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Currency Mismatch, Balance-sheet effect and Monetary Policy*

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Abstract

This paper analyzes the impact of the currency mismatch between assets and liabilities on monetary policy. The currency mismatch causes macroeconomic instability through balance-sheet effects. To analyze the problem, we apply a small open economy dynamic stochastic general equilibrium model with international credit-market imperfections. As a result, despite the currency mismatch and high trade openness, a targeting rule to address the terms of trade is not efficient. This result depends on the fact that the two balance sheet-based channels, a debt-side channel and an asset-side channel, exist. We indicate that stabilization on the asset side is more important for determining monetary policy than is stabilization on the debt side. Therefore, we suggest that authorities in emerging economies adopt a targeting rule to stabilize fluctuations on the asset side.

keywords: Currency mismatch; Balance-sheet effect; Small open economy; DSGE

JEL classification: E47; F34; F41; F47

1. Introduction

Emerging economies have faced liability problems to the extent that most of their external debts are denominated developed country currencies such as the U.S. dollar and borrowed short-term debt. Eichengreen and Hausman (1999) (2005) call this currency mismatch in liability and maturity “original sin”. Moreover, emerging economies are also unable to hedge their foreign-currency debt in forward markets because a foreign-currency debt plus a hedge is equivalent to a domestic-currency debt. The reality in most emerging markets is that forward markets involving the domestic currency are either non-existent or thin and illiquid. Therefore, original sin and particularly currency mismatch between assets and liabilities represent a serious monetary policy management problem because they cause macroeconomic instability through balance-sheet effects. For instance, when firms face the currency mismatch, an exchange rate depreciation deteriorates their balance sheets, which leads to higher

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capital costs and contractions in capital spending. Asian currency and financial crises in 1997 and 1998 are the most prominent examples.

A number of previous studies, such as Aghion, Bacchetta and Banerjee (2001), Calvo and Reinhart (2002), Eichengreen and Hausman (1999) (2005), Mckinnon and Schnabl (2004), insist that authorities in emerging economies should set their own monetary policy, considering fluctuations of exchange rates. Calvo and Reihart (2002) insist that small open economies face fear of floating, that is, fluctuations in their exchange rates, because of their high trade openness, high pass-through and the original sin problem. In particular, Aghion et al. (2001) describe two-period multiple equilibrium models in which the presence of foreign currency liabilities are a part of endogenous currency crises. In Aghion et al. (2001), sticky prices prevent the nominal value of firms' output from rising with the value of their debt during a currency depreciation. Thus, depreciation damages firms' balance sheets, which is a key element in the onset of endogenous currency crises. Moreover, they indicate that under such circumstances, on the one hand, monetary policy expansions have the usual effects, but the same time, they tighten businesses through the balance sheet channel because these expansions depreciate their countries' currencies.

However, by contrast, Cespedes, Chang and Velasco (2004) show that using a model[1] with an open financial accelerator and nominal wage rigidities, flexible exchange-rate regimes dominate fixed-rate regimes even in the presence of dollar liabilities and Bernanke-Gertler-type balance-sheet effects. This is because real devaluation occurs in both regimes as a result of balance-sheet effects when there is a negative external shock. In flexible-rate regimes, it occurs as a result of real depreciation, and in the fixed case, it will occur through domestic deflation. As a result, there is a contraction of output under both regimes. This contraction is greater in the fixed-rate case due to the presence of nominal wage rigidities. Actually, in recent years, a number of emerging economies[2] have adopted inflation-targeting regimes. However, if exchange rate fluctuations destabilize balance sheets and real investment, then exchange rate stability may be an important target of monetary policy. Does exchange rate stability or terms-of-trade stability really have no practical impact on the setting of monetary policy? With regard to trade, Gali and Monacelli (2005), in a benchmark study of monetary policy in a small open economy using a dynamic stochastic general equilibrium (DSGE) model without international credit-market imperfections, indicate that the performance of domestic price index (DPI) inflation targeting and not that of consumer price index (CPI) inflation targeting is dominant, regardless of the trade openness. Okano (2007) and Devereux, Lane and Xu (2006) show that unlike the case of Gali and Monacelli (2005), in a case of local currency pricing, the performance of CPI inflation targeting proves better than that of DPI inflation targeting.

As a result, our interest is in how the currency mismatch affects the choice of monetary rules, such as DPI inflation targeting or CPI inflation targeting and in its impact on macroeconomic fluctuations. For instance, it is suggested by Aghion et al. (2001), Eichengreen and Hausman (1999) (2005) and Calvo and Reinhart (2002) that emerging market economies may be much more reluctant to allow freely floating exchange rates due to the problem in the presence of balance sheet constraints on external borrowing. In particular, we are interested in the complexities and difficulties of monetary policy management under the currency mismatch noted by Aghion et al. (2001).

For this purpose, we develop a DSGE model, in which a small open economy model has

[1] This model is not a dynamic stochastic general equilibrium model.

[2] In Asia, Korea, Thailand, Indonesia, and more recently the Philippines have adopted inflation-targeting regimes.

an open economy financial accelerator mechanism as the external borrowing restriction. Echoing previous DSGE studies with similar settings, such as Gertler, Gilchrist and Natalucci (2007) and Devereux et al. (2006), in quite different settings, we focus on the dynamics of the terms of trade and its influence on macroeconomic fluctuation. In concrete terms, the terms of trade in our model are an endogenous variable and not a shock variable according to the AR(1) process. Therefore, external shocks in our model are foreign demand shocks and foreign interest rate shocks because the terms of trade represent a kind of relative price and change with domestic macroeconomic circumstances. The dynamics of the terms of trade creates a trade-off in monetary policy indicated by Aghion et al. (2001).

Our conclusion is that although it is true that the balance-sheet effects greatly amplify macroeconomic fluctuation, as shown by previous studies, despite the currency mismatch, a targeting rule to address the terms of trade (or the exchange rate) is not efficient, and DPI inflation targeting is dominant. This result depends on the fact that there exist two balance-sheet channels, an asset-side channel and a debt-side channel, and we indicate that fluctuations on the asset side have a greater influence on the magnitude of the balance-sheet effect. Therefore, the currency mismatch in the liabilities alone is not enough to affect the choice of monetary rules, and we suggest that authorities in emerging economies operate their own monetary policies to stabilize fluctuations on the asset side.[3]

The paper is structured as follows. In section 2, we lay out the general equilibrium model. Section 3 derives the equilibrium in log-linear form and its canonical representation in terms of output gap and inflation. In Section 4, we define external shocks and the macroeconomic implications of alternative monetary policy regimes. Section 5 analyzes numerically under each monetary policy regime. Section 6 concludes.

2. The model

Our basic model is a small open economy DSGE model similar to that of Gali and Monacelli (2005). The key addition to this model is an international financial accelerator mechanism based on Bernanke, Gertler, and Gilchrist (1998) and Cespedes et al. (2004). This mechanism acts as liability dollarization and affects the balance sheet. As a result, we assume that the economy is characterized by three types of rigidities: price stickiness, capital adjustment cost, and international financial market frictions. The economy is populated by a representative household, a monetary authority, domestic firms, capital producers, and entrepreneurs. Households have infinite horizons, and their basic activities are working, consuming, and saving. Domestic firms set nominal prices in a staggered fashion in the way proposed by Calvo (1983) and Yun (1996). This nominal rigidity gives monetary policy an influence on real activity in the short run. Capital producers build new capital using investment goods with capital adjustment costs and sell it to the entrepreneurs. Entrepreneurs are assumed to be risk neutral. They produce capital using home goods as inputs in period t, then invest it and receive capital returns in period $t+1$. We also assume that "original sin" exists in international financial markets; in other words, foreign debt is denominated in terms of the foreign good. This assumption introduces an additional source of fluctuation of net worth. Unexpected changes

[3] In this regard, we note that this result does not imply that authorities ought to adopt DPI inflation targeting. In the case of local currency pricing, the asset side includes volatility in exchange rates, and a deflator for a firm's sector is closer to the CPI, as shown in Devereux et al. (2006) and Okano (2007).

in relative prices or the real exchange rate generate variations in entrepreneurs' net worth, directly affecting the risk premium that they have to pay and, consequently, the investment that they can afford. Hence, this affects production and net worth in the next period (and so on), generating a persistent pattern.

If there are variables marked by small letters, they are logarithms of the variables[4] originally indicated by capital letters. Variables with a superscript * hold for the rest of the world.

Next, we analyze the structure of the model in greater detail.

