What makes the Leader-Follower Relationship between Monetary Policies Stronger?

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Abstract

During recent decades the monetary policies of central banks have shown significant co-movements which were mostly led by the policy changes of major countries such as the US. In order to investigate the factors that strengthen the asymmetric relationship between central banks, we develop a small open economy dynamic stochastic general equilibrium (DSGE) model that explicitly incorporates the agency problem in the banking sector besides other standard frictions such as price stickiness and assets transaction costs. The home monetary policy is modelled as a standard inward looking Taylor rule for the interest rate. Our estimated DSGE model based on South Korean data suggests that the leader-follower relationship between monetary policies arises from the external terms of trade channel. A foreign interest rate shock influences the external terms of trade via the modified uncovered interest rate parity condition with an assets transaction cost. The resulting fluctuations of terms of trade impact home output and inflation via the expenditure switching effect. The relationship between home and foreign rates is stronger when (a) the international assets transaction cost is lower, (b) openness of the home country is higher, (c) the home central bank adopts more aggressive inflation targeting, and (d) the banking friction in the home economy is greater.

1 Introduction

The monetary policy of the US Federal Reserve (Fed) has widespread international effects on the policy decisions of central banks in other countries. Since the beginning of the financial crisis in the late 2000s, many central banks sequentially cut interest rates following the policy changes of the US. After the beginning of the expansionary policy in the US in 2007:Q3, UK and Canada cut policy rates in the next quarter. In 2008:Q3, Australia and New Zealand started to cut policy rates, and in 2008:Q4, EU, and many other advanced and developing economies began expansionary policies which included Indonesia, South Korea, Malaysia, Norway, Poland, South Africa, Sweden, Thailand, and others.

Figure 1 indicates that it was not the first time that central banks followed the policy decisions of the major players such as the Fed. In the early 2000s, many central banks lowered interest rates right after the rapid monetary expansion of the US in response to the 'dot com' bubble collapse and the 9/11 incident. In the mid-2000s, most central banks started to raise their policy rates in order to combat the global inflationary pressure, which also accompanied the policy stance of the US. Since most co-movements of central banks' policies have been led by the US policy changes, high correlations between them demonstrate the strong leader-follower relationships. Table 1 presents correlation coefficients between the US Federal Funds rate (FFR) and the short-term rates in other countries. Except for India[1], the correlation coefficients are quite high.

Table 1: Correlation Coefficients with US Federal Funds Rate

Country	Coeff.	Country	Coeff.	Country	Coeff.	Country	Coeff.
Australia	0.64	Canada	0.95	Chile	0.57	Czech	0.73
Indonesia	0.52	India	0.24	Israel	0.72	South Korea	0.81
New Zealand	0.71	Norway	0.62	Poland	0.67	South Africa	0.54
Sweden	0.60	Taiwan	0.79	Thailand	0.68	UK	0.85

Note: Correlation coefficients of three month rates with US FFR during 1999:Q1-2015:Q2

We address two questions in this paper. First, what is the transmission channel of the asymmetric leader-follower relationship between foreign and home policy rates? Second, which structural factors endemic to the home economy strengthen this leader-follower relationship between foreign and home policy rates? We use

[1] See Banerjee and Basu (2015) for an explanation for the low correlation coefficient for India.

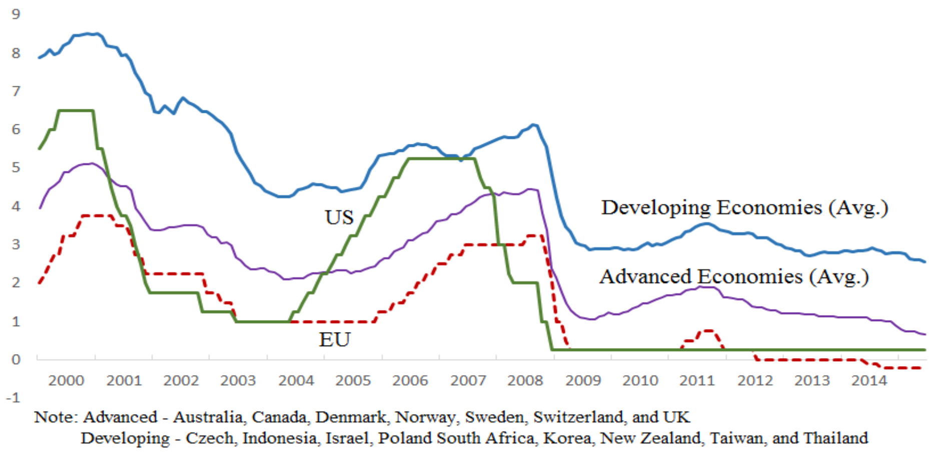

Figure 1: Monetary Policy Rates since 2001: US, EU, and other countries

a standard inward looking interest rate Taylor rule (Taylor, 1993) with domestic inflation targeting and output stabilization goal to address these two questions. Our model demonstrates that even if the central bank in the home economy follows the same inward looking Taylor rule, one may still observe significant sensitivity of the home policy rate to a foreign interest rate shock. This is related to the fluctuations of home output and inflation in response to a foreign rate shock via the linkage to terms of trade and the real exchange rate.

We estimate our dynamic stochastic general equilibrium (DSGE) model with South Korean data using Bayesian procedures. Based on our estimated DSGE model, the impulse responses to a negative foreign interest rate shock have the following properties. When the foreign interest rate is lowered, home agents decrease their foreign asset holdings. Based on the modified uncovered interest rate parity condition with the international assets transaction cost, it leads to an initial home currency appreciation: the relative export price rises and the relative import price declines. The resulting change in terms of trade yields a decrease in exports and an increase in imports (expenditure switching effect). The fall in net exports makes home output decrease via a negative demand side effect. As home producers cut back production, the real marginal cost declines. Combined with a fall in the relative import price, this leads to an initial decline in the home inflation rate. Following the standard Taylor rule, the home central bank lowers the interest rate. This explains the transmission channel of a foreign rate shock to the home policy rate.

Regarding the second question, our model sensitivity analysis suggests that the positive correlation between home and foreign rates is stronger when (a) the international assets transaction cost facing the home country is lower, (b) openness of the home country is higher, and (c) the home central bank is more active in targeting inflation. The lower transaction cost and higher openness reduce the home agents' foreign asset holdings. This makes the expenditure switching effect stronger. Also, with stronger inflation targeting the home central bank cuts its interest rate more sharply given an initial decrease in inflation.

Besides these three determinants, in our model the banking friction has a special role in determining the correlation between home and foreign interest rates. A novel feature of our model is the inclusion of a banking friction as in Gertler and Karadi (2011) in terms of the agency cost. In this respect, our model differs from other studies such as Kolasa and Lombardo (2014) which focus on non-financial frictions as in Bernanke, Gertler and Gilchrist (1999). Even though Dedola, Karadi and Lombardo (2013) extend the banking friction model to the open economy, they focus on the international spillovers of the real economic shocks. In our model, a greater banking friction strengthens the co-movements of home and foreign interest rates via the leverage ratio. To the best of our knowledge, this particular banking transmission channel of a foreign interest rate shock is new to the literature.

The paper is organized as follows. In the following section we review the related literature. In section 3 we lay out our small open economy model. In section 4, we present the estimation and calibration results. In section 5, impulse responses and variance decomposition results are presented. Section 6 concludes.

2 Literature Review

There are numerous empirical investigations of the policy relations between central banks. Maćkowiak (2006) indicates that the US monetary policy affects the short-term rates of other countries, and Bergin and Jordà (2004) show the European countries' significant responses to the US and German monetary policies before 1998. Clarida, Galí and Gertler (1998) show the influence of German policy on the policies of UK, France and Italy during 1979-1993. In a recent study, Kucharčuková, Claeys and Vašíček (2014) find immediate policy changes of non-EU European countries following the ECB's policy.

Regarding the international spill-over effects of monetary policy, there are influential studies that explore optimal monetary policy rules in open economy models. For instance, Ball (1998), Corsetti and Pesenti (2005) and De Paoli (2009) conclude that the optimal policy needs to focus on reducing the volatility of the exchange rate as well as domestic variables such as output and the inflation rate. On the other hand, Galí and Monacelli (2005) and Batini, Harrison and Millard (2003) argue that domestic inflation targeting is optimal.

There is a voluminous literature analyzing the issue of monetary policy interdependence in a global economy within a cooperative framework such as Benigno and Benigno (2006) and Pappa (2004). However, it is not obvious what exactly triggers this policy coordination in their models. The gains from the coordination are non-trivial only when both economies are highly interdependent through trade. However, for instance, by some measures the US economy is not very open. Coenen, et al. (2010) indicates that for the US the gains from the monetary policy cooperation are small due to its low degree of openness.

A stream of literature expands the financial accelerator framework of Bernanke, Gertler and Gilchrist (BGG) (1999) to the open economy environment; Davis and Huang (2011), Faia (2007), Gertler, Gilchrist and Natalucci (2007), Kolasa and Lombardo (2014) and Unsal (2013). These studies follow the BGG framework and focus on the agency problem in the non-financial sector rather than the banking sector. Even though Bruno and Shin (2013) and Hwang (2012) incorporate a banking friction in an open economy framework, Bruno and Shin (2013) is not based on a DSGE model and Hwang (2012) assumes an additional cost of lending in loan making which is not based on the agency problem.

Our key results accord well with the findings of Dées and Saint-Guilhem (2009) which argues that the global economic integration strengthens the spill-over effects of a large economy's shock in the world. Ehrmann and Fratzsher (2006) indicate that it is the degree of global integration not the bilateral integration that strengthens the transmission channel of a foreign monetary policy.

3 A Small Open Economy Model

3.1 Model Description

The theoretical framework consists of a general equilibrium small open economy model. There are two economies; home and foreign. The foreign economy can be interpreted as the rest of the world. Some international variables such as the foreign inflation rate, foreign aggregate demand and interest rate are exogenously given, which is a standard feature of a small open economy. Also, home households can purchase both home and foreign assets by holding deposits. As in Benigno (2009), since the home currency is not a global currency, home assets cannot be traded in international markets.

There are seven types of agents in the model: households, financial intermediaries, the central bank, the government, capital producers, final and intermediate goods producers. Intermediate goods are produced with capital and labour inputs. Final goods are produced with domestic intermediate goods and imported intermediate goods. These final goods are purchased for consumption by households, investment by capital producers and government spending. Households provide labour to the intermediate goods producers, receiving wages, and getting the dividends (cash flows) from goods/capital producers and financial intermediaries. The government receives income tax from the households, and the central bank sets the nominal risk free interest rate.

Financial intermediaries obtain funds from household deposits. Home households deposit their money at both home and foreign financial intermediaries. Financial intermediaries purchase claims on intermediate goods producers, transferring funds between households and producers. As in Gertler and Karadi (2011), the financial intermediaries face borrowing constraints due to the agency problem, which can be interpreted as the financial friction.

In the open economy setup, incomplete markets are assumed and financial integration across borders is not perfect as in Benigno (2009)[2]. There is an international assets transaction cost which is determined by the aggregate foreign assets (deposits) position of the economy. Due to this cost, standard UIP does not hold. Since risk sharing is not complete, the amount of consumption and its composition (domestic goods relative to imported) are not identical across the

[2]Similar features can be found in Basu and Thoenissen (2011) and Banerjee and Basu (2015).

two countries[3]. We assume no trade barriers or trade costs. We also assume the elasticity of demand is symmetric in the two countries. The law of one price then holds (Corsetti, Dedola and Leduc, 2010).

