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Foreign Output Shocks and Monetary Policy Regimes in Small Open Economies: A DSGE Evaluation of East Asia

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Abstract: East Asia's small open economies were hit in varying degrees by the sharp drop in the output of major industrial countries during the global financial and economic crisis of 2008-2009. This highlights the role of monetary policy regimes in cushioning small open economies from adverse external output shocks. To assess the welfare impact of external shocks on key macroeconomic variables under different monetary policy regimes, we numerically solve and calculate the welfare loss function of a dynamic stochastic general equilibrium (DSGE) model. We find that CPI inflation targeting minimizes welfare losses for import-to-GDP ratios from 0.3 to 0.9. However, welfare under the pegged exchange rate regime is almost equivalent to CPI inflation targeting when the import-to-GDP ratio is one while the Taylor-type rule minimizes welfare when the import-to-GDP ratio is 0.1. We calibrate the model and derive welfare implications for eight East Asian small open economies.

***Keywords*:** Trade channel, Import-to-GDP ratio, small open economies, welfare, exchange rate regimes, inflation targeting, Taylor rule, foreign output shock.

***JEL Classification*:** F40, F41, E52, F31

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1. Introduction

The global financial and economic crisis of 2008-2009 was triggered by the bursting of the US housing market bubble. The sharp decline in housing prices drastically reduced the values of mortgaged–backed financial instruments and inflicted heavy losses on US financial institutions, which curtailed their credit to the real economy. As a result of the ensuing credit crunch, US real GDP began its steep decline in the first quarter of 2008. From this benchmark date, the cumulative contraction in US real GDP growth relative to trend is estimated to be –6.7%. The financial institutions of other industrial countries had bought large amounts of US mortgaged–backed financial instruments. As a result, the financial crisis spread to other industrial countries. Real GDP of the other G7 countries began declining around the first quarter of 2008, and from this benchmark date, suffered an average cumulative contraction in real GDP growth of 7.8% relative to trend.[1]

Despite the limited exposure of their financial institutions to US mortgaged–backed financial instruments, East Asian economies experienced large declines in real GDP. Table 1 shows the cumulative contraction in real GDP growth, relative to trend, of 11.8% to 13.08% for Singapore, Taiwan and Hong Kong, and 7.3% to 8.26 % for Malaysia, Philippines, Korea and Thailand. The least affected country is Indonesia with a cumulative loss of 1.11%. Table 1 suggests that the primary channel for the transmission of the global crisis to East Asia was the trade channel. The cumulative contraction of real export growth ranged from 10.51% for Singapore to 38.78% for Thailand. Indonesia experienced the least cumulative loss of 5.96%. It is not surprising that exports have a large impact on the real GDP of East Asian countries in light of their heavy export dependence. The ratio of export to GDP ranges from 31.56% to 42.88% for Indonesia, Philippines and Korea, around 50% for Taiwan and Thailand, and over 100% for Malaysia, Singapore and Hong Kong. In short, East Asian emerging markets with relatively sound financial systems were affected by the crisis primarily through the G7 output shock.

[1] We consider 2008 Q1 as the benchmark date of the 2008 financial crisis. We follow Blanchard and Gali (2007) in calculating the cumulative change in real GDP gain or loss over eight quarters following benchmark date relative to the trend given by the cumulative real GDP growth rate over the preceding eight quarters.

Table 1. Selected Economic Indicators of Small Open Economies in East Asia

Country	Cumulative % change in Real GDP Growth	Average % change in CPI Inflation	Average % change in exchange rate	Cumulative % change in real export growth	% of export over GDP	% of import over GDP	Monetary Policy (2008)
				Newly Industrializing Countries			
Hong Kong	–13.08	0.38	–0.42	–18.40	158.60	172	Fixed Exchange Rate under the currency board
Singapore	–11.8	2.03	3.98	–10.51	215.05	191	Pegged to a basket of currencies
Korea	–7.65	1.32	27.16	–15.62	36.20	39	Inflation Targeting
Taiwan	–12.04	0.14	–3.01	–23.00	53.46	40	Aims for stable prices and intervenes in the foreign exchange market
				ASEAN – 4			
Malaysia	–7.32	0.21	6.92	–20.34	102.24	90	Aims for stable prices and stable effective exchange rate
Indonesia	–1.11	–2.55	9.17	–5.96	31.54	27	Inflation Targeting
Philippines	–7.49	1.77	12.28	–19.99	42.88	48	Inflation Targeting
Thailand	–8.26	–1.11	7.61	–38.78	57.61	64	Inflation Targeting
Benchmark: USA	–6.72	–1.29				11	Taylor rule

Notes: We consider 2008 Q1 as the benchmark date of the 2008 financial crisis. We follow Blanchard and Gali (2007) in calculating the cumulative change in real GDP gain or loss over eight quarters following benchmark date relative to the trend given by the cumulative real GDP growth rate over the preceding eight quarters. The change in CPI inflation (national currency to US dollar) is the average rate of inflation (depreciation or appreciation) in eight quarters following each of the benchmark date minus the average inflation (depreciation or appreciation) rate over the eight quarters immediately following the benchmark date. A positive (negative) sign in the fourth column indicates the depreciation (appreciation) of the national currency against the US dollar. All quarterly data are from CEIC Data on Emerging Markets except for export and import as a percentage of GDP which are from the World Development Indicator online (August 2011). When available, seasonally adjusted Real GDP are used. Information on countries that target inflation are from Truman (2003) except for Indonesia which is from the Bank of Indonesia website. Information on the monetary policy of Singapore is from the Monetary Authority of Singapore website. Information on the monetary policies of Malaysia and Taiwan are from the Economic Intelligent Unit's 2008 Country Reports. Murray *et al.* (2009) argue that the US Fed followed the Taylor principle from 1985 to 2009. Exchange rate is defined as national currency per US dollar.

Table 1 also shows the various monetary and exchange rate policies adopted by East Asian countries. Hong Kong and Singapore have fixed and pegged exchange rate regimes respectively while Korea, Indonesia, Philippines and Thailand have adopted inflation targeting policies. In contrast, Taiwan and Malaysia aim to stabilize prices and intervene in the foreign exchange rate markets. These policies seem to be consistent with the average change in the exchange rates relative to trend. Countries which target exchange rate – Hong Kong, Taiwan and Singapore – showed lower average changes in exchange rates than countries which target inflation – Indonesia, Korea, Philippines and Thailand.[2] The exception is Malaysia, which target both variables but experienced an average change in exchange rate closer to inflation targeting countries.[3] In addition, countries which target the exchange rate suffered a visibly larger cumulative decline in real GDP compared to countries which target inflation. Inflation has been generally low for all countries.[4]

The global crisis of 2008-2009 highlights the vulnerability of small open economies to adverse external shocks. The crisis, or more precisely the severe recession in industrialized countries due to the crisis, had a pronounced output effect even on fundamentally sound small open economies with strong fundamentals, such as those of East Asia. This raises some important questions which we try to address in this paper. Why were some countries more affected than others in the face of a negative foreign output shock? What role did monetary and exchange rate policy regimes play in mitigating the negative foreign output shock? Could East Asian countries have done better in the presence negative foreign output shocks with alternative policy regimes? The rest of the paper is organized as follows. Section 2 explores the relationship between monetary and exchange rate policy regimes and macroeconomic performance. Section 3 specifies our model, Section 4 reports and discusses the main results, and Section 5 concludes the paper.

[2] Hong Kong, Taiwan and Singapore experienced the smallest average percentage change in exchange rates of –0.42%, –3.01% and 3.98%, respectively. In contrast, Korea, Indonesia, Philippines and Thailand experienced an average percentage change in exchange rates in the range of 6.92% to 27.16%.

[3] Malaysia experienced an average change in exchange rates of 6.90%.

[4] In fact, Indonesia and Thailand experienced deflation.

2. Role of Monetary and Exchange Rate Policies in Cushioning External Shocks

The current crisis calls for a re–examination of the macroeconomic policies in general and monetary and exchange rate policies in particular. Stiglitz (2008) argues that inflation targeting is inappropriate, especially for emerging economies where energy and commodities make up a larger share of the household budget than in industrialized countries. Other economists have also suggested alternative monetary policy targets such as nominal GDP.[5] In addition, Blanchard *et al.* (2010) argue that there may be a case for the emerging-market central bankers' practice of targeting inflation while also intervening in the foreign exchange markets. Despite the criticism of inflation targeting, de Carvalho Filho (2010) finds that inflation targeting countries outperformed non–inflation targeting countries in the post-2008 period. He argues that during the crisis, inflation targeting countries lowered nominal interest rates by more, resulting in even larger real interest rate differentials and a powerful monetary stimulus.

