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Abstract

This paper develops a small-scale, structural general equilibrium model for the Thai economy. Using Bayesian estimation, we evaluate the conduct of monetary policy under inflation targeting regime. Specifically, we focus on three main issues. First, we investigate whether exchange rate movements are incorporated in the monetary policy formulation. Second, we conduct welfare evaluation under alternative monetary policy settings. Third, we explore how the varying degree of openness could affect the transmission mechanism. Using data over the past 20 years, we find that the Bank of Thailand adjusted policy interest rate in response to exchange rate movements and this helped to reduce both output and inflation fluctuations from global shocks and improves welfare. While higher degree of openness is found to flatten the slope of the Phillips curve, it does not necessarily reduce monetary policy effectiveness. This is because openness also affects the policy coefficients in the central bank's endogenous reaction function.

Keywords: small open economy models; monetary policy rules; exchange rates; Bayesian analysis; Thai economy

JEL Classifications: C32; E52; F41

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1 Introduction

One of the important issues for a small open economy is whether the central bank should respond to exchange rate fluctuations when setting policy interest rate. Conventional micro-founded models often show that there is little to be gained by adding exchange rate to the policy rule. To the extent that the central bank takes into account of exchange rate impacts on inflation and output, the optimal policy rule for the open economy is isomorphic to the closed economy case (Clarida et al. 2001).

However, the validity of this finding may depend critically on assumptions used in the models. For example, when allowing for incomplete exchange rate pass-through in the import prices, such claim is no longer true (Monacelli, 2005). In later work by Monacelli (2013), it is shown that openness (regardless whether it is trade on consumption or on production) can fundamentally change the nature of optimal policy to be different from the closed economy setting, leading policy-makers to actively manage the term of trade via exchange rate stabilization. Furthermore, when central banks have imperfect knowledge about the states of the economy and exchange rate changes can signal future developments of the economy, it would be optimal for central banks to use policy rate in response to changes in the exchange rates (Pavasuthispaisit, 2010).

Based on New Keynesian DSGE model, Lubik and Schorfheide (2007) estimate monetary policy rules in four inflation-targeting small-open economies. This structural estimation approach has advantage over univariate setup in that it preserves endogenous interaction between exchange rate and interest rate. They find that Australia and New Zealand set interest rates in response to exchange rates but it is not the case of Canada and the United Kingdom. However, Dong (2013) revisited Lubik and Schorfheide's findings by extending the model estimation to cover periods since the adoption of inflation-targeting framework, it is found that all three central banks in Canada, New Zealand and the United Kingdom did not adjust their policy rates in response to exchange rate movements and the results are less clear for Australia. This result appears to be consistent with Taylor (2001) who finds little improvement to explicitly add exchange rate into the policy reaction function since the exchange rate movements are indirectly taken into account. While such a debate may remain unsettled, there is clearly a need for further research, particularly for the case of emerging market economies. For example, Garcia et al. (2011) employ a DSGE model to argue that financially-vulnerable emerging markets are likely to benefit more from exchange rate smoothing.

The role of exchange rate plays an even more important for developing economies that have adopted inflation targeting (IT) framework. It is not only that countries with less well-developed financial system are more likely to suffer higher output losses associated with exchange rate fluctuations, but it might also create confusions about the commitment to inflation target and complicate policy implementation. This is due to IT emerging markets with less flexible exchange rate arrangements tends to intervene more frequently. In a comprehensive work by Stone et al. (2009), the authors provide model-based analysis to support an explicit but limited role of exchange rate in the IT framework. Specifically, it is argued that the benefits of a more explicit role of exchange rate depends on (i) the nature of economic structure (ii) the shocks to which it is exposed and (iii) how the exchange rate is explicitly taken into account in policy rate setting. It is concluded that "it is not possible to draw strong policy conclusions for diverse economies on the basis of simulation results using small and necessarily simplified models and there is greater scope for further work", (p.2).

Based on panel regressions using data from 16 countries during 1989-2006, Aizenman et al. (2011) find that inflation-targeting emerging markets follow a mixed strategy whereby interest rate setting is based on both inflation and real exchange rates. And the policy responses to real exchange rate fluctuations are stronger for commodity-exporting countries that are more vulnerable to terms-of-trade shocks. More recent evidence by Cabral et al. (2020) which follow similar empirical approach covering 24 countries with a more recent data during 2000-2015, it is found that the role of exchange rate in the policy reaction function still remains significant but quantitatively less across IT emerging market countries, compared with non-IT countries.

In the case of Thailand, the Bank of Thailand has adopted inflation targeting framework for more than two decades since May 2000. There have been positive developments in many aspects of the monetary policy formulation, particularly on the policy communication for improved transparency. When facing with large movements in the exchange rate, however, public debates often arise on the appropriate response and sometimes cast doubts about the applicability of the broad IT framework. For example, it is argued that targeting inflation is not appropriate given that Thailand has very high level of trade openness, relative to other IT countries and hence cannot control domestic prices effectively (Saicheau et al. 2012).

Motivated by these considerations, this paper aims to revisit the role of exchange rate under the IT regime in the Thai economy. Specifically, our research investigation is whether exchange rate movements have been taken into account in the Thai monetary policy formulation. In order to avoid the endogenous interaction between exchange rate and interest rate, we instead employ a small open economy DSGE model based on Gali and Monacelli (2005) and Lubik and Schorfheide (2007) and estimate structural parameters for the Thai economy and monetary policy reaction function using the Bayesian techniques. We then use the model to conduct welfare evaluation of Thai monetary policy rule with and without exchange rate response. Furthermore, given that Thai economy is highly open in terms of international trade, we look at the impacts of how varying the degree of openness on (i) structure of the economy via the Phillips curve; (ii) policy coefficient in the central bank reaction function; (iii) monetary transmission mechanism; and (iv) welfare loss.

Our result indicates that the Bank of Thailand systematically set interest rate in response not only to output and inflation but also to exchange rate fluctuations. This is consistent with other papers that focus specifically on the Thai monetary policy. For example, Taguchi and Wanasilp (2018) estimate several reduced-form policy rules using data from 2000-2017 and find significant results of exchange rate response in the policy rules. Lueangwilai (2012), which also employed Lubik and Schorfheide (2007) model for the Thai economy, also found similar result. In addition to the previous literature, we find that higher degree of openness does not only flattens the slope of the Phillips curve, but also induce the optimal policy response to inflation stronger.