3.2 Intermediate Goods Producers

Each home intermediate good firm i produces a tradeable differentiated good $Y_t(i)$ with a Cobb-Douglas technology. $K_t(i)$ and $L_t(i)$ are the amounts of capital and labour that are used for production. The variable A_t denotes the level of technology common to all firms.

$$Y_t(i) = A_t K_t(i)^{\psi} L_t(i)^{1-\psi} \tag{1}$$

At the end of each period, intermediate goods firms borrow funds from financial intermediaries by issuing claims (S_t) to them. They purchase the capital stock (K_{t+1}) from the capital producer for production next period. As in Gertler and Karadi (2011), the number of claims issued by the firm i is the same as the amount of capital it purchases ($S_t(i) = K_{t+1}(i)$). Thus, given a relative price of capital Q_t, in units of the output good per unit of capital, we have

$$Q_t S_t(i) = Q_t K_{t+1}(i). \tag{2}$$

After production in period t, the intermediate good firm i pays back $r_{S,t}Q_{t-1}S_{t-1}(i)$ to the financial intermediaries for $S_{t-1}(i)$, where $r_{S,t}$ is the gross real return of each claim. In order to repay the fund $r_{S,t}Q_{t-1}S_{t-1}(i)$ at time t, the firm i resells the used and depreciated capital, $(1-\delta)K_t$, to the capital producer with the price of Q_t, where δ is the depreciation ratio. Since $S_{t-1}(i) = K_t(i)$, the real cost of using $K_t(i)$ in production by funding from the financial intermediaries is $[r_{S,t}Q_{t-1} - (1-\delta)\,Q_t]\,K_t(i)$. Given the level of real wages (W_t) paid to households, the total real cost is $r_{K,t}K_t(i) + W_t L_t(i)$ where the user cost of capital is given by $r_{K,t} = r_{S,t}Q_{t-1} - (1-\delta)\,Q_t$. Figure 2 illustrates the flow of funds between financial intermediaries, intermediate goods producers and capital producers.

Since all firms face the same input prices with identical technology, the real marginal cost (MC_t) is the same across firms. Given a constant-returns-to-scale

[3]With a complete financial markets assumption there exists a unique stochastic discount factor and real interest rates are identical in both countries (Woodford, 2007).

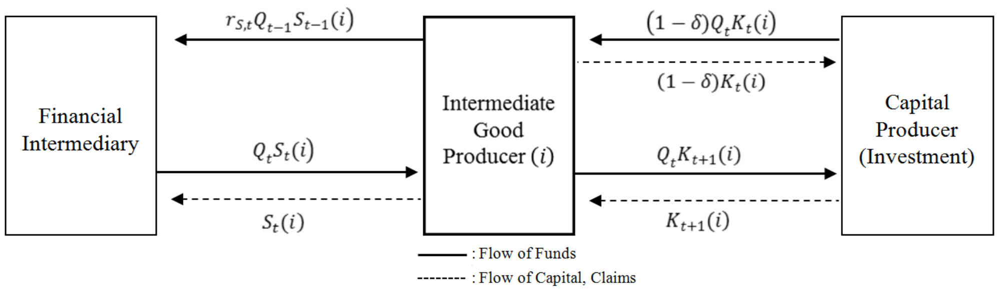

Figure 2: Flow of Funds after Production; Intermediate Good Producer (i)

technology, the optimality condition implies

$$\frac{L_t(i)}{K_t(i)} = \frac{1-\psi}{\psi}\frac{r_{K,t}}{W_t} \tag{3}$$

$$MC_t = \frac{1}{A_t\psi^{\psi}(1-\psi)^{1-\psi}} r_{K,t}^{\psi} W_t^{1-\psi}. \tag{4}$$

The home intermediate goods of firm i are either purchased in the home economy or exported abroad: $Y_t(i) = Y_{H,t}(i) + Y^*_{H,t}(i)$, where $Y_{H,t}(i)$ is the amount of home good i sold in the domestic market and $Y^*_{H,t}(i)$ is the amount of home good i sold in the foreign market (home exports)[4]. The demand function for an individual intermediate good is determined by the cost minimization problem of the final good producer in each economy. Defining $P_{H,t}(i)$ and $P^*_{H,t}(i)$ as the prices of home produced goods in home and foreign currencies respectively, the demand function for good i in each economy is given by

$$Y_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} Y_{H,t} \qquad Y^*_{H,t}(i) = \left(\frac{P^*_{H,t}(i)}{P^*_{H,t}}\right)^{-\varepsilon} Y^*_{H,t} \tag{5}$$

where ε is the elasticity of substitution among individual intermediate goods in both the home and foreign market. $Y_{H,t}$ and $Y^*_{H,t}$ are aggregate demands for home goods in both markets. $P_{H,t}$ and $P^*_{H,t}$ are the aggregate prices. The aggregate demands and prices follow the aggregator form of Dixit and Stiglitz (1977):

[4]Notation: For quantity variables (inputs and outputs), the subscript H or F denotes the country of production. An asterisk indicates foreign consumption/use, while the lack of an asterisk indicates home consumption/use. Prices denominated in foreign currency are indicated with an asterisk.

$$
\begin{aligned}
Y_{H,t} &= \left[\int_0^1 Y_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} & \qquad P_{H,t} &= \left[\int_0^1 P_{H,t}(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \\
Y^*_{H,t} &= \left[\int_0^1 Y^*_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} & \qquad P^*_{H,t} &= \left[\int_0^1 P^*_{H,t}(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}}
\end{aligned}
$$

In a symmetric way, the demand functions for foreign intermediate good j in the home and foreign (indexed as F) economies are

$$
Y_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\varepsilon} Y_{F,t} \qquad Y^*_{F,t}(j) = \left(\frac{P^*_{F,t}(j)}{P^*_{F,t}}\right)^{-\varepsilon} Y^*_{F,t} \tag{6}
$$

where $P^*_{F,t}(j)$ is the foreign currency price of the foreign-produced intermediate good. The aggregators are

$$
\begin{aligned}
Y_{F,t} &= \left[\int_0^1 Y_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{1-\varepsilon}} & \qquad P_{F,t} &= \left[\int_0^1 P_{F,t}(j)^{1-\varepsilon} dj\right]^{\frac{1}{1-\varepsilon}} \\
Y^*_{F,t} &= \left[\int_0^1 Y^*_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{1-\varepsilon}} & \qquad P^*_{F,t} &= \left[\int_0^1 P^*_{F,t}(j)^{1-\varepsilon} dj\right]^{\frac{1}{1-\varepsilon}}
\end{aligned}
$$

Following a classical view of the New Open Economy Macroeconomics literature (i.e. Obstfeld and Rogoff, 1995), home firms set export prices in domestic currency, which means producer currency pricing (PCP). Firms choose identical prices for both domestically purchased goods and exported goods. Also, as in Obstfeld and Rogoff (1995), there are no trade costs or trade barriers. Assuming demand elasticities are constant and symmetric across borders, the law of one price (LOOP) holds, which means $P_{H,t}(i) = \mathcal{E}_t P^*_{H,t}(i)$ (Corsetti, Dedola and Leduc, 2010), where $\mathcal{E}_t$ denotes the nominal exchange rate in units of home currency per unit of foreign currency. With the LOOP, the aggregate price indices for domestically purchased goods ($P_{H,t}$) and exported goods ($P^*_{H,t}$) have a relationship

$$
P_{H,t} = \mathcal{E}_t P^*_{H,t}, \tag{7}
$$

and assuming symmetric price aggregation for the foreign economy and by the law of one price for foreign-produced goods $P_{F,t}(j) = \mathcal{E}_t P^*_{F,t}(j)$,

$$P_{F,t} = \mathcal{E}_t P^*_{F,t}. \tag{8}$$

Since the home intermediate goods producer i is selling its goods in both home and foreign markets, its revenue in period t is the sum of the revenue from each market. Its real cash flow at t is

$$\frac{P_{H,t}(i)}{P_t} Y_{H,t}(i) + \frac{\mathcal{E}_t P^*_{H,t}(i)}{P_t} Y^*_{H,t}(i) - r_{K,t} K_t(i) - W_t L_t(i). \tag{9}$$

Alternatively defining $\Phi\left(Y_{H,t}(i) + Y^*_{H,t}(i)\right)$ as the nominal costs of producing $Y_{H,t}(i) + Y^*_{H,t}(i)$, the nominal cash flow at time t can be expressed as

$$P_{H,t}(i) Y_{H,t}(i) + \mathcal{E}_t P^*_{H,t}(i) Y^*_{H,t}(i) - \Phi(Y_{H,t}(i) + Y^*_{H,t}(i)). \tag{10}$$

Following Calvo (1983), in the home market an individual intermediate good producer can adjust its price with a probability $1 - \xi$ each period. As in Yun (1996), when it cannot optimally change the price, its home price is increasing at the steady state home inflation rate ($\bar{\Pi}$). The steady state inflation of the home and foreign economies are assumed to be the same ($\bar{\Pi} = \bar{\Pi}^*$). Define $\tilde{P}_{H,t}$ and $\tilde{P}^*_{H,t}$ as the home and foreign prices of home produced goods optimized at time t. Also define $P_{H,t+\tau|t}$ and $P^*_{H,t+\tau|t}$ as the prices τ periods later if no further optimization has taken place. Since the LOOP holds, the price of home produced goods in the foreign economy is indexed to not only the steady state inflation rate ($\bar{\Pi}^*$), but also the inverse of the nominal exchange rate change[5]. Then

$$\begin{aligned} P_{H,t+\tau|t} &= \bar{\Pi} P_{H,t+\tau-1|t} = \bar{\Pi}^\tau \tilde{P}_{H,t} \\ P^*_{H,t+\tau|t} &= \left(\frac{\mathcal{E}_{t+\tau-1}}{\mathcal{E}_{t+\tau}}\right) \bar{\Pi}^* P^*_{H,t+\tau-1|t} = \left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+\tau}}\right) \bar{\Pi}^{*\tau} \tilde{P}^*_{H,t}. \end{aligned}$$

In the foreign economy, the price stickiness parameter (ξ^*) and the elasticity of substitution among intermediate goods (ε^*) are assumed to be the same as the home economy. Considering the nominal exchange rate ($\mathcal{E}_{t+\tau}$), for the firm whose last price reset was at time t, the home currency value of exports at time $t + \tau$ ($Y^*_{H,t+\tau|t}$) would be $\bar{\Pi}^{*\tau} \mathcal{E}_t \tilde{P}^*_{H,t} Y^*_{H,t+\tau|t}$. The home producer who has a chance to

[5] Assuming the LOOP and $\bar{\Pi} = \bar{\Pi}^*$, we have $P_{H,t+\tau|t} = \bar{\Pi}^\tau \tilde{P}_{H,t} = \bar{\Pi}^{*\tau} \mathcal{E}_t \tilde{P}^*_{H,t}$. From $P_{H,t+\tau|t} = \mathcal{E}_{t+\tau} P^*_{H,t+\tau|t}$, $\bar{\Pi}^{*\tau} (\mathcal{E}_t / \mathcal{E}_{t+\tau}) \tilde{P}^*_{H,t} = P^*_{H,t+\tau|t}$.

optimize its price maximizes

$$\sum_{\tau=0}^{\infty}\beta^{\tau}\xi^{\tau}E_t\left\{D_{t,t+\tau}\left[\bar{\Pi}^{\tau}\tilde{P}_{H,t}\left(\frac{P_{H,t+\tau|t}}{P_{H,t+\tau}}\right)^{-\varepsilon}Y_{H,t+\tau}+\bar{\Pi}^{*\tau}\mathcal{E}_t\tilde{P}^{*}_{H,t}\left(\frac{P^{*}_{H,t+\tau|t}}{P^{*}_{H,t+\tau}}\right)^{-\varepsilon}Y^{*}_{H,t+\tau}-\Phi(Y_{t+\tau|t})\right]\right\} \tag{11}$$

where $\beta^{\tau}D_{t,t+\tau}(=\beta^{\tau}\Lambda_{t,t+\tau}\frac{P_t}{P_{t+\tau}})$ is the stochastic discount factor for nominal payoffs. The real discount factor $\Lambda_{t,t+\tau}$ will be defined later. $Y_{t+\tau|t}$ denotes output at $t+\tau$ for a firm that last reset its price at date t, which is the sum of the domestically sold goods ($Y_{H,t+\tau|t}$) and the exported home goods ($Y^{*}_{H,t+\tau|t}$).

