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Do Inflation Targeters in Southeast and East Asia Respond to Exchange Rate Movements?

Kunihiro Hirao
Sumitomo Mitsui Trust Bank, Tokyo, Japan

Akihiro Kubo
Graduate School of Economics, Osaka City University, Osaka, Japan
Corresponding author: kubo@econ.osaka-cu.ac.jp

Abstract

We use a small open economy dynamic stochastic general equilibrium model to explore whether inflation-targeting central banks in Indonesia, South Korea, and Thailand responded to exchange rates in recent years. In developing this model, we account for the fact that the central banks respond to inflation, output, and exchange rates as an augmented Taylor rule. By performing posterior odds tests, we find that the augmented Taylor rule fits the data much better than a basic Taylor rule in each country. The exchange rate is of higher priority than output, especially for the Bank of Thailand.

Keywords: exchange rates; monetary policy; small open economy DSGE model

1. Introduction

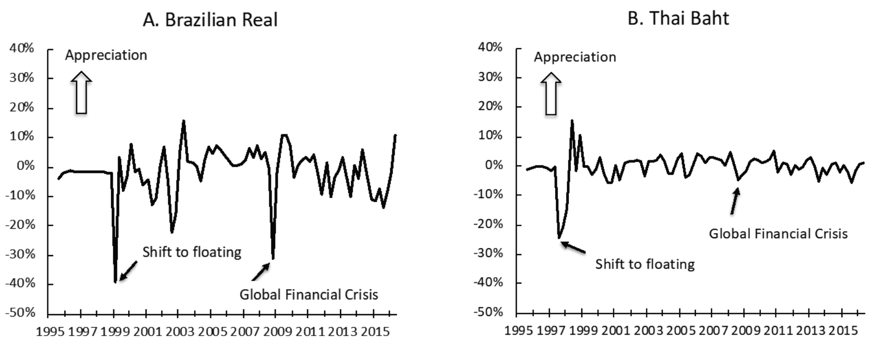
The role of exchange rates in monetary policy remains a controversial topic. Especially in emerging economies, central banks face a tradeoff between stability in their domestic economies and exchange rates. Amato and Gerlach (2002) and Svensson (2010) argue that exchange rate channels are an important transmission mechanism associated with inflation targeting in a small open economy. While many emerging economies engage in inflation targeting and institutionally adopt free- or managed-floating exchange rate regimes, it has become increasingly critical to manage exchange rate movements due to large external shocks (e.g., the high prices of international commodities and the global financial crisis originating in the United States).

Many previous studies empirically investigate the relative weights attributable to the exchange rate in a monetary policy reaction function (i.e., an augmented Taylor rule) to derive an optimal monetary policy rule. Some researchers use single equation or partial equilibrium analyses to examine the augmented Taylor rule (e.g., Aizenman, Hutchison, & Noy, 2011; Cavoli, 2009; Galimberti & Moura, 2013; Ghosh, Ostry, & Chamon, 2016; Hutchison, Sengupta, & Singh, 2013; Nojković & Petrović, 2015; Taylor, 2001). Others suggest that the exchange rate should not enter the reaction function, especially under an inflation-targeting framework that has floating rates, in accordance with the "impossible trinity," namely that countries cannot have fixed exchange rates, free capital movement, and an independent monetary policy all simultaneously (e.g., Bernanke, Laubach, Mishkin, & Posen, 1999).

On the other hand, recent literature on the New Keynesian dynamic stochastic general equilibrium (DSGE) model focuses on this issue. For example, Lubik and Schorfheide (2007) employ a simplified version of the DSGE model developed by Galí and Monacelli (2005) for advanced inflation-targeting countries and find that whereas Canada and the UK respond to exchange rates, Australia and New Zealand do not. In the context of emerging economies, Garcia et al. (2011) implement simulation exercises by employing relatively small-scale DSGE models with various inflation-targeting frameworks and suggest that if the emerging economy is financially vulnerable, the "hybrid" monetary policy rule that includes the exchange rate outperforms a basic, Taylor rule. In addition, Pavasuthipaisit (2010) develops a large-scale DSGE model and finds that central banks respond to exchange rate movements with a high degree of integration into international finance. However, to the best of my knowledge, there are few DSGE studies on the theme that use recent data.

