocks in total, with seven external-related disturbances. This specification would enhance the effects of the foreign economy on this emerging country with one of the most open economies in the world. On the other hand, it also prevents the problem of the singularity in the underlying model. This is because the number of exogenous disturbances is higher than the number of observed variables.

3.4.2 Data

In this paper, we use five Vietnamese macroeconomic variables and three foreign economy variables. The period of $1999Q1 - 2017Q1$ is chosen because of the available data on this emerging country. The Vietnamese variables include CPI-deflated output growth, CPI inflation, policy interest rate, the real exchange rate, and terms of trade. The quarterly data on output growth is provided by the General Statistics Office (GSO) of Vietnam. On the other hand, four remaining Vietnamese variables are collected from the IMF IFS's online database. Meanwhile, three US macroeconomic variables are used as the proxy for the foreign economy. We do this because in the literature on the small open economy, the US economy is typically treated as the foreign one (see Buncic and Melecky (2008), Choi and Hur (2015), Gabriel et al. (2016), and Rees et al. (2016)). All data sources are presented in Appendix 3.8.1. In addition, it is worth noting that in this paper, we do not detrend or demean the data before estimation. Instead, we will do this within the estimation procedure by including intercepts in the measurement equations. Finally, the data used for estimation is presented in Figure 3.5 below.

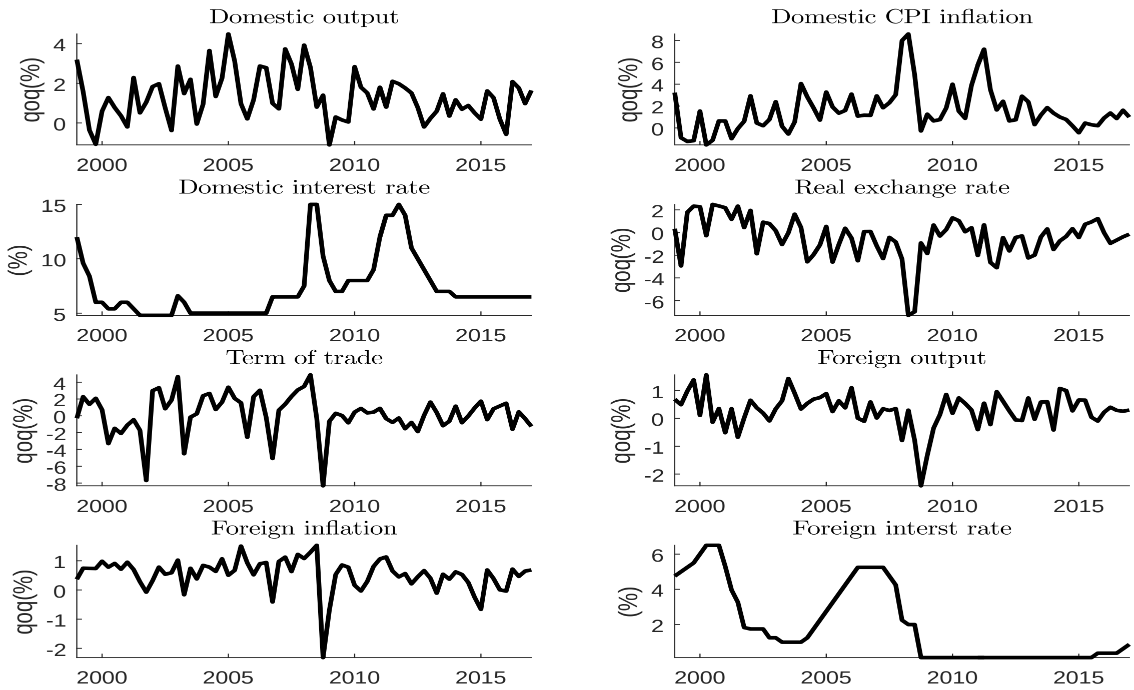


Figure 3.5: The quarterly data about the Vietnamese and foreign economies

3.4.3 Forming the posterior density

The theoretical log-linearized model, which is described in section 3.4.2, will be linked to the actual data via the measurement equation system in appendix 3.8.2. Indeed, the log-linearized DSGE model can be expressed as a state-space framework below. This is because the state space system represents the backward looking solution of the forward looking model under the assumption of rational expectations.

The state equation	$\Omega_t = A\Omega_{t-1} + B\varepsilon_t$	(3.4.3.1)
The observed equation	$\Phi_t = C\Phi_{t-1} + D\Omega_t + F\epsilon_t$	(3.4.3.2)
The shocks and measurement errors	$\varepsilon_t \sim N(0, I_q)$ and $\epsilon_t \sim N(0, I_r)$	(3.4.3.3)

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 and Θ presents the matrix of parameters A, B, C, D, F, I_q and I_r.

The Bayes theorem enables the combining of 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

$$p(\Theta|\Phi_t) \propto p(\Theta)p(\Phi_t|\Theta) \tag{3.4.3.4}$$

In terms of the log form, the posterior density in (3.4.3.4) will be

$$\begin{aligned} \ln p(\Theta|\Phi_t) &\propto \ln p(\Theta) + \ln p(\Phi_t|\Theta) \\ &\propto \ln p(\Theta) + \ln L \end{aligned} \tag{3.4.3.5}$$

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.

$$q(\vartheta \mid \Theta^{i-1}) \sim \mathbf{N}(\Theta^{i-1}, c^2\Sigma) \tag{3.4.3.6}$$

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 (3.4.3.4). A candidate ϑ, which is randomly generated from the above density, leads to an increase in the conditional posterior density such as $p(\vartheta|\Phi_t)p(\Theta^{i-1}|\Phi_t)$. It is then accepted that $\Theta^i = \vartheta$. Otherwise, it is rejected and $\vartheta = \Theta^{i-1}$. Thus, we typically control the parameter c to get a designed acceptance ratio. This acceptance ratio is computed below.

$$\text{The acceptance ratio} = \frac{\text{A number of accepted draws}}{\text{A total number of proposal draws}} \tag{3.4.3.7}$$

3.5 Estimation

There are only three parameters which are fixed before estimation. The first two parameters associated with discount factors in both domestic and foreign economy are calibrated according to the standard literature on the real business cycle. For example, the first parameter is the domestic discount factor ($\beta = 0.99$). The second parameter is the foreign economy discount factor ($\beta^* = 0.9987$). The last parameter is the foreign

Phillips curve ($\psi^* = 0.10$) which is identical to Ireland (2011). Thus, in this paper, 38 structural parameters and eight nonstructural parameters associated with measurement errors are identified and estimated within the underlying model by using the Bayesian technique.

3.5.1 Prior Information

The prior densities for 38 estimated structural and 8 non-structural parameters are mainly based on the previous literature. The second column in Table 3.1 gives an overview of prior information. Because of space constraint, we shortly introduce the discussions about these prior densities. The detailed discussions can be found in the supplemental material that is available upon request.

In general, this paper uses four types of the prior distribution. They are the beta, gamma, inverse-gamma, and uniform densities. Accordingly, the beta distribution is used for the degree of openness, inverse Frisch, consumption habit, Calvo price, indexation, and persistent shock parameters. Meanwhile, the gamma distributions are applied to parameters in the Taylor rule. On the other hand, the inverse-gamma distribution is applied to the parameters associated with risk premium, domestic and imported goods substitute elasticities and the standard deviation of ten structural disturbances. Finally, the uniform densities are used for eight non-structural parameters of intercepts in the measurement equation. The further discussions are given below.

We use the gamma distribution with a mean of 0.6 and a standard deviation of 0.05 as the prior density for the degree of openness (α). On the other hand, based on the studies by Schmitt-Grohé and Uribe (2003), Adolfson et al. (2007), Justiniano and Preston (2010b), we impose the inverse gamma distribution with a mean of 0.01 and a standard deviation of infinity as a prior density for risk premium elasticity χ. There are two advantages of using this prior specification. First, the prior standard deviation of infinity would create more flexibility in estimation. Second, it is uninformative regarding this parameter in the case of Vietnam. This prior strategy is identical to the frontier study of García-Cicco et al. (2010). Indeed, García-Cicco et al. (2010) use the uniform density as the prior distribution for all estimated parameters, including the parameter of risk premium elasticity, χ.

Based on the studies by Havranek et al. (2015), the prior inverse value of elasticities of intertemporal substitution, σ, follows the gamma distribution with a mean of 1.2 and a standard deviation of 0.4. Meanwhile, the magnitude of the inverse Frisch elasticity of labor supply (φ) is a controversial issue in macroeconomics (Christiano et al. (2010)). Due to the high fraction of a number of under-35-year-old people in Vietnam, we believe that the Frisch elasticity of labor supply, ($1/\varphi$), would be large. A high value of the Frisch elasticity of labor supply reflects the strong response of labor supply to wage and the properties of aggregate data. Thus, we use the gamma distribution with a mean of

0.5 and a standard deviation of 0.25 as the prior inverse value, (φ).

On the other hand, according to the standard literature on the real business cycle, price changes every four months. Furthermore, typically, the degree of Calvo price is lower in the importing firm than domestic firm. However, in this paper, the prior density is identical to these two firms. This prior strategy is identical to Justiniano and Preston (2010b). Thus, we use the beta distribution with a mean of 0.75 and a standard deviation of 0.1 as the prior density for θ_H and θ_F.

In the literature, habit formation varies widely across countries and data types. Accordingly, this estimated parameter is typically higher on the macro than on the micro level (see Fuhrer (2000), Christiano et al. (2005), Havranek et al. (2017)). For Vietnam, we therefore use the beta distribution with a mean of 0.6 and a standard deviation of 0.1 as the prior density for this parameter. On the other hand, the two parameters for price indexation, δ_H and δ_F, enable us to describe the inflation dynamic as backward- and forward-looking behavior (Gali and Gertler (1999), Galí et al. (2005), Christiano et al. (2005), Smets and Wouters (2007)). Based on the standard literature, we use the beta distribution with a mean of 0.5 and standard deviation of 0.25 as the prior density for these two parameters.

Taylor (2000) and Garcia et al. (2011) argued that including the exchange rate in the monetary policy rule is crucial in the case of the developing and emerging economies. Furthermore, like other developing Asian countries, Vietnam mainly depends on exports and adopts a partial float exchange rate regime. Thus, the inclusion of the exchange rate in the Taylor rule would give a significant improvement to modelling the policy interest rate. On the other hand, Figure 3.5 shows that the policy interest rate in Vietnam is not as volatile as inflation, output, and real exchange rate over the period $1999Q1 - 2017Q1$. This implies that the policy rule should include a smoothing parameter, ψ_i. Since this smoothing parameter is in the range $(0 - 1)$, we use the beta distribution with a mean of 0.75 and standard deviation of 0.25 as prior density. We set the gamma distribution with a mean of 1.5 and standard deviation of 0.25 for the parameter of inflation, ψ_π. Hence, this value ensures that our model does not suffer from the issue of indeterminacy. The three remaining parameters, output gap, output growth, and exchange rate, (ψ_y, $\psi_{\Delta y}$, $\psi_{\Delta e}$), follow the gamma distribution with a mean of 0.5 and a standard deviation of 0.25.

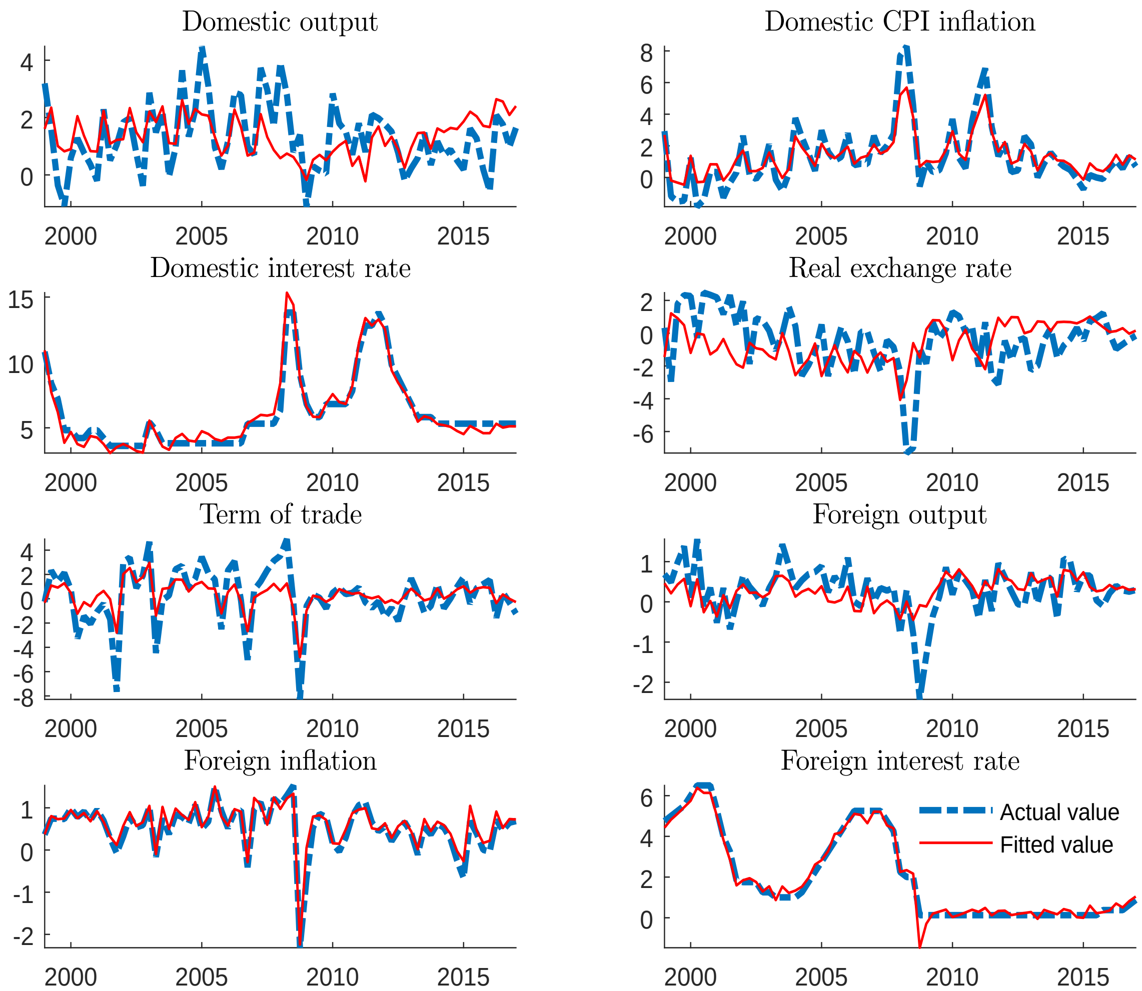
The foreign economy block has 13 parameters to be estimated. Indeed, these 13 parameters are priors as one of three distributions (gamma, beta, and inverse gamma). For instance, the inverse gamma density is used as the prior distribution for all four shock innovations. Meanwhile, their persistent parameters are priors as the beta density. An exception for the smoothing parameter is that the three remaining parameters in the foreign monetary policy rule are priors as the gamma distribution. It is worth noting that Ireland (2011) calibrated the steady-state growth. In this paper, however, this parameter is estimated with its prior density of the gamma distribution. Finally, both foreign habit and price indexation are priors as the beta distribution.