2.1 Households

A typical small open economy is inhabited by a representative household who seeks to maximize

$$U_t \equiv E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\varphi}}{1+\varphi} \right), \tag{1}$$

where L_t denotes hours of labor and $\beta \in (0,1)$ is the discount factor, σ and φ are the inverse of the elasticity of substitution in consumption and the inverse of the labor supply elasticity, respectively. C_t is a composite consumption index defined by

$$C_t \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $C_{H,t}$ is an index of the consumption of domestic goods and $C_{F,t}$ is an index of imported goods. Notice that under our specification η measures the elasticity of substitution between domestic and foreign goods and η>0. Such indices are given by the CES function:

$$C_{H,t} \equiv \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}; C_{F,t} \equiv \left(\int_0^1 C_{F,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}},$$

where $i \in [0, 1]$ denotes the variety of the good. The elasticity of substitution among goods within each category is given by ε. We assume ε>1.

The optimal allocation of any given expenditure within each category of goods yields the demand functions:

$$C_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} C_{H,t}; C^*_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} C^*_{H,t}, \tag{3}$$

where the price indexes for domestic and imported goods are, respectively,

$$P_{H,t} \equiv \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}; P_{F,t} \equiv \left(\int_0^1 P_{F,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}},$$

and the overall Consumer Price Index (CPI) is given by

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[4] This means $x_t \equiv \log \frac{X_t}{X} \approx \frac{X_t - X}{X}$, where X denotes a variable in the steady state.

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

The representative household aims to optimally allocate its expenditure for the total consumption between domestic produced and imported consumption goods. The result of this optimizing behavior follows optimal allocation functions for all t :

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

for all $i \in [0, 1]$.

The maximization of Eq.(1) is subject to a sequence of intertemporal budget constraints of the form:

$$\int_0^1 [P_{H,t}(i)C_{H,t}(i) + P_{F,t}(i)C_{F,t}(i)]di + E_t[Q_{t,t+1}B_{t+1}] \leq B_t + W_t L_t + \Gamma_t,$$

for t=0, 1, 2,..., where B_{t+1} is the nominal payoff in period t+1 of the portfolio held at the end of period t, W_t is the nominal wage and Γ_t is dividend payments. All of the previous variables are expressed in units of domestic currency. $Q_{t,\ t+1}$ is the stochastic discount factor for nominal payoffs. We assume that households have access to a complete set of contingent claims, which are traded internationally. Note that money does not appear in either the budget constraint or the utility function: throughout this paper, we specify monetary policy in terms of an interest rate rule; hence, we do not need to introduce money explicitly in the model.

Once we account for the above optimality conditions Eqs.(3) and (4), we can rewrite the nominal intertemporal budget constraint as:

$$P_t C_t + E_t[Q_{t,t+1}B_{t+1}] \leq B_t + W_t L_t + \Gamma_t. \tag{5}$$

We can then rewrite the remaining optimality conditions for the household's problem as follows:

$$C_t^{\sigma} L_t^{\varphi} = \frac{W_t}{P_t} \tag{6}$$

$$\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right) = Q_{t,t+1}, \tag{7}$$

which are standard optimality conditions and taking conditional expectations on both sides of Eq.(7) and rearranging terms, we obtain a conventional stochastic Euler equation:

$$\beta R_t E_t\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right) = 1, \tag{8}$$

where R_t=$E_tQ_{t,\ t+1}$ is the price of a riskless one-period bond (denominated in the domestic currency) and, hence, R_t is its gross nominal return.

In the rest of the world[5] a representative household faces a problem identical to the one outlined above. A set of analogous optimality conditions characterizes the solution to the consumer's problem in the world economy. We assume, however, that the size of the small open

[5] For convenience, we consider this to be the world economy.

economy is negligible relative to the rest of the world, which allows us to treat the latter as a closed economy.

Under the assumption of complete securities markets, a first-order condition analogous to Eq.(7) must also hold for consumers in the foreign country:

$$\beta E_t \left\{ \left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\sigma} \frac{P^*_t EX_t}{P^*_{t+1} EX_{t+1}} \right\} = Q_{t,t+1}. \tag{9}$$

Combining Eq.(7) and Eq.(9), together with the definition of the real exchange rate $Q_t \equiv \frac{EX_t P^*_t}{P_t}$, it follows that:[6]

$$C_t = \vartheta C^*_t Q_t^{\frac{1}{\sigma}}, \tag{10}$$

for all t, where ϑ is a constant, which will generally depend on the initial conditions regarding the relative net asset positions. Henceforth, and without a loss of generality, we assume symmetric initial conditions,[7] in which case we have $\vartheta=1$.[8]

2.2. Domestic firms

2.2.1. Technology

Domestic firms purchase labor from households and capital from entrepreneurs in order to produce their goods. Each firm produces a differentiated good with a linear technology represented by the production function

$$Y_t(i) = L_t(i)^{1-a} K_{t-1}(i)^a, a \in (0,1). \tag{11}$$

where a denotes capital intensity.

A firm solves the following standard cost minimization problem:

$$\min \left(W_t L_t(i) + V_t^n K_{t-1}(i) \right)$$
$$s.t.\ A_t L_t(i)^{1-a} K_{t-1}(i)^a - Y_t \geq 0.$$

The nominal return to capital is the marginal product of capital and labor demand functions, respectively derived as

$$V_t^n = aMC_t^n \frac{Y_t(i)}{K_{t-1}(i)} \tag{12}$$

$$W_t = (1-a)MC_t^n \frac{Y_t(i)}{L_t(i)}, \tag{13}$$

where MC_t^n denotes the nominal marginal costs for the firms.

2.2.2. Price-setting behavior

We assume that firms set prices in a staggered fashion, as in Calvo (1983) and Yun

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[6] For more details, see Appendix A.

[7] In other words, we assume zero net foreign asset holdings and an ex ante identical environment.

[8] Following Chari, Kehoe and McGrattan (2002), when $C_{-1}=C^*_{-1}=P_{-1}=P^*_{-1}=1$, we have $\vartheta=1$.

(1996). Hence, a measure $1-\phi_H$ of (randomly selected) firms sets new prices each period, with an individual firm's probability of reoptimization in any given period being independent of the time elapsed since it last reset its price. Let $\overline{P}_{H,t}$ denote the adjusted price set by firms, which obtain the chance to change their prices in period *t*.

Under Calvo-Yun-style price-setting behavior, the pricing rules are given by:

$$P_{H,t} \equiv \left[\phi_H P_{H,t-1}^{1-\varepsilon} + (1-\phi_H) \overline{P}_{H,t}^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{14}$$

When setting a new price in period *t*, firms seek to maximize the expected discounted value of profits:

$$\max \sum_{k=0}^{\infty} \phi_H^k Q_{t,t+k} Y_{t+k}(i) \left(\overline{P}_{H,t}(i) - MC_{t+k}^n \right) \tag{15}$$

$$s.t. Y_{t+k}(i) = \left(\frac{\overline{P}_{H,t}(i)}{P_{H,t+k}} \right)^{-\varepsilon} Y_{t+k}.$$

The FOC is as follows:

$$\sum_{k=0}^{\infty} \phi_H^k E_t \left[Q_{t,t+k} Y_{t+k} (\overline{P}_{H,t} - \zeta MC_{t+k}^n) \right] = 0, \tag{16}$$

with $\zeta \equiv \frac{\varepsilon}{\varepsilon-1}$ representing a constant markup.

2.3. Entrepreneurs

Entrepreneurs play a crucial role in our model. Entrepreneurs manage the firms in our model, which produce wholesale goods and borrow to finance the capital used in the production process. Entrepreneurs are risk neutral and have a finite expected horizon for planning purposes. The probability that an entrepreneur will survive into the next period is *v*.[9] Entrepreneurs issue debt contracts to finance their desired capital stock in excess of net worth.

Entrepreneurs purchase the capital K_{t+1} at the real price Z_t from capital producers and then invest it in firms at price V_{t+1}^n in period *t+1*. Firms use it as capital in producing domestic goods. Purchases of capital are now financed by entrepreneurs' net worth and by borrowing. Entrepreneurs have access to an international financial market, but due to the existence of "original sin," they are forced to borrow in foreign currency and take on unhedged foreign currency debt. Foreign currency debt is affected by the world's risk-free interest rate R_t^*, which is random but becomes known at *t*, and the risk premium rate $1+\varrho_t$.