The theoretical and empirical literature also suggest that countries with flexible exchange rate regimes can better insulate their economies from negative real shocks.[6] More relevant to East Asian countries and the transmission of foreign output shocks during the 2008-2009 crisis, Hoffmann (2007) shows that countries which allow the nominal exchange rate to fluctuate achieve a steadier adjustment of real GDP. The smaller decline of real GDP under flexible exchange rate regimes is explained by real exchange rate depreciation, which partly offsets the negative impact of foreign output shocks by improving export competitiveness.

The main purpose of this study is to investigate the relative effectiveness of

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[5] A debate on nominal GDP targeting among economists could be accessed online at http://economistsview.typepad.com/economistsview/2010/12/bernanke-and-mishkin-on-nominal-gdp-growth-targeting.html

[6] Friedman (1953) and subsequently Mundell (1961) argue that in the presence of price stickiness, flexible exchange rates act as a shock absorber in a small open economy. When an economy is hit by real shocks, the economy with flexible exchange rates allows relative prices to adjust more quickly than an economy with fixed exchange rates so output adjustment will be smaller and smoother. While the theoretical literature including Poole (1970), Dornbusch (1980), Läufer (1994), and more recently Obstfeld and Rogoff (2000), Devereux (2004), and Devereux, *et al.*(2006) show conditions under which the Friedman-Mundell proposition does not hold, empirical literature such as Broda (2004), Edwards and Levy-Yeyati (2005) and Hoffman (2007) have shown support for the proposition.

alternative monetary policy regimes in mitigating negative external output shocks in a small open economy. We develop a simple dynamic stochastic general equilibrium (DSGE) model with a goods market characterized by imperfect competition and nominal rigidities.[7] We describe the response of a small open economy to negative foreign output shocks under various types of monetary policy regimes - a fixed or pegged exchange rate rule, a CPI inflation targeting rule, inflation and exchange rate targeting rule, domestic inflation targeting, Taylor–type rule, nominal output targeting, and real output targeting. The open economy framework allows us to consider the exchange rate channel in the transmission of foreign output shocks to the economy. Foreign output shocks are assumed to be exogenous to country-level variables.

In contrast to many DSGE models which consider only two factor inputs, we follow Kim and Loungani (1992) in considering oil as an input in a constant elasticity of substitution (CES) production function where oil and capital are substitutes. Hence, we incorporate in the model the fact that more developed economies have lower ratios of energy use per capital compared with less developed economies. In addition, exchange rate depreciation could affect imported prices of oil which in turn, affects domestic output.

As in Monacelli (2004), capital is subject to adjustment costs. The model has a monetary policy regime that assigns different weights on the output gap, inflation and deviations of nominal exchange rate from theoretical parity. By explicitly analyzing the response of the economy to foreign output shocks under different types of monetary policy regimes, we address the extent to which output volatility can be attributed to foreign output shocks. In addition, we help to identify the dynamics of various macroeconomic aggregates including output, inflation, terms-of-trade, nominal and real exchange rates and nominal interest rate.

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[7] In recent years, there has been an outpouring research on open economy DSGE models that incorporate imperfect competition and nominal rigidities. Since the publication of the *Redux* model by Obstfeld and Rogoff (1995 and 1996), the research on open-economy macroeconomics has produced a synthesis of dynamic intertemporal approaches with sticky-price models of macroeconomic fluctuations. This synthesis has subsequently become widely known as the new open economy macroeconomics, NOEM. This new class of models has allowed economists to tackle many classical problems with new tools and at the same time generated new ideas and questions.

3. The Model

In this section, we lay out our model, which is broadly based on Monacelli's (2004) dynamic stochastic general equilibrium (DSGE) model of a small open economy. We incorporate oil in the model as an input to a CES production function following Kim and Loungani (1992).[8] The other inputs of domestic production are labor and capital. Identical and infinitely lived households consume baskets of differentiated domestic and foreign tradable goods. Households derive income from working and renting physical capital to the domestic firms.

3.1. Households

Households consume baskets of differentiated domestic and foreign goods which are both tradable and indexed by j. $P_{H,t} \equiv \left(\int_0^1 P_{H,t}\left(j\right)^{1-\vartheta} dj \right)^{1/1-\vartheta}$ and $P_{F,t} \equiv \left(\int_0^1 P_{F,t}\left(j\right)^{1-\vartheta} dj \right)^{1/1-\vartheta}$ are defined as the utility–based price indices associated to the baskets of domestic and foreign varieties of goods, respectively. The subscript H is the index for home and F for foreign. The price indices are expressed in units of domestic currency. $P_{H,t}\left(j\right)$ and $P_{F,t}\left(j\right)$ are prices of the individual domestic and foreign good j, respectively, where $\vartheta > 1$ is the elasticity of substitution between varieties within each category. In each period, the households optimally allocate their expenditure on differentiated goods within each category. The demand functions are:

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\vartheta} C_{H,t}; \quad C_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\vartheta} C_{F,t} \tag{1}$$

for all j goods within the interval of 0 and 1 where the goods are produced by a continuum of firms and the firms are owned by domestic households.

[8] Backus and Crucini (2000) also follow Kim and Loungani in nesting capital and oil as a CES function within a Cobb-Douglas production function. Rotemberg and Woodford (1996) and Blanchard and Gali (2007) consider oil as an input to production together with labor. In contrast, Finn (2000) introduces a capital utilization rate and assumes oil and capital as complimentary. Whether capital and oil are substitutes or complements is unresolved in empirical literature. Apostolakis (1990) surveys the literature.

$C_{H,t} \equiv \left(\int_0^1 C_{H,t}(j)^{\vartheta-1/\vartheta} dj \right)^{\vartheta/\vartheta-1}$ and $C_{F,t} \equiv \left(\int_0^1 C_{F,t}(j)^{\vartheta-1/\vartheta} dj \right)^{\vartheta/\vartheta-1}$ are composite indices of domestic and foreign goods, respectively. The households consume a CES composite of both home products (C_H) and foreign products (C_F):

$$C_t = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1} \tag{2}$$

where $\gamma \in [0,1]$ is the share of home–produced goods in total consumption so $(1-\gamma)$ represents the share of foreign–produced goods. $\rho > 1$ is the elasticity of substitution between domestic and foreign goods. For simplicity, we assume that the investment composite index $In_t(In_{H,t}, In_{F,t})$ has an identical expression. The utility–based consumer price index is given by:

$$P_t = \left(\gamma P_{H,t}^{1-\rho} + (1-\gamma) P_{F,t}^{1-\rho} \right)^{1/1-\rho} \tag{3}$$

The optimal allocation of any given expenditure between domestic and foreign goods yields the consumption demand:

$$C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_t} \right)^{-\rho} C_t ; C_{F,t} = (1-\gamma) \left(\frac{P_{F,t}}{P_t} \right)^{-\rho} C_t \tag{4}$$

The domestic economy is populated by a continuum of infinitely–lived identical households indexed by i. From here on, we will drop the indexation for simplicity. Across time, the representative domestic household maximizes the utility function:

$$E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] \tag{5}$$

where $\sigma > 0$ and $\varphi > 0$. β is the discount factor and $\beta \in (0,1)$. $1/\sigma$ is the intertemporal elasticity of substitution, and φ is the elasticity of labor substitution. E_t is the expectation operator. C_t is the consumption and N_t is the labor supply of the representative household at time t. In each period, the representative household holds bonds denominated in domestic currency, rents out his capital to the home–based monopolistic competitive firm and derives income from working. Therefore, the household's budget constraint can be written as:

$$P_t (C_t + In_t) + E_t (B_{t+1}) = W_t N_t + Z_t K_t + (1+i_t) B_t + \tau_t \tag{6}$$

where B_t is the quantity of nominal bonds acquired at time t which expire at $t+1$, i_t is the nominal interest rate, W_t is the nominal wage, Z_t is the nominal rental cost and τ_t represents the lump–sum transfer payment.

As in Monacelli (2004), capital accumulation is represented by:

$$K_{t+1} = (1-\delta)K_t + \Phi\left(\frac{In_t}{K_t}\right)K_t \tag{7}$$

where δ is the physical depreciation rate of capital. The function $\Phi(.)$, which is increasing and concave, assumes the adjustment cost in capital accumulation. That is, In_t units of investment translate into $\Phi(In_t/K_t)K_t$ units of additional capital.