3.5.2 Estimated results and discussions

The majority of the 49 theoretical model parameters will be estimated using the Bayesian technique. Based on the state-space form, the log-likelihood function is evaluated using the Kalman filter. Afterward, several optimization algorithms are used to find the mode of the posterior density $p(\Theta|\Phi_t)$ in (3.4.3.5). Using this mode, we propose a multivariate normal distribution $q(\vartheta \mid \Theta^{i-1})$ in (3.4.3.6). Then, we generate $300,000$ draws from this proposal density. On the other hand, we specify the parameter c to target an acceptance rate of around 30 %. Indeed, this value is typically used in the literature. Meanwhile, we determine $75,000$ discards. Indeed, this estimation procedure of the Markov Chain Monte Carlo (MCMC) method with the Metropolis-Hastings algorithm is conducted by using the DYNARE Toolbox of Adjemian et al. (2011).

In this paper, we use an estimated small open economy NK-DSGE model for policy analysis. Thus, all estimated model parameters should bear both statistical and economic meanings. Therefore, in this section, we briefly interpret the estimated results. Accordingly, we find that the data is very informative for most estimated parameters. As an example, the prior density significantly differs from its posterior distribution (see Figures 3.15-3.17 in Appendix 3.8.3). On the other hand, Table 3.1 presents the detail of estimation. Meanwhile, Figure 3.6 shows the predicted values and actual data. Indeed, the predicted values present the Kalman filtered one-sided estimate of the observed variables. Accordingly, the estimated result of the Taylor rule and domestic CPI inflation dynamics for Vietnam is one of the most striking estimations. For instance, there are small differences between fitted and actual data. Other predicted values, such as real exchange rate and output, include some points which differ from their actual data in magnitude. However, overall, they still share the key trend of movement in common with actual data.

Figure 3.6: Actual and its fitted values



The comparison between fitted values and actual data is a good criterion to assess how well an estimated model fits the data. However, in the current literature on estimating the NK-DSGE model, not every study reports this result, even in the most influential study by Smets and Wouters (2003). On the other hand, it's fair to say that it is difficult to have a model that can generate its predicted values perfectly fitting actual data. As an example, in a well-known study by Adolfson et al. (2007), the predicted value could not fit the European data perfectly well either, in particular real wage, import, and world output. Other studies by the economists at the Reserve Bank of Australia also shared the same problem. In particular, the fitted values of non-farm GDP and export share of GDP significantly differ from their actual data on Australia in the study by Nimark (2009). A similar pattern is also found in the study by Jääskelä and Nimark (2011). More specifically, the fitted values of real wage, investment, employment, export, and import commodity export differed considerably from their actual data on Australia. Therefore, we argue that our estimated model fits data on the Vietnamese and foreign economies relatively well.

Due to space constraint, we present a brief discussion about selected parameters. The detailed information can be found in the supplemental material, available upon request.

The estimated mean of the debt elasticity parameter χ is 0.004. This estimated result is as small as what we expect. Futhermore, it is located in the range that is shared with the standard literature (Schmitt-Grohé and Uribe (2003), Adolfson et al. (2007), Justiniano and Preston (2010b)). The presence of this parameter reflects imperfect capital mobility in Vietnam. This issue leads to the failure of the Uncovered Interest Rate Parity. Thus, the difference between the real interest rate in Vietnam and its counterpart in the U.S economy is not identical to change in the exchange rate (USD/VND).

Two estimated Calvo prices are 0.86 for the domestic firm and 0.49 for the importing firm. This implies that in Vietnam the frequency of changing price is every seven quarters in the case of the domestic firm, whereas it is around every two quarters in the case of the importing firm. We see that in Vietnam the domestic firm's price is much stickier than the importing firm's local-currency price. This fact is not only in the case of Vietnam but also in other advanced economies, including Euro, Canada and Australia (Adolfson et al. (2007), Justiniano and Preston (2010b)). The intuitive explanation is that the importing firm's local-currency price is strongly influenced by the volatilities of the exchange rate, but not for the domestic firm.

The posterior mean of price indexation is small, such as $\delta_H = 0.06$ and $\delta_F = 0.30$. Such a small posterior value is identical to that in the pioneer and influential study by Gali and Gertler (1999) on the hybrid New Keynesian Phillips curve. For example, these authors argued: "*While the benchmark pure forward-looking model is rejected on statistical grounds, it appears still to be a reasonable first approximation of reality*". However, we still argue that an appropriate method of modelling the inflation dynamic for Vietnam should account for not only expected future inflation but also its past. This is because the CPI inflation in Vietnam tends to be higher than in advanced nations.

Regarding the Taylor rule, an estimated value of smoothing parameter, ψ_i, is 0.89. This implies that the policy interest rate in Vietnam is highly persistent. This estimated value captures well the fact that this policy rate is not as volatile as inflation, output growth, and the exchange rate (see Figure 3.5). On the other hand, an estimated parameter of 1.03 for inflation differs slightly from unity. Thus, we argue that the SBV pursued the moderately anti-inflation policy over the period of 1999Q1 to 2017Q1. Indeed, there are two striking opposite episodes of inflation during this stage. The first one took place in the early 2000s. Accordingly, the Vietnamese economy suffered from deflation (2000: -1.70 %; 2001: -0.43%). Thus, the SBV pursued the anti-deflation strategy. Conversely, the second episode took place during and after the 2008-global recession. In particular, the Vietnamese economy faced the two-digit inflation (2008: 23.116% ; 2011: 18.676%). Therefore, the SBV pursued the anti-inflation strategy.

Meanwhile, two estimated values for output, ψ_y and $\psi_{\Delta y}$, are 0.19 and 0.92. This implies that the SBV adjusts its policy interest rate more strongly in response to output growth rather than the output gap. A similar pattern takes place in several advanced nations, such as Australia, Canada, and New Zealand (see Justiniano and Preston (2010b)).

Moreover, the estimated value for the coefficient associated with the exchange rate in the Taylor rule is the most striking difference from that in other advanced countries. Specifically, this estimated value, $\psi_{\Delta e}$, is 0.81 in Vietnam. This value is significantly higher than that in advanced nations. For example, Adolfson et al. (2007) estimated this parameter to be -0.0009 for the euro area. Meanwhile, Justiniano and Preston (2010b) found 0.29, 0.29, and 0.07 for Canada, Australia, and New Zealand, respectively. This fact can attribute to the difference in the exchange rate regime in Vietnam and these advanced countries. Accordingly, the SBV has adopted a managed-float exchange rate, whereas the exchange rate is freely floating in advanced nations. Indeed, the fluctuations in the exchange rate (USD/VND) are managed within a band which is set by the central bank. Thus, such a highly estimated value for the coefficient of the exchange rate, $\psi_{\Delta e}$, would confirm the vital role of the presence of the exchange rate in modelling policy rule in emerging economies (Taylor (2000) and Garcia et al. (2011)).

Table 3.1: Prior densities and posterior estimates

Parameters		Prior densities			Posterior densities			
		Type	Mean	SD	Mean	SD	Lower	Upper
Degree of openness	α	**B**	0.60	0.05	0.556	0.051	0.4668	0.6329
Risk premium elasticity	χ	**I**	0.01	inf	0.004	0.001	0.0022	0.0055
Inverse intertemporal elasticity of substitution	σ	**G**	1.20	0.40	1.026	0.282	0.5824	1.5011
Inverse Frisch	φ	**B**	0.50	0.25	0.552	0.239	0.1750	0.9428
Calvo domestic price	θ_H	**B**	0.75	0.10	0.858	0.016	0.8335	0.8839
Calvo import price	θ_F	**B**	0.75	0.10	0.494	0.068	0.3762	0.6004
Elasticity H-F goods	η	**I**	1.50	inf	0.628	0.096	0.4763	0.7766
Habit	h	**B**	0.60	0.10	0.593	0.078	0.4661	0.7174
Domestic price indexation	δ_H	**B**	0.50	0.25	0.063	0.046	0.0006	0.1210
Foreign price indexation	δ_F	**B**	0.50	0.25	0.301	0.182	0.0160	0.5750
Taylor rule, smoothing	ψ_i	**B**	0.50	0.25	0.885	0.021	0.8511	0.9194
Taylor rule, inflation	ψ_π	**G**	1.50	0.25	1.030	0.183	0.7045	1.3134
Taylor rule, output	ψ_y	**G**	0.50	0.25	0.187	0.056	0.1057	0.2780
Taylor rule, output growth	$\psi_{\Delta y}$	**G**	0.50	0.25	0.916	0.349	0.3263	1.3940
Taylor rule, exchange rate	$\psi_{\Delta e}$	**G**	0.50	0.25	0.810	0.301	0.2773	1.1821
Technology shock, persistent	ρ_z	**B**	0.80	0.10	0.630	0.074	0.5131	0.7473
Preference shock, persistent	ρ_g	**B**	0.80	0.10	0.772	0.067	0.6626	0.8734
Import cost-push shock, persistent	ρ_{cp}	**B**	0.80	0.10	0.929	0.029	0.8874	0.9766
Risk premium shock, persistent	ρ_{rp}	**B**	0.80	0.10	0.928	0.028	0.8839	0.9727
sd technology	σ_z	**I**	0.50	inf	20.00	1.098	18.899	21.579
sd preference	σ_g	**I**	0.50	inf	11.66	2.819	7.1927	16.472
sd import cost-push	σ_{cp}	**I**	0.50	inf	1.602	0.575	0.6555	2.5220
sd risk premium	σ_{rp}	**I**	0.50	inf	0.292	0.065	0.1750	0.3861
sd terms of trade	σ_{tot}	**U**	0.00	10.0	1.263	0.504	0.3615	2.0391
sd policy	σ_m	**I**	0.50	inf	0.366	0.050	0.2821	0.4314
Foreign steady state growth	ρ_{z*}	**G**	1.003	0.13	0.901	0.107	0.7306	1.0741
Foreign habit	h*	**B**	0.40	0.10	0.530	0.071	0.4131	0.6494
Foreign persistent cost-push	ρ_{p*}	**B**	0.80	0.10	0.679	0.103	0.5107	0.8527
Foreign persistent preference	ρ_{a*}	**B**	0.80	0.10	0.875	0.044	0.8075	0.9411
Foreign price indexation	α^*	**B**	0.75	0.10	0.446	0.110	0.2670	0.6266
Foreign policy rule, smoothing	ρ_{i*}	**B**	0.60	0.20	0.904	0.015	0.8790	0.9278
Foreign policy rule, inflation	ρ_{ip*}	**G**	1.50	0.25	1.427	0.182	1.1181	1.7127
Foreign policy rule, output gap	ρ_{iy*}	**G**	0.50	0.25	0.153	0.047	0.0796	0.2276
Foreign policy rule, output growth	$\rho_{\Delta y*}$	**G**	0.50	0.25	0.832	0.249	0.4248	1.2078
sd foreign policy	σ_{i*}	**I**	0.160	inf	0.111	0.011	0.0942	0.1286
sd foreign preference	σ_{a*}	**I**	0.08	inf	2.948	0.615	1.9774	3.8368
sd foreign cost-push	σ_{cp*}	**I**	0.002	inf	0.367	0.074	0.2401	0.4852
sd foreign technology	σ_{z*}	**I**	0.009	inf	0.010	0.050	0.0075	0.0211
Mean domestic output	μ_y	**U**	0.00	10.0	1.440	0.060	1.3479	1.5382
Mean domestic inflation	μ_π	**U**	0.00	10.0	1.772	0.515	0.9318	2.6597
Mean real exchange rate	μ_q	**U**	-1.0	0.00	-0.554	0.129	-0.7157	-0.2892
Mean terms of trade	μ_{tot}	**U**	0.00	10.0	0.168	0.122	0.0000	0.4385
Mean domestic rate	μ_i	**U**	0.00	15.0	7.939	2.304	3.8651	11.0264
Mean foreign inflation	$\mu_{\pi*}$	**U**	0.00	10.0	0.610	0.109	0.4099	0.9885
Mean foreign output	μ_{y*}	**U**	0.00	10.0	0.304	0.035	0.2124	0.3173
Mean foreign rate	μ_{i*}	**U**	0.00	10.0	2.814	1.624	0.7337	3.7025

Distribution: ***B***, *beta;* ***G***, *gamma;* ***I***, *inverse-gamma;* ***U***, *uniform.*

For the shock processes, we find that four domestic disturbances (technology, preference, import cost-push, and risk premium) are either relatively or highly persistent. Regarding ten structural smoothed shocks, these volatilities exhibit relatively well the fluctuations in the Vietnamese and foreign economies over the period of $1999Q1 - 2017Q1$. For example, based on Figure 3.19 in Appendix 3.8.3, these ten structural smoothed variables fluctuate significantly throughout the special episodes, such as the early-2000 technology Y2K and 2008 global Recessions. In particular for the early-2000 technology-related crisis, there are substantial fluctuations in both domestic and foreign economy technology innovations. A similar pattern takes place in the case of shocks to external monetary and preference.