Entrepreneurs invest in capital for next period, which capital producers produce by assembling home goods. The entrepreneurs' budget constraint[10] in nominal terms is

$$P_{H,t} N_t + EX_t P_t^* D_t = Z_t^n K_t, \tag{17}$$

where $EX_t P_t^* D_t$ denotes the amount of bonds borrowed abroad in the domestic currency, $P_{H,t} N_t$ is their nominal net worth in period *t*, and Z_t^n is the nominal capital price in period *t*.

This budget constraint rewritten in real terms is as follows:

$$N_t + S_t D_t = Z_t K_t, \tag{18}$$

[9] This assumption ensures that entrepreneurial net worth (the firm equity) will never be enough to fully finance the new capital acquisitions.

[10] This budget constraint expresses entrepreneurs' balance sheet.

where Z_t denotes the real price of capital.

The entrepreneurs' demand for capital depends on the expected marginal return and the expected marginal external financing cost at *t+1*, E_tF_{t+1}, which equals the expected real interest rate on external (borrowed) funds. Consequently, the optimal entrepreneurs' capital demand guarantees that

$$E_tF_{t+1} = E_t\left[\frac{V_{t+1} + (1-\delta)Z_{t+1}}{Z_t}\right], \tag{19}$$

where δ is the capital depreciation rate, while the expected marginal return of capital is given by the right-hand-side terms in Eq.(19), in which V_{t+1} is the marginal productivity of capital at *t+1* and $(1-\delta)Z_{t+1}$ is the real value of one unit of capital used in *t+1*.

Bernanke et al. (1998) assume the existence of an agency problem that makes external finance more expensive than internal funds,[11] and solve a financial contract that maximizes the payoff to the entrepreneur, subject to the lender's earning the required rate of return. They show that given parameter values associated with the cost of monitoring the borrower, the characteristics of the distribution of entrepreneurial returns, and the expected life span of firms, their contract essentially implies an external finance premium that depends on the entrepreneurs' leverage ratio. The underlying parameter values determine the elasticity of the external finance premium with respect to the firm's leverage.

Accordingly, the marginal external financing cost of borrowing abroad is not simply the world risk-free rate R_t^*, which is random but becomes known at *t*. Instead, entrepreneurs borrow abroad at the gross interest rate $R_t^*(1+\varrho_t)$, where $1+\varrho_t$ is a risk premium. Thus, the demand for capital should satisfy the following optimality condition:[12]

$$E_tF_{t+1} = E_t\left[\frac{(1+\varrho_t)R_t^*\Delta S_{t+1}}{\Pi_{t+1}^*}\right], \tag{20}$$

where $E_t(R_t/\Pi_{t+1})$ is an expected real interest rate and ΔS_{t+1} is the rate of change of the terms of trade. Following Bernanke et al. (1998), we assume that the risk premium is given by

$$1+\varrho_t = \Psi\left(\frac{Z_tK_t}{N_t}\right), \tag{21}$$

with $\Psi(1)=1$ and $\Psi'(\cdot)>0$.

Lenders charge a higher risk premium when they observe that a lower fraction of the capital investment is financed out of an entrepreneur's own net worth. That is, the risk premium is an increasing function of the value of investment relative to net worth. For concreteness, we shall assume the following functional form for Ψ:

$$\Psi(g) = g^{\psi}, \psi > 0.$$

[11] The entrepreneurs costlessly observe their output, which is subject to a random outcome. The financial intermediaries incur an auditing cost to observe the output. After observing their project outcome, entrepreneurs decide whether to repay their debt or to default. If they default, the financial intermediaries audit the loan and recover the project's generated value, less the monitoring costs.

[12] For more details, see Bernanke et al. (1998), who derive an optimal contract between entrepreneurs and financial intermediaries under an asymmetric information problem.

At the beginning of each period, after observing the realization of the nominal exchange rate EX_t, entrepreneurs receive the capital return and repay foreign debt. As a consequence, their net worth is:[13]

$$P_{H,t}N_t = \nu\left[F_t Z^n_{t-1}K_{t-1} - (1+\varrho_{t-1})R^*_{t-1}EX_t P^*_{t-1}D_{t-1}\right],$$

where $0<\nu<1$.
This equation shows that a domestic currency depreciation will increase the ex post debt burden, reduce entrepreneurial net worth and thus reduce future investment. It is another key equation of the model, as it generates the balance sheet channel, which provides the rationale for paying more attention to the exchange rate.

$$\begin{aligned} N_t &= \nu\left[F_t Z_{t-1}K_{t-1} - (1+\varrho_{t-1})\frac{R^*_{t-1}}{\Pi^*_t}S_t D_{t-1}\right] \\ &= \nu\left[F_t Z_{t-1}K_{t-1} - (1+\varrho_{t-1})\frac{R^*_{t-1}}{\Pi^*_t}\Delta S_t (Z_{t-1}K_{t-1} - N_{t-1})\right]. \end{aligned} \tag{22}$$

The first term and the second term of the right hand side of Eq.(22) denote the asset side and the debt side of the balance sheet, respectively.

It is important to note a relationship between the domestic interest rate and terms of trade. For instance, a reduction in interest decreases $E_t\Delta S_{t+1}$ in Eq.(20) through the uncovered interest parity. However, at the same time, it increases ΔS_t and leads to a rise in the risk premium, as shown in Eqs.(21) and (22). Therefore, an authority in a small open economy faces the trade-off.

2.4. Capital producers

Capital producers use a linear technology to produce capital goods, sold at the end of period t. They use final domestic goods purchased from retailers as investment goods I_t that are combined with the existing capital stock to produce new capital goods K_t. The new capital goods replace depreciated capital and add to the capital stock. Capital producers are also subject to quadratic capital adjustment costs, which are specified as $\frac{\chi}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}$.

An index of investment goods I_t is given by the CES function

$$I_t = \left(\int_0^1 I_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Entrepreneurs allocate expenditures across goods in order to minimize their total cost. This yields the following capital demand function, which is analogous to those associated with household consumption:

$$I_t(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} I_t, \tag{23}$$

[13] We assume that entrepreneurial consumption is small and that it drops out of the model.

where $P_{H,t} \equiv \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}$.[14]

Capital producers' optimization problem in real terms consists of choosing the quantity of investment I_t, to maximize their profits, so that:

$$\max_{I_t} E_t \left[Z_t I_t - I_t - \frac{\chi}{2}\left(\frac{I_t}{K_{t-1}} - \delta \right)^2 K_{t-1} \right].$$

Thus, FOC is

$$E_t \left[Z_t - 1 - \chi\left(\frac{I_t}{K_{t-1}} - \delta \right) \right] = 0, \tag{24}$$

which is the standard Tobin's Q equation, which relates the price of capital to the marginal adjustment costs. The capital adjustment costs slow down the response of investment to different shocks. In the absence of the capital adjustment costs, the capital price Z_t is constant and equal to 1. Therefore, the capital adjustment costs allow the price of capital to vary, which contributes to the volatility of entrepreneurial net worth. The quantity and price of capital are determined in the market for capital.

The aggregate capital stock evolves according to

$$K_t = I_t + (1-\delta)K_{t-1}. \tag{25}$$

2.5. Market clearing condition

Let $C_{H,t}(i)$ denote the world demand for the domestic good i. Then, market clearing in the small economy requires

$$Y_t(i) = C_{H,t}(i) + C^*_{H,t}(i) + I_t(i), \tag{26}$$

for all $i \in [0,1]$ and all t, Combining this with the foreign market clearing condition $Y^*_t = C^*_t + I^*_t$, we obtain

$$\begin{aligned} Y_t(i) &= \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left[(1-\alpha)\left(\frac{P_{H,t}}{P_t} \right)^{-\eta} C_t + \alpha^* \left(\frac{P_{H,t}}{EX_t P^*_t} \right)^{-\eta} C^*_t + I_t \right] \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left\{ \left[\vartheta(1-\alpha)\left(\frac{P_{H,t}}{P_t} \right)^{-\eta} Q_t^{\frac{1}{\sigma}} + \vartheta\alpha \left(\frac{P_{H,t}}{EX_t P^*_t} \right)^{-\eta} \right] (Y^*_t - I^*_t) + I_t \right\}. \end{aligned} \tag{27}$$

where the first equality follows from Eqs. (3) and (4) (together with an analogous expression for the rest of the world), and the second equality makes use of Eq.(10) and the condition $\vartheta\alpha = \alpha^*$ required for a zero trade balance in the steady state.

[14] Following Gali (1994), note that we are assuming that a given good is sold to both consumers and capital producers at the same price. In other words, capital producers are not discriminate across consumer types, an assumption that can be justified by ruling out obvious arbitrage opportunities.