The remainder of the paper is organized as follows. Section 2 lays out the baseline small open economy model. Section 3 employs the Bayesian techniques to estimate model parameters for the Thai economy and we report impulse responses in Section 4. Section 5 conducts welfare analysis, comparing monetary policy rules with and without exchange rate response. Section 6 analyzes varying degree of openness for monetary policy implications. Section 7 summarizes the paper.

2 A small open economy model

This study estimates a small open economy model for Thai economy using the dynamic stochastic general equilibrium (DSGE) approach, specified along the lines of Gali and Monacelli (2005) and Lubik and Schorfheide (2007), referred to as LS (2007) hereinafter.

A typical small open economy is inhibited by a representative household who consumes, provides labor and pays tax. A representative household seeks to maximize his utility which consists of a composite consumption good and labor. The composite consumption good is a combination of domestic and foreign goods. The households receive the profits generated by the monopolistically competitive domestic intermediate goods producers.

2.1 Households

Domestic households solve the following decision problem

$$Max \sum_{t=0}^{\infty} E_t \beta^t \left(\frac{C_t / Z_t^{1-\sigma} - 1}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right)$$

Subject to

$$P_t C_t + \frac{1}{R_t} D_{t+1} + \frac{1}{R_t^*} D_{t+1}^* \leq W_t N_t + D_t + \varepsilon_t D_t^* + \int \Phi_t(i)\, di$$

where C_t is the consumption of a composite good,N_t is hour worked, P_t is the nominal price level of the composite good, D_{t+1} is holding of a security that pays 1 unit of the domestic currency (Thai baht) and its current price is $\frac{1}{R_t}$ which is the inverse of the one period gross nominal risk-free interest rate in baht, D_{t+1}^* is holding of a security that pays 1 unit of the foreign currency (US dollar) and its current price is $\frac{1}{R_t^*}$ which is the inverse of the one period gross nominal risk-free interest rate in US dollar, ε_t is the nominal exchange rate (baht/US dollar), $\Phi_t(i)$ are nominal dividends earned from domestic firm i. Z_t is the world technology process which is assumed to follow a random with drift.

After detrending consumption and nominal wages according to $c_t = C_t/Z_t$ and $w_t = W_t/Z_t$, the first order conditions can be written as

$$N_t^{\varphi} = c_t^{-\sigma} w_t$$

$$c_t^{-\sigma} = \beta E_t[R_t c_{t+1}^{-\sigma} (z_{t+1}\pi_{t+1})^{-1}]$$

$$0 = E_t[R_t - R_t^* e_{t+1} \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} (z_{t+1}\pi_{t+1})^{-1}$$

where $z_t = Z_t/Z_{t-1}$, $\pi_t = P_t/P_{t-1}$ is the gross of inflation rate, and $e_t = \mathcal{E}_t/\mathcal{E}_{t-1}$ is the gross of depreciation rate.

2.2 Firms

There are three types of firms in the economy. One types are firms that buy quantities of domestic and foreign goods and package them into a composite good that is used for consumption by the households. These firms maximize profits in a perfectly competitive environment. A second type of firms is firms producing domestic intermediate goods. They are monopolistic competitors and have monopoly power over the varieties they produce and set prices in a staggered way. Following Calvo (1983), these firms can re-optimize prices in each period with a probability. The firms that are unable to re-optimize their prices will increase their prices according to the steady state inflation rate. The firms' production function is linear in labor. There are third perfectly competitive firms that buy the domestic intermediate goods, package them and resell the composite good to the first type firms that aggregate domestic and foreign produced goods.

Firm type I: There are firms that buy quantities $C_{H,t}$ and $C_{F,t}$ of domestic and foreign produced goods and package them into a composite good that is used for consumption by the households. Let $P_{H,t}$ be the domestic price of home produced goods and let $P_{F,t}$ be the domestic price of foreign produced goods. These firms maximize profits in a perfectly competitive environment.

$$Max\ P_t C_t - \ P_{H,t} C_{H,t} - \ P_{F,t} C_{F,t}$$

subject to

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

The first-order conditions can be written as

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t$$

$$C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t$$

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

Firm type II: There are firms that behave perfectly competitive, purchasing the domestic intermediate goods, package them, and resell the composite goods to the firms that aggregate as well as abroad. These firms solve the following problem

$$Max\ P_{H,t} Y_t - \int_0^1 \ P_{H,t}\,(i) Y_t\,(i)\,di$$

subject to

$$Y_t = \left[\int_0^1 Y_t\,(i)^{\frac{\epsilon-1}{\epsilon}}\,di\right]^{\frac{1}{1-\epsilon}}$$

The first-order conditions can be written as

$$Y_t(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon} Y_t$$

$$Y_{H,t} = \left[\int_0^1 P_{H,t}\,(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}}$$

where $Y_t(i)$ is the demand for the intermediate good i.

Firm type III: There are firms producing the domestic intermediate goods $Y_t(i)$. These firms behave monopolistic competitive. Firms can re-optimize prices in each period with probability $1-\theta$. We assume that firms are unable to re-optimize their prices, $P_{H,t}(i)$ will increase according to the steady state inflation rate $\pi_{H,ss}$. The firms use today's prices of state-contingent securities to discount future nominal profits. The firms' production function is linear in labor:

$$Y_t(i) = Z_t N_t\ (i)$$

where Z_t productivity is not firm specific and its growth rate $z_t = Z_t/Z_{t-1}$ follows an AR(1) process

$$(lnz_t - \gamma) = (\rho_z lnz_{t-1} - \gamma) + \varepsilon_t^z$$

where γ is the steady state growth rate of productivity. The firms' problem is given by

$$MaxE_t[\sum_{\tau=0}^{\infty} \theta^\tau \mathcal{Q}_{t+\tau|t} Y_{t+\tau}\,(i) \left(\tilde{P}_{H,t}\,(i)\,\pi_{H,ss}^\tau\right) - MC_{t+\tau}^n]$$

subject to

$$Y_{t+\tau}\,(i) \leq \left(\frac{\tilde{P}_{H,t}\,(i)\,\pi_{H,ss}^\tau}{P_{H,t+\tau}}\right)^{-\epsilon} Y_{t+\tau}$$

where $MC_{t+\tau}^n = \frac{W_{t+\tau}}{Z_{t+\tau}}$ is the nominal marginal cost and $\mathcal{Q}_{t+\tau|t}$ is the time price of a security that pays 1 Baht in period $t+\tau$. Giving the symmetric equilibrium in which all firms solve the same problem, we eliminate the index i. The firms' first-order condition can then be written as

$$E_t[\sum_{\tau=0}^{\infty} \theta^\tau \mathcal{Q}_{t+\tau|t} \left(\frac{\tilde{P}_{H,t}\pi_{H,ss}^\tau}{P_{H,t+\tau}}\right)^{-\epsilon} Y_{t+\tau} \left[(\epsilon-1)\,\tilde{P}_{H,t}\pi_{H,ss}^\tau - MC_{t+\tau}^n\right] = 0$$