Given the LOOP and the steady state inflation rate, $\bar{\Pi}=\bar{\Pi}^{*}$, the price setting problem facing the home intermediate goods producer is given by[6]:

$$\max_{\tilde{P}_{H,t}}\sum_{\tau=0}^{\infty}\beta^{\tau}\xi^{\tau}E_t\left\{D_{t,t+\tau}\left[\bar{\Pi}^{\tau}\tilde{P}_{H,t}\left(\frac{P_{H,t+\tau|t}}{P_{H,t+\tau}}\right)^{-\varepsilon}Y_{t+\tau}-\Phi(Y_{t+\tau|t})\right]\right\}.$$

which yields the following relative domestic price equation.

$$\frac{\tilde{P}_{H,t}}{P_t}=\frac{\frac{\varepsilon}{\varepsilon-1}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}E_t\left(D_{t,t+\tau}\bar{\Pi}^{-\varepsilon\tau}\Pi^{\varepsilon}_{H,t+\tau|t}\Pi_{t+\tau|t}Y_{t+\tau}MC_{t+\tau}\right)}{\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}E_t\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi^{\varepsilon}_{H,t+\tau|t}Y_{t+\tau|t}\right)} \tag{12}$$

where $MC_{t+\tau}$ is the real marginal cost at $t+\tau$, and $\tilde{\beta}=\beta\xi$. $\Pi_{t+\tau|t}=P_{t+\tau}/P_t$ is cumulative inflation in the home country and $\Pi_{H,t+\tau|t}=P_{H,t+\tau}/P_{H,t}$ is cumulative inflation of home produced goods. Defining Π_t as the inflation rate at period t from the previous period, the equation (12) can be written in a recursive linearized form as:

$$\widehat{\left(\frac{\tilde{P}_{H,t}}{P_t}\right)}=(1-\beta\xi)\widehat{MC}_t+\beta\xi E_t\left(\widehat{\frac{\tilde{P}_{H,t+1}}{P_{t+1}}}+\hat{\Pi}_{t+1}\right). \tag{13}$$

where we define $\hat{x}_t=(x_t-\bar{x})/\bar{x}$ for any generic variable x_t and $\bar{x}$ is the steady state level of x_t. The appendix A.4 provides the details of the derivation of (12) and (13).

The aggregate price index $P_{H,t}$ evolves over time according to the recursive form below as in Yun (1996) and Kollmann (2002).

[6]The rate of depreciation of home currency is zero in the steady state which means $\bar{\Pi}=\bar{\Pi}^{*}$. The steady state of the model is outlined in the appendix A.2.

$$P_{H,t} = \left[\xi\left(P_{H,t-1}\bar{\Pi}\right)^{1-\varepsilon} + (1-\xi)\tilde{P}_{H,t}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{14}$$

$$\frac{P_{H,t}}{P_t} = \left[\xi\left(\frac{\bar{\Pi}}{\Pi_t}\right)^{1-\varepsilon}\left(\frac{P_{H,t-1}}{P_{t-1}}\right)^{1-\varepsilon} + (1-\xi)\left(\frac{\tilde{P}_{H,t}}{P_t}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{15}$$

3.3 Final Goods Producers

Final goods producing firms in home and foreign markets produce final goods Z_t and Z_t^* combining domestic and imported intermediate goods in each economy. Final goods are purchased for households' consumption, investment and government spending, and these goods are non-tradable. Each representative final goods producer in both economies faces a constant returns to scale CES technology,

$$Z_t = \left[\alpha^{\frac{1}{\theta}} Y_{H,t}^{\frac{\theta-1}{\theta}} + (1-\alpha)^{\frac{1}{\theta}} Y_{F,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{16}$$

$$Z_t^* = \left[\alpha^{*\frac{1}{\theta}} Y_{F,t}^{*\frac{\theta-1}{\theta}} + (1-\alpha^*)^{\frac{1}{\theta}} Y_{H,t}^{*\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{17}$$

where the parameter θ is the intratemporal elasticity of substitution between domestic and imported intermediate goods, which is identical in home and foreign economies. $\alpha \in (0,1)$ and $\alpha^* \in (0,1)$ represent the weights of domestic goods in home and foreign economies (home bias), respectively. Motivated by the fact that the foreign country is large and nearly closed, its relative weight on the aggregate imported goods in the final good production $(1-\alpha^*)$ is close to zero (but not zero).

Cost minimization by home intermediate goods producers yields the following demand equations for the intermediate goods in the home economy.

$$Y_{H,t} = \alpha\left(\frac{P_{H,t}}{P_t}\right)^{-\theta} Z_t \tag{18}$$

$$Y_{F,t} = (1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{-\theta} Z_t, \tag{19}$$

with a price index

$$P_t = \left[\alpha P_{H,t}^{1-\theta} + (1-\alpha)P_{F,t}^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{20}$$

which implies

$$1 = \alpha \left(\frac{P_{H,t}}{P_t}\right)^{1-\theta} + (1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{1-\theta}. \tag{21}$$

Due to the LOOP, the home inflation rate ($\Pi_t = P_t/P_{t-1}$) is defined as a function of inflation rates of the home goods price in the home market ($\Pi_{H,t} = P_{H,t}/P_{H,t-1}$) and the foreign goods price in the foreign market ($\Pi^*_{F,t} = P^*_{F,t}/P^*_{F,t-1}$), and the exchange rate change ($\mathcal{E}_t/\mathcal{E}_{t-1}$) can be written as:

$$\Pi_t = \left[\alpha \Pi_{H,t}^{1-\theta}\left(\frac{P_{H,t-1}}{P_{t-1}}\right)^{1-\theta} + (1-\alpha)\,\Pi_{F,t}^{*1-\theta}\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}\right)^{1-\theta}\left(\frac{P_{F,t-1}}{P_{t-1}}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{22}$$

The analogous equations of the foreign country (with superscript *) can be written as:

$$Y^*_{F,t} = \alpha^* \left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\theta} Z^*_t \tag{23}$$

$$Y^*_{H,t} = (1-\alpha^*) \left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\theta} Z^*_t \tag{24}$$

with a price index

$$P^*_t = \left[\alpha^* P_{F,t}^{*1-\theta} + (1-\alpha^*)P_{H,t}^{*1-\theta}\right]^{\frac{1}{1-\theta}} \tag{25}$$

$$1 = \alpha^* \left(\frac{P^*_{F,t}}{P^*_t}\right)^{1-\theta} + (1-\alpha^*)\left(\frac{P^*_{H,t}}{P^*_t}\right)^{1-\theta}. \tag{26}$$

where the total amount of final goods production in the foreign economy (Z^*_t) is exogenously given. Also, in the foreign economy

$$\Pi_t^* = \left[\alpha^* \Pi_{F,t}^{*1-\theta} \left(\frac{P_{F,t-1}^*}{P_{t-1}^*} \right)^{1-\theta} + (1-\alpha^*) \Pi_{H,t}^{1-\theta} \left(\frac{\mathcal{E}_{t-1}}{\mathcal{E}_t} \right)^{1-\theta} \left(\frac{P_{H,t-1}^*}{P_{t-1}^*} \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{27}$$

Given the LOOP ($\mathcal{E}_t P_{H,t}^* = P_{H,t}$ and $\mathcal{E}_t P_{F,t}^* = P_{F,t}$) and defining the real exchange rate $\mathcal{E}_{R,t} = \mathcal{E}_t P_t^* / P_t$, the intermediate goods' relative prices in home and foreign economies are related to each other as follows:

$$\frac{P_{H,t}^*}{P_t^*} = \frac{P_{H,t}}{P_t} \mathcal{E}_{R,t}^{-1} \tag{28}$$

$$\frac{P_{F,t}^*}{P_t^*} = \frac{P_{F,t}}{P_t} \mathcal{E}_{R,t}^{-1} \tag{29}$$

Combining the equations (24) and (28), the aggregate demand for imported goods in the foreign economy ($Y_{H,t}^*$, home exports) can be rewritten as

$$Y_{H,t}^* = (1-\alpha^*) \left(\frac{P_{H,t}}{P_t} \right)^{-\theta} \mathcal{E}_{R,t}^{\theta} Z_t^*. \tag{30}$$

Given that home final goods have a different input mix than foreign final goods, the real exchange rate is not necessarily unity (Corsetti, Dedola and Leduc, 2010). Assuming the foreign inflation rate is at its long-run level $(\bar{\Pi}^*)^7$, $\mathcal{E}_{R,t}$ evolves according to a process below, where $\Delta\mathcal{E}_t = \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}$.

$$\mathcal{E}_{R,t} = \bar{\Pi}^* \Delta\mathcal{E}_t \Pi_t^{-1} \mathcal{E}_{R,t-1} \tag{31}$$

The equation (31) shows the short run dynamics of real exchange rate given that the steady state real exchange rate ($\mathcal{E}_t P_t^* / P_t$) is a constant pinned down by the equations (20) and (25). One can also pin down the level of the nominal exchange rate by the relative money supplies of home and foreign countries. The steady state nominal and real exchange rates have no effects on the short run dynamics in our small open economy model and thus we abstract from these details.

[7] I.e., in equation (27), Π_t^* is fixed at $\bar{\Pi}^*$.

3.4 Households

There is a continuum of identical households in this economy, indicated by $h \in (0,1)$. As in Gertler and Karadi (2011), there are two types of members in each household: workers and bankers. At any moment the fraction $1-f$ of the members are workers, and f are bankers who are running financial intermediaries. Workers can consume and deposit money at home and foreign financial intermediaries. Households (Workers) supply labour to the intermediate goods firms and receive wages. The household h has a preference over consumption and labour supply as follows:

$$E_\tau \sum_{t=\tau}^{\infty} \beta^{t-\tau} \left[\frac{C_t(h)^{1-\sigma}}{1-\sigma} - \frac{L_t(h)^{1+\chi}}{1+\chi} \right] \tag{32}$$

where $C_t(h)$ and $L_t(h)$ denote individual levels of consumption and labour supply at time t, respectively. σ represents the coefficient of relative risk aversion of households or the reciprocal of the intertemporal elasticity of substitutions, and χ is the inverse of the elasticity of labour supply. The household h faces a nominal flow budget constraint,

$$\begin{gathered} P_t C_t(h) + R_t^{-1} B_{H,t}(h) + [1-\Gamma(b_{F,t})]^{-1} R_t^{*-1} \mathcal{E}_t B_{F,t}(h) = \\ P_t(1-m) W_t L_t(h) + D_t(h) + B_{H,t-1}(h) + \mathcal{E}_t B_{F,t-1}(h) + P_t \Omega_t(h) \end{gathered}$$

where P_t is the overall price level, and R_t and R_t^* are home and foreign nominal risk-free interest rates determined by central banks. $R_t^{-1} B_{H,t}(h)$ and $R_t^{*-1} \mathcal{E}_t B_{F,t}(h)$ are nominal amount of deposits in home and foreign financial intermediaries at time t. $B_{F,t}(h)$ is denominated in foreign currency, and all deposits are for one period. $m \in (0,1)$ is an income tax ratio, and $D_t(h)$ is the sum of dividends from Intermediate goods and capital producing firms, owned by households. $\Omega_t(h)$ is the real net transfer from the financial intermediary sector, which will be explained later. The real budget constraint for each household h can be obtained by dividing the nominal one by the overall price level, P_t.

$$\begin{gathered} C_t(h) + \left(\frac{R_t}{\Pi_{t+1}}\right)^{-1} b_{H,t}(h) + [1-\Gamma(b_{F,t})]^{-1} \left(\frac{R_t^*}{\Pi_{t+1}}\right)^{-1} \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} b_{F,t}(h) = \\ (1-m) W_t L_t(h) + D_t(h) + b_{H,t-1}(h) + b_{F,t-1}(h) + \Omega_t(h) \end{gathered}$$

where $b_{H,t}(h)$ and $b_{F,t}(h)$ denote real amounts of home and foreign deposits, respectively ($b_{H,t}(h) = B_{H,t}(h)/P_{t+1}$ and $b_{F,t}(h) = \mathcal{E}_{t+1} B_{F,t}(h)/P_{t+1}$). Also, defining $r_s = R_s/\Pi_{s+1}$ and $r_{F,s} = R_s^*/\Pi_{s+1}$, $\underset{t\to\infty}{lim}\prod_{s=1}^{t} r_s^{-1} b_{H,t}(h) = 0$ and $\underset{t\to\infty}{lim}\prod_{s=1}^{t} r_{F,s}^{-1} b_{F,t}(h) = 0$ (no-Ponzi scheme).