Plugging Eq.(27) into the definition of aggregate output, $Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$, we obtain[15]

$$Y_t - I_t = \vartheta(Y_t^* - I_t^*)S_t^{\eta}\left[(1-\alpha)Q_t^{\frac{1}{\sigma}-\eta} + \alpha\right]. \tag{28}$$

3. Log-linearization of the Model

In this section, we describe the details on the log-linearization of the model. Variables marked by small letters are logarithms of the variables originally indicated by capital letters.

3.1. Terms of trade and real exchange rate

The log-linearization of the CPI formula around a steady state with $P_{H,t}=P_{F,t}$ yields

$$p_t \equiv (1-\alpha)p_{H,t} + \alpha p_{F,t} = p_{H,t} + \alpha s_t, \tag{29}$$

where $s_t=p_{F,t}-p_{H,t}$ denotes the log terms of trade, i.e., the price of foreign goods in terms of home goods.

It follows that domestic inflation, defined as the rate of change in the index of domestic goods prices, i.e., $\pi_{H,t}=p_{H,t+1}-p_{H,t}$ and CPI-inflation $\pi_t=p_t-p_{t-1}$, are linked according to

$$\pi_t = \pi_{H,t} + \alpha \triangle s_t \tag{30}$$

which makes the gap between our two measures of inflation proportional to the percent change in the terms of trade, with the coefficient of proportionality given by the index of openness α.

In addition, we assume throughout that the law of one price holds, implying that

$$P_{F,t}(i) = EX_t P_{F,t}^*(i),$$

where EX_t is the nominal exchange rate, which is the price of a foreign currency in terms of the home currency, and $P_{F,t}^*$(i) is the price of foreign good *i* denominated in the foreign currency. Integrating over all goods, we obtain $P_{F,t}=EX_tP_{F,t}^*$, in log-linear form:

$$p_{F,t} = e_t + p_{F,t}^*. \tag{31}$$

Combining the previous results, we can rewrite the terms of trade as

$$s_t \equiv e_t + p_t^* - p_{H,t}. \tag{32}$$

We define the real exchange rate as

$$Q_t \equiv \frac{EX_t P_t^*}{P_t}.$$

Log-linearizing the above equation and using Eqs.(29) and (32), we can rewrite the real exchange rate as the terms of trade:

[15] For more details, see Appendix B.

$$q_t = s_t + p_{H,t} - p_t$$
$$= (1-\alpha)s_t. \tag{33}$$

Thus, we have that the log real exchange rate is proportional to the log terms of trade, with the proportionality coefficient being an inverse function of the degree of openness.

3.2. Aggregate demand and output

First, the Euler equation (8) in log-linear form is given by:

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}(r_t - E_t \pi_{t+1}). \tag{34}$$

Log-linearizing Eq.(10) and using Eq.(33), we obtain

$$c_t = c_t^* + \left(\frac{1}{\sigma}\right) q_t = c_t^* + \left(\frac{1-\alpha}{\sigma}\right) s_t. \tag{35}$$

Log-linearizing Eq.(28) yields

$$(y_t - \sigma_i i_t) = (y_t^* - \sigma_i i_t^*) + \frac{\theta}{\sigma} s_t, \tag{36}$$

where $\sigma_i \equiv \frac{I}{Y}$ denotes the steady-state share of the capital stock within total output and $\theta \equiv (1-\sigma_i)[1+\alpha(2-\alpha)(\sigma\eta - 1)] > 0$.

We can combine Eq.(35) with Eq.(36) to yield

$$c_t = \Phi(y_t - \sigma_i i_t) + (1-\Phi)(y_t^* - \sigma_i i_t^*), \tag{37}$$

where $\Phi \equiv \frac{1-\alpha}{\theta} > 0$.

Finally, we can combine Eqs.(30) and (37) with the consumer's log-linear Euler equation (34). This yields the New-Keynesian IS curve as follows:

$$y_t = E_t\{y_{t+1}\} - \frac{\theta}{\sigma}\left(r_t - E_t\{\pi_{H,t+1}\}\right) + (\theta - 1)E_t\{\Delta y_{t+1}^* - \sigma_i \Delta i_{t+1}^*\} - \sigma_i E_t\{\Delta i_{t+1}\}. \tag{38}$$

3.3. Aggregate supply and inflation

Log-linearizing Eq.(16) and rearranging,[16] we can describe the dynamics of inflation in terms of marginal cost as follows:

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda \hat{mc}_t, \tag{39}$$

where $\lambda \equiv \frac{(1-\phi_H)(1-\beta\phi_H)}{\phi_H}$ and $\hat{mc}_t \equiv mc_t - mc$ is the log deviation of real marginal cost $mc_t^n - p_{H,t}$ from its steady-state value $mc = -log\frac{\varepsilon}{\varepsilon-1} \equiv -\mu$.

3.4. Marginal cost and open financial accelerator

The determination of the real marginal cost as a function of domestic output in the small open economy differs somewhat from that in the closed economy, due to the existence of wedges between output and consumption and between domestic and consumer prices. Indeed, we have

[16] See Appendix C for details about the optimal price setting behavior.

$$
\begin{aligned}
mc_t &= mc_t^n - p_{H,t} = w_t - p_{H,t} + l_t - y_t \\
&= (w_t - p_t) + (p_t - p_{H,t}) + l_t - y_t \\
&= \sigma c_t + (1+\varphi) l_t + \alpha s_t - y_t \\
&= \sigma\left[(y_t^* - \sigma_i i_t^*) + \frac{(1-\alpha)}{\sigma} s_t\right] + \frac{1+\varphi}{1-a}(y_t - z_t - a k_{t-1}) + \alpha s_t - y_t \\
&= (\Lambda - 1) y_t + \sigma(y_t^* - \sigma_i i_t^*) + s_t - a\Lambda k_{t-1},
\end{aligned} \tag{40}
$$

where $\Lambda \equiv \frac{1+\varphi}{1-a} > 1$. Thus, we see that marginal cost is increasing in the terms of trade and in world output. Both variables ultimately influence the real wage through the wealth effect on labor supply resulting from their impact on domestic consumption. In addition, changes in the terms of trade have a direct effect on the product wage, for any given real wage. Meanwhile, decreasing capital drives up marginal cost. This variable ultimately influences the real capital return through the external cost of borrowing.

Finally, we describe the behaviors of entrepreneurs and capital producers in log-linear form. Log-linearizing entrepreneurs' marginal return of capital stock Eq.(19) and the marginal external financing cost Eq.(20) are given by

$$
f_t = \frac{v}{f} v_t + \frac{1-\delta}{f} z_t - z_{t-1} \tag{41}
$$

$$
E_t f_{t+1} = (r_t^* - E_t \pi_{t+1}^*) + \rho_t + \Delta s_{t+1}, \tag{42}
$$

and the log-linearization of the risk premium Eq.(21) is

$$
\rho_t = \psi(z_t + k_t - n_t). \tag{43}
$$

According to Eq.(22), entrepreneurs' net worth in log-linear form is as follows:

$$
\begin{aligned}
\frac{n_t}{v f} &= \frac{k}{n} f_t - \left(\frac{k}{n} - 1\right)(r_{t-1}^* - \pi_t^* + \Delta s_t) - \psi\left(\frac{k}{n} - 1\right)\left(k_{t-1} + z_{t-1} - n_{t-1}\right) + n_{t-1} \\
&= \frac{k}{n} f_t - \left(\frac{k}{n} - 1\right) E_{t-1} f_t + n_{t-1}.
\end{aligned} \tag{44}
$$

Capital producers' behavior Eq.(24) and the evolved aggregate capital stock Eq.(25) in log-linear form are given by

$$
z_t = \chi(i_t - k_{t-1}) \tag{45}
$$

$$
k_t = \delta i_t + (1-\delta) K_{t-1}. \tag{46}
$$

3.5. Trade balance

Let $nx_t \equiv \left(\frac{1}{Y}\right)\left[Y_t - \frac{P_t}{P_{H,t}} C_t - I_t\right]$ denote net exports in terms of domestic output, expressed as a fraction of steady-state output Y. In the particular case of $\sigma = \eta = 1$, it follows from Eqs.(10) and (28) that $P_{H,t}Y_t = P_tC_t + P_{H,t}I_t$ for all t, thus implying balanced trade at all times. More generally,

$$\begin{aligned} nx_t &= (1-\Phi)[(y_t - \sigma_i i_t) - (y_t^* - \sigma_i i_t^*)] - \alpha s_t \\ &= \frac{\alpha\omega}{\theta}[(y_t - \sigma_i i_t) - (y_t^* - \sigma_i i_t^*)], \end{aligned} \tag{47}$$

where $\omega \equiv (2-\alpha)(\sigma\eta - 1) + (1-\sigma)$.