3.6 Analysis

In this section, we investigate the sources of the business cycle fluctuations in Vietnam. To do so, we use three different methods: impulse response function, forecast error variance decomposition, and historical decomposition.

3.6.1 Impulse response functions

This section presents the responses of six macroeconomic variables to several selected structural shocks. The other response to other structural disturbances can be found in the supplemental document. The dashed line implies the 90-percent probability band. Accordingly, there are, in general, three striking features of the dynamic behavior of these variables toward ten structural disturbances as follows.

The first feature is that the dynamic responses of the six variables are all of the expected signs. For example, the demand-side disturbances, such as preference, risk premium, move domestic output, and CPI inflation, are in the same direction. Conversely, the supply-side disturbances, such as technology innovation, import cost-push, move domestic output, and CPI inflation are in the opposite direction.

The second feature is that in most cases, the Vietnamese macroeconomic variables notably respond to the estimated shocks. However, two external-sector related disturbances, the terms of trade and foreign technology shocks, cause a very mild change in macroeconomic fluctuation in Vietnam.

The last feature is that no shock permanently influences the Vietnamese economy. Indeed, variables quickly go back to their steady-state level after the shock, except for domestic CPI inflation and interest rate. Regarding domestic CPI inflation, it gradually returns to its steady-state level due to the presence of the nominal friction, such as price rigidity in the underlying model. Meanwhile, the persistent changes in the domestic interest rate are explained by the highly estimated value for a parameter associated with smoothing in the policy rule ($\psi_i = 0.89$). In fact, the actual data on this variable shows a persistent pattern as well (see Figure 3.5).

The dynamic behavior of each variable toward each structural shock is presented below.

Shock to domesic monetary policy

Figure 3.7 shows how six macroeconomic variables respond to an estimated monetary policy shock (contractionary monetary policy). Accordingly, it translates into a rise of 40 basis points (bps) in the domestic interest rate. Meanwhile, output growth, CPI inflation, and terms of trade fall. Moreover, Figure 3.7 presents a stronger response in domestic output growth than domestic CPI inflation. As an example, the estimated monetary policy disturbance causes an over-60-basis-point decline in domestic output growth, but a slightly over-40-basis-point fall in domestic CPI inflation. Hence, during the period of anti-inflation, the SBV should implement a contractionary monetary policy with caution. Via the UIP, on the other hand, the domestic contractionary monetary policy causes the appreciations of both real and nominal exchange rate (USD/VND). Indeed, the nominal and real exchange rates appreciate around 150 bps, and 100 bps, respectively.

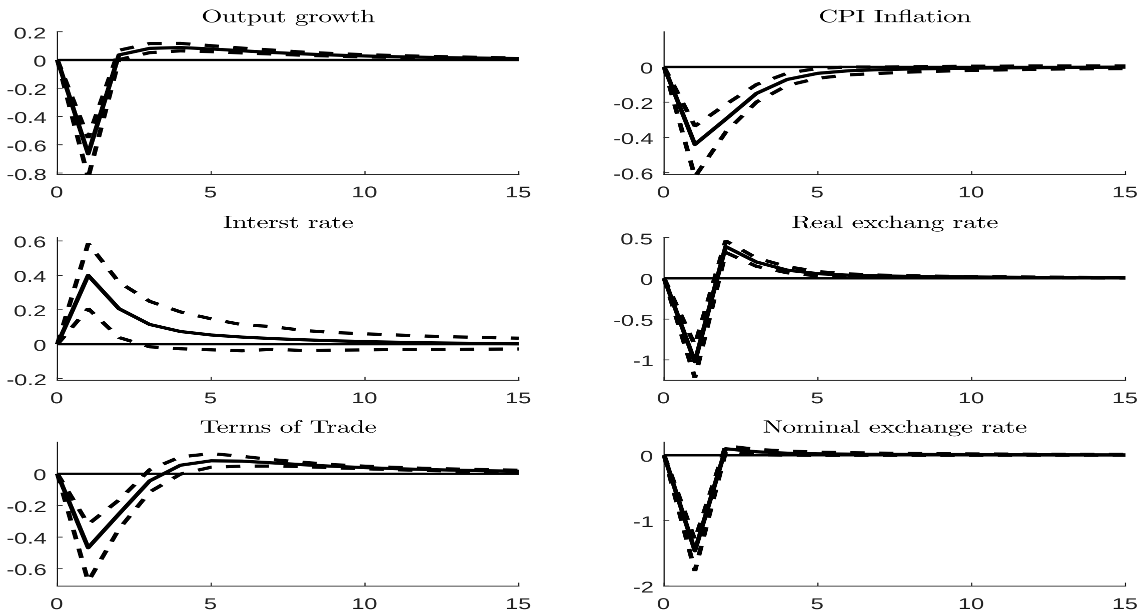


Figure 3.7: Shock to the domesic contractionary monetary policy

Shock to domesic technology

Figure 3.8 presents the shock to domestic stationary productivity technology. As a supply-side disturbance, it leads to an expansion of 40 bps in output growth, but a decline of approximately 100 bps in the domestic CPI inflation. On the other hand, there is an increase of over 100 bps in terms of trade. Intuitively, because of a rise in productivity, there is a fall in the real marginal cost, which in turn lowers the domestic-goods price $P_{H,t}$.

As a result, domestic CPI inflation declines, but the terms of trade rise. Along with this, the real exchange rate depreciates. Meanwhile, via the policy rule, a fall in domestic CPI inflation translates to a decrease of around 50 bps in the domestic interest rate. Finally, via the UIP, the nominal exchange rate appreciates.

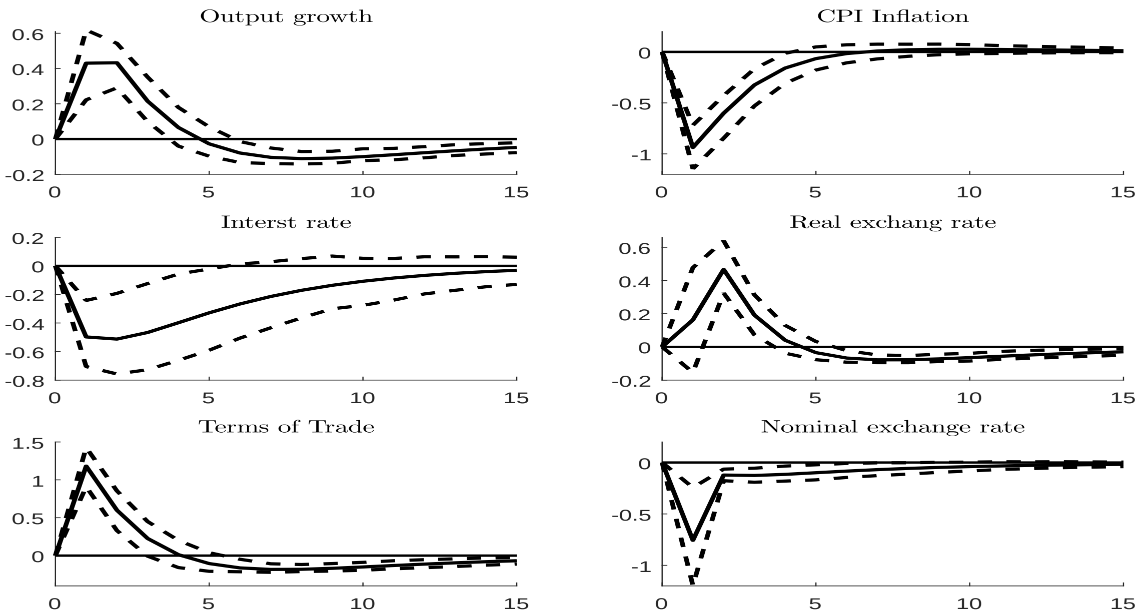


Figure 3.8: Positive shock to domesic technology

Shock to domestic preference

Figure 3.9 presents the shocks to domestic preference. Indeed, a positive shock to preference can be interpreted as an increase in domestic consumption demand. Thus, it leads to an expansion of over 100 bps in domestic output growth. On the other hand, as a domestic demand-side disturbance, it causes higher domestic CPI inflation. Indeed, domestic CPI inflation rises by 10 bps. However, the response of domestic CPI inflation is negligible. This is because its probability band includes zero. This disappointing finding will be discussed further in Section 3.6.2.

Via the policy rule, on the other hand, the increases in domestic output growth and CPI inflation generate rises in the domestic interest rate. Indeed, it peaks at around 75bps after three quarters. Meanwhile, via the UIP, this rise in the domestic interest rate leads to the appreciation of the nominal exchange rate (over 50 bps). On the other hand, due to the higher price of domestic goods $P_{H,t}$, the terms of trade declines. Thus, the real exchange rate appreciates by over 50 bps.

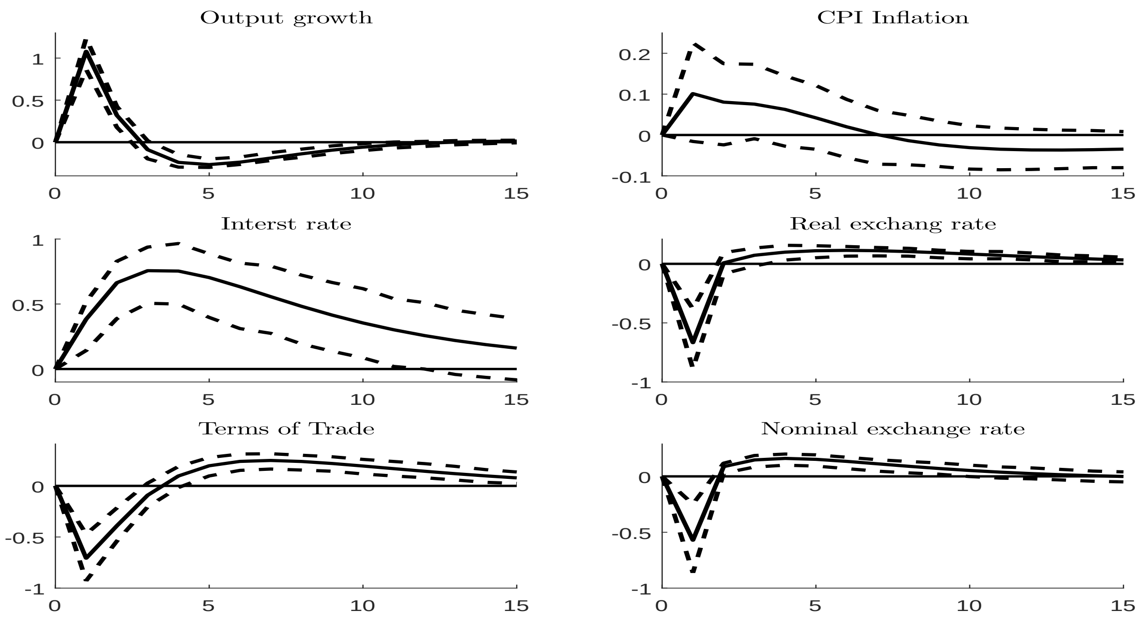


Figure 3.9: Positive shock to domesic preference

Shock to import cost-push

Figure 3.10 presents the positive shock to import cost-push. This adverse shock firstly increases the imported-goods price inflation, $\pi_{F,t}$. It then translates to into an over-50-basis-point increase in domestic CPI inflation via the aggregate price. Besides, a rise in the imported price inflation, $\pi_{F,t}$, causes the terms of trade to increase by almost 100 bps. On the other hand, via the link with the LOOP gap, the real exchange rates witness the appreciation of 100 bps. Meanwhile, the rise in domestic CPI inflation translates to an increase in the domestic interest rate via the policy rule. It, in turn, leads to the appreciation of the nominal exchange rate. Thus, these appreciations of both the nominal and real exchange rates decrease the domestic output growth.