The fraction of the firms that are allowed to re-optimize their price while all others update their price by the steady state inflation rate. Therefore,

$$P_{H,t} = [\theta \tilde{P}_{H,t}^{1-\epsilon} + (1-\theta)(\pi_{H,ss} P_{H,t-1})^{1-\epsilon}]^{\frac{1}{1-\epsilon}}$$

The re-optimize price firms solve the problem

$$MaxW_tN_t$$

subject to

$$Y_t = Z_tN_t$$

We can express both the nominal marginal costs and prices chosen by firms that are able re-optimize in terms of the price of domestic good.

$$mc_t = \frac{MC_t^n}{P_t^H} = \frac{W_t}{Z_tP_t^H}$$

$$\tilde{p}_{H,t} = \frac{\tilde{P}_{H,t}}{P_{H,t}}$$

2.3 Term of trade and real exchange rate

Terms of trade are defined as the relative price of the domestic price of home and foreign produced goods. Assume that the law of one price for foreign goods holds. Both an exchange rate depreciation and foreign inflation reduce the terms of trade or make imports more expensive. Define the terms of trade as

$$Q_t = \frac{P_{H,t}}{P_{F,t}}$$

We assume that the law of one price for foreign goods hold

$$P_{F,t} = \mathcal{E}_tP_{F,t}^*$$

where $P_{F,t}^*$ is the price of the foreign produced goods in the foreign country, measure in foreign currency. We assume $P_{F,t}^*$ is approximately equal to the foreign CPI P_t^* and the term of trade can be expressed as

$$Q_t = \frac{P_{H,t}}{\mathcal{E}_tP_{F,t}^*}$$

Both exchange rate depreciation and foreign inflation reduce the terms of trade, making imports more expensive. Let P_t be the domestic CPI. The real exchange rate is defined as

$$S_t = \frac{\mathcal{E}_tP_t^*}{P_t}$$

Thus the relative price can be expressed as

$$\frac{P_{H,t}}{P_t} = Q_t S_t$$

Giving that in equilibrium $\mathcal{Q}_{t+\tau|t} = \beta^{\tau} \frac{c_{t+\tau}^{-\sigma} P_t Z_t}{c_t^{-\sigma} P_{t+\tau} Z_{t+\tau}}$. Thus the optimal pricing rule can be re-stated as

$$\tilde{p}_{H,t} = \frac{\epsilon}{1-\varepsilon} \frac{E[\sum_{\tau=0}^{\infty} (\beta\theta^{\tau}) \frac{c_{t+\tau}^{-\sigma}}{c_t^{-\sigma}} \left(\frac{\pi_{H,ss}^{\tau}}{\Pi_{s=1}^{\tau} \pi_{H,t+s}} \right)^{-\epsilon} S_{t+\tau} Q_{t+\tau} y_{t+\tau} mc_{t+\tau} \Pi_{s=1}^{\tau} \pi_{H,t+s}]}{E[\sum_{\tau=0}^{\infty} (\beta\theta^{\tau}) \frac{c_{t+\tau}^{-\sigma}}{c_t^{-\sigma}} \left(\frac{\pi_{H,ss}^{\tau}}{\Pi_{s=1}^{\tau} \pi_{H,t+s}} \right)^{-\epsilon} S_{t+\tau} Q_{t+\tau} y_{t+\tau} \pi_{H,ss}^{\tau}]}$$

and we can write

$$1 = [\theta \tilde{P}_{H,t}^{1-\epsilon} + (1-\theta)(\frac{\pi_{H,ss}}{\pi_{H,t-1}})^{1-\epsilon}]^{\frac{1}{1-\epsilon}}$$

2.4 Domestic market

Goods market clearing in the representative small open economy requires that the aggregate demand for domestically produced goods equals the domestic demand and foreign demand. The market for domestically produced goods clears if the following condition in terms of variables detrended by Z_t is satisfied

$$y_t = c_{H,t} + c_{H,t}^*$$

We can rewrite it as

$$y_t = (1-\alpha)(S_t Q_t)^{-\eta} c_t + \alpha \vartheta Q_t^{-\eta} c_t^*$$

2.5 Rest of the world

The relationship between domestic and foreign consumption is derived from the perfect risk sharing assumption. The level of consumption in the two countries can be expressed as

$$c_t = \vartheta c_t^* S_t^{\frac{1}{\sigma}}$$

where ϑ is the relative size of the domestic economy. We can rewrite the market clearing condition for the domestically produced goods

$$y_t = \vartheta c_t^* Q_t^{-\eta} [(1-\alpha) S_t^{\frac{1}{\sigma}-\eta} + \alpha]$$

Since all state-contingent securities are in zero net supply we obtain the following global resource constraint from the budget constraints of the domestic and foreign households

$$c_t + S_t c_t^* = Q_t S_t y_t + S_t y_t^*$$

2.6 Steady states

The central bank at home and abroad are determining the steady state inflation rates π_{ss} and π_{ss}^*. Moreover, we assume that $S_0 = S_{ss} = 1$. The consumption Euler equation implies that the domestic nominal interest rate is $R_{ss}=\frac{Z_{ss}\pi_{ss}}{\beta}$. A constant real interest rate implies that the nominal exchange rate depreciation in steady state is $e_{ss} = \frac{\pi_{ss}}{\pi_{ss}^*}$. Uncovered interest rate parity determines the foreign nominal rate: $R_{ss}^*= \frac{R_{ss}}{e_{ss}}$. Therefore, the terms of trade are

$$Q_{ss} = \left[\frac{1}{1-\alpha}(S_{ss}^{\eta-1} - \alpha)\right]^{\frac{1}{1-\eta}} = 1$$

Steady state inflation for the domestic goods is $\pi_{ss}^* = \pi_{ss}$. According to the small open economy assumption $c_{ss}^* = y_{ss}^*$. Clearing of the domestic goods market requires $y_{ss} = \vartheta y_{ss}^*$. Perfect risk sharing condition implies $c_{ss} = \vartheta c_{ss}^*$. The supply side condition for the domestic good determines the steady state labor input $N_{ss}=y_{ss}$. Finally, we can determine y_{ss} from the marginal cost condition

$$y_{ss} = \left(\frac{\epsilon - 1}{\epsilon}\right)^{\frac{1}{\varphi+\sigma}}$$

The monetary policy is described by an interest rate rule, where the central bank adjusts its instrument in response to movements in CPI inflation and output. To evaluate the whether the Bank of Thailand respond to exchange rate movements, we allow for the possibility of including nominal exchange rate depreciation Δe_t in the policy rate:

$$R_t = \rho_R R_{t-1} + (1-\rho_R)\left[\psi_1 \pi_t + \psi_2 y_t + \psi_3 \Delta e_t\right] + \varepsilon_t^R$$

where the policy coefficients $\psi_1,\ \psi_2, \psi_3 \geq 0$. To match the persistence in nominal interest rates, we include a smoothing term in the rule with $0 \leq \rho_R \leq 1$. ε_t^R is an exogenous policy shock which can be interpreted as the non-systematic component of monetary policy. If $\psi_3 > 0$, the central bank responds to exchange rate in conducting the monetary policy. If $\psi_3 = 0$, the policy rule does not include the exchange rate.