Households bear the international assets transaction cost ($\Gamma(b_{F,t})$) when changing the foreign deposits holding. As in Schmitt-Grohé and Uribe (2003) and Benigno (2009) the assets transaction cost is determined by the total amount of the foreign deposits holding in the entire economy. Each household regards this cost as given when choosing an optimal consumption and the foreign asset holding combination. Each household receives a lower return compared to the steady state when they increase or reduce foreign deposit holding from the steady state.

$$\Gamma(b_{F,t}) = \mu_T \left(\frac{b_{F,t}}{\bar{b}_F} - 1 \right) \tag{33}$$

Defining as $\lambda_{M,t}$ the Lagrange multipliers associated with the flow budget constraint, the first order conditions facing the household h are:

$$\begin{aligned}
\lambda_{M,t} &= C_t(h)^{-\sigma} && (34)\\
\lambda_{M,t}(1-m)W_t &= L_t(h)^{\chi} && (35)\\
\beta R_t E_t \left[\left(\frac{C_{t+1}(h)}{C_t(h)} \right)^{-\sigma} \frac{1}{\Pi_{t+1}} \right] &= 1 && (36)\\
\beta R_t^* \left[1 - \Gamma(b_{F,t})\right] E_t \left[\left(\frac{C_{t+1}(h)}{C_t(h)} \right)^{-\sigma} \frac{1}{\Pi_{t+1}} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] &= 1 && (37)
\end{aligned}$$

Combining the equations (33) and (34) yields the following modified uncovered interest rate parity (UIP) condition:

$$R_t = R_t^* \left[1 - \Gamma(b_{F,t})\right] E_t \left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right). \tag{38}$$

In the producer's optimization problem (11), $\Lambda_{t,t+\tau}$ is now determined by the household's perceived intertemporal rate of substitution in consumption as follows:

$$\Lambda_{t,t+\tau} = \left(\frac{C_{t+\tau}(h)}{C_t(h)} \right)^{-\sigma}. \tag{39}$$

3.5 Financial Intermediaries

Financial intermediaries are modelled as in Gertler and Karadi (2011). There is a continuum of financial intermediaries indexed by $j \in (0,1)$ in the home market. Each intermediary obtains the money from the household deposits. Using this fund and its own net worth, it holds claims on intermediate goods producers. The nominal balance sheet of an individual financial intermediary can be written as

$$P_t Q_t S_t(j) = P_t N_t(j) + R_t^{-1} B_{H,t}(j) \tag{40}$$

where $N_t(j)$ is the amount of real net worth that an intermediary j holds at the end of period t. Q_t is the relative price of each claim which is identical to all the financial intermediaries. $R_t^{-1} B_{H,t}(j)$ is the amount of funds borrowed from households (deposits). Using $B_{H,t}(j)/P_{t+1} = b_{H,t}(j)$,

$$Q_t S_t(j) = N_t(j) + \left(\frac{R_t}{\Pi_{t+1}}\right)^{-1} b_{H,t}(j). \tag{41}$$

Defining $r_{S,t}$ the real gross return from the intermediate goods firms for each claim, the real profit at each period is accumulated as net worth.

$$N_t(j) = r_{S,t} Q_{t-1} S_{t-1}(j) - b_{H,t-1}(j) \tag{42}$$

Using (41) and (42), we get the following law of motion of net worth.

$$N_{t+1}(j) = (r_{S,t+1} - r_t)\, Q_t S_t(j) + r_t N_t(j) \tag{43}$$

where

$$r_t = \frac{R_t}{\Pi_{t+1}}. \tag{44}$$

Defining as $r_{S,t} - r_{t-1}$ the excess return on the claims at time t, Gertler and Karadi (2011) note that it is positive due to the limits to arbitrage imposed by banking frictions.

The probability that a banker continues its business next period is ζ. At each time the number of bankers exiting from the financial intermediary sector is assumed to be the same as the number of new bankers. Since the exiting bankers bring the final net worth to the households, each banker maximizes the expected final net worth which can be expressed by

$$V_t(j) = E_t \sum_{\tau=t}^{\infty} (1-\zeta)\zeta^{\tau-t}\beta^{\tau-t}\Lambda_{t,\tau+1}N_{\tau+1}(j) \tag{45}$$

where $N_{\tau+1}(j) = (r_{S,\tau+1} - r_\tau) Q_\tau S_\tau(j) + r_\tau N_\tau(j)$. Assuming $(r_{S,\tau+1} - r_\tau)$ is positive, the financial intermediary will increase its assets indefinitely. However, a moral hazard problem sets a limit on the borrowing ability of each intermediary: at the beginning of each period, the banker can divert a fraction λ of its funds. When diverting at t, the banker exits from the business with $\lambda Q_t S_t$. However, at the same time, the banker needs to sacrifice the entire expected value of the business, $V_t(j)$. Therefore, an incentive constraint must be satisfied in order for the lenders to supply funds to the banking business.

$$V_t(j) \geq \lambda Q_t S_t(j)$$

The expected value of the terminal wealth ($V_t(j)$) can be expressed as

$$V_t(j) = \upsilon_t Q_t S_t(j) + \eta_t N_t(j) \tag{46}$$

with

$$\upsilon_t = E_t \left[(1-\zeta)\, \beta\Lambda_{t,t+1}(r_{S,t+1} - r_t) + \beta\Lambda_{t,t+1}\zeta x_{t+1}\upsilon_{t+1} \right] \tag{47}$$

$$\eta_t = E_t \left[(1-\zeta) + \beta\Lambda_{t,t+1}\zeta h_{t+1}\eta_{t+1} \right] \tag{48}$$

where υ_t is the expected discounted marginal gain of expanding assets $Q_t S_t(j)$ by one unit, holding $N_t(j)$ constant; η_t is the expected discounted value of having one additional unit of $N_t(j)$ while holding $S_t(j)$ constant. x_{t+1} is the gross growth rate of assets and h_{t+1} is the gross growth rate of net worth at $t+1$.

$$x_{t+1} = Q_{t+1}S_{t+1}(j)/Q_t S_t(j) \qquad h_{t+1} = N_{t+1}(j)/N_t(j). \tag{49}$$

The incentive constraint can be written as

$$\eta_t N_t(j) + \upsilon_t Q_t S_t(j) \geq \lambda Q_t S_t(j)$$

If $\lambda \leq \upsilon_t$, the incentive constraint is not binding since the value of the banking business is always larger than the gain from diverting funds. As in Gertler and

Karadi (2011), with reasonable parameters and $0 < \upsilon_t < \lambda$, the constraint is binding in the equilibrium of this model. The amount of funds an intermediary can obtain depends positively on its net worth:

$$Q_t S_t(j) = \phi_t N_t(j) \qquad \text{where} \qquad \phi_t = \frac{\eta_t}{\lambda - \upsilon_t}. \tag{50}$$

The variable ϕ_t can be interpreted as the leverage ratio of the intermediary. By the constraint (50), the leverage ratio is determined where the benefit of diverting funds is balanced by the opportunity cost.

Using the leverage ratio, the evolution of net worth of a financial intermediary j who continues its banking business at t can be expressed by

$$N_t(j) = \left[\left(r_{S,t} - r_{t-1} \right) \phi_{t-1} + r_{t-1} \right] N_{t-1}(j). \tag{51}$$

In addition,

$$h_t = \left(r_{S,t} - r_{t-1} \right) \phi_{t-1} + r_{t-1} \tag{52}$$

$$x_t = \frac{\phi_t}{\phi_{t-1}} \left(\frac{N_t(j)}{N_{t-1}(j)} \right) = \frac{\phi_t}{\phi_{t-1}} h_t. \tag{53}$$

Since the leverage ratio (ϕ_t) does not depend on individual factors, the aggregate demand for claims is:

$$Q_t S_t = \phi_t N_t. \tag{54}$$

where N_t is the aggregate net worth. Since at each period only a fraction ζ of bankers can survive and there will be new entry to the banking sector, N_t can be expressed as the sum of existing net worth ($N_{e,t}$) and net worth of new bankers ($N_{n,t}$).

$$N_t = N_{e,t} + N_{n,t} \tag{55}$$

Given the survival ratio ζ, the existing net worth is

$$N_{e,t} = \zeta \left[\left(r_{S,t} - r_{t-1} \right) \phi_{t-1} + r_{t-1} \right] N_{t-1} \tag{56}$$

and net worth of exiting bankers is

$$N_{x,t} = (1-\zeta)\left[(r_{S,t} - r_{t-1})\,\phi_{t-1} + r_{t-1}\right] N_{t-1}. \tag{57}$$

When the exiting bankers transfer the terminal net worth ($N_{x,t}$) to the household sector, the households need to pay income tax to the government. In order to avoid double taxation, no tax is levied on financial intermediaries when they get the net return ($r_S - 1$) from the equity claims (S) purchase. Given the income tax ratio m, the actual amount of net worth transferred to the households is $(1-m)N_{x,t}$.

At each period new bankers from the households enter the financial intermediary sector with new net worth ($N_{n,t}$). The amount of new net worth is assumed to be a fraction $\frac{\omega}{1-\zeta}$ of the total amount of assets of exiting bankers. Given that at t this amount is $(1-\zeta)Q_t S_{t-1}$, net worth of new bankers transferred from the households can be expressed as

$$N_{n,t} = \omega Q_t S_{t-1} \tag{58}$$

and from the equation (55) the aggregate net worth (N_t) then evolves as follows:

$$N_t = \zeta\left[(r_{S,t} - r_{t-1})\,\phi_{t-1} + r_{t-1}\right] N_{t-1} + \omega Q_t S_{t-1} \tag{59}$$

where $r_{S,t} - r_{t-1}$ indicates the external finance premium. With net worth (N_t), the existing and new financial intermediaries borrow money from households and purchase the claims on intermediate goods producers.

Aggregating the equation (41) across all intermediaries we get the balance sheet of the banking system as follows:

$$Q_t S_t = N_t + r_t^{-1} b_{H,t}. \tag{60}$$

3.6 Capital Producing Firm

As in Gertler and Karadi (2011), at the end of each period t after the intermediate goods production, a representative capital producing firm purchases $(1-\delta)K_t$ units of used capital from intermediate goods firms given a relative capital price

Q_t. By investing (I_t), it produces new capital (K_{t+1}). Following this process, the capital accumulation is

$$K_{t+1} = (1-\delta)K_t + I_t. \tag{61}$$

After the investment, the capital producing firm resells the new capital K_{t+1} to the intermediate goods producers with price Q_t. Therefore, from this capital trade the representative capital producing firm can get the real cash flow as follows:

$$Q_t K_{t+1} - Q_t(1-\delta)K_t = Q_t I_t$$

For investment I_t, the capital producer purchases $[1 + g(A_{I,t}I_t/I_{t-1})]\, I_t$ amount of final goods, where $g(\cdot)$ can be interpreted as an investment adjustment cost and $A_{I,t}$ is an investment adjustment cost shock with an expected value of one. The capital producing firm solves

$$\underset{I_t}{max} \sum_{t=\tau}^{\infty} \beta^{t-\tau} E_\tau \left\{ \Lambda_{\tau,t} \left[Q_t I_t - I_t - g\left(\tfrac{A_{I,t}I_t}{I_{t-1}}\right) I_t \right] \right\}.$$

The first order condition can be written as

$$Q_t = 1 + g\left(\frac{A_{I,t}I_t}{I_{t-1}}\right) + \frac{A_{I,t}I_t}{I_{t-1}} g'\left(\frac{A_{I,t}I_t}{I_{t-1}}\right) - \beta E_t \left\{ A_{I,t+1}\Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t}\right)^2 g'\left(\frac{A_{I,t+1}I_{t+1}}{I_t}\right) \right\} \tag{62}$$

where the investment adjustment cost is given as

$$g\left(\frac{I_t}{I_{t-1}}\right) = \frac{\mu_I}{2}\left(\frac{A_{I,t}I_t}{I_{t-1}} - 1\right)^2. \tag{63}$$

3.7 Government

The home government purchases G_t of final goods, and the government spending is financed by taxing labour and bank's net worth. With the income tax ratio m, the government budget constraint is

$$m(W_t L_t + N_{x,t}) = G_t. \tag{64}$$

Plugging the equation (57) into (64) then yields[8]

$$m\left[W_tL_t + (1-\zeta)(r_{S,t}Q_{t-1}S_{t-1} - b_{H,t-1})\right] = G_t. \tag{65}$$

3.8 Central Bank

The home central bank adjusts the short-term interest rate in response to the inflation and the output changes. The desired level of policy rate is determined by a standard Taylor (1993) rule. However, the central bank is taking gradual steps toward a desired policy rate as in Judd and Rudebusch (1998). With a monetary policy smoothing parameter $\rho_R \in (0,1)$, the interest rate rule can be written as

$$R_t = \kappa R_{t-1}^{\rho_R}\left(\Pi_t^{\gamma_P} Y_t^{\gamma_Y}\right)^{1-\rho_R}\mu_t \tag{66}$$

where Y_t denotes aggregate output $(\int_0^1 Y_t(i)di)$. κ is a scale parameter, and γ_P and γ_Y represent the policy weights on the inflation rate and the output changes, respectively. μ_t is a policy shock with an expected value of one. The home monetary policy can be approximated with the following deviations forms, where $\hat{x}_t = (x_t - \bar{x}_t)/\bar{x}_t$ and $\bar{x}$ is the steady state level of x_t.

$$\hat{R}_t = \rho_R\hat{R}_{t-1} + (1-\rho_R)\left(\gamma_P\hat{\Pi}_t + \gamma_Y\hat{Y}_t\right) + \hat{\mu}_t \tag{67}$$

On the other hand the foreign policy rate (R_t^*) is treated as exogenous given the small open economy assumption.