In this paper, we apply a small open economy DSGE framework to three emerging Asian countries—Indonesia, South Korea, and Thailand—to explore the significant features of *de facto* exchange rate regimes in these countries. After the 1997 Asian currency crisis these central banks abandoned pegged or fixed exchange rate regimes and shifted to more flexible floating and managed-float regimes. However, the experiences of Asian countries after the crisis present a more difficult question for floating regimes than those of Latin American emerging countries. Figure 1 shows the fluctuations in the Brazilian Real in Panel A, and the relative calm of the Thai Baht, even after the global financial crisis in 2008, in Panel B. Calvo and Reinhart (2002) suggest that the Asian countries actually intervened in the foreign exchange market due to their "fear of floating." Yamada (2013) also claims that despite employing a float system, they managed exchange rate movements, which implies that a large difference between *de facto* and *de jure* regimes exists for exchange rates. These are the main interest of this study's empirical work.

Figure 1. Appreciation in US dollar exchange rates



Source: International Monetary Fund.

Consistent with Lubik and Schorfheide (2007), we perform posterior odds tests to investigate our hypothesis of whether these central banks respond to exchange rates. Our main result is that an augmented Taylor rule, where the interest rate is set to stabilize both the fluctuations in the exchange rate and the domestic economy, fit data much better than a basic Taylor rule in each country. This result implies that the exchange rate is one important indicator in decision-making around monetary policy. The exchange rate is of higher priority than output, especially for the Bank of Thailand.

The remainder of this paper proceeds as follows. Section 2 describes the model. Section 3 provides an overview of the Bayesian estimation methodology and the data. Section 4 discusses the estimation results. Finally, Section 5 concludes.

2. The Model

This section outlines the log-linear approximation of the small open economy New Keynesian model, as Jääskelä and Jennings (2011) and Jääskelä and Kulish (2010) describe. Galí and Monacelli (2005) proposed the theoretical framework, extending the benchmark New Keynesian closed economy model (e.g., Clarida, Gali, & Gertler, 1999; Svensson, 2000; Walsh, 2003; Woodford, 2003). In the subsequent subsections, variables with a star superscript correspond to the large, foreign economy. Details of the model's micro foundations for the small open economy's IS and New Keynesian Phillips curves can be found in the Appendix.

2.1 The Large Economy

The consumption and saving Euler equation implies that the current foreign output gap depends on its expected future level and the *ex ante* short-term interest rate, as follows:

$$x_t^* = E_t x_{t+1}^* - \frac{1}{\sigma}(r_t^* - E_t \pi_{t+1}^*) + \varepsilon_{x,t}^* \tag{1}$$

where x_t^* is the foreign output gap, r_t^* is the foreign nominal short-term interest rate, σ is strictly positive and governs intertemporal substitution, and E_t denotes expectations conditional on information at time $t. \varepsilon_{x,t}^*$ is an independent and identically distributed (iid) foreign total factor productivity shock with zero mean and a standard deviation of σ_{x^*}.

Foreign firms' optimal price decision produces the Phillips curve

$$\pi_t^* = \beta E_t \pi_{t+1}^* + \kappa x_t^* + \varepsilon_{\pi,t}^* \tag{2}$$

where π_t^* is the dynamic deviation of the consumer price inflation rate in the foreign country, β is the household discount factor (bounded by zero and one), and the parameter κ is strictly positive and captures the degree of price rigidity. $\varepsilon_{\pi,t}^*$ is an iid foreign markup shock with zero mean and a standard deviation of σ_{π^*}.