Instead of solving endogenously for the terms of trade, we add a law of motion for their growth rate to the system:

$$\Delta q_t = \rho_q \Delta q_{t-1} + \varepsilon_{q,t}$$

An increase in world output raises demand for the domestically produced goods so that the terms of trade or its relative price improve, while a decline in domestic output has the opposite effect.

The rest of the world output and inflation y_t^* and π_t^* are assumed to be exogenous and evolve per univariate AR(1) processes with autoregressive coefficients ρ_{y^*} and ρ_{π^*} respectively. The innovations of the AR(1) processes are denoted by $\varepsilon_{y^*,t}$ and $\varepsilon_{\pi^*,t}$.

$$y_t^* = \rho_{y^*} y_{t-1}^* + \varepsilon_{y^*,t}$$

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \varepsilon_{\pi^*,t}$$

Tables 1 and 2 below summarize the model variables and parameters. The model variables are those that model attempts to dynamically explain given the exogenous shocks to the model economy. The model parameters are those that model could take as given or estimate them by using the actual data.

Table 1: Model variables

Model variables	
y_t	Domestic output
R_t	Interest rate rule
π_t	Domestic inflation
z_t	Technology growth rate
Δq_t	TOT growth rate
y_t^*	World output
$\bar{y}_t$	Natural level of domestic output
Δe_t	Exch. rate diff
Δy_t^*	World output growth rate
π_t^*	A world inflation

3 Bayesian estimation and empirical implementation

In this section, we employ the Bayesian estimation techniques to estimate the DSGE small open economy model parameters for Thai economy. The DSGE model and the Bayesian estimation of the DSGE model have become increasingly popular since the late 1990s. For example, Tanboon (2008) uses a small open economy DSGE model for the Bank of Thailand's policy analysis. Phrommin (2018) employs

Table 2: Model parameters

Policy rule parameters	
ρ_R	Persistence in nom. int. rate; smoothing term
ψ_1	Policy coeff. w.r.t. inflation
ψ_2	Policy coeff. w.r.t. output
ψ_3	Policy coeff. w.r.t. nom. exch. rate diff.
Non-policy rule parameters	
α	Import share
β	Discount factor
κ	Slope coeff. of the Phillips curve
τ	Intertemporal substitution elasticity
ρ_z	Persistence in the technology growth rate
ρ_q	Persistence in TOT growth rate
ρ_{π^*}	Persistence in world inflation shock
ρ_{y^*}	Persistence in world output
Shock standard deviation	
$\varepsilon_{z,t}$	Stan.dev in the technology growth rate
$\varepsilon_{q,t}$	Stan.dev in TOT growth rate
$\varepsilon_{\pi^*,t}$	Stan.dev in world inflation shock
$\varepsilon_{y^*,t}$	Stan.dev in world output
$\varepsilon_{R,t}$	Stan.dev in nom. int. rate
z	Trend

the Bayesian method to approximate the DSGE model parameters to evaluate monetary policy under headline and core inflation targeting in Thailand. Chaiboonsri, Wannapan and Sriboonchitta (2018) investigate the Bayesian DSGE model to the international tourism sector.

Finding the posterior distribution of the DSGE parameters conditional on the sample data by using the DSGE model likelihood and the priors on the DSGE parameters is the objective of the Bayesian influence process. The posterior is the density of parameters knowing the data. Using the Bayesian rule, the posterior distribution can be computed as:

$$\mathrm{p}\left(\theta \mid \Upsilon^{\mathrm{T}}, \mathrm{M}\right) = \frac{\mathrm{p}\left(\Upsilon^{\mathrm{T}} \mid \theta, \mathrm{M}\right) \mathrm{p}\left(\theta \mid \mathrm{M}\right)}{\mathrm{p}\left(\Upsilon^{\mathrm{T}} \mid \mathrm{M}\right)}$$

where p (.) stands for a probability density function and M stands for the DSGE model, thus the $\mathrm{p}\left(\theta \mid \Upsilon^{\mathrm{T}}, \mathrm{M}\right)$ is the posterior distribution of the parameters conditional on the DSGE model and the information set of an observed macro-time series until period T or $\Upsilon^{\mathrm{T}} = \{\mathrm{y}_1, \mathrm{y}_2, \mathrm{y}_3, \ldots, \mathrm{y}_{\mathrm{T}}\}$. The term $\mathrm{p}\left(\Upsilon^{\mathrm{T}} \mid \theta, \mathrm{M}\right)$ is the likelihood density of the DSGE model parameter. The likelihood is the probability of obtaining the data given choices of parameter θ. It reflects information about parameters contained in the data. The likelihood is probability that the model is correct to obtain the data for each value of θ.

The prior is described by a density function of the form $\mathrm{p}(\theta \mid \mathcal{M})$. The prior represents pre-experimental knowledge of parameter values. It quantifies what is known about the parameters before observing data. The probability of data is $\mathrm{p}\left(\Upsilon^{\mathrm{T}} \mid \mathrm{M}\right)$. It is the marginal density of the data conditional on the DSGE model. The likelihood and the prior distribution can be combined to form the posterior distribution.

Given that the model parameter values from the previous section are not known for certain, the uncertainty can be described by a probability distribution. Bayesian method treats the model parameters as random variables. Their uncertainties are explained by probability distributions called the prior distributions. The model is then solved and the observed data relevant to the parameters is collected. The data changes the uncertainty which is illustrated by an updated probability distribution called the posterior distribution. Thus, the posterior distribution reveals the information both in the data and the prior distribution.