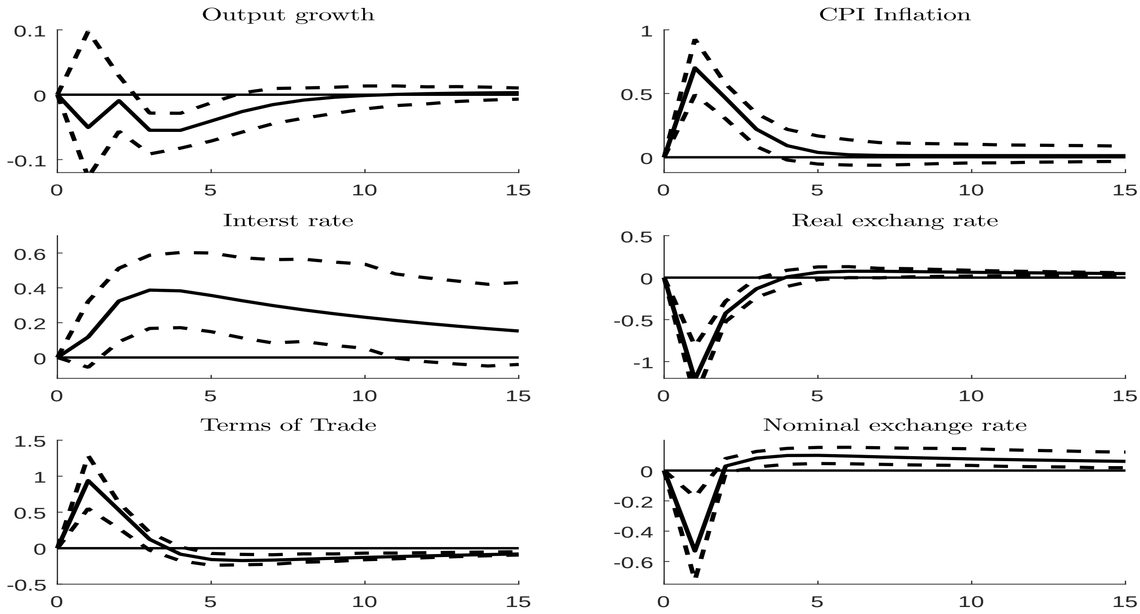


Figure 3.10: Positive shock to import cost push

Shock to risk premium

An estimated shock to risk premium appreciates both nominal and real exchange rates by approximately 150 bps, and 120 bps, respectively. The appreciation of the exchange rate decreases the price of imported goods $\pi_{F,t}$. As a result, there is an increase in imports, which worsen the trade balance and domestic output growth (40 bps). On the other hand, the fall in $\pi_{F,t}$ results in a decline of around 60 bps in terms of trade and 40 bps in domestic CPI inflation. Finally, via the policy rule, all declines in domestic CPI inflation, output growth, and nominal exchange rate generate a fall of 100 bps in domestic interest rate.

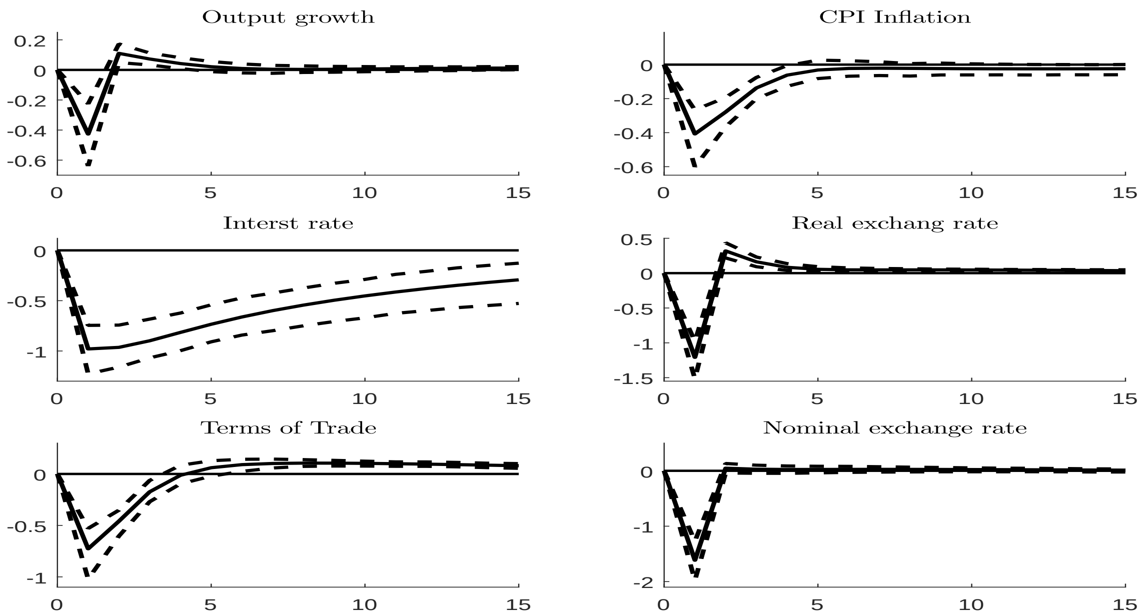


Figure 3.11: Positive shock to risk premium

Furthermore, we examine the short-run exchange-rate pass-through (ERPT) for Vietnam. We do so by using the shock to risk premium. This is because this shock can be viewed as an autonomous change in the expectation about the future exchange rate (see the equation (3.3.9.9)). In addition, the ERPT measures how domestic CPI responds to the changes in the nominal exchange rate, which is $100 * \Delta p_t/\Delta e_t$. Thus, the ERPR also implies the transmission of the international spillovers on the Vietnamese economy through the exchange rate channel.

Based on the impulse response function in Figure 3.11, the short-run incomplete ERPT in Vietnam is $100 * \frac{\Delta \pi_t}{\Delta e_t} = 100 * \frac{40bps}{150bps} = 26.67$ % after 3 months. It is worth noting that the estimated ERPT is not directly comparable because of differences in samples and the underlying assumptions. However, we argue that the ERPT of 26.67% is relatively higher in Vietnam in comparison to other emerging and developed countries. More specifically, the greater and more-rapid EPRT in Vietnam compared to industrialized countries reflects well the unique feature of developing countries (see Frankel et al. (2012)).

Such rapid and high ERPT in Vietnam can be explained as follows. Accordingly, in our model specification, the incomplete ERPT is influenced by two channels[2]: marginal cost and import price stickiness. In terms of marginal cost channel, the changes in the exchange rate pass through domestic price via terms of trade, s_t. The magnitude of this effect is governed by a highly estimated degree of openness, $\alpha = 0.56$ (see the equation (3.3.9.6) and Table 3.1). On the other hand, the second channel related to imported price stickiness, θ_F, reveals a relatively frequent change in price in Vietnam, such as every six months.

Shock to the terms of trade

This section is interesting since we examine a crucial issue about the role of the terms of trade shock to aggregate activities. Indeed, the current literature shows mixed findings on this issue. For example, the conventional view argued that the effects of the the terms of trade shock on aggregate activities account for 30 % (Mendoza (1995), Kose (2002)). However, based on the estimated SVAR and MXN[3] models, a recent striking study of Schmitt-Grohé and Uribe (2018) argued that this shock displays a modest role of 10 % in driving aggregate activities in 30 poor and emerging nations.

Figure 3.12 presents the positive shock to the terms of trade. Accordingly, an esti-

[2]The third channel is mark-up. In particular, in the imperfectly competitive market, firms can charge a markup on cost. Furthermore, it is worth noting that this channel will influence the ERPT only if the assumption about time-varying mark-up is made (see Aron et al. (2013)). However, there is no mark-up in this underlying model. Thus, in our model specification, the incomplete ERPT is mainly influenced by two sources: marginal cost and import price stickiness.

[3]The MXN model includes an importable sector (the m sector), an exportable sector (the x sector), and a nontradable sector (the n sector). The detailed MXN model can be referred to Schmitt-Grohé and Uribe (2018).

mated shock to the terms of trade results in increases in CPI inflation and interest rate. On the other hand, it leads to an expansion in output. However, these responses of output to the terms-of-trade shock are negligible. As an example, its 90 % probability band includes zero. Thus, the terms-of-trade shock is not the primary source of business cycle fluctuations in Vietnam. This finding is identical to a recent striking study by Schmitt-Grohé and Uribe (2018). In particular, these authors argued: "*On average across countries a positive terms-of-trade shock causes an improvement in the trade balance and an expansion in output, this improvement is statistically insignificant (as measured by the error bands including 0) in 18 countries for the trade balance and in 24 countries for output in our panel of 38 countries. Similar results obtain for the other variables included in the SVAR. These findings are a prelude to the main result of this section, namely that SVAR evidence suggests that terms-of-trade shocks are not a major source of fluctuations in emerging and developing countries during the sample period considered.*"

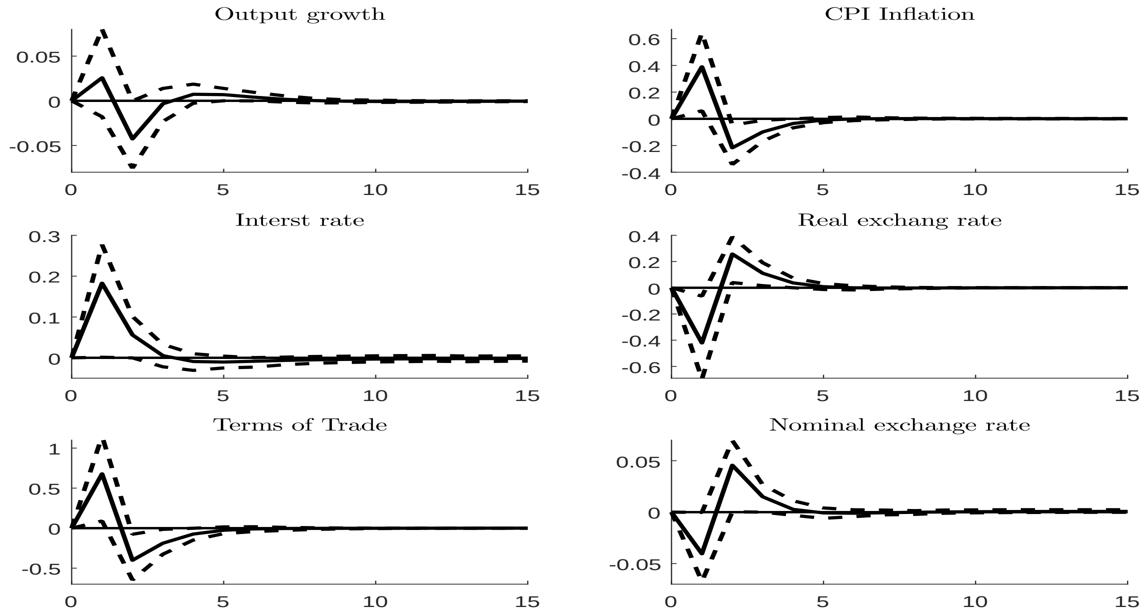


Figure 3.12: Positive shock to Terms of Trade

3.6.2 Forecast Error Variance decomposition

We go further to investigate the business cycle fluctuations in Vietnam with the help of the forecast error variance decomposition (FEVD) technique. Accordingly, Table 3.2 presents how each structural shock contributes to the variations in six Vietnamese macroeconomic variables: output, inflation, interest rate, real and nominal exchange rates, and terms of trade.

Overall, the fluctuations in all cases of the nominal variables, such as domestic CPI inflation, interest rate, exchange rates and the terms of trade, are mainly explained by the external-sector related disturbances. This finding is not surprising at this finding since

Vietnam is one of the most open economies in the world. However, the changes in the real aggregate variable, such as domestic output growth, are largely driven by its domestic shock, in particular, domestic consumption demand (domestic preference shock). Similar to the IRF-based analysis, on the other hand, the FEVD technique also reveals a very mild role of a shock to the terms of trade.

Table 3.2: Forecast Error Variance decomposition

Quarters	Foreign shocks				Domestic shocks					
	σ_{i*}	σ_{a*}	σ_{cp*}	σ_{z*}	σ_z	σ_g	σ_{cp}	σ_{rp}	σ_{tot}	σ_m
	Domestic output growth									
01	0.02	7.52	0.23	0.00	8.64	54.39	0.12	8.48	0.03	20.57
04	0.34	6.97	0.31	0.00	16.10	50.78	0.33	7.66	0.10	17.40
08	0.35	6.99	0.35	0.00	15.75	52.67	0.39	7.01	0.09	16.40
12	0.35	7.01	0.35	0.00	16.66	52.10	0.39	6.88	0.09	16.18
20	0.35	7.02	0.35	0.00	17.03	51.80	0.39	6.87	0.09	16.10
40	0.35	7.02	0.36	0.00	17.04	51.77	0.40	6.89	0.09	16.08
	Domestic CPI inflation									
01	0.14	1.67	2.45	0.00	44.46	0.52	24.89	8.41	7.68	9.79
04	0.18	3.18	4.41	0.00	42.92	0.82	23.90	8.34	6.57	9.68
08	0.24	3.31	4.49	0.00	42.75	0.89	23.79	8.35	6.52	9.67
12	0.24	3.30	4.56	0.00	42.65	1.01	23.72	8.39	6.49	9.64
20	0.24	3.29	4.55	0.00	42.48	1.26	23.65	8.48	6.46	9.60
40	0.24	3.29	4.53	0.00	42.34	1.38	23.63	8.58	6.44	9.56
	Domestic interest rate									
01	2.73	6.02	0.82	0.00	14.34	8.51	0.80	55.58	1.93	9.26
04	0.97	11.26	2.59	0.00	11.36	22.13	5.32	43.06	0.47	2.83
08	0.62	12.50	2.32	0.00	9.30	25.79	6.62	40.69	0.30	1.85
12	0.55	12.40	2.07	0.00	8.49	25.98	7.27	41.34	0.26	1.64
20	0.51	12.03	1.93	0.00	7.98	25.43	7.83	42.51	0.25	1.53
40	0.50	11.84	1.90	0.00	7.85	25.19	7.99	42.99	0.24	1.51
	Real exchange rate									
01	2.03	1.10	1.94	0.00	0.54	9.13	30.20	29.94	3.63	21.48
04	2.36	1.11	2.66	0.00	4.81	7.84	28.42	27.16	4.38	21.26
08	2.31	1.24	2.96	0.00	5.00	8.47	28.14	26.72	4.28	20.89
12	2.28	1.33	3.01	0.00	5.18	8.76	28.04	26.52	4.23	20.65
20	2.27	1.37	3.00	0.00	5.24	8.81	28.12	26.48	4.20	20.52
40	2.26	1.37	3.00	0.00	5.23	8.81	28.23	26.45	4.19	20.47
	Nominal exchange rate									
01	4.28	0.17	0.05	0.00	9.23	5.26	4.54	42.04	0.03	34.40
04	4.20	0.20	0.13	0.00	9.72	6.01	4.72	41.14	0.06	33.83
08	4.11	0.27	0.19	0.00	9.90	6.84	5.15	40.33	0.06	33.15
12	4.08	0.29	0.20	0.00	9.92	6.95	5.47	40.09	0.06	32.94
20	4.06	0.29	0.21	0.00	9.91	6.93	5.84	39.91	0.06	32.79
40	4.04	0.30	0.21	0.00	9.87	7.03	6.16	39.71	0.06	32.62
	Terms of trade									
01	0.47	1.04	2.62	0.00	33.57	12.03	21.21	12.73	11.07	5.26
04	0.42	1.90	5.20	0.00	31.04	11.51	20.35	13.24	11.38	4.95
08	0.43	2.04	5.27	0.00	30.07	13.93	20.30	12.65	10.44	4.87
12	0.41	2.35	5.39	0.00	29.57	15.15	20.06	12.54	9.85	4.68
20	0.40	2.51	5.34	0.00	29.25	15.31	20.16	12.85	9.60	4.58
40	0.39	2.52	5.32	0.00	29.16	15.33	20.18	12.97	9.56	4.57

Note: Values are measured in percent. Variables with the symbol star (*) belong to foreign economy.