4. External shocks and alternative monetary policies

We assume that demand and interest rate shocks in the rest of the world are described according to the following AR (1) processes:

$$r_t^* = \varrho_{r^*} r_{t-1}^* + \varepsilon_{r^*,t}, \quad y_t^* = \varrho_{y^*} y_{t-1}^* + \varepsilon_{y^*,t}. \tag{48}$$

We assume that the two monetary policies are represented by a simple targeting rule.

$$r_t = \phi_r r_{t-1} + \phi_\pi \tilde{\pi}_t, \tag{49}$$

where $\tilde{\pi}_t$ is an inflation index and $\phi_r = 0.1, \phi_\pi = 1.5$. The $\tilde{\pi}_t$ corresponds either to $\pi_{H,t}$, if the target is in terms of the DPI, or to π_t if the target is in terms of CPI. In the case of α=1, we can rewrite CPI inflation targeting rule as a nominal exchange rate targeting rule, which the monetary authorities adjust interest rates so as to keep the nominal exchange rate from changing.

Below, we provide a comparison of the equilibrium properties of several macroeconomic variables under the above simple rules for a calibrated version of our model economy.

5. Numerical analysis

In this section, we illustrate the equilibrium behavior of the small open economy under the alternative policy regime described above. We resort to a series of dynamic simulations and adopt the following benchmark parameterization.

5.1. Calibration

Table 1 reports the calibration values for the parameters. According to previous studies that have estimated DSGE models, Gali and Monacelli (2005) and Bernanke et al.(1998), Devereux et al. (2006), we assume that the subjective discount factor, β, is set equal to 0.99 and that the inverse of elasticity of substitution in consumption, σ, and the inverse of the labor supply elasticity φ are set equal to 1.5 and 3, respectively. The parameter ε, which measures the degree of the retailers' monopoly power, is set equal to 6, implying a steady-state price markup of 20%, and the price stickiness parameter, ϕ_H, is set equal to 0.75, a common value used in the literature. The elasticity of substitution between domestic goods and foreign goods in consumption is set equal to 1.5.

Following Bernanke et al. (1998), the steady-state external finance premium, ρ, is set to 1.0075, and we set the steady-state ratio of capital to net worth, $\frac{k}{n}$, equal to 2. This implies a firm leverage ratio, defined as the ratio of debt to assets, of 0.5. Finally, we also use Bernanke et al.'s (1998) value of 0.9728 for the survival rate of entrepreneurs, v, implying an expected working life for entrepreneurs of 36 years. The elasticity of the external finance premium with respect to a change in the leverage position of entrepreneurs, ψ, is set equal to 0.067. Following Christensen and Dib (2008) the capital adjustment cost parameter is set equal to

0.59. The depreciation rate, δ, is assigned the commonly used value of 0.025.

5.2. Macroeconomic volatility

To illustrate the different model dynamics implied by the balance-sheet effects under alternative monetary policies, we plot the impulse responses of key macroeconomic variables to the external shocks in two models: (1) a baseline model (α=0.5) and (2) a high-trade-openness model (α=0.8). Figures 1 - 4 display the impulse responses to a 1% shock to the foreign interest rate and foreign demand. Each variable's response is expressed as the percentage deviation from its steady-state level. Table 2 shows the standard deviation of variables for all of the shocks.

In the all case, the basic mechanism of the balance-sheet effect is evident in the impulse responses. The changes of the net worth lead to the change in the risk premium. Eventually, these changes impact output through fluctuations in investment and capital stock. The presence of this mechanism implies a significant amplification and propagation of the external shocks on investment and capital stock.

Figures 1(a) - 4(a) show the responses to a 1% foreign interest rate shock under each monetary policy. As shown in Eq.(42), the increase in the foreign interest rate causes a sharp increase of the marginal external financing cost and leads to a decline in investment. This change affects the terms of trade, as shown in Eq.(36). The increase in the terms of trade increases total debt in the domestic currency and decreases the entrepreneur's net worth. These changes bring about the balance-sheet effect. The balance-sheet effect causes a further decline in investment. Moreover, the decline in investment decreases the real price of capital z_t, as shown in Eq.(45). This negatively affects the asset side and leads to a decline in the entrepreneur's net worth. Therefore, a foreign interest rate shock causes serious balance-sheet effects by worsening both sides of the balance sheet.

Figures 1(b) - 4(b) show the responses to a 1% foreign demand shock under each monetary policy. The shock declines the terms of trade, as shown in Eq.(36). This change in the terms of trade has two balance-sheet effects: one is a debt-side channel and the other is an asset-side channel. The change causes a decline in the rate of change of the terms of trade Δs_t. This effect decreases total debt in the domestic currency and increases the entrepreneur's net worth. On the other hand, the change in the terms of trade causes a rise in the expected change of the terms of trade Δs_{t+1}. This causes a rise in the external financing cost and leads to a decline in investment and market's value of capital z_t. This effect decreases the entrepreneur's net worth.

Figures 3 and 4 show the results of IRF in the cases with high trade openness. High trade openness amplifies fluctuations of all variables, as shown in Table 2.

As will be noted from Table 2, in each case, DPI inflation targeting provides better performance than CPI inflation targeting, which is a kind of managed float. This result is different from previous studies discussing the currency mismatch, such as Aghion et al. (2002), and supports Devereux et al. (2006). This depends on the stability of entrepreneurs' assets including the value of their capital stock and endogenous changes in the terms of trade. As shown in Eq.(44), fluctuations on the asset side also affect net worth. Therefore, the stabilization on the asset side in real terms decreases the balance-sheet effect. Moreover, in the case of DPI inflation targeting, as shown in Eq.(39) and Eq.(40), the authority has to control marginal costs to stabilize DPI inflation, which causes endogenous changes in the terms of trade, indirectly stabilizing them. As a result, DPI inflation targeting rule is more effective to calm down the balance-sheet effect.

The result implies that the balance-sheet effects, which change the risk premium, include two channels: are a debt-side channel and an asset-side channel. Previous studies focus on the former. In our model, however, on the one hand, we corroborate that the currency mismatch brings instability, but at the same time, we show that the latter channel is more important in stabilizing macroeconomic fluctuations.

6. Concluding Remarks

This paper provides a small open-economy DSGE model that incorporates a currency mismatch between assets and liabilities. Using this DSGE model, we investigate how external shocks impact a country's national economy through various channels, and we analyze how monetary policy reacts to these shocks. According to the results, we corroborate that the balance-sheet effect, especially caused by foreign interest rate shocks, plays an important role for investment and eventual capital accumulation and amplifies macroeconomic fluctuations. Moreover, we find that the balance-sheet effects include two channels, a debt-side channel and an asset-side channel, and that DPI inflation targeting is more effective than CPI inflation targeting in easing the balance-sheet effect, despite the currency mismatch and high trade openness. This result implies that the stabilization of fluctuations on the asset side is more important for the stabilization of macroeconomic fluctuations.

In our conclusion, the currency mismatch in liability alone is not enough to affect this particular choice in monetary policy and authorities in emerging economies ought to set their monetary policy to stabilize asset-side fluctuations.

Appendix A. International Risk Sharing

We assume that household conditions connected to a complete international market and perfect mobility can be expressed as

$$R_t = R_t^* E_t \left\{ \frac{EX_{t+1}}{EX_t} \right\}. \tag{A.1}$$

The small open economy's Euler equation is

$$\beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} = R_t^{-1}, \tag{A.2}$$

and the foreign Euler equation is

$$\beta E_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} \right\} = R_t^{*-1}. \tag{A.3}$$

We plug Eqs.(A.2) and (A.3) in Eq.(A.1) to substitute out the R_t and R_t^*. After this step, we obtain

$$E_t\left\{\frac{EX_t}{EX_{t+1}}\right\}\beta E_t\left\{\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma}\frac{P_t^*}{P_{t+1}^*}\right\}=\beta E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\frac{P_t}{P_{t+1}}\right\}. \quad \text{(A.4}$$

Assuming the same rate of the discount factor β,

$$\frac{EX_t P_t^*}{P_t}\left(\frac{C_t}{C_t^*}\right)^{-\sigma}=E_t\left\{\frac{EX_{t+1}P_{t+1}^*}{P_{t+1}}\left(\frac{C_{t+1}}{C_{t+1}^*}\right)^{-\sigma}\right\}.$$

We then use the relationship for the real exchange rate, $Q_t\equiv\frac{EX_tP_t^*}{P_t}$, and continue:

$$C_t=E_t\left\{Q_{t+1}^{-\frac{1}{\sigma}}\left(\frac{C_{t+1}}{C_{t+1}^*}\right)\right\}C_t^*Q_t^{\frac{1}{\sigma}}$$

$$C_t=\vartheta C_t^*Q_t^{\frac{1}{\sigma}}. \quad \text{(A.5)}$$

This equation expresses the equilibrium condition. A constant ϑ depends on the initial conditions regarding the relative net asset positions. This indicates that the expected development of consumption influences the current domestic consumption.