The first order conditions are derived from maximizing the utility function subject to the budget constraint and the capital accumulation and can be written as:

$$\frac{C_t^{-\sigma}}{N_t^{\varphi}} = \frac{P_t}{W_t} \tag{8}$$

$$\beta E_t\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} = E_t\left(\frac{1}{1+i_{t+1}}\frac{P_{t+1}}{P_t}\right) \tag{9}$$

$$Q_t = C_t^{-\sigma}\left[\Phi_{In}\left(\frac{In_t}{K_t}\right)\right]^{-1} \tag{10}$$

$$Q_t = \beta E_t\left[C_{t+!}^{-\sigma}\frac{Z_{t+1}}{P_{t+1}} + Q_{t+1}\left(1-\delta+\Phi\left(\frac{In_{t+1}}{K_{t+1}}\right) - \frac{In_{t+1}}{K_{t+1}}\Phi_{In}\left(\frac{In_{t+1}}{K_{t+1}}\right)\right)\right] \tag{11}$$

Eq. (8) states the relationship between the utility from consumption and disutility from labor. Eq. (9) is the Euler equation governing the dynamic evolution of consumption. Eq. (10) specifies the intertemporal conditions for efficiency in investment. It determines the investment rate as a function of Q_t, which is the market value of one unit of new capital. Eq. (11) is the evolution of Q_t over time. We assume that there is neither average nor marginal costs of adjustment in the steady state. Hence, the steady state $\Phi(.)$ is subject to $\bar{Q} = \Phi'\left(\frac{In}{K}\right)^{-1} = 1$ and $\Phi\left(\frac{In}{K}\right) = \delta = \frac{In}{K}$. The specifications for the rest of the world assume foreign households have similar preferences as in the home country. The foreign demand for home produced good j is

$$C^*_{H,t}(j)=\left(\frac{P^*_{H,t}(j)}{P^*_{H,t}}\right)^{-\vartheta} C^*_{H,t}=\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\vartheta} C^*_{H,t} \text{ where } C^*_{H,t}=\left(1-\gamma^*\right)\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\rho} C^*_t .$$

3.2. Domestic Firms

There is a continuum of monopolistically competitive firms indexed by $j\in[0,1]$. Following Kim and Loungani (1992), we employ a nested CES production function with constant return to scale. Firms use labor, capital and oil according to the following specification:

$$Y_t(j)=A_t\left[\iota K_t^{1-\upsilon}(j)+(1-\iota)O_t^{1-\upsilon}(j)\right]^{(1-\alpha)/(1-\upsilon)} N_t^{\alpha}(j) \tag{12}$$

where $0<\alpha<1$, $\iota>0$ and $\upsilon>0$. The elasticity of substitution between capital and oil is equal to $1/v$ while labor share in production is given by α.

In the production unit, the constant return to scale production technology implies that the unit cost equals to the nominal marginal cost (*MC*). Hence, the efficiency conditions for the choice of labor, capital and oil are:

$$mc_t\frac{\partial Y_t(j)}{\partial N_t(j)}=\frac{W_t}{P_{H,t}}; \tag{13}$$

$$mc_t\frac{\partial Y_t(j)}{\partial K_t(j)}=\frac{Z_t}{P_{H,t}}; \text{ and} \tag{14}$$

$$mc_t\frac{\partial Y_t(j)}{\partial O_t(j)}=\frac{\varepsilon_t P^*_{O,t}}{P_{H,t}} \tag{15}$$

respectively. mc_t is the real marginal cost, $P^*_{O,t}$ is the oil price denominated in foreign currency and ε_t is the nominal exchange rate.

Following Calvo (1983), firms set prices on a staggered basis. In each period, firms that adjust their prices are randomly selected with a fraction $1-\phi_p$ of all firms adjusting while the remaining fraction ϕ_p not adjusting their prices. The parameter ϕ_p represents the degree of nominal rigidity. A larger ϕ_p implies fewer firms adjust their prices and the expected time between price changes will be longer. As a pricing unit, domestic firm *j* faces domestic and foreign demand. Profits at some future date *t*+*k* are affected by the choice of price at time *t* only if the firm does not get another opportunity to adjust its price between t and $t+k$. The probability of a firm not adjusting its price from t to $t+k$ is ϕ_p^k. Hence, the domestic firm j will set price $P_{H,t}^{New}$ to maximize the profit function:

$$E_t\left\{\sum_{k=0}^{\infty}\beta^k\phi_p^k\Lambda_{t,t+k}\left[P_{H,t}^{new}(j)-MC_{t+k}(j)\right]Y_{t+k}(j)\right\} \tag{16}$$

subject to the overall demand $Y_{t+k}(j)\leq\left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}}\right)^{-\vartheta}\left[C_{H,t+k}+C_{H,t+k}^{*}\right]$ where $\Lambda_{t,t+k}$ is the time-varying portion of the firm's discount factor. The optimal pricing condition is:

$$P_{H,t}^{new}(j)=\left(\frac{\vartheta}{\vartheta-1}\right)\frac{E_t\left\{\sum_{k=0}^{\infty}\beta^k\phi_p^k\Lambda_{t,t+k}MC_{t+k}(j)Y_{t+k}(j)\right\}}{E_t\left\{\sum_{k=0}^{\infty}\beta^k\phi_p^k\Lambda_{t,t+k}Y_{t+k}(j)\right\}} \tag{17}$$

The above equation describes the dynamic markup for price setting. When the price signal ϕ_p equals to zero, Eq. (17) becomes $P_{H,t}^{new}(j)=(\vartheta/\vartheta-1)MC_t$. With symmetric equilibrium, the domestic aggregate price index is:

$$P_{H,t}=\left[\phi_p P_{H,t-1}^{1-\vartheta}+(1-\phi_p)\left(P_{H,t}^{new}\right)^{1-\vartheta}\right]^{(1/1-\vartheta)} \tag{18}$$

3.3. Price Level, Terms of Trade and Real Exchange Rate

The nominal exchange rate ε_t is the price of one unit of foreign currency in terms of domestic currency. With the law of one price, $P_{H,t}\equiv\varepsilon_t P_{H,t}^{*}$ and $P_{F,t}\equiv\varepsilon_t P_{F,t}^{*}$. The terms of trade, S_t, is defined as the price of the imported good relative to the price of the domestic good ($S_t\equiv\frac{P_{F,t}}{P_{H,t}}=\frac{\varepsilon_t P_{F,t}^{*}}{P_{H,t}}$). The real exchange rate is then defined as $\varepsilon_t^r\equiv\frac{\varepsilon_t P_t^{*}}{P_t}$.

For a small open economy, domestic price changes do not affect the foreign price level so without loss of generality, we assume that $P_{F,t}^{*}=P_t^{*}$ where the foreign price level is determined by the prices of non–oil goods and oil. Hence, it can be expressed as $P_t^{*}=\left(P_{NO,t}^{*}\right)^{\gamma_{no}}\left(P_{O,t}^{*}\right)^{1-\gamma_{no}}$. For simplicity, we normalize $P_{NO,t}^{*}$ to one so the foreign non–oil inflation, $\pi_{NO,t}^{*}$, is zero. The total CPI inflation is defined as $\pi_t\equiv\log(P_t/P_{t-1})$ and the domestic inflation is defined as $\pi_{H,t} \equiv \log\left(P_{H,t}/P_{H,t-1}\right)$. The no arbitrage condition can be written as $1+i_t^* / 1+i_t = \varepsilon_t / \varepsilon_{t+1}$.

3.4. Monetary Policy and Exchange Rate Regimes

Following Monacelli (2004), the monetary policy regime acts such that deviations of inflation, output and nominal exchange rate from their long–run target have feedback effects on short-run movements of the nominal interest rate as described by:[9]

$$\left(1+\overline{i}_t\right) = \left(\frac{P_t}{P_{t-1}}\right)^{\omega_\pi} Y_t^{\omega_y} \varepsilon_t^{\frac{\omega_\varepsilon}{1-\omega_\varepsilon}} \tag{19}$$

where $\overline{i}_t$ is the inflation target and ω_π, ω_y and ω_ε are weights assigned to the movements of CPI inflation, output and nominal exchange rate, respectively. Eq. (19) could also be modified to consider domestic inflation rather than CPI inflation and the inflation term could be written as $\left(P_{H,t}/P_{H,t-1}\right)^{\omega_{\pi H}}$ where $\omega_{\pi H}$ is the weight on domestic inflation. The actual short–run interest rate is determined based on the monetary authority's desire to smooth changes in the nominal interest rate:

$$\left(1+i_t\right) = \left(1+\overline{i}_t\right)^{1-\chi} \left(1+i_{t-1}\right)^{\chi} \tag{20}$$

The exogenous stochastic processes for the foreign output, foreign interest rate, domestic technology and nominal oil price can be summarized as $Y_t^* = Y_{t-1}^{\rho^{y*}} \exp\left(\xi_t^{y*}\right)$, $\left(1+i_t^*\right) = \left(1+i_{t-1}^*\right)^{\rho^{i*}} \exp\left(\xi_t^{i*}\right)$, $A_t = A_{t-1}^{\rho^a} \exp\left(\xi_t^a\right)$ and $P_{O,t}^* = \left(P_{O,t-1}^*\right)^{\rho^{po}} \exp\left(\xi_t^{po}\right)$, respectively.[10]

3.5. Welfare

We analyze the impact of various monetary policy regimes based on social welfare loss function minimized by the central banks. The function is based on the second-order Taylor expansion of the household's utility around the steady state as in Rotemberg and Woodford (1998, 1999) and Woodford (2003) and extended to small open economies by

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[9] See also Taylor (1993), Clarida *et al.* (1999) and Monacelli (2004).