The model parameters are divided into three groups, the policy rule parameters, the non-policy rule parameters and the shock standard deviation. The model parameters are collected in the vector Φ defined as

$$\Phi = [\rho_R,\ \psi_1,\ \psi_2,\ \psi_3, \alpha, \beta, \kappa, \tau, \rho_z, \rho_q, \rho_{\pi^*}, \rho_{y^*}, \varepsilon_{z,t}, \varepsilon_{q,t}, \varepsilon_{\pi^*,t}, \varepsilon_{y^*,t}, \varepsilon_{R,t}]$$

where $\rho_R,\ \psi_1,\ \psi_2,\ \psi_3$ are the policy rule parameters.

In the empirical analysis, the vector of observables will be composed of annualized inflation rates, annualized interest rates, output growth, depreciation rates, and terms of trade changes and assumed that the observations are demeaned. The vector of observations is related to the model variables according to

$$Y_t = [4R_t, 4\pi_t, \Delta y_t + z_t, \Delta e_t, \Delta q_t]$$

For the empirical analysis, Thai data set are comprised of observations on real GDP growth, the CPI inflation, the Bank of Thailand's policy interest rate, changes in nominal effective exchange rate, and changes in terms of trade. All data are in quarterly basis and from 2000Q1 to 2019Q4 which is the period of the inflation targeting regime. All series are seasonally adjusted.

Prior selection

The belief or pre knowledge of the value of the model's parameters is specified in the prior of the Bayesian techniques. We use the data from 2000Q1-2019Q4 for the pre-sample analysis. The persistence parameters are derived from fitting AR(1) process to the Thai output growth rate for ρ_z, to TOT for ρ_q , to the world inflation for ρ_{π^*} to the ration of world GDP to Thai GDP for ρ_{y^*} and we fit AR(1) process to the Bank of Thailand policy rate for ρ_R.

The import share is the average import consumption goods to consumption expenditure during the observation period. The interest rate at the steady state is the average of the Bank of Thailand policy rate during the sample periods. The trend is the average growth rate of Thai economy. The policy parameters are obtained from LS(2007) which uses the common value associated with the Taylor rule. The shock parameters are difficult to estimate. We follow LS(2007) for the value of the shock parameters. The priors of the parameters are exhibited in Table 3 below

Table 3: The priors

Parameters	**Prior**		
	Density	Mean	St.dev
Non-policy rule parameters			
Import share α	beta	0.11	0.03
Interest rate at the steady state r_{ss}	gamma	2.225	0.985
Slope coef. of the Phillips curve κ	gamma	0.50	0.25
Intertemporal substitution elasticity τ	beta	0.50	0.20
Persistence in the tech growth rate ρ_z	beta	0.5238	0.05
Persistence in TOT growth rate ρ_q	beta	0.2913	0.20
Persistence in world inflation shock ρ_{π^*}	beta	0.8697	0.10
Persistence in world output ρ_{y^*}	beta	0.846	0.05
Policy parameters			
Persistence in nom. int. rate ρ_R	beta	0.50	0.20
Coeff. w.r.t. inflation ψ_1	gamma	1.50	0.50
Coeff. w.r.t. output ψ_2	gamma	0.25	0.13
Coeff. w.r.t. nom. exch. rate diff ψ_3	gamma	0.25	0.13
Shock parameters			
St.dev in the tech growth rate $\varepsilon_{z,t}$	Inv gamma	1.00	4
St.dev in TOT growth rate $\varepsilon_{q,t}$	Inv gamma	1.50	4
St.dev in world inflation shock $\varepsilon_{\pi^*,t}$	Inv gamma	0.55	4
St.dev in world output $\varepsilon_{y^*,t}$	Inv gamma	1.50	4
St.dev in nom. int. rate $\varepsilon_{R,t}$	Inv gamma	0.50	4
Trend z	Normal	0.2012	0.95

Posterior distribution

Using the structural model alongside with the Thai data, the Bayesian statistics depicts the posterior distribution. The table 4 below shows the mean and the 90% interval of the posterior distribution of the model parameters.

The import share α and the slope of the Phillips curve κ is somewhat higher

Table 4: The posteriors

Parameters		Prior		Posterior		
	Density	Mean	St.dev	Mean	90% Interval	
Non-policy rule parameters						
Import share α	beta	0.11	0.03	0.2115	0.1686	0.2584
Interest rate at the steady state r_{ss}	gamma	2.225	0.985	2.1901	0.8304	3.7449
Slope coeff. of the Phillips curve κ	gamma	0.50	0.25	0.5780	0.3902	0.7415
Intertemporal substitution elasticity τ	beta	0.50	0.20	0.2790	0.2331	0.3344
Persistence in the tech growth rate ρ_z	beta	0.5238	0.05	0.4443	0.3972	0.5024
Persistence in TOT growth rate ρ_q	beta	0.2913	0.20	0.3156	0.0903	0.5606
Persistence in world inflation shock ρ_{π^*}	beta	0.8697	0.10	0.4946	0.3450	0.6581
Persistence in world output ρ_{y^*}	beta	0.846	0.05	0.9343	0.8956	0.9750
Policy parameters						
Persistence in nom. int. rate ρ_R	beta	0.50	0.20	0.6388	0.5466	0.7369
Coeff. w.r.t. inflation ψ_1	gamma	1.50	0.50	3.2701	2.5202	4.2547
Coeff. w.r.t. output ψ_2	gamma	0.25	0.13	0.1976	0.1010	0.2870
Coeff. w.r.t. nom. exch. rate diff ψ_3	gamma	0.25	0.13	0.4787	0.2636	0.7708
Shock parameters						
St. dev in the tech growth rate $\varepsilon_{z,t}$	Inv. gamma	1.00	4	0.7338	0.2934	1.2391
St. dev in TOT growth rate $\varepsilon_{q,t}$	Inv. gamma	1.50	4	1.6297	0.4437	2.8600
St. dev in world inflation shock $\varepsilon_{\pi^*,t}$	Inv. gamma	0.55	4	0.4005	0.1442	0.7316
St. dev in world output $\varepsilon_{y^*,t}$	Inv. gamma	1.50	4	1.0206	0.4234	1.6172
St. dev in nom. int. rate $\varepsilon_{R,t}$	Inv gamma	0.50	4	0.3776	0.1438	0.6486
Trend z	Normal	0.2012	0.95	0.2424	0.1981	0.2874

than that of the prior. The interest rate at the steady state is about the same. However, the intertemporal substitution elasticity τ is obviously lower than the prior value. The posterior values of the persistence parameters mostly are near the prior except for the persistence in world inflation shock ρ_{π^*} which is markedly lower. The posterior means of the shock parameters are not deviate much from their priors.