Appendix B. Market-Clearing Condition

The market-clearing condition holds for the domestic product i and can be expressed in the following form:

$$Y_t(i)=C_{H,t}(i)+C_{H,t}^*(i)+I_t(i). \quad \text{(B.1)}$$

The domestic and foreign demand functions for the domestic product, i, are, respectively,

$$C_{H,t}(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}C_{H,t}\,;C_{H,t}^*(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}C_{H,t}^*\,;I_t(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}I_t,$$

for t=0,1,2,... and we then plug these equations to the previous market-clearing formula:

$$Y_t(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}C_{H,t}+\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}C_{H,t}^*+\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}I_t. \quad \text{(B.2)}$$

The domestic and foreign optimal allocation of expenditures for the domestic product, i, are, respectively,

$$C_{H,t}=(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t\,;C_{H,t}^*=\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*. \quad \text{(B.3)}$$

Substituting these equations for $C_{H,t}$ and $C_{H,t}^*$ in the previous equation, we obtain the total demand function for the domestic product i.

$$Y_t(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}\left[(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t+\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*+I_t\right].$$

Plugging this equation into the definition of aggregate output $Y_t\equiv\left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}}di\right)^{\frac{\varepsilon}{\varepsilon-1}}$, we have

$$\begin{aligned}Y_t&=\int_0^1\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}\left[(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t+\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*+I_t\right]di\\&=\left(\frac{1}{P_{H,t}}\right)^{-\varepsilon}\left[(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t+\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*+I_t\right]\int_0^1 P_{H,t}(i)^{-\varepsilon}di,\end{aligned}$$

Using $P_{H,t}=\left(\int_0^1 P_{H,t}(i)^{1-\varepsilon}di\right)^{\frac{1}{1-\varepsilon}}$, we obtain

$$\begin{aligned}Y_t&=\left(\frac{1}{P_{H,t}}\right)^{-\varepsilon}\left[(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t+\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*+I_t\right]P_{H,t}^{-\varepsilon}\\&=(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t+\alpha^*\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}C_t^*+I_t.\end{aligned}$$

Now we use $\vartheta\alpha=\alpha^*$ [17] as well as the foreign market-clearing condition, $Y_t^*=C_t^*+I_t^*$, the previous equation can now be rewritten as

$$\begin{aligned}Y_t&=(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}\vartheta(Y_t^*-I_t^*)Q_t^{\frac{1}{\sigma}}+\vartheta\alpha\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}(Y_t^*-I_t^*)+I_t\\&=\vartheta(Y_t^*-I_t^*)\left[\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}(1-\alpha)Q_t^{\frac{1}{\sigma}}+\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}\alpha\right]+I_t.\end{aligned}$$

Moreover, substituting $Q_t\equiv\frac{EX_tP_t^*}{P_t}$ and $S_t\equiv\frac{P_{F,t}}{P_{H,t}}$ in this equation, we obtain

$$Y_t=\vartheta(Y_t^*-I_t^*)\left[\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}(1-\alpha)Q_t^{\frac{1}{\sigma}-\eta}\left(\frac{EX_tP_t^*}{P_t}\right)^{\eta}+\left(\frac{P_{H,t}}{EX_tP_t^*}\right)^{-\eta}\alpha\right]+I_t$$

$$Y_t-I_t=\vartheta(Y_t^*-I_t^*)S_t^{\eta}\left[(1-\alpha)Q_t^{\frac{1}{\sigma}-\eta}+\alpha\right]. \qquad \text{(B.4)}$$

Appendix C. Optimal Price Setting

Following Calvo (1983) and Yun (1996), we assume that each individual firm resets its

[17] This assumption means a zero trade balance in the steady state. For more details, see Gali and Monacelli (2005).

price with probability $1-\phi_H$ each period, independently of the time elapsed since the last adjustment. Thus, each period a measure $1-\phi_H$ of firms reset their prices, while a fraction ϕ_H maintain their prices. Let $\overline{P}_{H,t}(j)$ denote the price set by a firm, *j*, adjusting its price in period *t*. Under the Calvo-Yun price-setting behavior, $P_{H,t+k}(j)=\overline{P}_{H,t}(j)$ with probability ϕ_H^k for *k*=0,1,2... . Because all firms resetting prices in any given period will choose the same price, we henceforth drop the *j* subscript.

When setting a new price in period *t*, firm *j* seeks to maximize the current value of its dividend stream, conditional on that price being effective:

$$max\sum_{k=0}^{\infty}\phi_H^k E_t Q_{t,t+k}[Y_{t+k}(\overline{P}_{H,t}-MC_{t+k}^n)] \tag{C.1}$$

$$s.t.\, Y_{t+k}(j)\le\left[\frac{\overline{P}_{H,t}}{P_{H,t+k}}\right]^{-\varepsilon}(C_{H,t+k}+C_{H,t+k}^*+I_t)\equiv Y_{t+k}^d(\overline{P}_{H,t}),$$

where $MC_t^n=\frac{W_tL_t}{(1-a)Y_t}$ denotes the nominal marginal cost. Thus, $\overline{P}_{H,t}$ must satisfy the first-order condition

$$\sum_{k=0}^{\infty}\phi_H^k E_t\left[Q_{t,t+k}Y_{t+k}(\overline{P}_{H,t}-\frac{\varepsilon}{\varepsilon-1}MC_{t+k}^n)\right]=0. \tag{C.2}$$

Using the fact that $Q_{t,t+k}=\beta^k\left[\frac{C_t}{C_{t+k}}\right]^{\sigma}\left[\frac{P_t}{P_{t+k}}\right]$, we can rewrite the previous condition as

$$\sum_{k=0}^{\infty}(\beta\phi_H)^k E_t\left[P_{t+k}^{-1}C_{t+k}^{-\sigma}Y_{t+k}(\overline{P}_{H,t}-\frac{\varepsilon}{\varepsilon-1}MC_{t+k}^n)\right]=0, \tag{C.3}$$

or, in terms of stationary variables,

$$\sum_{k=0}^{\infty}(\beta\phi_H)^k E_t\left[C_{t+k}^{-\sigma}Y_{t+k}\frac{\overline{P}_{H,t-1}}{P_{t+k}}(\frac{\overline{P}_{H,t}}{P_{H,t-1}}-\frac{\varepsilon}{\varepsilon-1}\Pi_{t-1,t+k}^H MC_{t+k}^n)\right]=0, \tag{C.4}$$

where $\Pi_{t-1,t+k}^H\equiv\frac{P_{H,t+k}}{P_{H,t-1}}$, and $MC_{t+k}=\frac{MC_{t+k}^n}{P_{H,t+k}}$. Log-linearizing the previous condition around perfect foresight, zero-inflation steady state with balanced trade, we obtain

$$\overline{p}_{H,t}=p_{H,t-1}+\sum_{k=0}^{\infty}(\beta\phi_H)^k E_t\pi_{H,t+k}+(1-\beta\phi_H)\sum_{k=0}^{\infty}(\beta\phi_H)^k E_t\hat{mc}_{t+k}, \tag{C.5}$$

where $\hat{mc}_t\equiv mc_t-mc$ is the log deviation of the real marginal cost from its steady- state value $mc=-log\frac{\varepsilon}{\varepsilon-1}\equiv-\mu$.