Foreign monetary policy follows a Taylor rule of the form:

$$r_t^* = \rho_r^* r_{t-1}^* + (1 - \rho_r^*)(\alpha_\pi^* \pi_t^* + \alpha_x^* x_t^*) + \varepsilon_{r,t}^* \tag{3}$$

where $\varepsilon_{r,t}^*$ is an iid foreign monetary policy shock with zero mean and standard deviation σ_{r^*}. α_π^* and α_x^* capture the reaction of the foreign interest rate to the deviation of the foreign inflation rate and the foreign output gap, respectively. In addition, the model includes a smoothing term, ρ_r^*.

2.2 The Small Open Economy

The small open economy IS curve thus takes following form:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma_\alpha}(r_t - E_t \pi_{t+1}) + [\alpha(\omega - 1) + \frac{\sigma_\alpha - \sigma}{\sigma_\alpha + \varphi}] E_t \Delta x_{t+1}^* - \frac{1 + \varphi}{\sigma_\alpha + \varphi}(1 - \rho_a) a_t + \varepsilon_{x,t} \tag{4}$$

where $\sigma_\alpha \equiv \frac{\sigma}{(1-\alpha)+\alpha\omega}$, $\omega \equiv \sigma\tau + (1 - \alpha)(\sigma\iota - 1)$, $\alpha \in [0,1]$ captures the degree of openness, τ is the intratemporal elasticity of substitution between foreign and domestically produced goods, ι is the elasticity of substitution across varieties of foreign-produced goods, φ >0 governs the elasticity of labor supply, and ρ_a represents the persistence parameter of the domestic productivity shock. $\varepsilon_{x,t}$ is an iid IS shock with zero mean and a standard deviation of σ_x.

The dynamics of domestic consumer price inflation, π_t, are governed by the following Phillips curve:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa_\alpha x_t + \varepsilon_{\pi,t} \tag{5}$$

where $\kappa_\alpha \equiv \lambda(\sigma_\alpha + \varphi)$; $\lambda \equiv \frac{(1-\xi)(1-\beta\xi)}{\xi}$; ξ governs the degree of price stickiness. $\varepsilon_{\pi,t}$ is an iid markup shock with zero mean and a standard deviation of σ_π.

Monetary policy in the small economy is assumed to follow the basic Taylor rule that sets the nominal interest rate, r_t, in response to its own lagged value as well as the deviation of consumer price inflation, π_t, output gap, x_t , from their steady-state values. The rule is

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\alpha_\pi \pi_t + \alpha_x x_t) + \varepsilon_{r,t} \tag{6}$$

where $\varepsilon_{r,t}$ is an iid monetary policy shock with zero mean and standard deviation σ_r. To set up the comparison with the augmented Taylor rule that responds to the real exchange rate movements, Δq_t, we start from a very simple specification,

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\alpha_\pi \pi_t + \alpha_x x_t + \alpha_q \Delta q_t) + \varepsilon_{r,t}. \tag{7}$$

The real exchange rate equation is thus determined by the real uncovered interest parity condition. The equation is

$$q_t = E_t q_{t+1} + (r_t^* - E_t \pi_{t+1}^*) - (r_t - E_t \pi_{t+1}) + \varepsilon_{q,t} \tag{8}$$

where $\varepsilon_{q,t}$ is an iid exchange rate shock with zero mean and standard deviation σ_q.

The model includes an additional independent shock, technology, given by

$$a_t = \rho_a a_{t-1} + \varepsilon_{a,t} \tag{9}$$

where $\varepsilon_{a,t}$ is an iid shock with zero mean and a standard deviation of σ_a.

3. Data and Estimation Methodology

This section describes the construction of the dataset used in the estimation. It then presents the estimation methodology and prior distributions chosen for the Bayesian analysis.

3.1 Data Description

We use data on three small open economies (Indonesia, South Korea, and Thailand) and the United States.[1] Specifically, we use quarterly real output

[1] While China and Japan tend to have more trade shares with the three small economies, the United States occupies relatively large shares in their trade and investment. Moreover, we assume that the United States economy is representative of the global business cycle.

growth, CPI inflation, short-term nominal interest rates, and bilateral real exchange rates for the US dollar for a sample period that begins from when inflation targeting commenced (Indonesia, South Korea, and Thailand in 2005Q3, 1998Q2, and 2000Q2, respectively) to 2016Q2. We obtained nearly all data from the IMF's International Financial Statistics database.