[10] The steady state and market equilibrium and the log-linearized equations are described in the Appendix.

Chung *et al.* (2007) and Divino (2009). The social welfare loss function is derived as in Walsh (2010) and could be expressed as:

$$W = -\Omega\, E_0 \sum_{t=0}^{\infty} \beta_t \left\{ \hat{\pi}_t^2 + \lambda(\hat{y}_t - \hat{y}_t^{flexible})^2 \right\} \tag{21}$$

Where $\Omega = \frac{1}{2} U_C \overline{C} \left[\frac{\varphi_p}{(1-\varphi_p)(1-\varphi_p\beta)} \right] (\vartheta^{-1} + \eta) \vartheta^2$, $\lambda = \left[\frac{(1-\varphi_p)(1-\varphi_p\beta)}{\varphi_p} \right] \frac{(\sigma+\phi)}{(1+\phi\vartheta)\vartheta}$

and $\hat{y}_t^{flexible}$ is obtained by setting the probability of non-adjustment in price, φ_p, close to zero.

3.6. Model Parameterization

The model is solved numerically.[11] We follow Monacelli's (2004) parameterization of a small open economy where the marginal disutility of work effort φ is set to 3. As commonly accepted in the Calvo (1983) pricing model, the probability of price non–adjustment, ϕ , is set at 0.75. The steady–state markup, $\vartheta/(\vartheta-1)$, equals to 1.2. The inverse of elasticity of intertemporal substitution, σ, is set at 0.50 and the labor share of output equals 0.70. The elasticity of substitution between home and foreign produced goods, ρ, is 1.01. The elasticity of investment rate to the price of capital η equals to 3.

As for the monetary policy regime parameters, the interest rate smoothing parameter, χ, is set at 0.5. We set $\omega_\varepsilon = 0.99$ for fixed or pegged exchange rate and $\omega_\varepsilon = 0.1$ for flexible exchange rate. Under the flexible exchange rate regime, the central bank could choose to target only CPI inflation and set ω_π= 1.5 and ω_y = 0 or only domestic inflation and set $\omega_{\pi H}$ = 1.5 and ω_y = 0; or choose to follow the Taylor rule so ω_π= 1.5 and ω_y = 0.5; or target nominal output and set ω_π= 1.5 and ω_y = 1.5 or real output and set ω_π= 0 and ω_y = 1.5. The central bank could also target CPI inflation and exchange rate and set ω_π= 1.5, $\omega_y = 0$ and $\omega_\varepsilon = 0.8$.

The serial correlation of the oil price shocks (ρ^{y^*}) equals to 0.90, which is from the

[11] The numerical solution of the model is described in Uhlig (1997).

time series evidence on price of the West Texas Intermediate (WTI) crude. The serial correlation parameters of foreign interest rate (ρ^{i^*}), foreign output (ρ^{y^*}) and technology (ρ^{a}) are also set to 0.90. The degree of the impact of oil price on the foreign price level (γ^{NO}) equals 0.01 for a positive oil price shock and 0.001 for a negative oil price shock. These settings reflect the asymmetric effect of oil price shocks.[12] We also consider these asymmetric effects in assuming that a positive oil price shock has significant effect on marginal cost while a negative oil price shock has negligible effect on marginal cost. The share of capital relative to oil in production (ι) is 0.90. The standard deviations from the steady state of oil price ($\sigma_{\xi}{}^{P_o^*}$) of foreign nominal interest rate ($\sigma_{\xi}{}^{i^*}$) and of technology (σ_{ξ}^{a}) are set at 1%. The standard deviation of foreign output from the steady state is set to –1% over one period.

We calculate the inverse of the elasticity of substitution between oil and capital, υ, to get an expression of the steady state of the oil to capital ratio as a function of the parameters υ, δ, β and ι.[13] We follow Kim and Loungani (1992) in setting the depreciation rate, δ, equals to 0.1225 and the discount rate, β, equals to 0.96. The share of oil relative to capital stock, ($1-\iota$), is 0.10. Given these parameter values, υ is calculated based on average energy–to–capital ratio of 0.65 for Indonesia, 0.59 for Philippines, 0.46 for Malaysia, 0.45 for Thailand, 0.27 for Korea, 0.22 for Singapore, 0.06 for Hong Kong and 0.05 for Taiwan and 0.11 for the USA which is our benchmark country. These values are used to calculate υ of 9.3 for Indonesia, 7.8 for Philippines, 5.2 for Malaysia, 5 for Thailand, 3.1 for Korea, 2.7 for Singapore, 1.45 for Hong Kong, 1.4 for Taiwan and 1.8 for the US.[14] The estimates for the US are comparable to Kim and Loungani's setting of υ equals to 1.7 and an elasticity of substitution of 0.59 for

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[12] For example, Chen *et al.* (2005) find empirical evidence that gasoline prices in the US responds quickly to a crude oil price increase but not to a decrease.

[13] The steady-state capital-oil ratio is given by $\left(\frac{\bar{K}}{\bar{O}}\right)^{-\upsilon} = \frac{(1-\iota)}{\iota}\bar{Z}$ where $\bar{Z} = \frac{1}{\beta} - 1 + \delta$, which is the steady-state rental cost of capital. The details of the derivation are in the Appendix.

[14] Data on energy use in kiloton of oil equivalent (KOE) and gross capital formation are from the World Economic Indicator (WDI) for Korea, Hong Kong, Singapore, Indonesia, Malaysia, Indonesia, Philippines and the United States and CEIC Database for Taiwan. We calculate energy use by multiplying energy use in KOE by the average price of a kiloton of crude oil in 2000 US dollars. We use the consumer price index (CPI) to convert energy use in 2000 US dollars to 1985 international dollars vis-à-vis the United States. Data on CPI and the price of crude oil are from the International Financial Statistics online.

the US. As a proxy for the parameter on the proportion of foreign goods in total consumption ($1-\gamma$), we use imports over GDP of East Asian countries as shown in Table 1.

4. Simulation Results and Welfare

In this section, we report and discuss our simulation results, including estimates of welfare losses under alternative monetary policy regimes.

4.1. Impulse Responses under Various Monetary Policy Regimes

The simulated impulse responses in Figures 1 to 7 represent the dynamic responses of real output, inflation, terms–of–trade, nominal and real exchange rates under seven monetary policy regimes: fixed or pegged exchange rate regime, the strict (CPI) inflation targeting, exchange rate and CPI inflation targeting, the Taylor rule, strict (domestic) inflation targeting, nominal GDP targeting and real GDP targeting.

Figure 1. Impulse Responses to a Shock in Foreign Output under Fixed/Pegged Exchange Rate

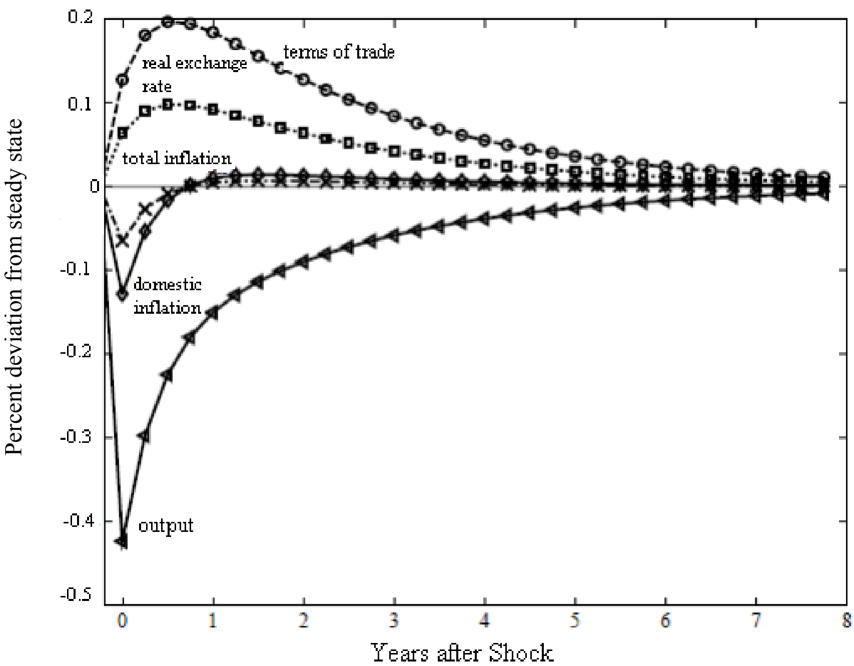


Figure 2. Impulse Responses to a Shock in Foreign Output under CPI Inflation Targeting