Note that we can rewrite the previous expression in more compact form as

$$\overline{p}_{H,t}-p_{H,t-1}=\beta\phi_H E_t(\overline{p}_{H,t+1}-p_{H,t})+\pi_{H,t}+(1-\beta\phi_H)\hat{mc}_t. \tag{C.6}$$

Alternatively, using the relationship $\hat{mc}_t=mc_t^n-p_{H,t}+\mu$ to substitute for $\hat{mc}_t$ in the previous equation, and after some straightforward algebra, we obtain a version of the price-setting rule in terms of expected nominal marginal costs:

$$\overline{p}_{H,t} = \mu + (1-\beta\phi_H)\sum_{k=0}^{\infty}(\beta\phi_H)^k E_t mc_{t+k}^n. \tag{C.7}$$

Under the Calvo-Yun-style price-setting behavior, the dynamics of the domestic price index are described by the equation

$$P_{H,t} \equiv \left[\phi_H P_{H,t-1}^{1-\varepsilon} + (1-\phi_H)\overline{P}_{H,t}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, \tag{C.8}$$

which can be log-linearized around the zero-inflation steady state to yield

$$\pi_{H,t} = (1-\phi_H)(\overline{p}_{H,t} - p_{H,t-1}). \tag{C.9}$$

Finally, we can combine the previous expression with (C.7) above to yield, after some algebra,

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda \hat{mc}_t, \tag{C.10}$$

$$where\ \lambda \equiv \frac{(1-\phi_H)(1-\beta\phi_H)}{\phi_H}.$$

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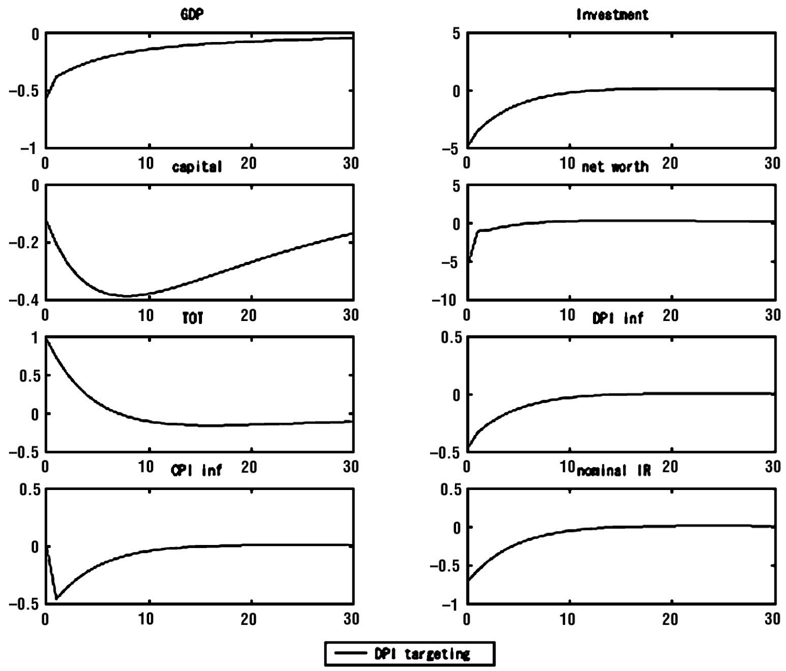
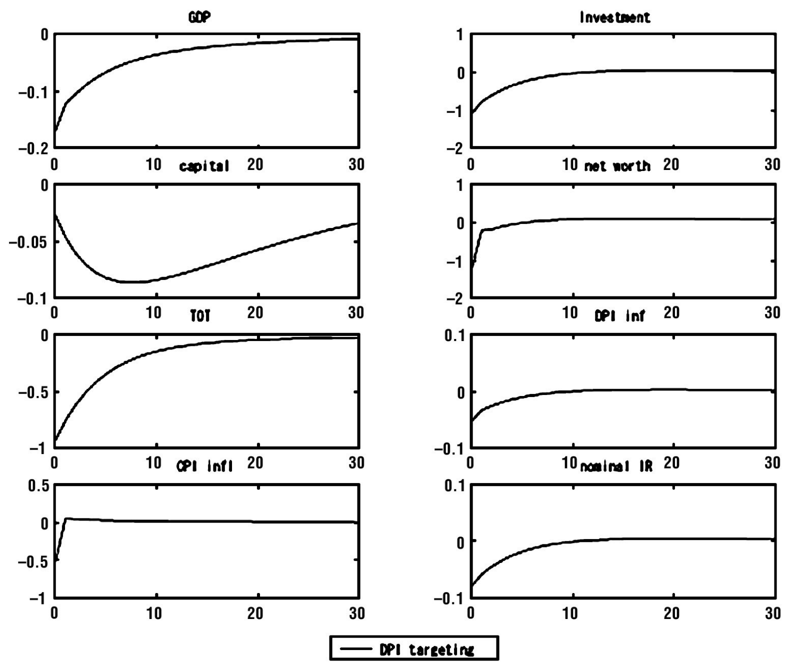
Figure 1 : Base line case: DPI targeting rule