3.2 Bayesian Estimation Methodology

We employ a Bayesian method, based on An and Schorfheide (2007) and Schorfheide (2000), to estimate the model parameters. This method is a bridge between calibration and maximum likelihood estimation with specified priors. The method allows for contributions from both the priors and particular features of the data. Given a set of priors $p(\theta)$, the posterior density of the model parameters θ is

$$p(\theta|Y^T) = \frac{L(Y^T|\theta)p(\theta)}{\int L(Y^T|\theta)p(\theta)d\theta}$$

where $L(Y^T|\theta)$ denotes the likelihood conditional on observed data, Y^T. We maximize the combination of the priors and the likelihood function to find the posterior mode used as the initial value in a random walk Metropolis-Hastings algorithm. By using the Markov chain Monte Carlo method, we characterize the posterior distribution of the parameters by drawing from the posterior density function $p(\theta|Y^T)$.

We calculate our estimation through a Bayesian approach in which the choice of priors for the structural parameters plays an important role. Table 1 provides the information on the prior distributions for all three countries; we selected them to maintain consistency with the literature (e.g., Jääskelä & Jennings, 2011; Lubik & Schorfheide, 2007). The posterior statistics are based on 100,000 draws using the Markov chain Monte Carlo method with a 50% burn-in period. We calibrate $\sigma = 1.5$, $\beta = 0.99$, $\kappa = 0.5$, $\rho_r^* = 0.8$, $\alpha_\pi^* = 2.0$, $\alpha_x^* = 0.5$, $\tau = 0.8$, $\iota = 0.8$, $\varphi = 3.0$, $\xi = 0.6$, and $\rho_a = 0.8$, allowing changes only in the parameters of the domestic monetary policy rules.[2] We set

[2] The variables meet the following criteria. First, country-specific knowledge about the structural parameters in other studies is employed (e.g., Chai-anant et al., 2008). Second, model parameters are chosen to reflect some of the stylized facts of the monetary transmission mechanism (e.g., Taylor, 2001). Third, the parameters used in other countries for similar models are taken as the benchmark (e.g., Jääskelä & Kulish, 2010).

the openness, α, to 0.2 (Indonesia), 0.3 (South Korea), and 0.6 (Thailand) based on the average trade openness (imports/GDP) in each sample period.

Table 1. Prior distributions

Parameters	PDF	Mean	Standard Error
Domestic monetary policy			
ρ_r	Beta	0.80	0.1
α_π	Gamma	1.50	0.5
α_x	Gamma	0.25	0.13
α_q	Gamma	0.25	0.13
Standard deviations of shocks			
σ_{x*}	Inverse Gamma	0.10	Infinite
$\sigma_{\pi*}$	Inverse Gamma	0.10	Infinite
σ_{r*}	Inverse Gamma	0.10	Infinite
σ_x	Inverse Gamma	0.10	Infinite
σ_π	Inverse Gamma	0.10	Infinite
σ_r	Inverse Gamma	0.10	Infinite
σ_q	Inverse Gamma	0.10	Infinite
σ_a	Inverse Gamma	0.10	Infinite

Notes: PDF = probability density function.

4. Estimation Results

We first present our estimation results for Thailand, discussing the model's marginal likelihoods to explore the model's ability to fit the data. We then compare the results with other policy rules. Thailand, from which the Asian currency crisis originated in 1997, was concerned about disorderly exchange rate movements and often controlled them. Thus, we focus on the evidence from Thailand. Finally, we present the results for Indonesia and South Korea.