Recall the policy rule as

$$R_t = \rho_R R_{t-1} + (1 - \rho_R)\left[\psi_1 \pi_t + \psi_2 y_t + \psi_3 \Delta e_t\right] + \varepsilon_{R,\ t}$$

For the Thai economy, we can rewrite the policy rule based on our estimation as

$$R_t = 0.6388 R_{t-1} + (1 - 0.6388)\left[3.2701\pi_t + 0.1976 y_t + 0.4787\Delta e_t\right] + \varepsilon_{R,t}$$

Regarding to the policy parameters, the persistence in nominal interest rate ρ_R is 0.6388 for Thai economy. It is slightly higher than the prior value. It is interesting that the coefficient with respect to inflation ψ_1 for Thai economy is significantly higher than the prior. The posterior mean is 3.2701. The coefficient with respect to output ψ_2 is moderately lower than the prior value. $\psi_2 = 0.19376$ for Thailand. The key parameters is the coefficient with respect to the changes in the nominal exchange rate ψ_3. The posterior mean of ψ_3 is 0.4787. This value is clearly higher than the prior value. According to the estimated policy parameters, the Bank of Thailand pursue a strongly anti-inflationary policy, demonstrates concern output movements, concentrates on the exchange rate movements and accepts the reasonable degree of interest rate smoothing.

In addition to estimating about parameter models, we are interested in assessing the hypothesis that the Bank of Thailand takes the exchange rate fluctuation into account. We therefore take the advantages of the posterior distributions. Koop (2003) suggests to use Bayes' rule to derive a probability statement whether a model is correct or not conditional on the data. The posterior model probability can be used to examine the degree of support for a model.

We are comparing which model we should prefer in light of Thai data. M_1 and M_2 are the models with the Bank of Thailand policy function excluding and including the exchange rate respectively. In order to compare two models, we use the ratio of their posterior model probability or the posterior odds ratio.

$$po_{12} = \frac{p(M_1|\Upsilon^T)}{p(M_2|\Upsilon^T)} = \frac{p(\Upsilon^T|M_1)p(M_1)}{p(\Upsilon^T|M_2)p(M_2)}$$

Using the same Thai data sets and the same priors for the two models, we assign equal prior weight to each model or $p(M_1) = p(M_2)$. That is the prior odds ratio is 1. In our experiment, the posterior odds ratio becomes the Bayes factor or the ratio of marginal likelihoods. To obtain the marginal density of the data conditional on the model, we use the Laplace approximation and the Harmonic Mean Estimator. The first is to assume a functional form of the posterior kernel that we can integrate and the second is to use the information from the Metropolis Hasting. These two approximations yield the same results as shown in Table 5.

Table 5: Posteriors odds

Models	M1			M2		
Priors	0.3	0.5	0.7	0.3	0.5	0.7
Log marginal density	-649.151	-649.151	-649.151	-642.319	-642.319	-642.319
Bayes ratio	0.000463	0.001080	0.002519	1.0000	1.0000	1.0000
Posterior model probability	0.000462	0.001070	0.002513	0.997487	0.99892	0.99954

M1: The policy rule without exchange rate.
M2: The policy rule with exchange rate

The log marginal density of the M2 is larger which results in the posterior odds ratio of 0.0010792. The Bayes factor is in favor of M2. In addition, the prior odds ratio is set above and below 1. Table 5 shows that as the prior weight rises, the posterior model probability increases. Bayes ratio of M1 increases with the prior weight. The log marginal density of M1 is below that of M2 regardless of level of the prior odds ratio. Therefore, the Thai data during the observation period gives weak evidence in favor of the simpler model M1.

This indicates that the Bank of Thailand sets its policy rate in response to exchange rate movement. Given the fact that Thailand is a small country and the degree of openness is quite high, our findings are consistent with the idea that the Bank of Thailand concerns and pays close attention to the exchange rate fluctuations.