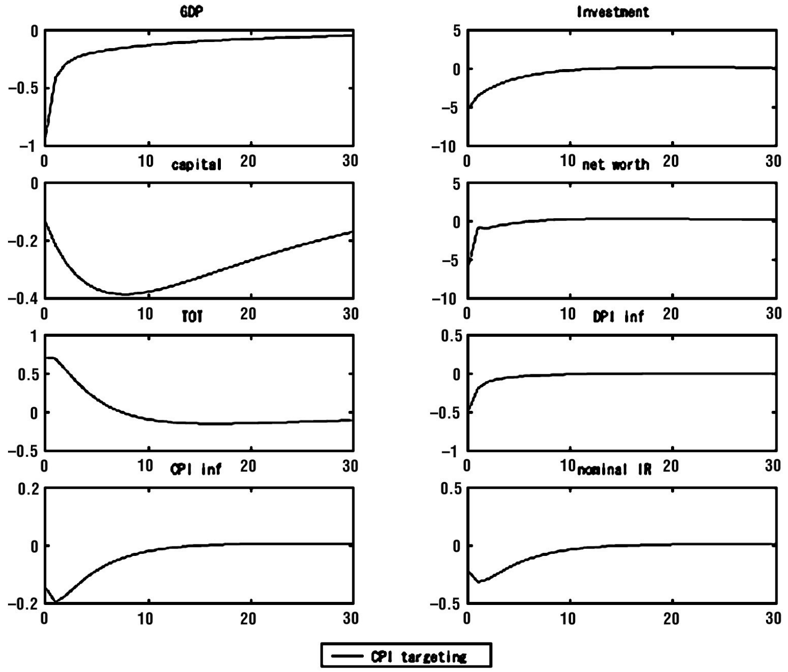


(a) Impulse response to foreign interest rate shock

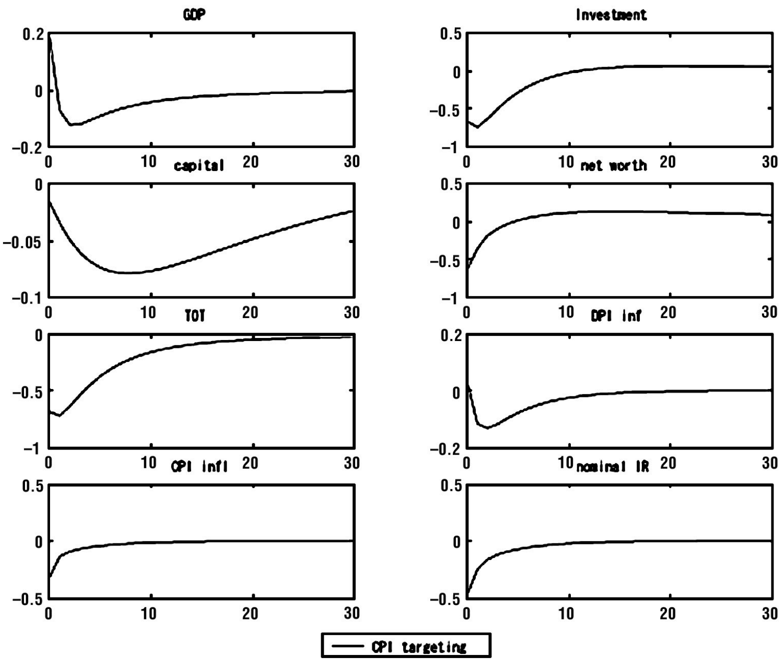


(b) Impulse response to foreign demand shock

Figure 2 : Base line case: CPI targeting rule

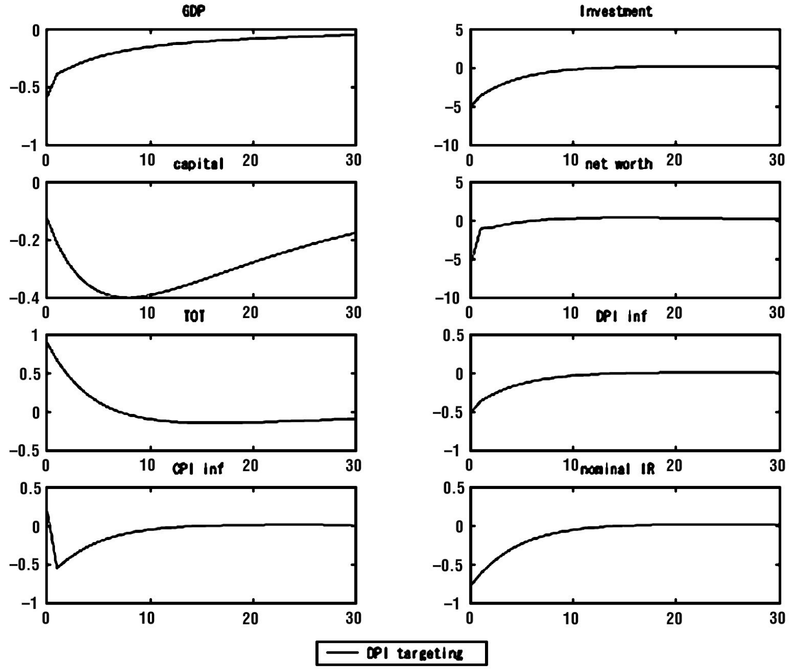


(a) Impulse response to foreign interest rate shock

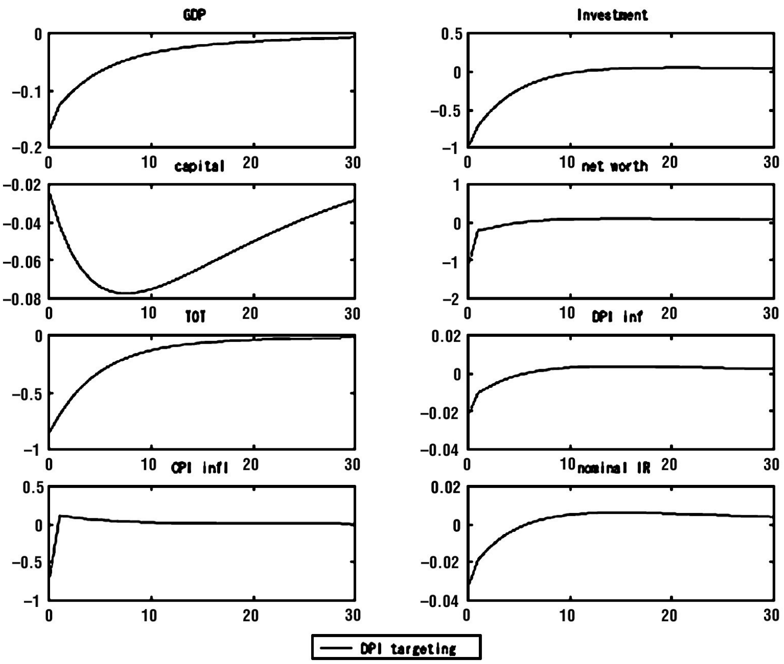


(b) Impulse response to foreign demand shock

Figure 3 : α =0.8: DPI targeting rule

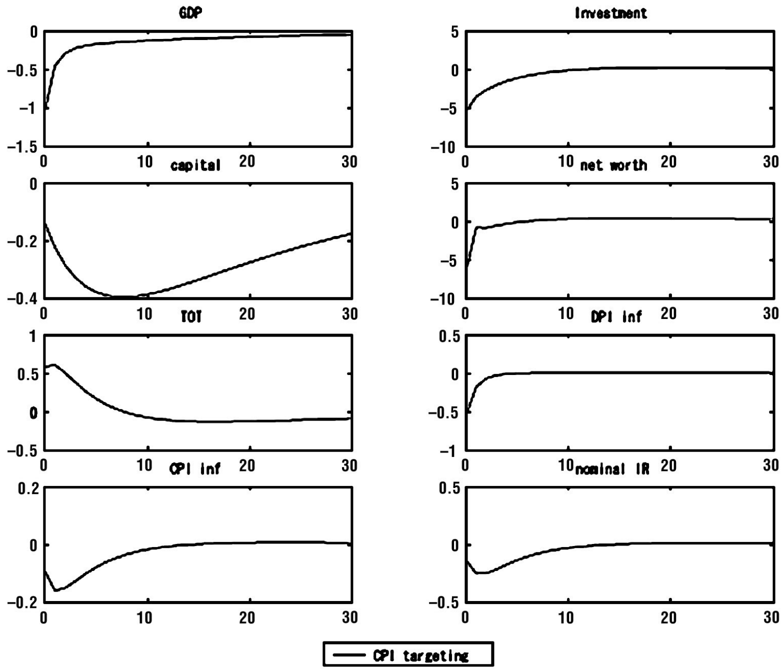


(a) Impulse response to foreign interest rate shock

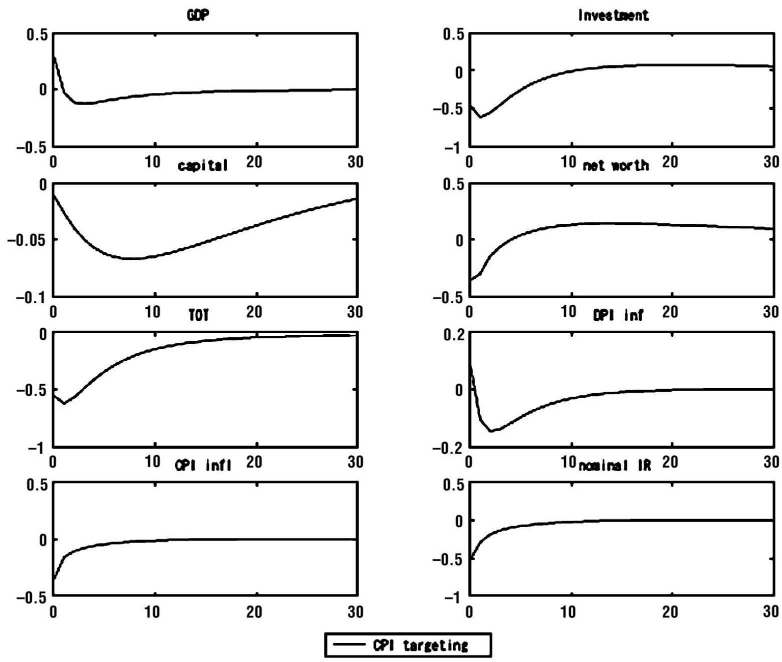


(b) Impulse response to foreign demand shock

Figure 4 : α =0.8: CPI targeting rule



(a) Impulse response to foreign interest rate shock



(b) Impulse response to foreign demand shock

Table 1 : Calibration of the Model

Parameter	Value	Description
β	0.99	Discount factor
α	0.5	Trade openness in the steady state
σ	1.5	Inverse of elasticity of substitution in consumption
φ	3	Inverse of elasticity of substitution in labor supply
η	1.5	Elasticity of substitution between domestic goods and foreign goods in consumption
$\bar{R}$	$\frac{1}{\beta}$	Safe interest rate in the steady state
ρ	1.0075	Gross risk premium in the steady state
$\frac{k}{n}$	2	Ratio of capital to net worth in the steady state
a	0.36	Share of capital in production function
$\frac{I}{Y}$	0.3	Share of investment goods in output
ε	6	Elasticity of substitution between varieties
ϕ_H	0.75	Parameter on price stickiness
ν	0.9728	Entrepreneurs' saving rate
δ	0.025	Capital depreciation rate
ψ	0.067	Elasticity of the external finance premium with respect to entrepreneurs' leverage ratio
χ	0.59	The capital adjustment cost parameter
ϱ_w	0.8	AR(1) Parameter on world demand shock
ϱ_{r^*}	0.8	AR(1) Parameter on world interest rate shock

Table 2 : IRF Standard Deviation of Variables for all shocks

Trade openness	$\alpha = 0.5$		$\alpha = 0.8$	
	DPI targeting	CPI targeting	DPI targeting	CPI targeting
Output	1.0767	1.2715	1.1106	1.3994
Investment	7.5020	7.6489	7.6888	7.8821
Net worth	6.2390	6.6809	6.3808	6.9562
Capital stock	1.7590	1.7601	1.8106	1.8153
Terms of trade	2.2777	2.0984	2.0758	1.8552
DPI inflation	0.7075	0.6126	0.7739	0.6722
CPI inflation	0.9003	0.5209	1.1589	0.5234
Nominal interest rate	1.1492	0.8433	1.2572	0.8443