4.1 Basic or Augmented?

Table 2 reports the posterior estimates of the parameters under the basic and augmented Taylor rules for Thailand, together with the log marginal data densities. We find excellent empirical performance of the augmented Taylor rule along two dimensions. First, the data appear informative in the augmented Taylor rule because all posterior distributions are more concentrated than those of the basic Taylor rule. Second, we also find a proximate 6-point difference in the log marginal data densities between the two rules, then assess this result by calculating a posterior odds ratio. The log marginal data density is 2.5 larger on a log scale, which translates into a posterior odds ratio of almost zero (if using the same value, we would find a posterior odds ratio of one). The ratio of essentially zero suggests strong evidence in favor of the model featuring the augmented Taylor rule. We conclude that the augmented Taylor rule specification is a superior model fit with the data, which implies that the Bank of Thailand responded to the exchange rate movements as well as inflation and output since the Asian currency crisis.

Table 2. Estimation results for the basic and augmented Taylor rules, Thailand

	Basic Taylor rule			Augmented Taylor rule		
Parameters	Mean	90% HPD interval		Mean	90% HPD interval	
ρ_r	0.87	0.84	0.89	0.88	0.85	0.90
α_π	1.09	1.00	1.22	1.08	0.99	1.19
α_x	0.33	0.11	0.54	0.30	0.10	0.51
α_q	–	–	–	0.46	0.21	0.70
σ_{x*}	5.58	4.73	6.34	5.54	4.73	6.31
$\sigma_{\pi*}$	4.77	4.02	5.48	4.78	4.07	5.46
σ_{r*}	1.36	1.16	1.57	1.35	1.16	1.54
σ_x	0.09	0.02	0.16	0.10	0.02	0.18
σ_π	5.27	4.50	6.11	5.41	4.58	6.19
σ_r	0.66	0.53	0.79	0.61	0.50	0.73

σ_q	–	–	–	5.00	4.25	5.65
σ_a	6.15	5.03	7.21	7.14	5.83	8.36
Model fit statistics						
ML		-1116.94			-1110.92	
PO		–			0.002	

Notes: HPD = highest probability density; ML = marginal likelihood; PO = posterior odds.

Source: Author's calculations.

On the other hand, the coefficient in both Taylor rules imply weak reaction to inflation compared with the prior mean. However, it seems to be rather consistent with the Bank of Thailand's pursuit of a moderately anti-inflationary policy as there has been almost no deviation from the target range since the adoption of inflation targeting.

4.2 Other Specifications

As we point out in Section 4.1, the result implies that the exchange rate is a relatively useful indicator for the Bank of Thailand. We investigate the priority of the exchange rate in setting monetary policy. We estimate two additional models with other inflation targeting rules, and then compare the posterior odds ratios of the respective models to evaluate the fit.[3] We estimate one with the augmented Taylor rule without output. This specification suggests that the Bank of Thailand purely responds to inflation and exchange rate movements and does not respond to output. The rule is

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\alpha_\pi \pi_t + \alpha_q \Delta q_t) + \varepsilon_{r,t}. \qquad (10)$$

In Table 3, we find that this rule is inferior to the augmented Taylor rule, but yields a superior fit over the basic Taylor rule. This result suggests that the Bank of Thailand reacts in response to inflation, output, and exchange rate movements, while the exchange rate has a higher priority than output.

[3] We estimate each model under the same equations except for the monetary policy specification, with the same data and priors.

Table 3. Comparison of policy rules

Policy rule		ML	PO
Thailand			
	$\alpha_\pi \pi_t + \alpha_x x_t$	-1116.9	–
	$\alpha_\pi \pi_t + \alpha_x x_t + \alpha_q \Delta q_t$	-1110.9	0.002
	$\alpha_\pi \pi_t + \alpha_q \Delta q_t$	-1113.0	0.029
	$\alpha_\pi \pi_t$	-1116.1	0.425
Indonesia			
	$\alpha_\pi \pi_t + \alpha_x x_t$	-812.2	–
	$\alpha_\pi \pi_t + \alpha_x x_t + \alpha_q \Delta q_t$	-807.2	0.007
South Korea			
	$\alpha_\pi \pi_t + \alpha_x x_t$	-1175.9	–
	$\alpha_\pi \pi_t + \alpha_x x_t + \alpha_q \Delta q_t$	-1172.0	0.020

Notes: ML = marginal likelihood; PO = posterior odds.