Output growth

Table 3.2 shows that variations in output growth in Vietnam are mainly led by domestic preference shock, σ_g. Accordingly, it accounts for more than half in both the short and long run. This finding is identical to the literature on the model with nominal rigidities in that the demand side has tended to play the dominant role (see Gali (2002)).

On the other hand, stationary technology shock contributes less than 18 %. Even though there is no observed data on employment, this relatively limited contribution would imply the opposite movements in output and employment in response to an increase in stationary technology shock in Vietnam. Indeed, this finding and its implication are identical to the standard literature on the NK-DSGE model (see Gali (2002), Smets and Wouters (2003), Adolfson et al. (2007)). For example, Gali (2002) argued: "*In a model with imperfect competition and sticky prices, a favorable technology shock is likely to induce a short-run decline in employment*". Meanwhile, both Smets and Wouters (2003) and Adolfson et al. (2007) found that an increase in stationary technology shock raises output, whereas it decreases employment. In particular, Smets and Wouters (2003) argued: "*The limited importance of productivity shocks (maximum 12% of forecast error variance in output) confirms the conjecture made in Gali (2002) that the negative correlation between output and employment in response to a productivity shock raises serious doubts about the quantitative significance of productivity shocks as a source of aggregate fluctuations*".

The exception for the first three months is that the role of monetary policy accounts for less than 20 % in explaining the variations in the Vietnamese output growth. On the other hand, all foreign shocks account for a proportion of around 15 %. This finding is a disappointment since the Vietnamese economy strongly depends on international trade and financial linkages. It implies misspecification in the SOE-NK-DSGE model that has been widely accepted in the current literature (Justiniano and Preston (2010a), Engel (2014), Gourinchas and Rey (2014)).

CPI inflation

The FEVD technique reveals that the fluctuations in the domestic CPI inflation in Vietnam are mainly driven by stationary technology disturbance (see Table 3.2). Accordingly, it accounts for over 40 %.

Meanwhile, policy shock accounts for less than 10 %. On the other hand, there is concrete evidence in favor of a sizeable influence of the external sector on the CPI inflation in Vietnam. More specifically, the shock to import cost-push, σ_{cp}, accounts for approximately one fourth. Therefore, all of seven foreign shocks are notably responsible for around 45 percent of the volatilities of the domestic CPI inflation in Vietnam.

On the other hand, the contribution of domestic preference shock accounts for a negligible percentage. Meanwhile, as analyzed before, the response of this variable to domestic preference shock is also the insignificantly statistical response. This fact can be explained as follows. The effect of domestic preference shock on the domestic CPI inflation is transmitted via several channels in between. At first, it influences domestic consumption via the New Keynesian IS curve. This impact is then transmitted to the domestic real marginal cost, mc_t. Through this channel, the domestic price inflation, π_H, will be impacted. Finally, this shock arrives at the domestic CPI inflation via the aggregate price. It is worthwhile noting that the magnitude of the effect of this shock on the domestic CPI inflation is only governed by the coefficient associated with the domestic real marginal cost, mc_t, in the domestic firm's hydrid NKPC[4]. Particularly, it is $\frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H(1+\beta\theta_H)}$. Therefore, the magnitude of the effect of this shock on the domestic CPI inflation will be either amplified or dampened by this coefficient. Indeed, the estimation leads to a small value[5] of 0.013. Consequently, there is a negligible contribution of the domestic preference shock to the CPI inflation as mentioned before.

Domestic interest rate

It is not surprising that the shock to risk premium is the primary source in driving the domestic interest rate in Vietnam. Accordingly, this shock accounts for over half for the first quarter and over 40 % for higher horizons.

The finding on the most significant contribution of the risk premium to the variations in the domestic interest rate can be explained by the strong connection between these two variables. More specifically, the changes in domestic interest rate are closely related to risk premium via two channels: uncovered interest rate parity and policy rule (see the equations (3.3.9.9) and (3.3.9.11)). As an example, an estimated value for a parameter associated with the exchange rate, $\psi_{\Delta e}$, in the policy is 0.81, which is high in magnitude.

On the other hand, the domestic shock, such as the domestic preference, σ_g, is the second-largest source of driving interest rate. An exception to the first quarter, for example is that preference shock accounts for around one fourth.

The nominal and real exchange rates

It is not surprising that the external-sector related shocks largely explain the fluctuations in these two external-sector linked variables. Regarding the real exchange rate, for example, it measures the relative ratio of foreign goods price in terms of local currency (VND) to domestic goods price (see the equation (3.3.9.4)). Thus, the shocks to

[4] The effect of preference shock on domestic consumption is governed by parameter, $\frac{1-h}{\sigma}$ (see the NKIS curve (3.3.9.1)). This effect will then translate into the domestic real marginal cost. The inverse parameter then governs it, $\frac{\sigma}{1-h}$. Therefore, the effect of domestic preference shock on domestic price inflation and CPI inflation is governed by only parameter, $\frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H(1+\beta\theta_H)}$.

[5] Mathematically, it is $\frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H(1+\beta\theta_H)}=\frac{(1-0.858)(1-0.99*0.858)}{0.858*(1+0.99*0.858)}=\frac{0.021}{1.587}=0.013$

import cost-push, σ_{cp}, and risk premium, σ_{rp}, are dominant sources of driving this variable. Notably, they share an approximately equal role of 28 %, and 26 % on the average, respectively. Meanwhile, a domestic disturbance, such as domestic monetary policy, accounts for slightly over 20 %. On the other hand, related to nominal exchange rate, risk premium (σ_{rp}), is the dominant source which is followed by domestic monetary policy. Accordingly, they account for around 40 %, and 33 %, respectively.

Terms of trade

Table 3.2 shows that stationary technology disturbance plays the primary role in driving the changes in the terms of trade. Indeed, it accounts for around 30 %. On the other hand, the import cost-push disturbance is the second-largest source (around 20%). Meanwhile, two shocks to domestic preference and risk premium share an approximately equal role of over 12 %. Regarding the role of the terms of trade shock, it is negligible (around 10 %). However, all seven foreign shocks make a notable contribution of around 55 %, whereas domestic monetary policy shock has an insignificant role.

3.6.3 Historical decomposition

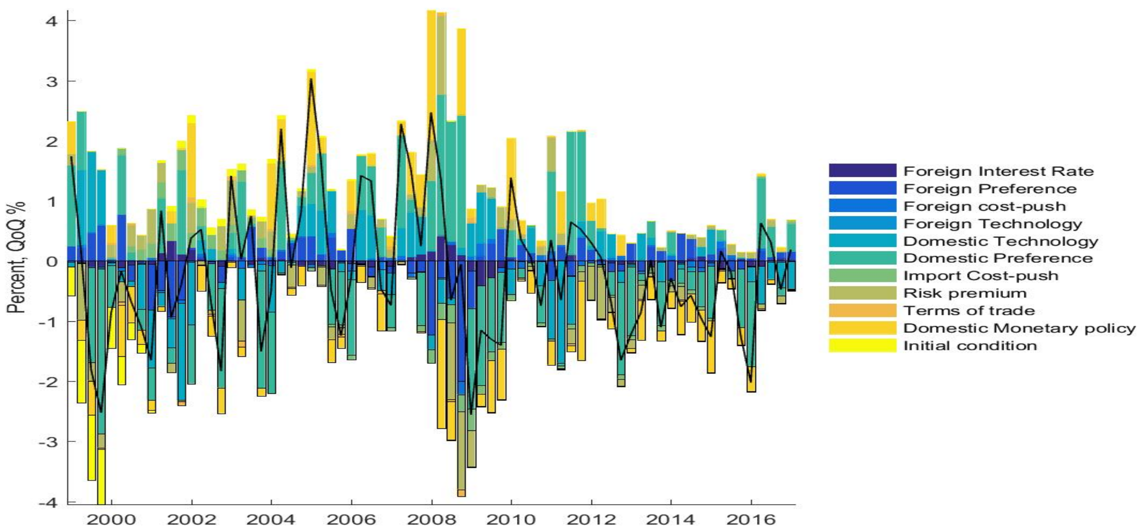
This section finds the sources that drove the output growth and CPI inflation in Vietnam throughout the period $1999Q1 - 2017Q1$. Thus, the historical decomposition technique is used. Figures $3.13 - 3.14$ show how each structural shock influences the fluctuations in these two Vietnamese macroeconomic variables. Accordingly, the black line presents the deviation of the smoothed value of the corresponding macroeconomic variable from its steady-state level.

Output Growth

Figure 3.13 presents the contribution of each structural shock to the output fluctuations for the period $1999Q1 - 2017Q1$. In general, in most of the episodes, the variations in the Vietnamese output growth rate are associated with the demand-side disturbance (preference shock and risk premium).

The first episode is the period after the 1997-Asian crisis. Accordingly, there was a fall in the Vietnamese output growth. Figure 3.13 reveals two main factors associated with this decline. The first one, which is the primary source, is the significant decline in domestic consumption demand (negative preference shock). The second one is the negative shock to the risk premium. This shock would imply the appreciation of the nominal exchange rate in the second half of 1999.

Figure 3.13: Output fluctuations, 1999Q1-2017Q1



The second episode is the period of the early 2000s. In particular, the Vietnamese output growth recovers. According to Figure 3.13, these economic recoveries are associated with the positive shock to the risk premium. Indeed, this shock presents the SBV's devaluation of VND relative to the USD. On the other hand, Figure 3.13 reveals three adverse shocks limiting the speed of the economic recovery. The first adverse one is domestic contractionary monetary policy. For example, the SBV raised its quarterly policy interest rate by 60 basis points in late 2000. Besides, this central bank made a considerable decrease in annual broad money growth. Regarding the two remaining adverse shocks, there are declines in foreign consumption demand and domestic stationary technology disturbances. These two adverse shocks might be linked with the early 2000 technology-related Recession, known as the Y2K crisis.

The third episode is the period of the economic boom of $2003-2007$. Based on Figure 3.13, two main factors lead to the economic boom. The first one is the positive shock to the domestic monetary policy. For example, the SBV had pursued the expansionary monetary policy. Accordingly, this central bank held its quarterly policy interest rate at a stable level of around 5 %. Indeed, this level was the lowest one over the period of 1999Q1-2017Q1. Additionally, this central bank increased its annual broad money growth by over 30 % per year, especially with the peak of approximately 50 % in 2007. Related to the second factor, domestic consumption expanded in most episodes. The expansionary monetary policy would cause these increases in domestic consumption. On the other hand, over this period, there is an insignificant contribution of the risk premium shock to the Vietnamese output growth. This fact might be explained by the relatively stable fluctuation in the nominal exchange rate before the global crisis.

The fourth episode is the global financial crisis. The global financial crisis took place in the US in 2007. However, it started to hit the Vietnamese economy in 2008. Figure 3.13 presents two dominant factors associated with a fall in output growth during the global financial crisis. The first one is the declines in foreign consumption. The second factor is the domestic contractionary monetary policy. Indeed, because of the pressure of high inflation in 2008, the SBV tightened its monetary policy. As a result, there were increases in the quarterly policy interest rate.

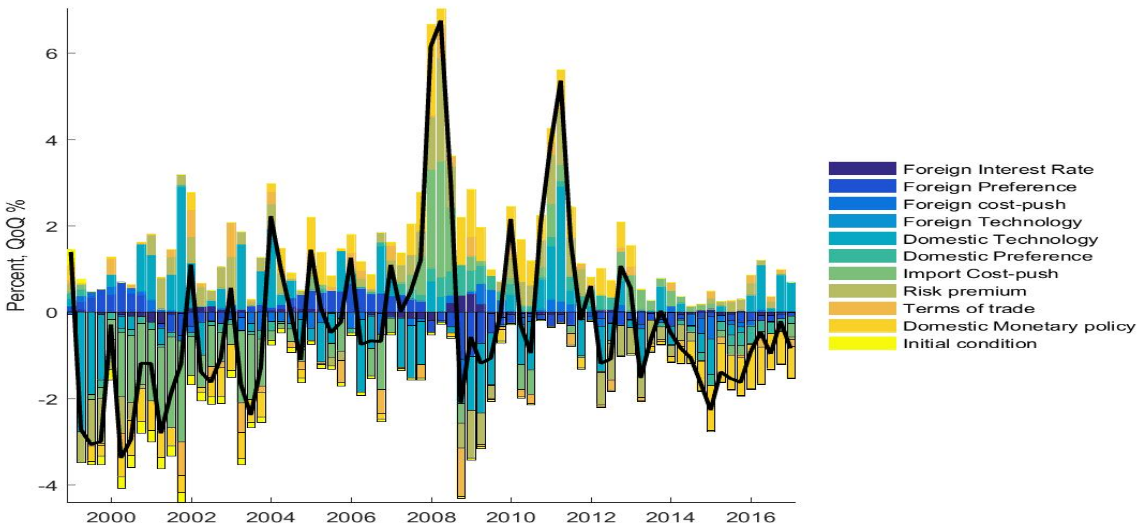
The last episode is the period after the global crisis. In Figure 3.13, there are two primary sources of driving output growth. The first one is a negative shock to monetary policy. The second one is an adverse shock to domestic consumption. These two adverse shocks would be linked to the monetary policy tightening over $2011 - 2012$ due to the two-digit inflation.