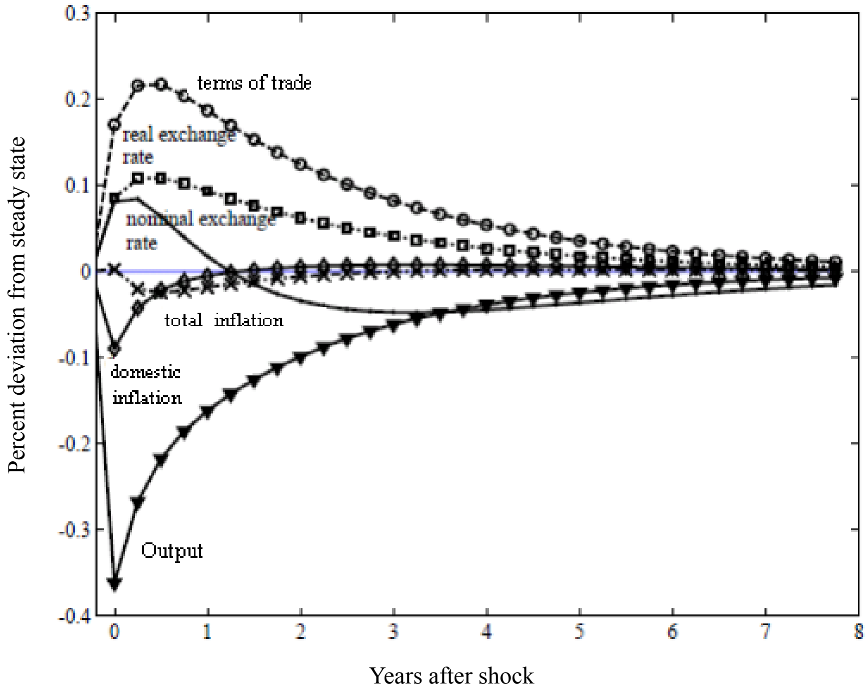


Figure 3. Impulse Responses to a Shock in Foreign Output under Exchange rate and Inflation Targeting

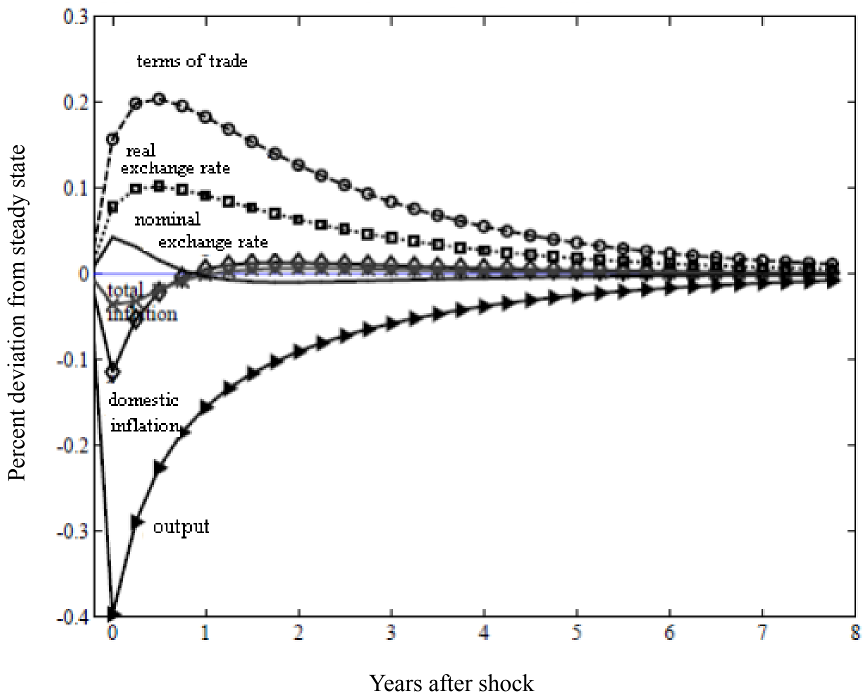


Figure 4. Impulse Responses to a Shock in Foreign Output under Taylor Rule

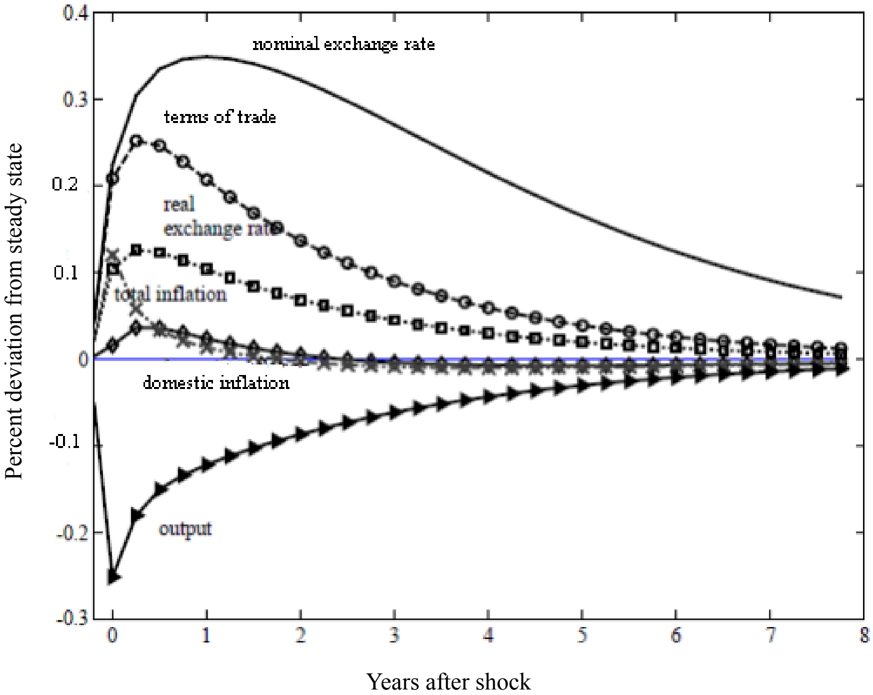


Figure 5. Impulse Responses to a Shock in Foreign Output with domestic inflation Targeting

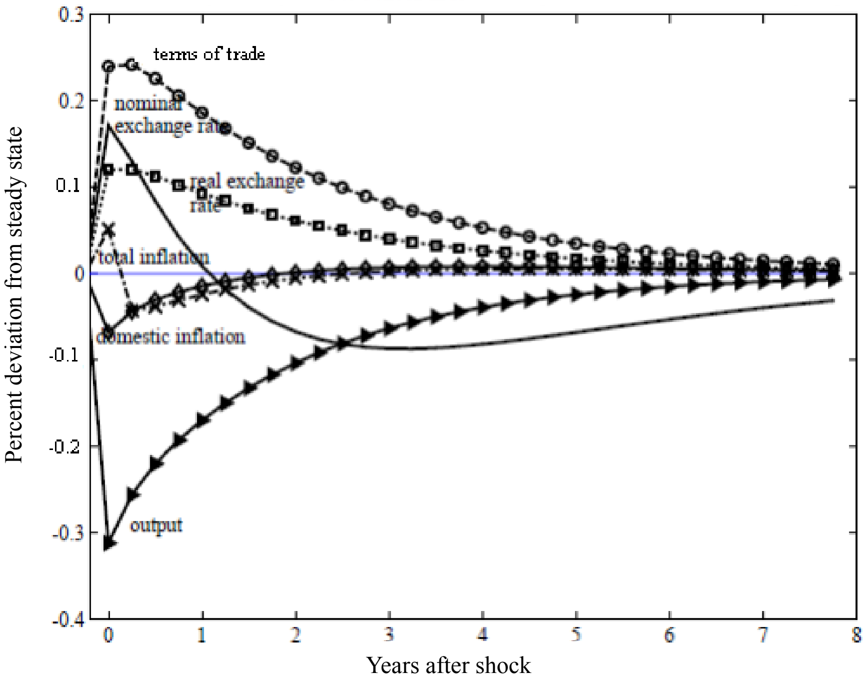


Figure 6. Impulse Responses to a Shock in Foreign Output with Nominal GDP Targeting