Source: Author's calculations.

We estimate another model with a single objective rule, called strict inflation targeting (Svensson, 1997), of the form

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\alpha_\pi \pi_t + \varepsilon_{r,t}. \quad (11)$$

This rule is also superior to the basic Taylor rule, as Table 3 shows. This result may imply that output is of considerably low priority for the Bank of Thailand.

4.3 Indonesia and Korea

Table 4 reports the posterior estimates of the policy-related parameters under the basic and augmented Taylor rules for Indonesia and South Korea. We find that although each result of comparison between the log marginal densities is similar to Thailand in Table 3, there are some differences in the posterior estimates. For instance, a few posterior distributions in the basic Taylor rule are more concentrated than those in the augmented Taylor rule, although slightly. This may imply that it is not clear which model provides superior informativeness about the data. In addition, both coefficients α_π in the augmented Taylor rule are lower than that for Thailand, while both coefficients α_x are higher. This relationship generally reflects a trade-off between inflation and output, implying that Indonesian and South Korean monetary authorities give output a relatively high priority. Finally, both coefficients α_q in the augmented Taylor rule are lower than that for Thailand.

Table 4. Estimation results for the basic and augmented Taylor rules, Indonesia and South Korea

	Basic Taylor rule			Augmented Taylor rule		
Parameters	Mean	90% HPD interval		Mean	90% HPD interval	
Indonesia						
ρ_r	0.72	0.66	0.78	0.72	0.66	0.78
α_π	1.03	0.99	1.07	1.02	0.99	1.07
α_x	0.71	0.29	1.12	0.60	0.22	0.99
α_q	–			0.42	0.20	0.64
South Korea						
ρ_r	0.72	0.68	0.77	0.72	0.68	0.76
α_π	1.05	0.99	1.12	1.03	0.99	1.09
α_x	0.94	0.64	1.22	1.02	0.72	1.33
α_q	–			0.20	0.10	0.29

Notes: HPD = highest probability density; ML = marginal likelihood; PO = posterior odds.

Source: Author's calculations.

On the other hand, according to an assessment of the posterior odds ratios, we find that the augmented Taylor rule significantly improves the fit of the model over the basic Taylor rule in Indonesia and South Korea, as Table 3 shows. This result can become ultimately strong evidence that the augmented Taylor rule is superior to the basic Taylor rule.

5. Concluding Remarks

In this paper, we investigated whether central banks in Indonesia, South Korea, and Thailand, which target inflation, responded to the exchange rate movements after the Asian currency crisis. We estimated a small open economy DSGE model with the Bayesian method, and then compared the model fit of different inflation targeting rules with and without an exchange rate. We then arrived at several findings. First, an augmented Taylor rule including the exchange rate proved fairly superior to a basic Taylor rule in Thailand, indicating that the Bank of Thailand responded to exchange rate movements as well as the main policy objectives. Second, the Bank of Thailand prioritized the exchange rate above output. This finding further strengthens the conclusion that the Bank of Thailand targeted the exchange rate. Finally, Indonesian and South Korean monetary authorities also responded to exchange rate movements, although these empirical findings were not as strong as those for Thailand.

These findings have significant policy implications. The bilateral exchange rate for the US dollar is an important part of the decision-making process in our sample countries. However, most critically, when the effects of an interest rate change are opposite to those of inflation and the exchange rate, monetary authorities must reassess the relative weights of their objectives. Moreover, such decisions of the monetary authorities were not consistent with the impossible trinity. This inconsistency might damage the credibility of the central bank.

Several key avenues of research can extend this study. In particular, researchers could include tail risk and the balance sheet of each central bank as a risk premium in the exchange rate equation of the model. Future studies could also account for financial flows. The capital account seems to matter as much for these economies as the current account. These would generate richer model dynamics. In addition, the real effective exchange rate could be used, as an alternative variable to the bilateral real exchange rate for the US dollar, with the large economy's variables expressed in the trade weighted form.