CPI Inflation

Figure 3.14 demonstrates the contribution of each structural shock to the domestic inflation fluctuations for the period $1999Q1 - 2017Q1$. Overall, the variations in the Vietnamese CPI inflation is mainly influenced by import cost-push and monetary policy shocks.

Over the period of $1999 - 2003$, Vietnam suffered from low inflation. According to Figure 3.14, two sources are associated with this low-inflation situation. The first one is the negative shock to import cost-push, which is a dominant source. Indeed, this negative shock would highly relate to the stable and lower-30-USD price of Brent Crude. On the other hand, the second source is a negative shock to monetary policy. This shock is associated with the monetary policy tightening. It is worth noting that, this monetary policy also limited the output growth as mentioned before. For example, the SBV raised its quarterly policy interest rate by 60 basis points in late 2000. Moreover, this central bank significantly declined its annual broad money growth rate in the early 2000s.

Figure 3.14: CPI inflation fluctuations, 1999Q1-2017Q1



In the episode before the global crisis, the Vietnamese CPI had been increasing since 2004. It is worth noting that this episode belongs to the economic boom. Figure 3.14 shows that these increases in the CPI inflation have resulted from an expansionary monetary policy. More notably, this Figure reveals three primary sources associated with the two-digit inflation of 23.116 % in 2008. Accordingly, the first one, which is a dominant source, is the import cost-push shock. This adverse shock to the import cost-push would be associated with the rocket in the world price of Brent crude over this stage. On the other hand, the second source is the risk premium shock, which is caused by the SBV's devaluations in early 2008. The third source is the adverse effect of expansionary monetary policy in the period of the economic boom. These three factors continue to cause a two-digit inflation of almost 19 % in 2011.

Over the remaining periods, the CPI inflation in Vietnam declined. Accordingly, Figure 3.14 indicates two primary sources. The first one is the negative effect of the risk premium shock. This disturbance was linked to the high appreciation of the nominal exchange rate from the second half of 2011 to early 2012. On the other hand, the second source is the monetary policy tightening. Indeed, the SBV implemented this monetary policy over the period of $2011 - 2012$.

3.7 Conclusion

In this paper, we develop a SOE-NK-DSGE model for Vietnam. Accordingly, this is the first attempt of developing and estimating the SOE-NK-DSGE model with the

Bayesian technique for Vietnam. Indeed, the specification of this model closely follows the influential studies by Gali and Monacelli (2005), Monacelli (2005), and Justiniano and Preston (2010b) on the small open economy. On the other hand, the failures of the SOE-NK-DSGE model in explaining the effects of the international spillovers on a small open economy are widely admitted in the current literature. Thus, in order to reduce this problem, we specify a higher number of foreign shocks than its domestic counterpart. In particular, the model has seven foreign disturbances and three domestic shocks. To an extent, this specification coincides with the fact that Vietnam is one of the most open economies in the world. The model is then estimated using the Bayesian technique and the time series for Vietnam and the USA between 1999Q1 and 2017Q1. As a result, the estimated model fits observed data relatively well. On the other hand, with the help of the impulse response function, forecast error variance, and historical decomposition techniques, several findings on the business cycle fluctuations in this emerging economy are revealed.

The underlying theoretical model of the SOE-NK-DSGE model is a small-sized type. For further research, this model can be enriched by incorporating other features as follows. As an example, in this paper, the domestic household directly supplies its labor to the domestic firm (see Figure 3.3). Therefore, there is no nominal friction of the wage stickiness. For further research, to introduce this friction, the model should adopt the assumption that the domestic household is unable to supply its labor directly to an intermediate goods firm. Instead of this, there is a labor-transforming firm. This firm aggregates a homogenous unit of labor and sells to intermediate goods at the wage $W_{H,t}$. On the other hand, this labor-transforming firm resets its wage according to the Calvo-style setting.

On the other, over the last decade, the structural model with financial friction has been one of growing interest. Thus, this small-sized model can include this friction by introducing a banking sector. Indeed, the domestic household holds a deposit at the bank. The bank, in turn, lends to the domestic intermediate goods firm. This borrowing is done to finance the intermediate goods firm's wage bill in advance (working capital channel as in the study by Adolfson et al. (2007)).

3.8 Appendices

3.8.1 Data sources

In the empirical analysis we use 10 following quarterly macroeconomic time series

Table 3.3: Data sources, 1998Q4-2017Q1

	Variables	Data sources
$\tilde{y}_t$	CPI-deflated GDP(log)	The GSO
$\tilde{p}_t$	CPI index (log)	The IMF-IFS Database
$\tilde{i}_t$	Central bank policy interest rate	The IMF-IFS Database
$\tilde{e}_t$	Nominal exchange rate against the USD (log)	The IMF-IFS Database
s_t	The 45-individual commodidy net export price index (log)	The IMF Database
$\tilde{q}_t$	CPI-based real exchange rate (log)	Calculated with $\tilde{p}_t$ and $\tilde{e}_t$
$\tilde{y}_t^*$	Foreign GDP (US) per capita at constant prices (log)	The Fed St. Louis
$\tilde{p}_t^*$	Foreign CPI index (US) (log)	The Fed St. Louis
$\tilde{i}_t^*$	The US interest rate	The Fed St. Louis

Note: *The GSO stands for the General Statistic Office of Vietnam.*

Note that in this paper we will not detrend or demean the data prior to estimation. Instead, we will do it within the estimation procedure by including intercepts in the measurement equations wherever applicable.

We use a number of following online database to collect data in table 3.3:

1. The CPI: https://data.imf.org/regular.aspx?key=61545861

2. The central bank policy interest rate: https://data.imf.org/regular.aspx?key=61545867

3. The Nominal exchange rate: https://data.imf.org/regular.aspx?key=61545850

4. Commodity terms of trade :
https://data.imf.org/?sk=2CDDCCB8-0B59-43E9-B6A0-59210D5605D2

5. Foreign real GDP per cap :
https://fred.stlouisfed.org/series/A939RX0Q048SBEA

6. Foreign CPI index : https://fred.stlouisfed.org/series/CPALTT01USQ661S

7. The Fed interest rate: https://data.imf.org/regular.aspx?key=61545867

Other annual macroeconomic indicators are used in this paper such as the broad money growth, etc. These indicators are collected from following online databases:

1. The annual broad money growth: https://datacatalog.worldbank.org/dataset/world-development-indicators

2. The annual growth rate of GDP: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=VN

3. The annual openness: https://data.worldbank.org/indicator/ne.trd.gnfs.zs

4. The global price of Brent Crude: https://fred.stlouisfed.org/series/POILBREUSDQ

5. The annual CPI inflation in Vietnam : `https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=VN`

6. The annual constant GDP-per-cap growth rate of Vietnam : `https://fred.stlouisfed.org/series/NYGDPPCAPKDVNM`

3.8.2 The measurement equation system

$$
\begin{aligned}
y_t^{obs} - y_{t-1}^{obs} &= \mu_y + y_t - y_{t-1} \\
p_t^{obs} - p_{t-1}^{obs} &= \mu_p + p_t - p_{t-1} \\
4 * i_t^{obs} &= \mu_i + 4 * i_t \\
q_t^{obs} - q_{t-1}^{obs} &= \mu_q + q_t - q_{t-1} \\
s_t^{obs} - s_{t-1}^{obs} &= \mu_s + s_t - s_{t-1} \\
y_t^{obs,f} - y_{t-1}^{obs,f} &= \mu_{y*} + y_t^* - y_{t-1}^* \\
p_t^{obs,f} - p_{t-1}^{obs,f} &= \mu_{p*} + p_t^* - p_{t-1}^* \\
4 * i_t^{obs,f} &= \mu_{i^*} + 4 * i_{t-1}^*
\end{aligned}
\tag{3.8.2.1}
$$

It is worth noting that in the original version of the state-space model, the measurement equation has both intercept and error terms. However, in this paper, the above measure equation has only intercept. There are two explanations for this specification. The first reason is to reduce the complexity of estimation. Moreover, in the underlying theoretical model, the number of shocks is higher than the number of observed variables. Thus, the problem of the singularity does not exist, and the inclusion of non-structural shocks in the measurement equation would not be necessary. The second reason is that the strategy of this specification is often used in the literature, such as the well-known studies of Smets and Wouters (2007), Del Negro et al. (2013) and others Choi and Hur (2015), Kolasa and Rubaszek (2018).