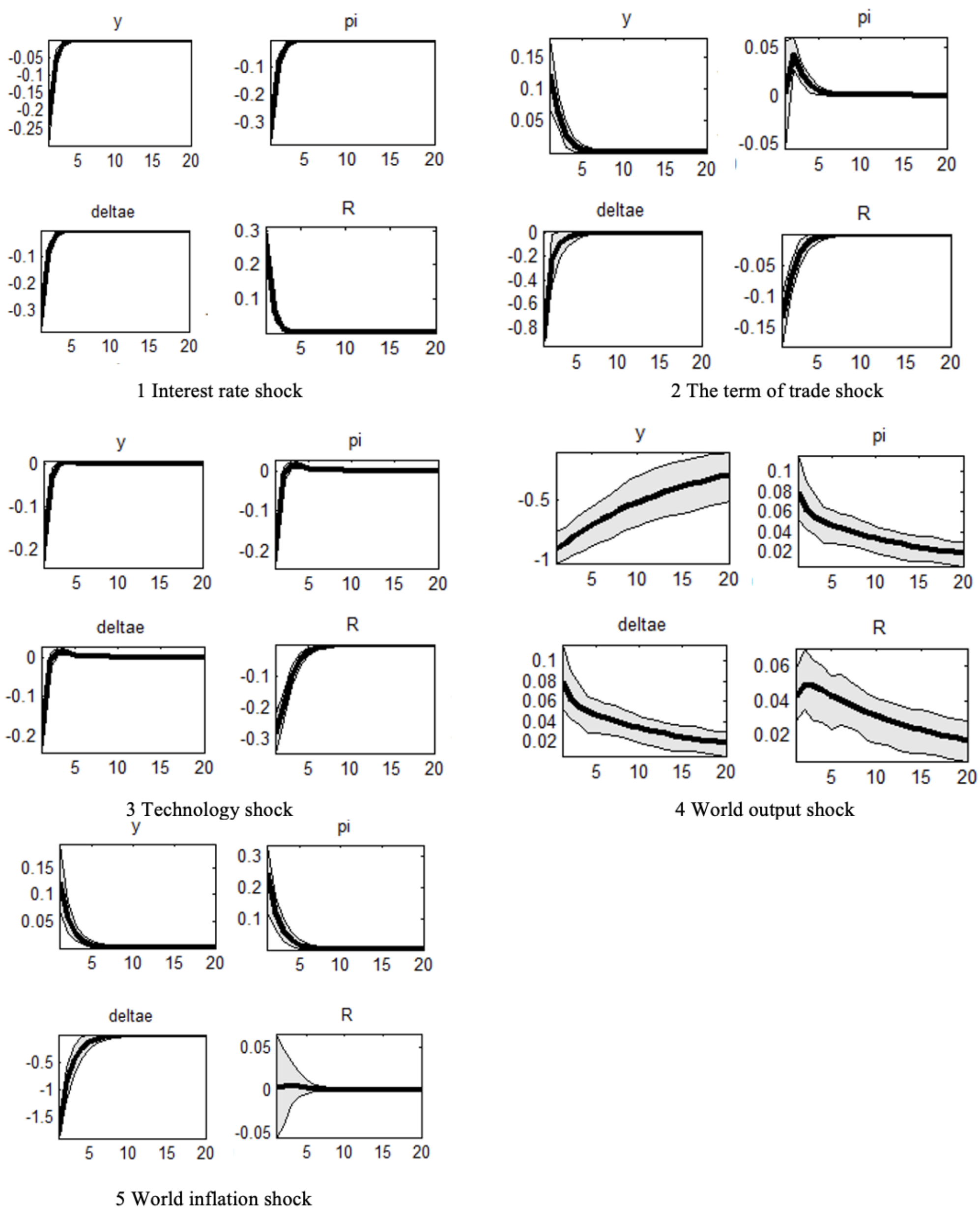
4 Impulse responses

We have estimated the monetary policy rule with the exchange rate from the previous section. To better understand the dynamics of the model and how this policy rule influences the Thai economy. We present in this section the numerical simulation of the model and describe the dynamic effects of various shocks on a several of macroeconomic variables for the Thailand. There are five shocks which are the interest rate, the term of trade, the technology, the world demand and the world inflation shocks.

Figure 1 illustrates the time paths of the key variables in the model response to one standard deviation of the shocks. Posterior means are the solid line and the 90% posterior probability intervals are the dashed lines. For the responses to the interest rate shock, monetary policy contraction appreciates Thai baht, lowers inflation and output. The results confirm that the transmission mechanism monetary policy is effective. The term of trade is defined as a ratio of the domestic price of domestic produced good and the domestic price of foreign produced goods. An increase in the term of trade comes from the domestic price of domestic produced good rises or the appreciation of the currency. An improvement in the term of trade appreciates the Thai baht, lower inflation and interest rate. Interest rate falls because the central bank reduces it to prevent the baht appreciation. However, the term of trade positive shock raises output. When the term of trade improves, a country exports a smaller number of units to purchase the same number of imports. This confirms some of findings that were already evident. The number of papers suggest that the term of trade is pro-cyclical. Mendoza (1995) asserts that the impact of the term of trade on output is positive.

A positive technology shock appreciates the Thai baht. It lowers inflation, interest rate and output. Unlike technology shock in the real business cycle model, the output responses are ambiguous in the New Keynesian economy. A technology improvement leads to a decline in employment and in turn causes output to fall. When output is below its long run level, inflation falls. The positive technology shock causes a high demand of domestic produced goods and the appreciation of the Thai baht. The central bank cuts interest rate to stimulate the economy. An increase in the demand shock from the rest of the world decreases the domestic output, raises inflation, increases interest rate and appreciates the Thai baht. he positive world output shock lowers the long run level of output due to the structure of the model. As a results, output is above its long run level leading to an increase in inflation. The central bank increases its policy rate to combat the higher inflation. The excess demand is not enough to compensate monetary policy contraction leading to a fall in output. Lastly, an increase in the import price inflation appreciates the Thai baht, raises inflation, lowers interest rate and increase the domestic output. As the world inflation increases, the demand of export rises and the Thai baht appreciates. Output increases for two reasons, one a high demand of export and another a lower interest rates.

Figure 1: Impulse responses



5 A welfare analysis

This section conducts welfare evaluation associated with two different monetary policies. While we have established that the Bank of Thailand incorporated exchange rate movements explicitly in the interest rate setting, it would be interesting to compare with the standard monetary policy rule where interest rate responds only to output and inflation.

Given the restriction that $\psi_3 = 0$, we re-estimate the open economy inflation targeting policy (OIT) function as shown below

$$R_t = 0.6687R_{t-1} + (1 - 0.6687)\left[3.29141\pi_t + 0.1992y_t\right] + \varepsilon_{R,t}$$

For the purpose of comparison, we re-write the monetary policy rule and labeled as exchange rate augmented inflation targeting policy (EIT) as follows.

$$R_t = 0.6388R_{t-1} + (1 - 0.6388)\left[3.2701\pi_t + 0.1976y_t + 0.4787\Delta e_t\right] + \varepsilon_{R,t}$$

Following Gali and Monacelli (2005), we introduce the second order approximation to the utility losses of domestic consumer resulting from deviation from the optimal policy. Those losses can be expressed as

$$W = -\frac{(1-\alpha)}{2}\sum_{t=0}^{\infty}\beta^t[\frac{\varepsilon}{\lambda}\pi_{H,t}^2 + (1+\varphi)y_t^2]$$

The equation above can be written in terms of the variance of inflation and the output gap as below

$$V = -\frac{(1-\alpha)}{2}[\frac{\varepsilon}{\lambda}var(\pi_t) + (1+\varphi)var(y_t)]$$

where $\lambda = (1-\beta\theta)(1-\theta)/\theta$. The welfare weight on the inflation variance and output gap variance are ε/λ and $1+\varphi$ respectively. We evaluate the welfare implications of the alternative monetary policies and compare these policies on the welfare ground.

Table 5 reports the welfare losses associated with the two monetary rules. we find that the EIT policy performs better in terms of the welfare loss in all shocks but the world inflation shock. This is because the exchange rate provides another channel to affect the interest rate. When the world inflation rises, the Thai baht appreciates. Then the central bank cuts its policy rate causing more output and inflation fluctuations.

Table 6: Welfare losses for alternative policies

Variables/Shock	TOT	World inflation	Technology	World output	Interest rate
OIT policy					
Output	0.007	0.000	0.039	8.156	0.082
Inflation	0.009	0.000	0.047	0.050	0.179
Welfare loss	0.13	0	0.70	13.44	2.59
EIT policy					
Output	0.019	0.020	0.038	7.441	0.071
Inflation	0.002	0.081	0.040	0.043	0.128
Welfare loss	0.045	1.14	0.5905	12.34	1.89

The elasticity of goods, $\varepsilon = 6$ and the elasticity of labor, $\varphi = 3$ from Gali and Monacelli (2005). Entries of output and inflation are variances and expressed in percent. Entries of the welfare loss are percent units of steady state consumption.

6 Openness and monetary policy

This section focuses on how varying degree of openness could potentially impact the conduct of Thai monetary policy. Specifically, we analyze the impacts on (i) the slope of the Phillips curve (ii) the reaction function of the Bank of Thailand (iii) transmission mechanism of monetary policy shocks and (iv) welfare losses. In addition, we provide a comparison between two monetary policy rules with (i.e.the EIT policy) and without (i.e. the OIT policy) responding to the exchange rate.