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Appendix. Small open economy's IS and New Keynesian Phillips curves

In accordance with Gali and Monacelli (2005), the small open economy's IS curve links consumption, as follows:

$$c_t = E_t c_{t+1} - \sigma^{-1}(r_t - E_t \pi_{t+1}) \qquad \text{(A. 1)}$$

Equilibrium in the goods market implies domestic output:

$$y_t = c_t + \frac{\alpha\omega}{\sigma} s_t \qquad \text{(A. 2)}$$

where s_t denotes the terms of trade between the small open economy and the large economy, $\omega \equiv \sigma\tau + (1-\alpha)(\sigma\iota - 1)$, α captures the degree of openness,

τ is the intratemporal elasticity of substitution between foreign and domestically produced goods, ι is the elasticity of substitution across varieties of foreign-produced goods.

By assuming that a condition analogous to the one above holds for all countries, we derive a world market clearing condition as follows:

$$y_t{}^* = c_t{}^* \quad \text{(A. 3)}$$

where $y_t{}^*$ and $c_t{}^*$ are indexes for world output and consumption.

Combining (A. 2) with international risk sharing, $c_t = c_t{}^* + \frac{(1-\alpha)}{\sigma} s_t$, and (A. 3), we get

$$y_t = y_t{}^* + \frac{1}{\sigma_\alpha} s_t \quad \text{(A. 4)}$$

where $\sigma_\alpha \equiv \frac{\sigma}{(1-\alpha)+\alpha\omega} > 0$.

Finally, combining (A. 1) with (A. 2), we obtain

$$y_t = E_t y_{t+1} - \frac{1}{\sigma_\alpha}(r_t - E_t \pi_{t+1}) + \alpha(\omega - 1) E_t \Delta y^*_{t+1} \quad \text{(A. 5)}$$

where $(\sigma\tau - 1) + (1 - \alpha)(\sigma\iota - 1) = \omega - 1$.

Each individual firm sets its price with probability $(1 - \xi)$ each period. $(1 - \xi)$ firms reset their prices. $\overline{P}_t$ denotes the prices set by domestic firms adjusting their prices in any given period.

$$\overline{P}_t - P_{t-1} = \beta\xi E_t(\overline{P}_t - P_{t-1}) + \pi_t + (1 - \xi)\hat{m}c_t \quad \text{(A. 6)}$$

where $\hat{m}c_t \equiv mc_t - mc$ is the deviation of real marginal cost from its steady state.

Finally, in the small open economy, we obtain the dynamics of domestic inflation in terms of real marginal cost:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \hat{m}c_t \quad \text{(A. 7)}$$

where $\lambda \equiv \frac{(1-\xi)(1-\beta\xi)}{\xi}$. The marginal cost can be determined in terms of domestic output, world output, and productivity:

$$mc_t = -\nu + (\sigma_\alpha + \varphi) y_t + (\sigma - \sigma_\alpha) y^*_t - (1 + \varphi) a_t \quad \text{(A. 8)}$$

where $\nu \equiv -\log(1 - \eta)$, η is an employment subsidy.

Let $x_t \equiv y_t - \overline{y}_t$ denote the domestic output gap as the deviation of domestic output from its natural level. Imposing $mc_t = -\mu$ for all *t*, we solve for domestic output in equation:

$$\overline{y}_t = \frac{\nu - \mu}{\sigma_\alpha + \varphi} - \alpha \frac{(\omega - 1)\sigma_\alpha}{\sigma_\alpha + \varphi} y_t^* + \frac{1 + \varphi}{\sigma_\alpha + \varphi} a_t. \qquad \text{(A. 9)}$$

In addition, from (A. 8), following $\hat{m}c_t = (\sigma_\alpha + \varphi)x_t$, we combine with (A. 7) and obtain a version of the New Keynesian Phillips curve:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa_\alpha x_t \qquad \text{(A. 10)}$$

where $\kappa_\alpha \equiv \lambda(\sigma_\alpha + \varphi)$.