3.8.3 Prior vs Posterior densities

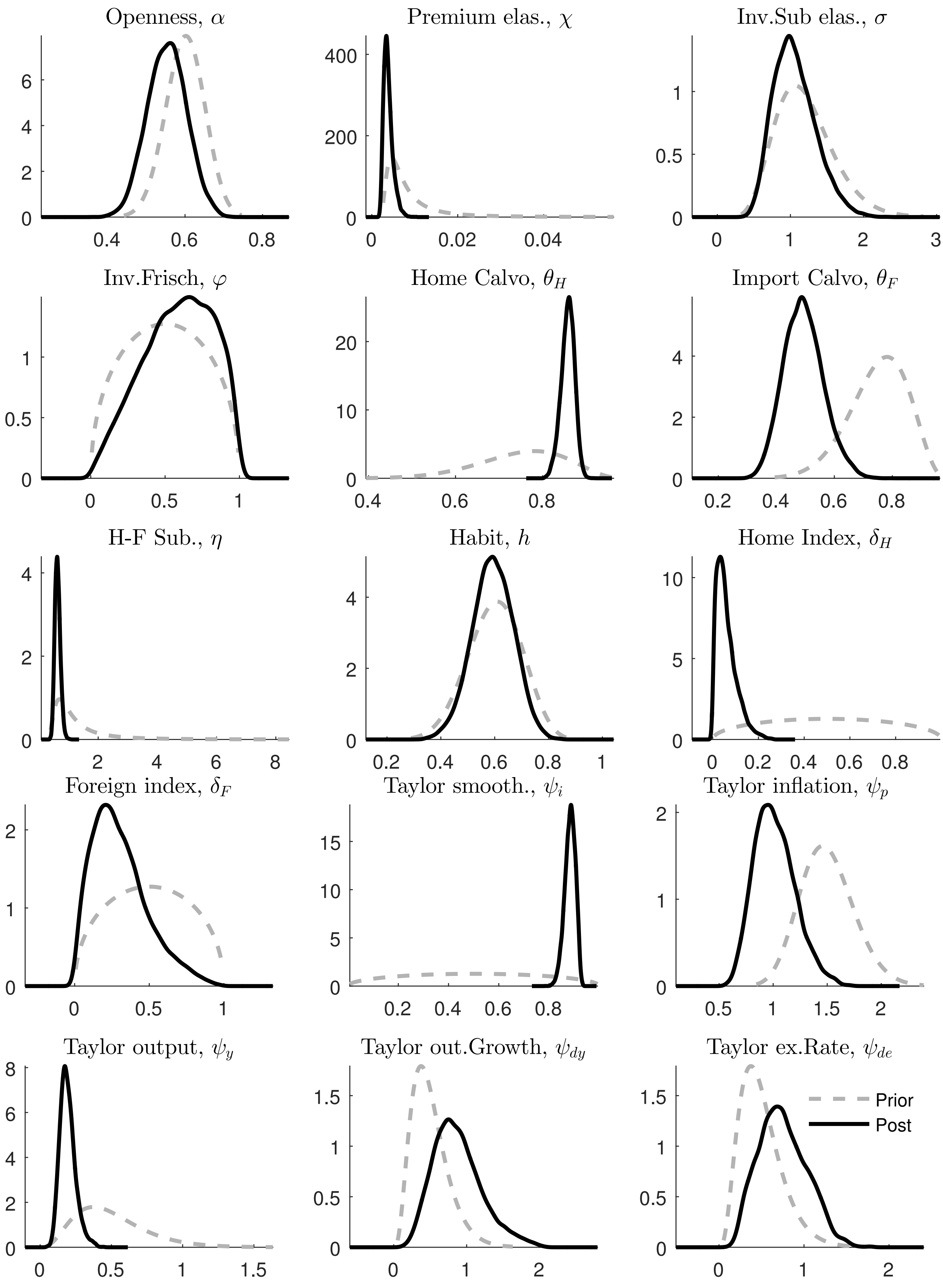


Figure 3.15: Prior and posterior densities

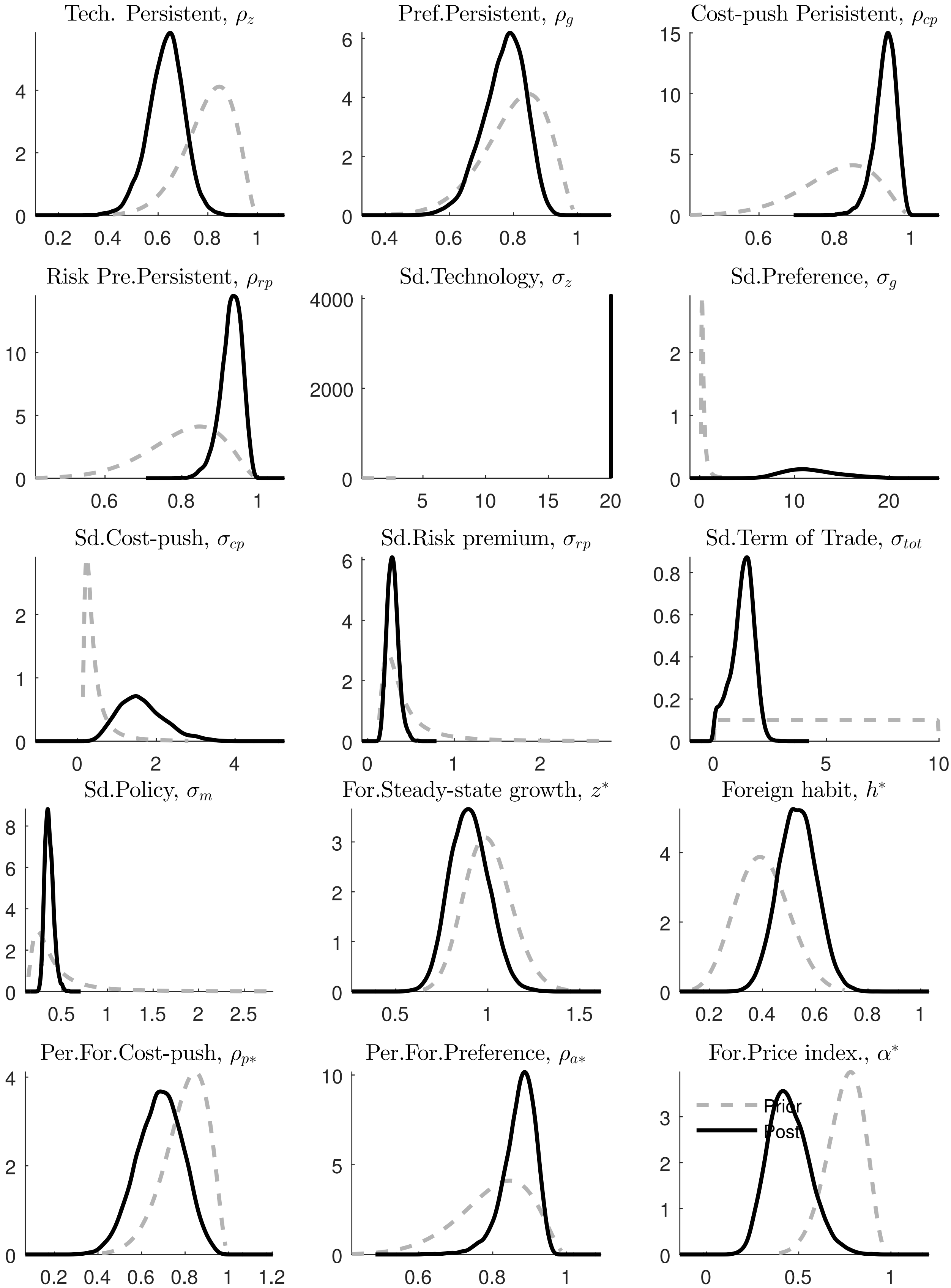


Figure 3.16: Prior and posterior densities

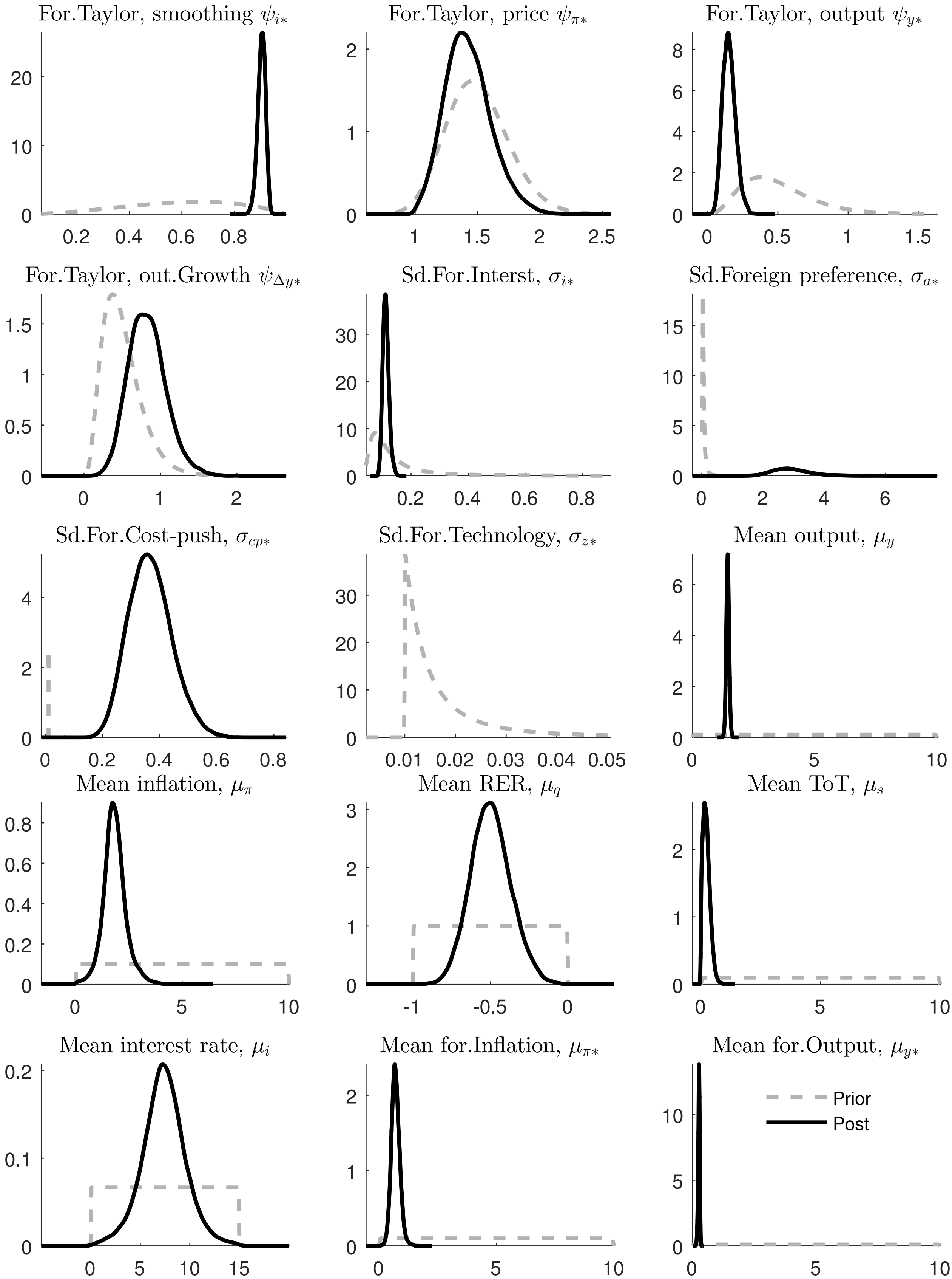


Figure 3.17: Prior and posterior densities

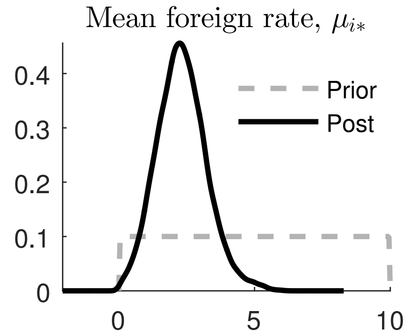
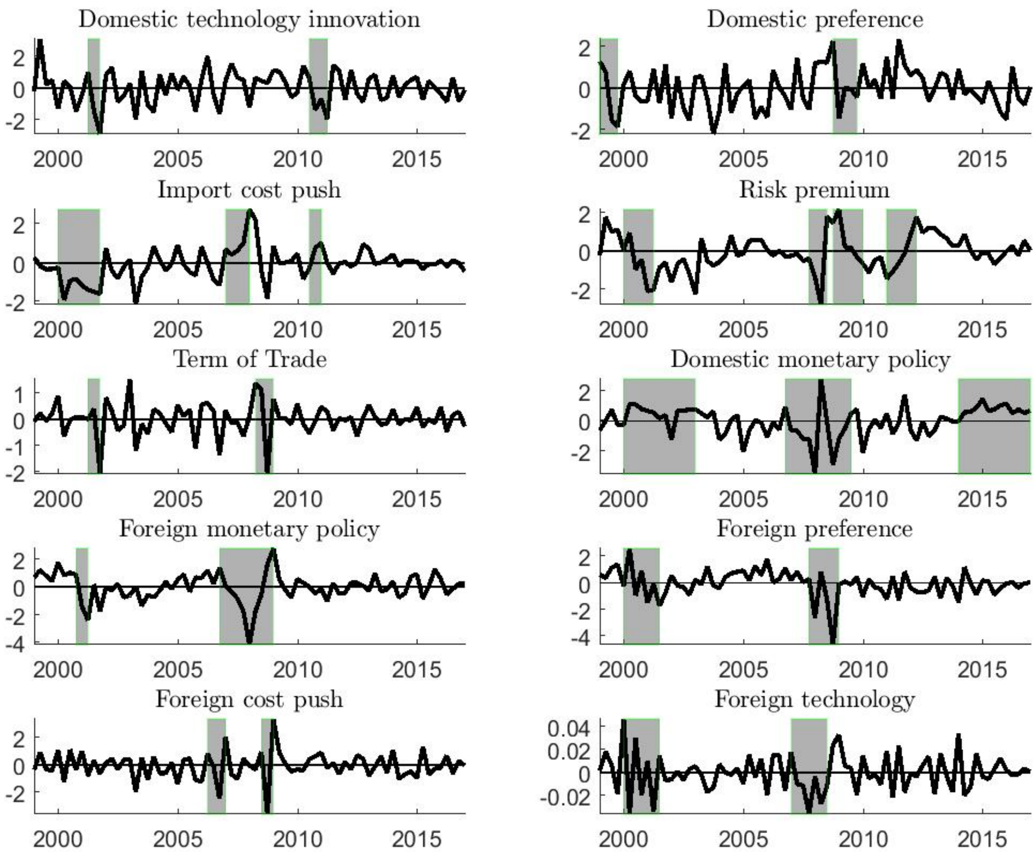


Figure 3.18: Prior and posterior densities

Figure 3.19: The smoothed shocks in Vietnam and foreign economy, 1999Q1-2017Q1



References

Adjemian, S., Bastani, H., Juillard, M., Karamé, F., Maih, J., Mihoubi, F., Perendia, G., Pfeifer, J., Ratto, M., and Villemot, S. (2011). Dynare: Reference Manual Version 4. *Dynare Working Papers Series no. 1.*

Adolfson, M., Laséen, S., and Lindé, J. (2008). Empirical properties of closed-and open-economy DSGE models of the Euro area. *Macroeconomic Dynamics*, 12(1):2–19.

Adolfson, M., Laseén, S., Lindé, J., and Villani, M. (2007). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics*, 72 (2):481–511.

Aguiar, M. and Gopinath, G. (2007). Emerging Market Business Cycles: The Cycle Is the Trend. *Journal of Political Economy*, 115(1):69–101.

Alba, J. D., Chia, W.-M., and Park, D. (2011). Foreign Output Shocks and Monetary Policy Regimes in Small Open Economies: A DSGE Evaluation of East Asia. *ERIA Discussion Paper Series ERIA-DP-2011-09.*

An, S. and Schorfheide, F. (2007). Bayesian Analysis of DSGE Models. *Econometric Reviews*, 26:113–172.

Aron, J., Farrell, G., Muellbauer, J., and Sinclair, P. (2014). Exchange Rate Pass-through to Import Prices, and Monetary Policy in South Africa. *Journal of Development Studies*, 50(1):144–164.

Aron, J., Macdonald, R., and Muellbauer, J. (2013). Exchange Rate Pass-Through in Developing and Emerging Markets: A Survey of Conceptual, Methodological and Policy Issues, and Selected Empirical Findings. *The Journal of Development Studies*, 50(1):101–143.

Benjamin, D. and Meza, F. (2009). Total Factor Productivity and Labor Reallocation: The Case of the Korean 1997 Crisis. *Advances in Macroeconomics*, 9(1):1625–1625.

Berg, Andrew, P. K. and Laxton, D. (2006a). A Practical Model-Based Approach to Monetary Policy Analysis: Overview. *IMF Working Paper WP/06/80.*

Berg, Andrew, P. K. and Laxton, D. (2006b). Practical Model-Based Monetary Policy Analysis—A How-To Guide. *IMF Working Paper WP/06/81.*

Boz, E., Daude, C., and Durdu, C. (2011). Emerging market business cycles: Learning about the trend. *Journal of Monetary Economics*, 58(6-8):616–631.

Boz, E., DURDU, C. B., and LI, N. (2015). Emerging Market Business Cycles: The Role of Labor Market Frictions. *Journal of Money, Credit and Banking*, 47(1):31–72.

Buncic, D. and Melecky, M. (2008). An Estimated New Keynesian Policy Model for Australia. *Economic Record*, 84(264):1–16.

Caglayan, M., Jehan, Z., and Mouratidis, K. (2016). Asymmetric Monetary Policy Rules for an Open Economy: Evidence from Canada and the UK. *International Journal of Finance and Economics*, 21:279–293.

Castillo, P., Montoro, C., and Tuesta, V. (2013). An Estimated Stochastic General Equilibrium Model with Partial Dollarization: A Bayesian Approach. *Open Economies Review*, 24(2):217–265.

Chang, C., Chen, K., Waggoner, D. F., and Zha, T. (2016). Trends and Cycles in China's Macroeconomy. *NBER Macroeconomics Annual 2015*, 30(2016):1–84.

Chari, V., Kehoe, P., and McGrattan, E. (2002). Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates. *Review of Economic Studies*, 69(3):533–563.

Cho, S. and Moreno, A. (2006). A Small-Sample Study of the New-Keynesian Macro Model. *Journal of Money, Credit and Banking*, 38(6):1461–1481.