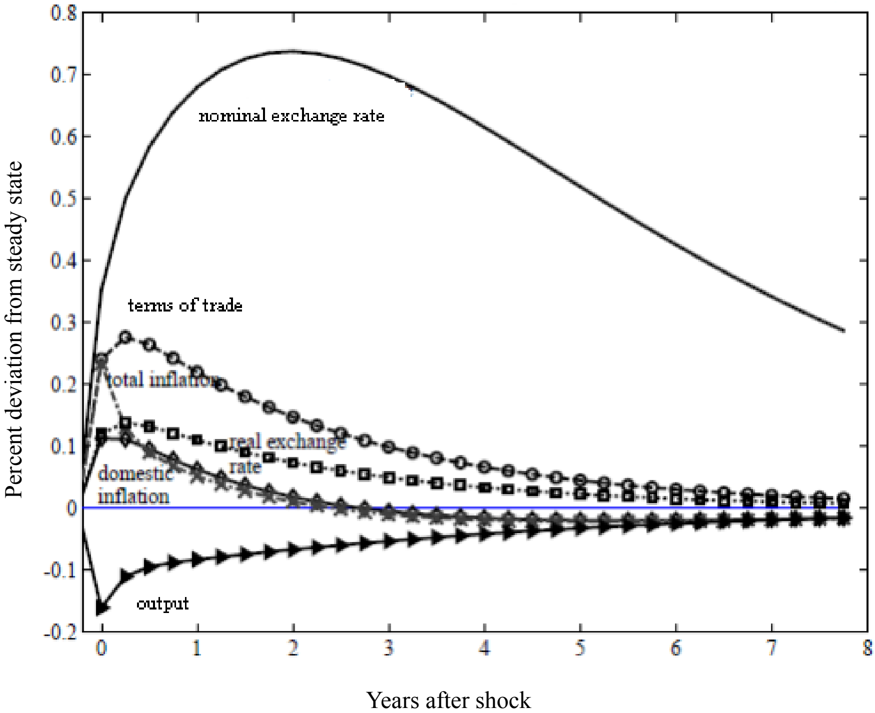
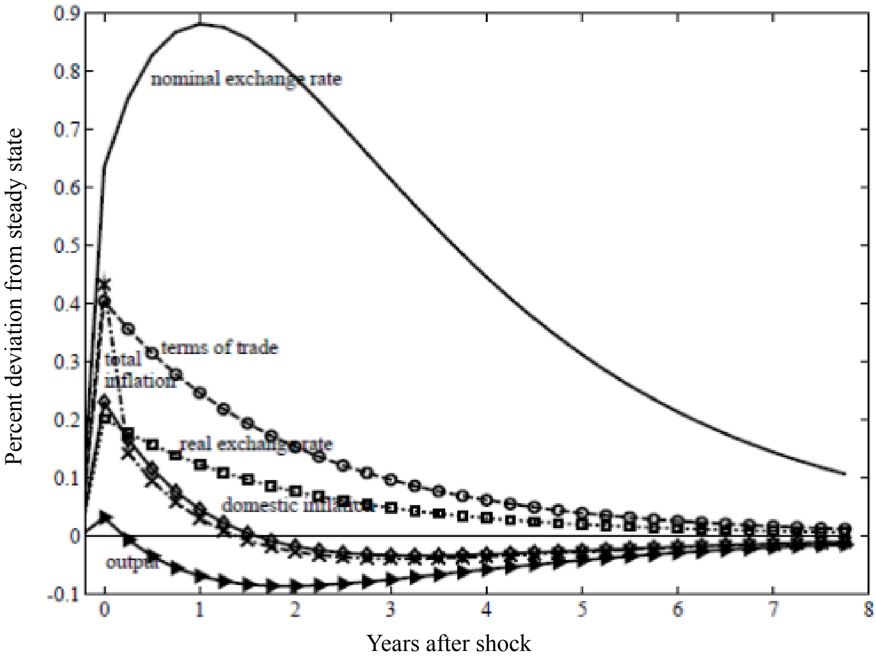


Figure 7. Impulse Responses to a Shock in Foreign Output under Real GDP Targeting

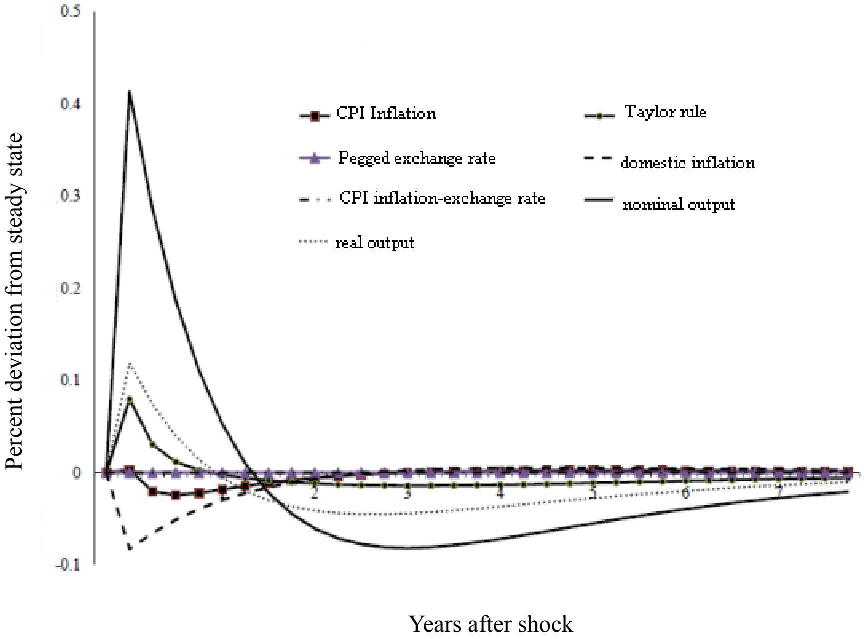


A negative foreign output shock has the biggest impact on domestic output under fixed or pegged exchange rate regime followed by CPI inflation and exchange rate targeting, CPI inflation targeting, domestic inflation targeting, Taylor–type rule, nominal GDP targeting and the least under real GDP targeting. For a 1% decline in foreign output, real output declines from its steady state by 0.42% under fixed exchange rate regime, 0.41% under CPI inflation-cum-exchange rate targeting, 0.36% under CPI inflation targeting, 0.23% under domestic inflation targeting, 0.25% under Taylor rule and 0.19% under nominal output. Under real output targeting, it rises by 0.03% in the first period before declining by 0.08%.

The mitigated effect on real output under real and nominal output targeting and to a lesser extent, Taylor-type rule, could be explained by the large and sharp depreciation in the nominal exchange rate following a negative foreign output shock. In the period following the 1% negative foreign output shock, nominal exchange rate depreciates from the steady state value by 0.64% for real output targeting, 0.35% for nominal output targeting and 0.24% for Taylor-type rule. In turn, the large exchange rate depreciation increases the prices of oil and other imports, causing higher total CPI inflation. Likewise, expectations of higher inflation and further depreciation raise the nominal interest rate.

The impact on the nominal interest rate is shown in Figure 8 where a 1% negative foreign output shock increases nominal interest rate by 0.41%, 0.11% and 0.08% from the steady state for nominal output targeting, real output targeting and Taylor-type rule, respectively. In contrast, nominal exchange rate depreciates only by 0.08%, 0.02% and 0.017% for CPI inflation, domestic inflation and CPI inflation-cum-exchange rate targeting, respectively. This leads to a reduction of CPI inflation from its steady state by 0.02% for CPI inflation targeting, 0.03% for pegged exchange rate regime and CPI inflation and exchange rate targeting, and 0.06% for domestic inflation targeting two periods after the shock. Hence, nominal interest rate in Figure 8 shows a decline from steady state values of 0.02%, 0.06% and 0.006% for CPI inflation, domestic inflation and CPI inflation-cum-exchange rate targeting, respectively. The nominal interest rate hardly changes under pegged exchange rate regime. The impulse responses clearly show a tradeoff between lower output volatility and higher inflation and nominal interest rate volatility.