3.9 Market Clearing

The international asset market clearing condition is given by

$$\left[1-\Gamma(b_{F,t})\right]^{-1} R_t^{*-1}\mathcal{E}_tB_{F,t} - \mathcal{E}_tB_{F,t-1} = P_tNX_t \tag{68}$$

[8]Given the equations (54) and (60), the equation (57) can be rewritten by $N_{x,t} = (1-\zeta)\left(r_{S,t}Q_{t-1}S_{t-1} - b_{H,t-1}\right)$.

where NX_t denotes net exports given by $P_t NX_t = \mathcal{E}_t P^*_{H,t} Y^*_{H,t} - P_{F,t} Y_{F,t}$. Given the LOOP ($\mathcal{E}_t P^*_{H,t} = P_{H,t}$), the equation (68) can be rewritten as

$$[1 - \Gamma(b_{F,t})]^{-1} R_t^{*-1} \Delta \mathcal{E}_{t+1}^{-1} \Pi_{t+1} b_{F,t} - b_{F,t-1} = \frac{P_{H,t}}{P_t} Y^*_{H,t} - \frac{P_{F,t}}{P_t} Y_{F,t} \tag{69}$$

where $b_{F,t-1} = \mathcal{E}_t B_{F,t-1}/P_t$ and $\Delta \mathcal{E}_{t+1} = \mathcal{E}_{t+1}/\mathcal{E}_t$.

The amount of the total intermediate goods produced in the home economy is equal to the sum of domestically purchased intermediate goods ($Y_{H,t}$) and exported intermediate goods ($Y^*_{H,t}$).

$$Y_t = Y_{H,t} + Y^*_{H,t} \tag{70}$$

with

$$Y_t = \int_0^1 Y_t(i)di \qquad \text{where} \qquad Y_t(i) = Y_{H,t}(i) + Y^*_{H,t}(i).$$

The amount of the aggregate final goods supply in the home market (Z_t) is equal to the sum of households' consumption, government spending, investment and the cost of investment adjustment. In other words,

$$C_t + I_t + G_t + g\left(\frac{I_t}{I_{t-1}}\right) I_t = Z_t. \tag{71}$$

The capital and the labour markets clear. The sum of the individual capital demand of each firm i is same to the sum of the equity claims purchased by the individual financial intermediary j at previous period, and this is represented by the aggregate capital. Also, the sum of the individual labour demand of each firm i is same to the sum of the individual labour supply of each household h.

$$K_t = \int_0^1 K_t(i)di = \int_0^1 S_{t-1}(j)dj \tag{72}$$

$$L_t = \int_0^1 L_t(i)di = \int_0^1 L_t(h)dh \tag{73}$$

The sum of the individual deposit holding of each household h is same to the sum of the individual debt of each financial intermediary j. Therefore, the domestic asset market clears as follows[9].

$$B_{H,t} = \int_0^1 B_{H,t}(h)dh = \int_0^1 B_{H,t}(j)dj \tag{74}$$

3.10 Exogenous Variables

Home technology (A_t), the investment adjustment cost ($A_{I,t}$), the home policy rate shock (μ_t), the foreign policy rate (R_t^*) and final goods production (Z_t^*) follow

$$A_t = \bar{A}^{1-\rho_A} A_{t-1}^{\rho_A} \varepsilon_{A,t} \tag{75}$$

$$A_{I,t} = \bar{A}_I^{1-\rho_{AI}} A_{t-1}^{\rho_{AI}} \varepsilon_{AI,t} \tag{76}$$

$$\mu_t = \bar{\mu}^{1-\rho_m} \mu_{t-1}^{\rho_m} \varepsilon_{m,t} \tag{77}$$

$$R_t^* = \bar{R}^{*1-\rho_{mf}} R_{t-1}^{*\rho_{mf}} \varepsilon_{m,t}^* \tag{78}$$

$$Z_t^* = \bar{Z}^{*1-\rho_Z} Z_{t-1}^{*\rho_Z} \varepsilon_{Z,t}^* \tag{79}$$

where variables with bars represent the steady state values. The expected values of variables $\varepsilon_{A,t}$, $\varepsilon_{AI,t}$, $\varepsilon_{m,t}$, $\varepsilon_{m,t}^*$ and $\varepsilon_{Z,t}^*$ are all unity, and coefficients $\rho_A, \rho_{AI}, \rho_m, \rho_{mf}, \rho_Z \in (0,1)$.

4 Parameters Estimation and Calibration

4.1 Data

In this section, a combination of two methods for model validation is used namely, Bayesian estimation and calibration. For model validation, South Korea is used as the test bed mainly for the following reasons. First, openness of the economy

[9]The appendix A.1 verifies the internal consistency of the model by showing that the national income identity holds.

(0.515) is close to the world average (0.463)[10]. Also, the size of GDP is small enough (around 1.7% of the global GDP), and the central bank is conducting an independent inflation targeting monetary policy. Finally, South Korea is a major emerging economy and all relevant quarterly real and financial data are available.

Given that there are five shocks, five series of quarterly data are used in Bayesian estimation: 1) output, 2) the inflation rate (CPI), 3) consumption, 4) investment and 5) the real exchange rate (effective). The sample period ranges from 1982:Q1 to 2014:Q4. Since the model analysis is based on the log-linearized equations, all the variables are percentage deviations from the long-run levels.

Calibrating the other parameters and steady state values, many of the long-run values of variables are derived from the quarterly data 1999-2014. For long-run inflation, quarterly changes of CPI are used and the steady state excess return is derived from the lending-deposit rate spreads. Deriving the steady state level of openness of the home economy, 'imports/GDP' and 'exports/GDP' data in 2013 are used. For the financial intermediary sector, the aggregate balance sheet data during 2008-2013 for all domestic banks are used. Data sources are reported in appendix A.5.

4.2 Bayesian Estimation

Log-linearizing the model around the steady state, a Bayesian estimation is performed for eight parameters which are not calibrated and also for second moments of five exogenous shocks[11]. These parameters are: (1) the share of the capital income in production (ψ), (2) price stickiness (ξ), (3) consumer's preference parameters (σ and χ), (4) elasticities of substitution between intermediate goods (ε) and between home and foreign goods (θ), (5) the investment adjustment cost (μ_I) and (6) the international assets transaction cost (μ_T).

For the Bayesian approach, the Metropolis-Hastings algorithm (MH) is used with 50,000 draws. The first three columns of Table 2 provide the assumptions regarding the prior distributions of parameters and exogenous shocks. The parameters between zero and unity (ψ and ξ) are assumed to have beta distributions with mean 0.33 and 0.75, respectively. Following Christoffel, Coenen and Warne (2008), the prior mean of the elasticity of substitution between home and foreign

[10] Data for openness and the share of GDP refer to year 2013.

[11] Appendix A.2 and A.3 outline the model's steady state and log-linearized equation system.

Table 2: Parameter Estimates using Bayesian Approaches

	Prior Distribution			Posterior Distribution				
	Type	Mean	St.error	Mode	Median	Mean	5%	95%
ψ	beta	0.33	0.02	0.354	0.352	0.352	0.324	0.381
ξ	beta	0.75	0.05	0.826	0.828	0.827	0.807	0.848
σ	normal	1.50	0.30	2.614	2.638	2.641	2.318	2.960
χ	normal	1.00	0.30	1.099	1.067	1.068	0.591	1.532
ε	gamma	6.00	1.00	6.405	6.494	6.545	4.974	8.192
θ	gamma	1.50	0.30	0.770	0.781	0.783	0.713	0.851
μ_I	gamma	4.00	0.50	2.076	2.159	2.189	1.659	2.677
μ_T	gamma	0.30	0.03	0.244	0.248	0.249	0.206	0.295
ε_A	inv.gamma	0.10	-	0.176	0.182	0.184	0.143	0.227
ε_{AI}	inv.gamma	0.10	-	0.231	0.232	0.232	0.205	0.259
ε_m	inv.gamma	0.10	-	0.013	0.013	0.013	0.012	0.015
ε_{mf}	inv.gamma	0.10	-	0.043	0.045	0.045	0.037	0.054
ε_{mf}	inv.gamma	0.10	-	0.064	0.066	0.067	0.057	0.076

goods (θ) is 1.5 and that of the investment adjustment cost (μ_I) is 4 with gamma distributions. As in Kollmann (2002) the prior mean of ε is 6 with a gamma distribution. Household preference parameters σ and χ have means 1.5 and 1 with normal distributions. The prior mean of the international transaction cost (μ_T) is 0.3. All the standard errors of the shocks are assumed to have inverse gamma distributions.

The result of parameter estimates shows all the estimated values of the parameters are significantly different from zero. The posterior mean of ψ is 0.35 during the sample period which means that capital has a share more than the conventional level, 0.33. Also, the estimation indicates greater price stickiness ($\xi = 0.83$) than the prior assumption. The elasticity of substitution between home intermediate goods is higher ($\varepsilon = 6.55$) than than the prior, and the elasticity between home and foreign goods ($\theta = 0.78$) is similar to the calibrated value of Coenen et al. (2010) (0.7). The posterior mean of the investment adjustment cost parameter (μ_I) is 2.19 and for the international transaction cost parameter (μ_T), it is 0.25. Regarding consumer's preference, both σ and χ have means higher than unity, 2.64 and 1.07 respectively.

4.3 Calibration

In many studies such as Galí and Monacelli (2005) and Christoffel, Coenen and Warne (2008), openness $(1-\alpha)$ is calculated by the 'import/GDP' ratio. However, in this model openness is defined as 'import/Aggregate Demand' (Y_F/Z), which can be derived from the 'import/GDP' and the 'export/GDP' ratio[12]. From the data, openness of South Korea is 0.515 in 2013[13] which was below 0.3 in 1990s. Also, given that 'export/GDP' of South Korea is 0.54 and its output is 1.7% of global output in 2013, openness of the rest of the world $(1-\alpha^*)$ is calibrated as 0.01.

In the financial intermediary sector, based on South Korean data the quarterly excess return from funding and lending is derived as 41bp from the long-run lending-deposit spread $(\bar{r}_S - \bar{r} = 0.0041)$, which is higher than 25bp in Gertler and Karadi (2011) for the US economy. Also, the long-run leverage is calculated from the ratio of 'loans to business/net equity' in the aggregate balance sheet of South Korean banks, which yields $\bar{\phi} = 4.51$ higher than 4.00 in Gertler and Karadi (2011). The fraction of funds diversion (λ) is related to the deposit holder's expected loss when a financial intermediary is at a state of bankruptcy. From the ratio of recovery of the financial crisis bailout since 1998, the calibration suggests $\lambda = 0.270$[14], which is lower than 0.381 of Gertler and Karadi (2013). The corresponding survival ratio of the banking business (ζ) is 0.899. This means that each banker returns final net worth $(N_{x,t})$ from the banking business to its household every 9.9 quarters (equal to 1/(1-0.899)) on average.