As shown in Table 6, we find that the slope of the Phillips curve becomes flatter as the Thai economy becomes more open and the amount of import share increases (our estimated import share is 0.21). So, flattening Phillips curve means that to achieve a given change in inflation, the output gap has to vary much more.

Table 7: Openness and slope of the Phillips curve

Openness	0.21	0.30	0.40
Slope of the PC	0.76	0.63	0.53

To understand how change in the degree of trade openness could impact the reaction function of Thai monetary policy, we look at the changing coefficients with respect to output, inflation and exchange rate. This is shown in Table 7. We find that the policy response to inflation is stronger as the degree of openness increases. In addition, monetary policy become less persistent (due to lower degree of interest rate smoothing) and interest rate reaction becomes less sensitive to exchange rate movements. However, we do not find that varying degree of openness significantly changes the policy coefficients in front of output gap in both the OIT and the EIT policies.

Next, we focus on the monetary transmission mechanism with the two different degree of openness (i.e. low vs high levels of openness) through the impulse responses of a monetary policy shock. Figure 2 illustrates the dynamic behaviors of the main macroeconomic variables in the model response to one standard deviation of the positive interest rate shocks. The impact of an increase the interest rate lowers output, inflation and appreciates the Thai baht.

As the degree of openness increases, the contractionary monetary policy under the OIT policy provides lower output, but the inflation and exchange rate remain unchanged. However, as the degree of openness increases, the contractionary monetary policy under the EIT policy provides lower output and inflation with more appreciation of the Thai baht. The monetary policy under the policy rule with exchange rate influences more to the economic behaviors with the higher degree of openness.

Table 8: Openness and policy parameters in monetary policy rules

Policy	**Policy parameters**	**Degree of openness**			
		0.1	**0.2**	**0.3**	**0.4**
OIT	Persistency in nom. Int. rate	0.7037	0.6748	0.6667	0.6549
	Coeff. w.r.t. inf	3.1769	3.3717	3.4256	3.5107
	Coeff. wr.t output	0.208	0.1918	0.1943	0.2036
EIT	Persistency in nom. Int. rate	0.6814	0.6461	0.6277	0.6274
	Coeff. w.r.t. inf	2.9538	3.1788	3.2041	3.2712
	Coeff. wr.t output	0.2271	0.201	0.2005	0.2068
	Coeff. w.r.t exchange rate	0.4683	0.4503	0.4334	0.4064

The relationship between the openness and the welfare loss of the two monetary policy rules is shown in table 8. When the degree of openness increases to 0.3 and 0.4, the EIT policy provides the lower welfare loss than the OIT policy under all shocks except for only the world inflation shock. This means that the policy with exchange rate generally performs better in term of welfare loss regardless of the level of openness.

Figure 2: Impulse responses of interest rate shocks with/without exchange rate

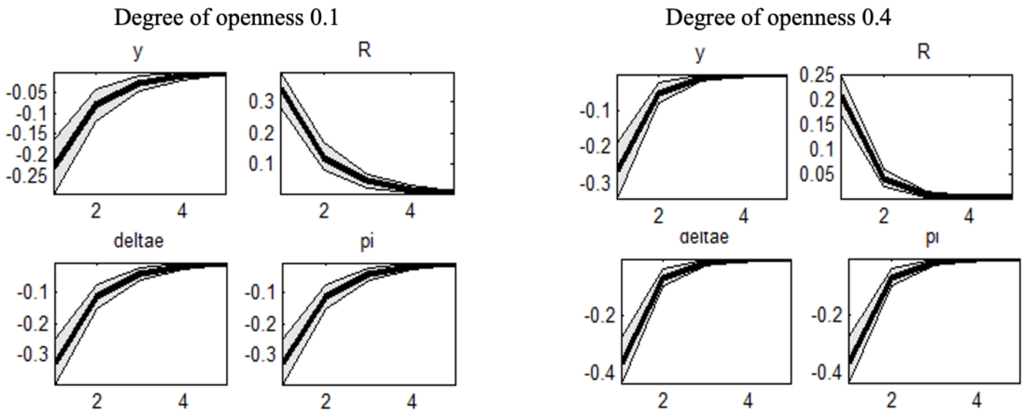


Table 9: Openness and welfare losses

	Variables/Shock	TOT	World inflation	Technology	World output	Interest rate
Openness=0.3	**OIT policy**					
	Output	0.016	0.000	0.034	8.528	0.090
	Inflation	0.016	0.000	0.041	0.049	0.180
	Welfare loss	0.215	0.000	0.549	12.549	2.350
	EIT policy					
	Output	0.032	0.019	0.032	7.754	0.077
	Inflation	0.004	0.067	0.035	0.043	0.131
	Welfare loss	0.094	0.852	0.478	11.382	1.723
Openness=0.4	**OIT policy**					
	Output	0.034	0.000	0.030	8.715	0.092
	Inflation	0.024	0.000	0.037	0.049	0.182
	Welfare loss	0.298	0.000	0.432	10.978	2.037
	EIT policy					
	Output	0.049	0.016	0.027	7.804	0.077
	Inflation	0.010	0.056	0.033	0.042	0.134
	Welfare loss	0.166	0.613	0.384	9.811	1.515

The elasticity of goods, ε = 6 and the elasticity of labor, φ = 3 from Gali and Monacelli (2005). Entries of output and inflation are variances and expressed in percent. Entries of the welfare loss are percent units of steady state consumption.

7 Summary

In this paper, we develop a general equilibrium model of small-open economy based on Lubik and Schorfheide (2007) and estimate structural parameters for Thai economy. We then use the model to shed light on the conduct of monetary policy under inflation targeting regime since the adoption in May 2000. Specifically, the paper focuses on three main dimensions. First, we estimate the monetary policy rule and find that the Bank of Thailand incorporate exchange rate movements into interest rate setting. Second, we conduct a welfare analysis to compare between policy rules with and without exchange rate response and find overall welfare improvements over the closed economy policy rule.

Third, given that Thailand is among the emerging market economies with relatively high trade openness, the paper investigates how the degree of openness could have impacts on monetary policy formulation. We find that higher degree of openness flattens the slope of the Phillips curve. Furthermore it also affect the endogenous response of monetary policy reaction function with stronger policy response to inflation. In addition, higher degree of openness also makes monetary policy to be less persistent and smaller reaction to exchange rate fluctuations. Based on our impulse responses of interest rate shock, we do not find evidence of declining monetary policy effectiveness as the economy becomes more open.

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