Figure 8. Impulse Responses of Interest Rate to a Negative Foreign Output Shock under Various Monetary Policies



4.2. Welfare Losses under Various Monetary Policies

We examine the impact of various monetary policies after a negative foreign output shock using a welfare loss function described in section 2.7 and shown in Table 2 with the model parameters of oil to capital ratio of 0.25 and import to GDP ratio of 0.5 taken as average values for East Asian countries. The results show the best to worst welfare outcomes as follows: CPI inflation targeting, CPI inflation-cum-exchange rate targeting, pegged exchange rate regime, domestic inflation targeting, Taylor-type rule, nominal output targeting and real output targeting. CPI inflation targeting delivers the best welfare outcome under negative foreign output shock. These results indicate that while CPI inflation targeting causes a decline of 0.36% from steady state real output, as opposed to 0.19%-0.25% under Taylor type–rule and nominal output targeting, both CPI inflation and nominal interest rate decline from their steady state values by around 0.02%, leading to a sharp rebound in real output. As mentioned above, this contrasts with a rise in nominal interest rate under Taylor-type rule and nominal and real output targeting.

Table 2. Welfare Loss after a Negative Foreign Output Shock under Different Monetary Policies

Monetary policy	Weights in the interest rate rule				Welfare loss
	ω_{π}	$\omega_{\pi H}$	ω_{y}	ω_{ε}	
Fixed / peg exchange rate regime	0	0	0	0.99	–1.96
CPI Inflation targeting	1.5	0	0	0.1	–0.57
Exchange rate and inflation targeting	1.5	0	0	0.8	–1.58
Taylor rule	1.5	0	0.5	0.1	–7.47
Domestic inflation targeting	0	1.5	0	0.1	–2.91
Nominal output targeting	1.5	0	1.5	0.1	–33.15
Real output targeting	0	0	1.5	0.1	–85.48

Notes: The Welfare loss is calculated based on the average percent of import over real GDP of 50% for the six East Asian countries excluding Hong Kong and Singapore which have percent import over GDP of 172% and 191%, respectively. The average oil-to-capital ratio is 0.25 and the average elasticity of substitution of oil to capital is 3.14 excluding the Philippines and Indonesia which have an average oil-to-capital (elasticity of substitution of oil for capital) of 0.58 (7.8) and 0.90 (9.3) respectively. In the model, the import to GDP is $(1–\gamma)$ while the elasticity of substitution of oil and capital is υ. ω_{π}, $\omega_{\pi H}$, ω_{y}, and ω_{ε} are the weights on overall inflation, domestic inflation, output gap and exchange rate in the interest rate rule equation.

Since there are large variations in import-to-GDP ratio among East Asian countries, we conduct sensitivity analysis based on this ratio, represented by the parameter $(1-\gamma)$. This is the proportion of import in household consumption in the model. Table 3 shows the estimates of welfare losses due to a 1% negative output shock for various ratios of import-to-GDP given an oil-to-capital ratio of 0.25 under different monetary policy regimes. The results show that for an economy with import-to-GDP ratio of one, CPI inflation targeting, pegged exchange rate regime and a combination of CPI inflation and exchange rate targeting minimize the welfare losses.[15]

In contrast, for an economy with import-to-GDP ratio of 0.1, Taylor-type rule delivers the best welfare outcome, followed by domestic inflation and then CPI inflation targeting. For countries with import-to-GDP ratios of 0.3 to 0.9, CPI inflation targeting delivers the best welfare outcomes. These results indicate that countries with a large

[15] CPI inflation targeting has a slightly higher welfare (less negative) compared to pegged exchange rate regime.

import component could control inflation just as well by targeting exchange rates since imported inflation makes up a large proportion of overall or CPI inflation. In contrast, countries with small import relative to GDP would be less affected by the depreciation of their currencies and the resulting imported inflation and would benefit from the lower output volatility associated with a Taylor-type interest rate rule.

Table 3. Welfare Loss after a Negative Foreign Output Shock under Different Monetary Policies and Various Values of Import over GDP

Import over GDP	Monetary policy						
	Fixed/ peg exchange rate regime	CPI Inflation Targeting	Exchange rate and inflation targeting	Taylor rule	Domestic inflation targeting	Nominal income targeting	Real income targeting
1	–0.170	–0.170	–0.170	–51.859	–42.253	–229.546	–644.085
0.9	–0.342	–0.180	–0.291	–38.550	–28.165	–168.759	–473.360
0.7	–1.286	–0.386	–1.014	–18.835	–10.385	–81.339	–221.218
0.5	–1.958	–0.571	–1.583	–7.468	–2.907	–33.151	–85.484
0.3	–1.785	–0.572	–1.510	–2.146	–0.772	–10.832	–26.843
0.1	–0.968	–0.389	–0.869	–0.327	–0.333	–2.416	–6.020

Note: We use import over GDP as a proxy for $(1–\gamma)$ in the model. The elasticity of oil- to-capital is set at 3.14 as in Table 2.

We also calibrate the model for a pair of countries based on their ratios of oil to capital and of import to GDP and calculate the welfare losses under various monetary policy regimes. The pairs of countries are Hong Kong and Singapore, Korea and Taiwan, Malaysia and Thailand, and Indonesia and the Philippines. The estimates of welfare losses under various monetary policy regimes are shown in Table 4. They show that either fixed/pegged exchange rate regimes or CPI inflation targeting deliver the best welfare outcomes for Hong Kong and Singapore. On the other hand, CPI inflation targeting delivers the best welfare outcomes for Indonesia, Korea, Malaysia, Philippines, Taiwan and Thailand.

Table 4. Welfare Loss after a Negative Oil Price Shock under Different Monetary Policies Calibrated for Various East Asian Countries

Countries	Monetary policy						
	Fixed / Peg exchange rate regime	CPI inflation targeting	Exchange rate and inflation targeting	Taylor rule	Domestic inflation targeting	Nominal income targeting	Real income targeting
Hong Kong and Singapore	–0.175	–0.175	–0.176	–53.441	–46.200	–243.183	–674.385
Korea and Taiwan	–1.952	–0.601	–1.618	–4.054	–1.462	–10.832	–50.834
Malaysia and Thailand	–0.726	–0.257	–0.579	–27.257	–16.377	–10.832	–313.530
Philippines and Indonesia	–1.849	–0.543	–1.516	–4.372	–1.354	–10.832	–43.436

Notes: Hong Kong and Singapore have an average import over GDP of 1, and elasticity of substitution of 2.1. Korea and Taiwan have an average import over GDP of 0.4 and an elasticity of substitution of oil and capital of 2.3. Malaysia and Thailand have an average import over GDP of 0.8 and an elasticity of substitution of oil and capital of 5.1. Philippines and Indonesia have an average import over GDP of 0.4 and an elasticity of substitution of oil and capital of 8.5.

4.3. Summary of Simulation Results and Welfare

Consistent with the empirical evidence documented by Hoffman (2007), the comparison between responses of alternative monetary policy regimes suggests that (1) both fixed exchange rate regime and inflation targeting tend to stabilize real exchange rate and inflation at the expense of substantial instability in the real economy, (2) the mitigated decline in real output under the Taylor–type rule is explained by the large depreciation of nominal and real exchange rates, and (3) inflation rate is lowest under CPI inflation targeting. In addition, the decline in output is smallest under nominal and real GDP targeting due to the higher rate of nominal and real exchange rate depreciation. However, both output targeting also led to the worst inflation outcome. Consistent with Friedman's predictions, long run differences across regimes are not significant.

We also compare the welfare effects of the various monetary policy regimes using a quadratic social welfare function. We show that with an average oil-to-capital ratio of

0.27 and import-to-GDP ratio of 0.5, CPI inflation targeting leads to the best welfare outcome, followed by inflation and exchange rate targeting, pegged or fixed exchange rate regime, domestic inflation targeting, Taylor rule and nominal and real output targeting. The simulation results show that a negative output shock causes the inflation rate and subsequently the nominal interest rate to decline under CPI inflation targeting. In contrast, inflation rises under Taylor rule or nominal and real output targeting due to the large depreciation in the nominal and real exchange rates. These empirical findings are consistent with de Carvalho Filho (2010).

If the import-to-GDP ratio is one, the welfare of countries with CPI inflation-cum-exchange rate targeting is comparable to countries with either pegged exchange rate or CPI inflation targeting. However, if the ratio is between 0.5 and 0.9, CPI inflation-cum-exchange rate targeting is only second best to CPI inflation targeting. If the ratio is less than 0.5, it is worse than either Taylor rule or CPI inflation or domestic inflation targeting.

Since East Asian countries vary a lot with respect to the ratio of import-to-GDP, ranging from 27% for Indonesia to more than 100% for Singapore and Hong Kong, we calculate the welfare of various monetary policy regimes for ratios between 10% and 100%. We find that with import-to-GDP ratio of one, welfare under the fixed or pegged regime is almost equivalent to welfare under CPI inflation targeting. This is consistent with the Chow and McNelis (2010) finding that Singapore's welfare will not significantly improve if it switches to more flexible exchange rate system and inflation targeting. Economies that depend heavily on imports such as Singapore and Hong Kong can moderate imported inflation by pegging the exchange rate. In contrast, for imports-to-GDP ratio of 0.10, the Taylor rule delivers the best welfare outcome. Exchange rate devaluation has a limited impact on imported inflation but still mitigates the fall in output. When import-to-GDP ratio is between 0.2 and 0.9, CPI inflation targeting delivers the best welfare outcome.