Using CPI, the long-run quarterly inflation rate $(\bar{\Pi})$ is calibrated as 1.0067 which means the annual inflation rate is 2.70% at the steady state. Also, using the data of the deposit rate, the long-run nominal interest rate $(\bar{R})$ is determined at 1.0107 with corresponding discount rate $(\beta = 0.996)$ and the real interest rate $(\bar{r} = 1.004)$. In the monetary policy rule, the smoothing parameter ρ_R is 0.8 following Gertler and Karadi (2013). For the weights on the output gap and

[12] National income identity in the appendix A.1 implies $1 = (C+I+G)/Y + (Y_H^* - Y_F)/Y$ at the steady state. From this Y_F/Z can be derived from $1 = Z/Y + Y_H^*/Y - Y_F/Y$.

[13] Using this way, various levels of openness by country (2013) can be observed such as US 0.160, Netherlands 0.810, Malaysia 0.798, and Czech Republic 0.758.

[14] Among the total amount of banks bailout regarding the financial crisis in 1997-1998, 44.6% has not been recovered during 1998-2014. Considering 60.6% of total loans are not insured by Korea Deposit Insurance Corporation (KDIC) (2014), the expected loss when an asset (deposit) is default can be calibrated as 27.0%.

the inflation rate, the parameter values of Taylor (1993) are used ($\gamma_P = 1.5$ and $\gamma_Y = 0.5$). The annual depreciation ratio of capital is 10% ($\delta = 0.025$). The tax rate (m) is 0.20 such that 'government spending/GDP ratio' in the model fits the average ratio of it for the sample period (14.7%). Using the long-run levels of net worth of the financial intermediary sector, the leverage and net foreign assets (NFA), the steady state ratio of b_H/b_F is determined at 1.98. For exogenous variables, the coefficient parameters, $\rho_A, \rho_{AI}, \rho_m, \rho_{mf}$, and ρ_Z, are 0.85 following Kolasa and Lombardo (2014). Table 3 summarizes the calibrated values of the baseline parameters.

Table 3: Parameters Calibration

parameter	value	parameter	value	parameter	value
α	0.485	ζ	0.899	m	0.20
α^*	0.990	ω	0.018	ρ_A	0.85
δ	0.025	λ	0.270	ρ_{AI}	0.85
β	0.996	γ_P	1.500	ρ_m	0.85
$\tilde{\beta}$	0.824	γ_Y	0.500	ρ_{mf}	0.85
ϕ	4.510	ρ_R	0.800	ρ_{zf}	0.85

5 Quantitative Analysis

5.1 Impulse Responses to a Foreign Interest Rate Shock

Given that the leader-follower relationship between home and foreign monetary policies is the focal point of attention in this paper, we report the results of impulse responses of home macroeconomic variables with respect to the foreign policy rate shock only. Figure 3 reports the baseline impulse response analysis with respect to a negative foreign interest rate shock; the foreign interest rate is lowered by 1% from the steady state level.

The lower foreign rate induces home residents to decrease their foreign asset holdings[15]. Given that the home policy rate is determined by the past inflation rate and the output gap, for the calibrated parameters the nominal exchange rate declines (home currency appreciation). This leads to an initial fall in the real

[15]This is in line with Park, Ramayandi and Shin (2014) which find the expansion of capital flows into developing economies during the period of quantitative easing of the US.

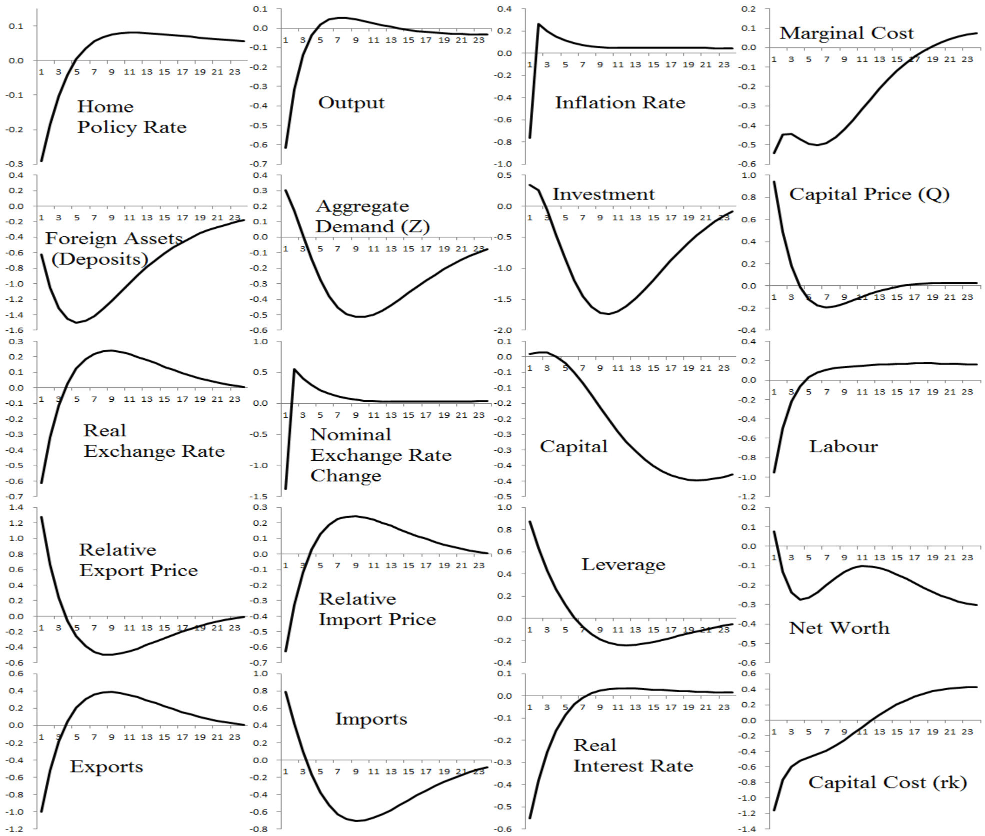

Figure 3: Responses to Foreign Policy Shock; Baseline Model

exchange rate, and thus the relative export price rises and the relative import price declines. The consequent decline in the terms of trade (defined as import price/export price) results in an expenditure switching effect. Export decreases and import increases.

A negative demand side effect induced by a fall in export lowers home tradeable output (Y_t). As home producers cut back production, the real marginal cost declines and so is employment L_t. Combined with a fall in the relative import price, this leads to an initial decline in the home inflation rate via the equation (22). Following the standard Taylor rule (equation (67)) the home central bank cuts its policy rate. This explains the baseline leader-follower relationship between home and foreign interest rates.

As the production of home tradeable goods ($Y_{H,t}$) falls and imports ($Y_{F,t}$) rises, the final goods production (Z_t) as seen in the equation (16) rises due to greater import content in its production ($1-\alpha$ exceeding 0.5, see equation (16)). Correspondingly, household's consumption and investment increase. The increase in investment boosts capital stock and the capital price (Q_t), and it lowers producer's cost of capital ($r_{K,t}$)[16]. In the financial intermediary sector, following the positive balance sheet effect caused by the increases in Q_t and in K_t the leverage of assets (ϕ_t) rises (see equation (51)).

5.2 Comparative Statics of Impulse Responses

5.2.1 Effect of a Change in the International Transaction Cost

Figure 4 indicates the effect of a change in the international assets transaction cost on the impulse responses to a foreign rate shock[17]. The lower transaction cost ($\mu_T = 0.1$) makes the home policy rate follow the foreign rate more aggressively than the higher cost case ($\mu_T = 0.8$).

As the international assets transaction cost (μ_T) is lower, the home agents' foreign asset holding decreases more in response to a negative foreign interest rate shock. Given the home policy rate, the nominal and real exchange rate decline more. Therefore, the relative import and export prices also change more, which implies a stronger expenditure switching effect. As a result, home output (Y_t) and inflation decline more significantly. Following the Taylor rule the home central bank responds by cutting the policy rate more sharply with the lower transaction cost. This gives rise to a stronger co-movements of home and foreign rates.

5.2.2 Effect of a Change in Openness

Figure 5 compares the impulse responses for two openness environments. With a higher openness ($\alpha = 0.2$) a fall in net exports yields a sharp decline in home output (Y_t), which implies a stronger expenditure switching effect. Even though the relative export and import prices change less, the larger portion of trade in the home economy leads to a greater decline in GDP (Y_t) than the other case with lower openness ($\alpha = 0.8$).

As home output (Y_t) declines more with higher openness the real marginal cost drops more, and initially the home inflation rate becomes lower. Combined

[16]The producer's capital hiring cost is $r_{K,t} = r_{S,t}Q_{t-1} - (1-\delta)\,Q_t$.

[17]All impulse responses reported hereafter compare the effects of lower and higher values from the baseline model.

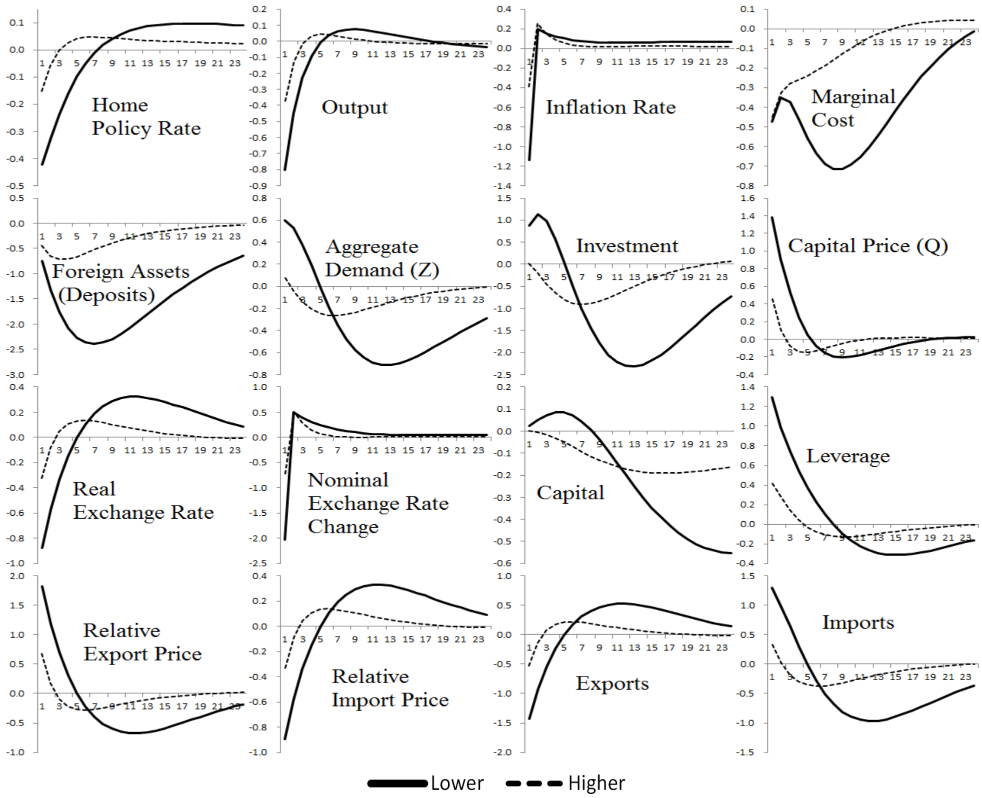

Figure 4: Responses to Foreign Policy Shock; Different Transaction Costs

with the fall in GDP, this leads to a more aggressive interest rate cut of the home central bank. Therefore, higher openness strengthens the correlation between home and foreign interest rates when there is a foreign rate shock.

5.2.3 Effect of Aggressive Inflation Targeting

Since inflation targeting was initially adopted by New Zealand in 1989, many central banks have established the inflation-targeting frameworks. During the first half of 1990s five more countries[18], and during 1997-2002, 15 more countries[19]. Given that still many central banks are in the process of adopting inflation-targeting regimes, it is meaningful to investigate the effect of such a policy framework on the relationship between central banks' policies.