Choi, J. and Hur, J. (2015). An examination of macroeconomic fluctuations in Korea exploiting a Markov-switching DSGE approach. *Economic Modelling*, 51:183–199.

Chowdhury, K. B. and Sarkar, N. (2017). Is the Hybrid New Keynesian Phillips Curve Stable? Evidence from Some Emerging Economies. *Journal of Quantitative Economics*, 15(3):427–449.

Christiano, L. J., Eichenbaum, M., and Evans, C. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113 (1):1–45.

Christiano, L. J., Trabandt, M., and Walentin, K. (2010). DSGE Models for Monetary Policy Analysis. *Handbook of Monetary Economics*, 3:285–367.

Cwik, T., Müller, G. J., and Wolters, M. H. (2011). Does trade integration alter monetary policy transmission? *Journal of Economic Dynamics and Control*, 35(4):545–564.

Dai, L., Minford, P., and Zhou, P. (2015). A DSGE model of China. *Applied Economics*, 47(59):6438–6460.

Del Negro, M., Eusepi, S., Giannoni, M., Sbordone, A., Tambalotti, A., Cocci, M., Hasegawa, R., and Linder, M. H. (2013). The FRBNY DSGE Model. *Staff Reports No.647, Federal Reserve Bank of New York.*

Del Negro, M. and Schorfheide, F. (2008). Forming priors for DSGE models (and how it affects the assessment of nominal rigidities). *Journal of Monetary Economics*, 55(7):1191–1208.

Del Negro, M., Schorfheide, F., Smets, F., and Wouters, R. (2007). On the fit of New Keynesian models. *Journal of Business and Economic Statistics*, 25:123–143.

Dizioli, A. and Schmittmann, J. M. (2015). A Macro-Model Approach to Monetary Policy Analysis and Forecasting for Vietnam. *IMF Working Paper WP/15/273.*

Dynan, K. (2000). Habit formation in consumer preferences: evidence from panel data. *American Economic Review*, 90(3):391–406.

Elekdag, S., Justiniano, A., and Tchakarov, I. (2005). An Estimated Small Open Economy Model of the Financial Accelerator. *IMF Working Paper No. 05/44.*

Elisa, P. and Padilla, I. (2011). Business cycles in a small open economy: The case of Hong Kong. *DFAEII Working Papers 2011-07, University of the Basque Country.*

Engel, C. (2014). Exchange Rates and Interest Parity. *Handbook of International Economics*, 4:453–522.

Feenstra, C., R., Inklaar, R., and Timmer, M. P. (2015). The Next Generation of the Penn World Table. *American Economic Review*, 105(10):3150–3182.

Frankel, J., Parsle, D., and Wei, S.-J. (2012). Slow pass-through around the world: A new import for developing countries? *Open Economies Review*, 23:213–251.

Frankel, J. A. (2010). Monetary Policy in Emerging Markets: A Survey. *NBER Working Paper No. 16125.*

Fuhrer, J. C. (2000). Habit formation in consumption and its implications for monetary-policy models. *American Economic Review*, 90(3):367–390.

Funke, M. and Paetz, M. (2010). What can an open-economy DSGE model tell us about Hong Kong's housing market? *BOFIT Discussion Papers 19.*

Gabriel, V., Levine, P., and Yang, B. (2016). An Estimated DSGE Open Economy Model of the Indian Economy with Financial Frictions. In C., G. and K, K., editors, *Monetary Policy in India*, pages 455–506. Springer, New Delhi.

Galí, J., Gertler, M., and López-Salido, J. D. (2005). Robustness of the estimates of the hybrid New Keynesian Phillips curve. *Journal of Monetary Economics*, 52(6):1107–1118.

Gali, J. (2002). New Perspectives on Monetary Policy, Inflation, and the Business Cycle. *NBER Working Paper No. 8767*.

Gali, J. and Gertler, M. (1999). Inflation dynamics: A structural economic analysis. *Journal of Monetary Economics*, 44(2):195–222.

Gali, J. and Monacelli, T. (2005). Monetary policy and Exchange Rate volatility in a small open economy. *The Review of Economic Studies*, 72 (3):707–734.

García-Cicco, J., Pancrazi, R., and Uribe, M. (2010). Real Business Cycles in Emerging Countries? *American Economic Review*, 100(5):2510–31.

Garcia, C. J., Restrepo, J. E., and Roger, S. (2011). How much should inflation targeters care about the exchange rate? *Journal of International Money and Finance*, 30:1590–1617.

Gourinchas, P.-O. and Rey, H. (2014). External Adjustment, Global Imbalances, Valuation Effects. *Handbook of International Economics*, 4:585–645.

Gu, B., Wang, J., and Wu, J. (2014). Business Cycles in an Estimated DSGE Model of China. *China Economic Journal*, 7(3):361–381.

Gust, C., Leduc, S., and Sheets, N. (2009). The adjustment of global external balances: Does partial Exchange-Rate Pass-Through to trade prices matter? *Journal of International Economics*, 79:173–185.

Gust, C., SylvainLeduc, and Vigfusson, R. (2010). Trade integration, competition, and the decline in Exchange-Rate Pass-Through. *Journal of Monetary Economics*, 57(3):309–324.

Hall, R. E. (1988). Intertemporal Substitution in Consumption. *Journal of Political Economy*, 96(2):339–357.

Hamilton, J. D. (1994). *Time Series Analysis*, volume 2. Princeton university press Princeton, NJ.

Harmanta, Purwanto, N. M. A., and Oktiyanto, F. (2014). Banking sector and financial friction on DSGE model: The case of Indonesia. *Bulletin of Monetary, Economics and Banking*, 17(1):22–54.

Havranek, T., Horvath, R., Irsova, Z., and Rusnak, M. (2015). Cross-country heterogeneity in intertemporal substitution. *Journal of International Economics*, 96(1):100–118.

Havranek, T., Rusnak, M., and Sokolova, A. (2017). Habit formation in consumption: A meta-analysis. *European Economic Review*, 95:142–167.

Huynh, P., Nguyen, T., Duong, T., and Pham, D. (2017). Leaning against the Wind Policies on Vietnam's Economy with DSGE Model. *Economies*, 5(1):1–18.

Ireland, P. N. (2004). Technology Shocks in the New Keynesian Model. *Review of Economics and Statistics*, 86(4):923–936.

Ireland, P. N. (2011). A New Keynesian Perspective on the Great Recession. *Journal of Money, Credit and Banking*, 43(01):32–54.

Iwata, Y. (2012). Non-Wasteful Government Spending in an Estimated Open Economy DSGE Model:Two Fiscal Policy Puzzles Revisited. *ESRI Discussion Paper Series No.285*.

Jääskelä, J. P. and Nimark, K. (2011). A Medium-Scale New Keynesian Open Economy Model of Australia. *Economic Record*, 87(276):11–36.

Justiniano, A. and Preston, B. (2010a). Can structural small open-economy models account for the influence of foreign disturbances? *Journal of International Economics*, 81(1):61–74.

Justiniano, A. and Preston, B. (2010b). Monetary policy and uncertainty in an empirical small open-economy model. *Journal of Applied Econometrics*, 25 (1):93–128.

Kehoe, P. and Midrigan, V. (2015). Prices are sticky after all. *Journal of Monetary Economics*, 75:35–53.

Kehoe, T. J. and Ruhl, K. J. (2009). Sudden stops, sectoral reallocations, and the Real Exchange Rate. *Journal of Development Economics*, 89:235–249.

Khieu, H. V. (2014). The Role of Monetary Policy in the New Keynesian Model: Evidence from Vietnam. *International Economic Journal*, 29(1):138–160.

Kilian, L. and Hicks, B. (2013). Did unexpectedly strong economic growth cause the oil price shock of 2003–2008? *Journal of Forecasting*, 32 (5):385–394.

Kolasa, M. and Rubaszek, M. (2018). Does the foreign sector help forecast domestic variables in DSGE models? *International Journal of Forecasting*, 34(4):809–821.

Kose, M. A. (2002). Explaining Business Cycles in Small Open Economies 'How Much Do World Prices Matter? *Journal of International Economics*, 56:299–327.

Le, H. (2014). Dynamics of Business Cycles in Vietnam: A comparison with Indonesia and Philippines. *MPRA Paper 57010, University Library of Munich.*

Lee, H. and To, M. T. (2014). Assessing the impacts of deeper trade reform in Vietnam in a General Equilibrium Framework. *MPRA Paper No.82271, University Library of Munich.*

Linardi, F. D. M. (2016). Assessing the Fit of a Small Open-Economy DSGE Model for the Brazilian Economy. *Working Paper Series 424, The Banco Central do Brasil.*

Liu, L. and Zhang, W. (2010). A New Keynesian model for analysing monetary policy in Mainland China. *Journal of Asian Economics*, 21:540–551.

Lubik, T. A. and Schorfheide, F. (2007). Do central banks respond to exchange rate movements? A structural investigation. *Journal of Monetary Economics*, 54(4):1069–1087.

Medina, J. P. and Soto, C. (2007). The Chilean Business Cycles through the Lens of a Stochastic General Equilibrium Model. *Working Papers No.457, Central Bank of Chile.*

Mendoza, E. (1995). The Terms of Trade, the Real Exchange Rate, and Economic Fluctuations. *International Economic Review*, 36:101–137.

Mendoza, E. G. (2010). Sudden Stops, Financial Crises, and Leverage. *American Economic Review*, 100(5):1941–66.

Mendoza, E. G. and Yue, V. Z. (2012). A General Equilibrium Model of Sovereign Default and Business Cycles. *The Quarterly Journal of Economics*, 127(2):889–946.

Monacelli, T. (2005). Monetary policy in a low pass-through environment. *Journal of Money, Credit and Banking*, 37:1047–1066.

Neumeyer, P. A. and Perri, F. (2005). Business cycles in emerging economies: the role of interest rates. *Journal of Monetary Economics*, 52(2):345–380.

Nimark, K. P. (2009). A Structural Model of Australia as a Small Open Economy. *Australian Economic Review*, 42(1):24–41.

Obstfeld, M. and Rogoff, K. (2007). The unsustainable US Current Account Position Revisited. In Clarida, editor, *G7 Current Account Imbalances: Sustainability and Adjustment*, pages 339 – 376. University of Chicago Press.

Oviedo, P. M. and Yue, V. Z. (2009). World Interest Rate and Business Cycles in Small Open Economies.

Palma, A. A. and Portugal, M. S. (2014). Preferences of the Central Bank of Brazil under the inflation targeting regime: Estimation using a DSGE model for a small open economy. *Journal of Policy Modeling*, 36(5):824–839.

Peterman, W. B. (2016). Reconciling Micro and Macro Estimates of the Frisch Labor Supply Elasticity: A Sensitivity Analysis. *Economic Inquiry*, 54(1):100–120.

Pham, B. T. (2018). Public investment and Vietnam business cycles: a DSGE approach.

Ramayandi, A. (2011). Impact of International Financial Shocks on Small Open Economies:The Case of Four ASEAN Countries. *ADB Economics Working Paper Series No. 253*.

Rees, D. M., Smith, P., and Hall, J. (2016). A Multi-sector Model of the Australian Economy. *Economic Record*, 92(298):374–408.

Sahminan, Utama, G., Rakman, R. N., and Idham (2017). A Dynamic Stochastic General Equilibrium (DSGE) Model to Assess the Impact of Structural Reforms on the Indonesian Economy. *Bulletin of Monetary Economics and Banking*, 20(2):149–180.

Sala, H., Pham, B. T., and Silva, J. I. (2019). Growth and real business cycles in Vietnam and the ASEAN-5. Does the trend shock matter? *Economic Systems*, forthcoming.

Saxegaard, M., Anand, R., and Peiris, S. J. (2010). An Estimated Model with Macrofinancial Linkages for India. *IMF Working Paper No. 10/21*.

Schmitt-Grohé, S. and Uribe, M. (2003). Closing small open economy models. *Journal of International Economics*, 61(1):163–185.

Schmitt-Grohé, S. and Uribe, M. (2018). How important are Terms-Of-Trade shocks? *International Economic Review*, 59(1):85–111.

Silveira, M. A. C. (2008). Using a Bayesian approach to estimate and compare new Keynesian DSGE models for the Brazilian economy: the role for endogenous persistence. *Revista Brasileira de Economia*, 62(3):333–357.

Smets, F. and Wouters, R. (2003). An estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, 1(3):1123–1175.

Smets, F. and Wouters, R. (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review*, 97 (3):586–606.

Steinbach, M., Mathuloe, P., and Smit, B. (2009). An open economy NEW KEYNESIAN DSGE model of the South African economy. *South African Journal of Economics*, 77(2):207–227.

Taylor, J. B. (2000). Using Monetary Policy Rules in Emerging Market Economies. *The 75th Anniversary Conference, "Stabilization and Monetary Policy: The International Experience," the Bank of Mexico.*

Uribe, M. and Schmitt-Grohé, S. (2017). Open Economy Macroeconomics. *Princeton University Press.*

Uribe, M. and Yue, V. Z. (2006). Country spreads and emerging countries: Who Drives Whom? *Journal of International Economics*, 69(1):6–36.

Wieland, V., Cwik, T., Müller, G., Schmidt, S., and Wolters, M. (2012). A new comparative approach to macroeconomic modeling and policy analysis. *Journal of Economic Behavior Organization*, 83 (3):523–541.

Woodford, M. (2003). Interest and Prices: foundations of a theory of monetary policy. *Princeton University Press (2003).*

Zeev, N. B., Pappa, E., and Vicondoa, A. (2017). Emerging economies business cycles: The role of commodity Terms of Trade News. *Journal of International Economics*, 108:368–376.

Zheng, T. and Guo, H. (2013). Estimating a small open economy DSGE model with indeterminacy: Evidence from China. *Economic Modelling*, 31:642–652.