5. Conclusions

The global financial and economic crisis of 2008-2009 underlined the vulnerability of small open economies to adverse external output shocks. Although East Asia's financial systems were largely immune from the global financial instability, their real economies were severely affected by the deep recession of the advanced economies. This re-ignites the debate about the appropriate monetary policy regime for a small open economy subject to external shocks. The primary objective of our paper is to evaluate and compare the welfare impact of external output shocks acting through the trade channel in eight East Asian countries with different monetary policy regimes. To do so, we use a simple dynamic stochastic general equilibrium (DSGE) model with sticky prices and imperfect competition in the goods market. The alternative monetary policy regimes considered are fixed or pegged exchange rate regime, CPI and domestic inflation targeting, CPI inflation-cum-exchange rate targeting, the Taylor rule, and nominal and real output targeting.

Although our DSGE model is highly simplified, we can use its simulation results to scrutinize Hoffman's empirical evidence and identify significant differences in responses to foreign output shocks across monetary policy regimes. Compared to a Taylor–type rule and nominal and real output targeting, fixed or pegged exchange rate regimes and inflation targeting prevents nominal exchange rate and inflation from adjusting and thus prevents the real exchange rate from depreciating. The negative impact of a fall in foreign output is thus largely passed to the domestic economy. The mitigated decline in real output under a Taylor–type rule and nominal and real targeting is explained by a larger depreciation of the nominal and real exchange rates. We also verify that inflation rate is lowest under CPI inflation targeting and nominal exchange rate is stable under pegs. Our simulation results are consistent with the de Carvalho Filho (2010) findings that inflation targeting countries have lower interest rates than non-inflation targeting countries.

Our simulation results are also broadly consistent with the stylized facts of the East Asian experience during the 2008-2009 economic crisis. As Table 1 shows, Hong Kong, Singapore and Taiwan, which target the exchange rate, experienced the smallest volatility in exchange rate but suffered the largest cumulative reduction in real GDP growth. On the other hand, the other East Asian countries, which practice inflation targeting, experienced larger currency depreciation but suffered a smaller cumulative reduction in real GDP growth. In addition, two of the inflation targeting countries, Indonesia and Thailand, experienced CPI deflation, as predicted by the model.

Our welfare analysis shows that Hong Kong and Singapore's pegged exchange rate regimes are optimal monetary policy regimes in light of their high ratios of imports to GDP. This is consistent with the Chow and McNelis (2010) finding for Singapore. We also find inflation targeting to be the optimal monetary regime for Indonesia, Korea, Malaysia, Philippines and Thailand. This is consistent with the study of Chung *et al.* (2007) for Korea. However, we find that Taiwan and Malaysia could improve their monetary policies by moving from CPI inflation-cum-exchange rate targeting toward targeting only inflation.

At a broader level, our analysis can provide some guidance about monetary policy regimes for small open economies. For such economies, which depend heavily on exports and trade for growth, the capacity of monetary policy to cushion the impact of adverse external output shocks is one of the most import criteria for the appropriate policy regime. The pronounced impact of the recession in the advanced economies on the small open economies during the global crisis of 2008-2009 underlines this point. Our DSGE model simulation results suggest that CPI inflation targeting delivers the best welfare outcome for most East Asian small open economies except for those with exceptionally high degree of import. Therefore, an important additional benefit of CPI inflation targeting for small open economies may be that it protects them better from external output shocks.

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Appendix

1. Steady State and Market Equilibrium

Steady state variables, denoted with a bar, are assumed to be constant. The steady state foreign price level and terms of trade are normalized to one. In a symmetric equilibrium, all firms make identical decisions $P_{H,t}(j) = P_{H,t}$, $Y_{H,t}(j) = Y_{H,t}$ and $N_t(j) = N_t$ hold for all j and t. Assuming the net supply of bonds is zero, the equilibrium in the domestic goods market requires $\overline{C}_H + \overline{C}_H^* + \overline{In} = \overline{Y}$. From Eq. (11), together with the assumption on the steady state capital adjustment, the rental cost on capital is:

$$\overline{Z} = \frac{1}{\beta} - 1 + \delta \tag{A1}$$

Eqs. (15) and (16) imply that the capital–oil ratio is given by:

$$\left(\frac{\overline{K}}{\overline{O}}\right)^{-\upsilon} = \frac{(1-\iota)}{\iota}\overline{Z} \tag{A2}$$

From Eqs. (13) and (14), the labor–output ratio is given by:

$$\frac{\overline{N}}{\overline{Y}} = \frac{\alpha \overline{MC}}{C^{\sigma} N^{\varphi}} \tag{A3}$$

From Eqs. (13), (14) and (15), the capital–output ratio is given by:

$$\frac{\overline{K}}{\overline{Y}} = \frac{(1-\alpha)\overline{MC}}{\overline{Z} + \Psi} \tag{A4}$$

where $\Psi = \left[\frac{(1-\iota)\overline{Z}}{\iota}\right]^{\frac{1}{\upsilon}}$.

In the steady state, we assume export equals to import so that $\overline{C}_H^* = \overline{C}_F + \overline{O}$. From Eq. (A1) and the fact that at steady state nominal interest rate is $\overline{i} = \frac{1}{\beta} - 1$ and investment is $\overline{In} = \delta \overline{K}$, consumption at the steady state can be expressed as:

$$\bar{C} = \left\{ 1 - \frac{(1-\alpha)\overline{MC}\left[\Psi + \delta\right]}{\bar{Z} + \Psi} \right\} \bar{Y} \tag{A5}$$

2. The Log–linearization of the Model

The model is solved by taking log–linear approximation around the steady state. We use a variable with a hat to denote the deviation from the steady state. The model is described by a system of linear equations.

Aggregate demand

By log–linearizing Eq. (3) and using the definition of inflation, we obtain:

$$\hat{\pi}_t = \gamma \hat{\pi}_{H,t} + (1-\gamma)\left(\hat{p}_{F,t} - \hat{p}_{F,t-1}\right) \tag{A6}$$

Log–linearizing Eq. (9), we get:

$$\sigma E_t\left(\hat{c}_{t+1}\right) - \sigma \hat{c}_t = E_t\left(\hat{i}_{t+1}\right) - E_t\left(\hat{\pi}_{t+1}\right) \tag{A7}$$

This equation shows that the household's consumption adjusts according to the evolution of nominal interest rate and the expected inflation rate. Higher expectation on future inflation rate will encourage household's current consumption over future consumption.

The uncovered interest parity implies $\hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t$. From Eqs. (1) and (2), together with the definition of the terms of trade, domestic demand on home and foreign goods are described as:

$$\hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_t;\ \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_t \tag{A8}$$

The market equilibrium is given by:

$$\bar{Y}\hat{y}_t = \bar{C}_H \hat{c}_{H,t} + \bar{C}_H^* \hat{c}_{H,t}^* + \overline{In}\,\widehat{in}_t \tag{A9}$$

3. Monetary Policy Regimes

By taking a log–linear approximation of Eqs. (19) and (20), we get:[16]

$$\hat{i}_t = \tilde{\omega}_\pi \hat{\pi}_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_\varepsilon \hat{\varepsilon}_t + (1-\chi)\hat{i}_{t-1} \tag{A10}$$

where $\tilde{\omega}_\pi = (1-\chi)\omega_\pi, \tilde{\omega}_y = (1-\chi)\omega_y, \tilde{\omega}_\varepsilon = (1-\chi)(\omega_\varepsilon/1-\omega_\varepsilon)$, $\hat{i}_t \approx \log\left(1+i_t/1+\bar{i}\right)$ and

[16] Here after, the lower case letters with ^ denote log-deviations from respective steady state values.

χ =0.75. This specification allows the approximation of the systematic behavior of monetary policy under various interest rate rules.

4. Aggregate Supply

The production function suggests that:

$$\hat{y}_t = \hat{a}_t + \alpha \hat{n}_t + \iota(1-\alpha)\hat{k}_t + (1-\iota)(1-\alpha)\hat{o}_t \tag{A11}$$

From the log–linearization of Eqs. (17) and (18), the forward–looking Phillips curve for domestic inflation is:

$$\hat{\pi}_{H,t} = \beta \hat{\pi}_{H,t+1} + \frac{(1-\phi)(1-\beta\phi)}{\phi} \widehat{mc}_t \tag{A12}$$

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