[18]Canada, Israel, UK, Australia and Sweden

[19]Czech, Poland, South Korea, Brazil, Chile, Colombia, South Africa, Thailand, Hungary, Iceland, Mexico, Norway, Ghana, Peru and Philippine (Hammond, 2012)

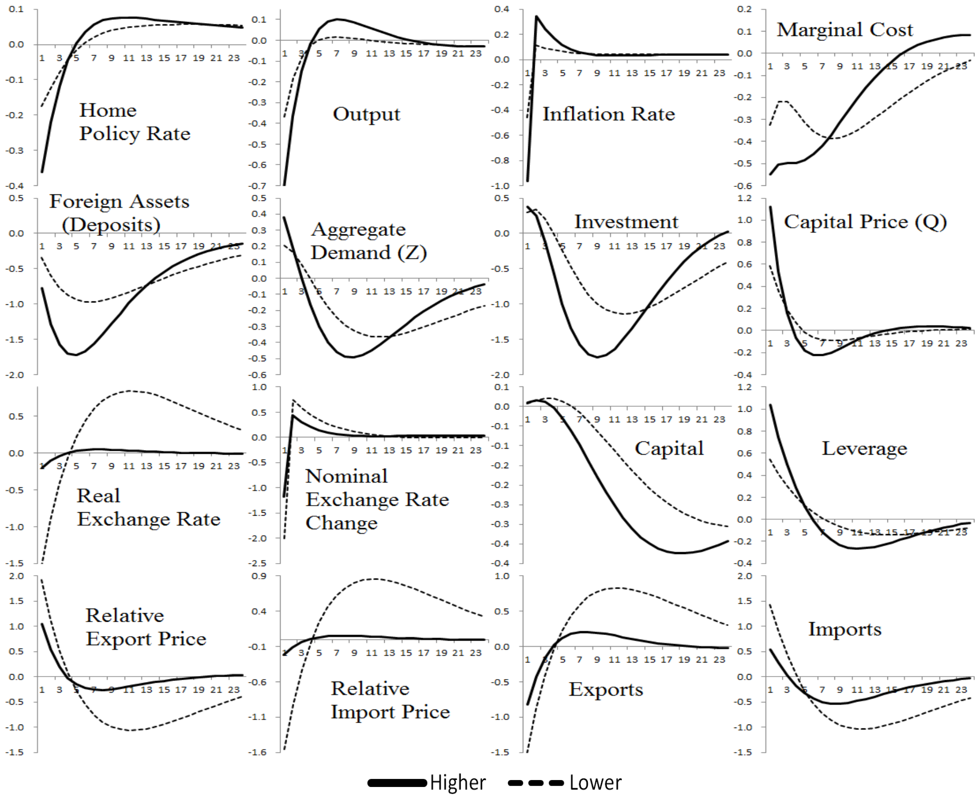

Figure 5: Responses to Foreign Policy Shock; Different Openness

The sensitivity analysis is performed with different degrees of inflation targeting (figure 6). The aggressiveness of targeting is measured by the parameter γ_P in the Taylor rule equation (63) with two different values: 1) strong targeting with $\gamma_P = 2.5$ and 2) weak targeting with $\gamma_P = 1.2$. Not surprisingly, in response to a negative foreign rate shock, the home central bank with strong inflation targeting cuts interest rate more aggressively than the case of weaker inflation targeting. The effect of a more aggressive inflation targeting on the domestic absorption (Z_t) is rather minimal.

5.2.4 Effect of a Strong Financial Friction

An important novelty of our small open economy DSGE model is that we include a banking friction in the model which adds a banking transmission channel of any shock including the foreign interest rate. How does the monetary policy

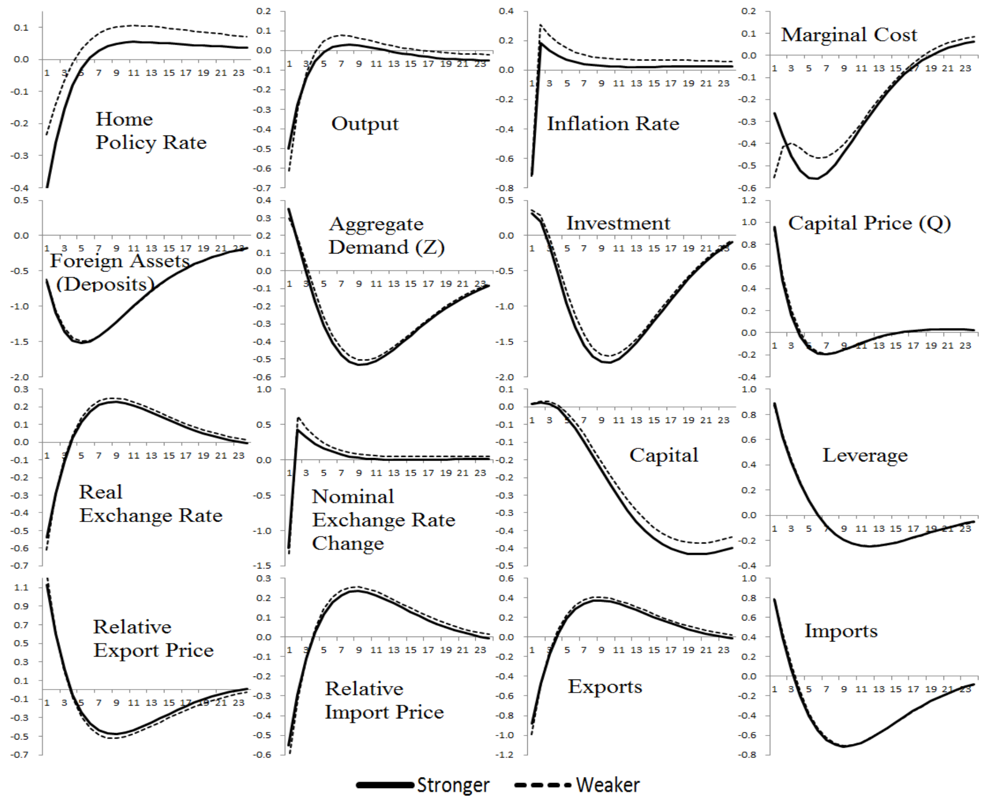

Figure 6: Responses to Foreign Policy Shock; Effect of Aggressive Inflation Targeting

interdependence depend on the degree of the banking friction? The banking friction is the result of the agency cost which gives rise to limits to arbitrage. The crucial parameter that accounts for this banking friction is λ (i.e. the fraction of the assets that the banker can divert). A higher value of λ means a greater banking friction. Figure 7 compares the impulse responses for low and high values of λ namely, 0.20 and 0.45 respectively.

Different degrees of the banking friction (different values of λ) in the home economy affect the intermediate co-movements of home and foreign rates along its transition path to the steady state. After the impact effect, home output (Y_t) and inflation rate increase and the interest rate rises. Also, capital stock and investment decrease, and net exports increase (an increase in exports and a decrease in imports). Combined with a fall in the capital price (Q_t), the balance sheet of the financial intermediary sector contracts (see the equation (57)). As a result, the leverage of banks (ϕ_t) falls.

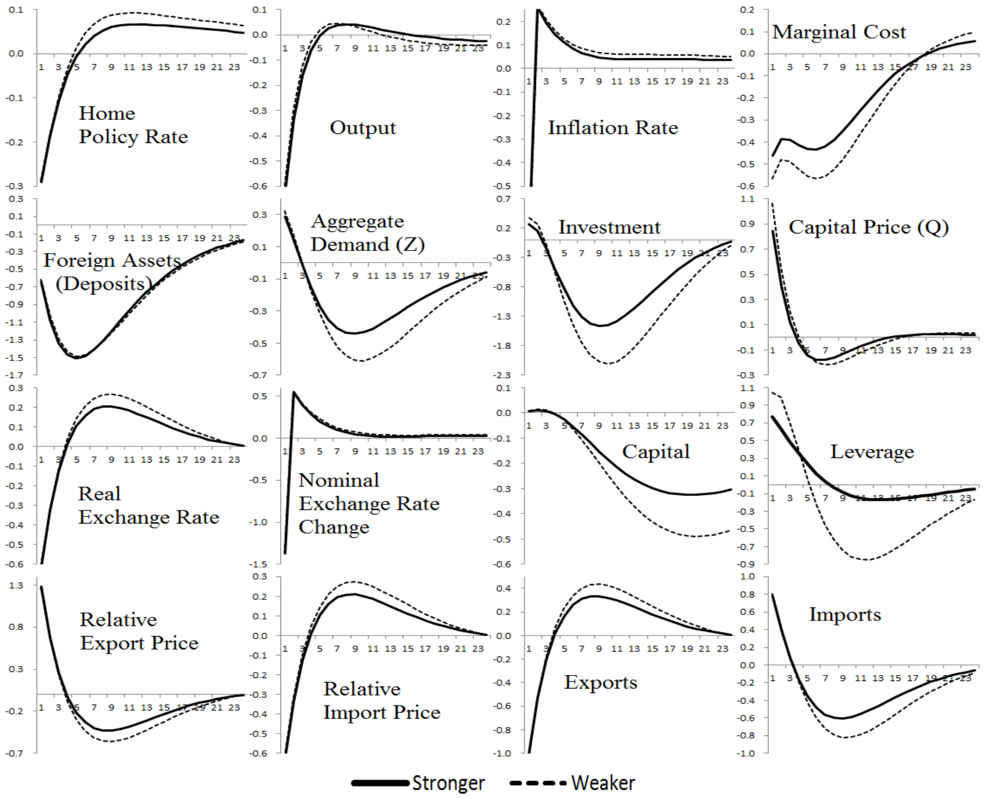

Figure 7: Responses to Foreign Policy Shock; Different Levels of Financial Friction

With a stronger financial friction the decline in the leverage is dampened by the higher value of λ[20]. Accordingly, the banks' balance sheet contraction is smaller, and capital stock and investment fall more sluggishly during the intermediate phase. Since investment uses both home and foreign goods, exports and imports change less. This corresponds to smaller variations in relative import and export prices, which means the relative import price rises less. This translates into a slower rise in inflation and a gradual rise in the home interest rate via the Taylor rule. While the foreign interest rate slowly rises back to its steady state, the slow rise in the home interest rate accompanying the foreign rate along the transition path makes the co-movement between home and foreign rates stronger.

[20]The leverage of banks' assets is $\phi_t = \eta_t/(\lambda - \nu_t)$. With a higher value of λ, the change of ϕ_t is smaller given the variations of η_t and ν_t compared to the case of lower λ.

5.3 Correlation between Home and Foreign Rates

The co-movements of home and foreign rates when there is a foreign rate shock is the center of attention in this paper, since it demonstrates the leader-follower relationship between them. A summary measure of the co-movement is the correlation coefficient between home and foreign rates with a foreign rate shock. Table 4 reports the results of the sensitivity analysis of this correlations to different parameters.

In the baseline model, with a foreign rate shock the correlation coefficient between home and foreign rates is 0.37. With the lower international assets transaction cost the correlation coefficient is higher (0.61) than the higher cost case (0.11). Also, as openness of the home economy is higher the correlation is stronger (0.47) than the lower openness case (0.37). When the home central bank adopts more aggressive inflation targeting the correlation is higher (0.65) than weaker targeting case (0.13). Finally, with a stronger financial friction (higher λ) the coefficient is higher (0.46) than the weaker friction case (0.29).

Table 4: Correlation Coefficient between R_t and R_t^* with a Foreign Rate (R_t^*) Shock

Case		$\text{Corr}(R_t, R_t^*)$	Case		$\text{Corr}(R_t, R_t^*)$
International	High	0.11	Inflation Targeting	Weak	0.13
Transaction Cost	Low	0.61		Strong	0.65
Openness	Low	0.37	Financial Friction	Weak	0.29
	High	0.47		Strong	0.46
Baseline Model		0.37			

5.4 Variance Decomposition

Table 5 presents the variance decomposition of the home interest rate with respect to all five exogenous shocks namely, home technology (ε_A), the investment adjustment cost (ε_{AI}), the home policy rate (ε_m), the foreign policy rate (ε_m^*) and the foreign aggregate demand (ε_Z^*). In the baseline model, as in any standard DSGE model the total factor productivity (TFP) shock accounts for the major chunk of fluctuations of the home interest rate (70.7%).

The foreign monetary policy accounts for 5.2% of home interest rate fluctuations in the baseline model. In the case of the lower international transaction cost it increases to 6.4%. Likewise greater openness (6.6%) and more aggressive inflation targeting (11.9%) also raise the contribution of the foreign monetary policy shock. However, it decreases with a stronger financial friction (4.6%) as the effect of TFP shock increases.

Table 5: Forecast Error Variance Decomposition (%) of Home Policy Rate (R)

Case		Parameter	ε_A	ε_{AI}	ε_m	ε_m^*	ε_Z^*
Baseline Model			70.7	1.5	21.0	5.2	1.7
International	High	$\mu_T = 0.8$	81.9	2.6	12.7	2.6	0.3
Transaction Cost	Low	$\mu_T = 0.1$	56.5	0.6	31.8	6.4	4.8
Openness	Low	$1-\alpha = 0.2$	71.8	1.6	23.4	1.2	1.9
	High	$1-\alpha = 0.8$	70.1	1.4	20.3	6.6	1.6
Inflation Targeting	Weak	$\gamma_P = 1.2$	71.1	2.4	20.2	4.5	1.9
	Strong	$\gamma_P = 2.5$	65.1	0.5	20.8	11.9	1.6
Financial Friction	Weak	$\lambda = 0.20$	69.8	1.6	21.3	5.9	1.5
	Strong	$\lambda = 0.45$	71.5	1.3	20.8	4.6	1.9

6 Conclusion

During recent decades many emerging countries central banks apparently followed the interest rate policies of major central banks such as the US Fed and the ECB. In this paper, we investigate the factors that strengthen such leader-follower relationship between central banks. We develop a small open DSGE model to address this question. Using a small open economy model with a standard inward-looking Taylor rule of the home country, we argue that such a leader-follower relationship between foreign and home policy rates could emerge through the terms of trade channel that affects GDP and the inflation rate of the home economy via the expenditure switching effect between domestic absorption and net exports.

Our DSGE model exhibits a stronger relationship between home and foreign policy rates when (a) the international assets transaction cost is lower, (b) openness of the home country is higher, (c) the home central bank adopts more aggressive inflation targeting, and (d) the banking friction in the home economy is greater. With the lower transaction cost and with higher openness, the expenditure switching effects are stronger. More active inflation targeting makes the home central bank adjust its policy rate more sharply given a change in inflation. A higher banking friction makes the co-movements between home and foreign rates stronger during the intermediate phase through the bank leverage channel.

Our paper is one of the very few in the extant literature which blends domestic financial frictions in an open economy DSGE model to understand monetary policy interdependence. In this paper, we have only focused on the financial friction emanating from the banking channel, that is the lender's moral hazard. A future extension of this paper would be to add a borrower's moral hazard problem in the model along the line of Bernanke, Gertler and Gilchrist (1999). Such an extension could provide a useful framework to analyze the international transmission channel of the unconventional monetary policy of the leading countries.

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A Appendix

A.1 National Income Identity

From the aggregate individual households' budget constraint and the asset market clearing condition,

$$C_t + \left(r_t^{-1} b_{H,t} - b_{H,t-1}\right) + NX_t = (1-m) W_t L_t + D_t + \Omega_t \tag{A.1}$$

where D_t is the sum of the aggregate real dividends from intermediate goods producers ($D_{G,t}$) and the capital producing firm ($D_{C,t}$) that can be illustrated as follows:

$$\begin{aligned}
D_{G,t} &= \left(\frac{P_{H,t}}{P_t}\right) Y_{H,t} + \left(\frac{\mathcal{E}_t P^*_{H,t}}{P_t}\right) Y^*_{H,t} - \left[r_{S,t} Q_{t-1} - (1-\delta) Q_t\right] K_t - W_t L_t \\
&= \left(\frac{P_{H,t}}{P_t}\right) \left(Y_{H,t} + Y^*_{H,t}\right) - r_{S,t} Q_{t-1} S_{t-1} + (1-\delta) Q_t K_t - W_t L_t \\
&= \left(\frac{P_{H,t}}{P_t}\right) Y_t - r_{S,t} Q_{t-1} S_{t-1} + Q_t K_{t+1} - Q_t I_t - W_t L_t \\
D_{C,t} &= Q_t K_{t+1} - (1-\delta) Q_t K_t - \left(1 + g\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \\
&= Q_t I_t - \left(1 + g\left(\frac{I_t}{I_{t-1}}\right)\right) I_t
\end{aligned}$$

where $Y_t = Y_{H,t} + Y^*_{H,t}$ by the goods market clearing condition and $P_{H,t} = \mathcal{E}_t P^*_{H,t}$. Also, given Ω_t[21], combining the equations (52), (53), (54) and (57) yields

$$r_{S,t} Q_{t-1} S_{t-1} - Q_t S_t = \left(b_{H,t-1} - r_t^{-1} b_{H,t}\right) + \Omega_t + m N_{x,t}. \tag{A.2}$$

From the equation (A.2) and $K_{t+1} = S_t$, we can rewrite the real dividends from intermediate goods producers as follows:

$$D_{G,t} = \left(\frac{P_{H,t}}{P_t}\right) Y_t + \left(r_t^{-1} b_{H,t} - b_{H,t-1}\right) - \left(\Omega_t + m N_{x,t}\right) - Q_t I_t - W_t L_t. \tag{A.3}$$

Plugging dividends equations into the households' aggregate budget constraint (A.1) and usingg government expenditure constraint ($m(W_t L_t + N_{x,t}) = G_t$), we can eventually derive the national income identity equation as follows:

$$C_t + I_t + G_t + NX_t + g\left(I_t / I_{t-1}\right) I_t = \left(\frac{P_{H,t}}{P_t}\right) Y_t. \tag{A.4}$$

[21] Ω_t is the net transfer from banking sector to the households, which is $\Omega_t = (1-m) N_{x,t} - \omega Q_t S_{t-1} = (1-\zeta)\left(r_{S,t} Q_{t-1} S_{t-1} - b_{H,t-1}\right) - \omega Q_t S_{t-1} - m N_{x,t}$.

A.2 Steady State

$$
\begin{aligned}
\bar{\Pi} &= 1.0067 (= \bar{\Pi}^*) \\
\bar{\Lambda} &= \bar{Q} = 1 \\
\bar{A} &= \bar{A}_I = 1 \\
\left(\overline{\frac{P^*_{F,t}}{P^*_t}}\right) &= \left(\overline{\frac{P^*_{H,t}}{P^*_t}}\right) = 1 \\
\bar{\Delta\mathcal{E}} &= 1 \\
\bar{r}_S &= \bar{r} + \bar{r}_P \\
\overline{MC} &= \frac{\varepsilon - 1}{\varepsilon} \\
\frac{\bar{L}}{\bar{K}} &= \frac{1-\psi}{\psi}\bar{r}_K \bar{W}^{-1} \\
\bar{Y} &= \left(\frac{\bar{L}}{\bar{K}}\right)^{1-\psi} \bar{K} \\
\bar{I} &= \delta \bar{K} \\
\bar{F} &= \frac{1}{1-\beta\xi} \\
\bar{Y} &= \bar{Y}_H + \bar{Y}^*_H \\
\bar{b}_H &= (\phi - 1)\bar{N}\bar{r} \\
\bar{b}_H / \bar{b}_F &= 1.98 \\
\bar{G} &= m[\bar{W}\bar{L} + (1-\zeta)(\bar{r}_S \bar{K} - \bar{b}_H)] \\
\bar{x} &= \bar{h} \\
\bar{\upsilon} &= \frac{(1-\zeta)\,\beta \bar{r}_P}{1 - \beta\zeta\bar{x}}
\end{aligned}
$$

$$
\begin{aligned}
\bar{r} &= \beta^{-1} \\
\bar{R} &= \bar{\Pi}\beta^{-1} = \bar{R}^* \\
\bar{\mathcal{E}_R} &= \bar{\mu} = 1 \\
\left(\overline{\frac{P_{H,t}}{P_t}}\right) &= \left(\overline{\frac{P_{F,t}}{P_t}}\right) = \left(\overline{\frac{\tilde{P}_{H,t}}{P_t}}\right) = 1 \\
\bar{r}_P &= 0.0041 \\
\bar{r}_K &= \bar{r}_S - (1-\delta) \\
\bar{W} &= \left[\frac{1}{\psi^{\psi}(1-\psi)^{1-\psi}} \bar{r}_K^{\psi} \overline{MC}^{-1}\right]^{\frac{1}{\psi - 1}} \\
\bar{\phi} &= 4.51 \\
\bar{K} &= \bar{\phi}\bar{N} \\
\bar{L} &= \frac{\bar{L}}{\bar{K}}\bar{K} \\
\bar{C} &= \left(\bar{L}^{-\varphi}\bar{W}\right)^{\frac{1}{\sigma}} \\
\bar{Z} &= \bar{C} + \bar{I} + \bar{G} \\
\bar{Y}_H &= \alpha \bar{Z} \\
\bar{Y}_F &= (1-\alpha)\bar{Z} \\
\bar{b}_F &= \left(\bar{R}^{*-1}\bar{\Pi} - 1\right)^{-1} (\bar{Y}^*_H - \bar{Y}_F) \\
\bar{h} &= \bar{\phi}\bar{r}_P + \bar{r} \\
\bar{\eta} &= \frac{1-\zeta}{1-\beta\zeta\bar{h}}
\end{aligned}
$$

A.3 Log-linearized Equations

$$\hat{Y}_t = \hat{A}_t + \psi\hat{K}_t + (1-\psi)\hat{L}_t \tag{A.5}$$

$$\widehat{MC}_t = -\hat{A}_t + \psi\left(\frac{1}{\bar{r}_s - (1-\delta)}\right)\left[\bar{r}_s\left(\hat{r}_{s,t} + \hat{Q}_{t-1}\right) - (1-\delta)\hat{Q}_t\right] + (1-\psi)\hat{W}_t \tag{A.6}$$

$$\hat{L}_t - \hat{K}_t = \left(\frac{1}{\bar{r}_s - (1-\delta)}\right)\left[\bar{r}_s\left(\hat{r}_{s,t} + \hat{Q}_{t-1}\right) - (1-\delta)\hat{Q}_t\right] - \hat{W}_t \tag{A.7}$$

$$\left(\widehat{\frac{\tilde{P}_{H,t}}{P_t}}\right) = \bar{F}^{-1}\widehat{MC}_t + \left(1-\bar{F}^{-1}\right)E_t\left(\widehat{\frac{\tilde{P}_{H,t+1}}{P_{t+1}}} + \hat{\Pi}_{t+1}\right) \tag{A.8}$$

$$\left(\widehat{\frac{P_{H,t}}{P_t}}\right) = \xi\left[\left(\widehat{\frac{P_{H,t-1}}{P_{t-1}}}\right) - \hat{\Pi}_t\right] + (1-\xi)\left(\widehat{\frac{\tilde{P}_{H,t}}{P_t}}\right) \tag{A.9}$$

$$\hat{Y}_{H,t} = -\theta\left(\widehat{\frac{P_{H,t}}{P_t}}\right) + \hat{Z}_t \tag{A.10}$$

$$\hat{Y}_{F,t} = -\theta\left(\widehat{\frac{P_{F,t}}{P_t}}\right) + \hat{Z}_t \tag{A.11}$$

$$0 = \alpha\left(\widehat{\frac{P_{H,t}}{P_t}}\right) + (1-\alpha)\left(\widehat{\frac{P_{F,t}}{P_t}}\right) \tag{A.12}$$

$$0 = \alpha^*\left(\widehat{\frac{P^*_{F,t}}{P^*_t}}\right) + (1-\alpha^*)\left(\widehat{\frac{P^*_{H,t}}{P^*_t}}\right) \tag{A.13}$$

$$\left(\widehat{\frac{P_{F,t}}{P_t}}\right) = \left(\widehat{\frac{P^*_{F,t}}{P^*_t}}\right) + \hat{\mathcal{E}}_{R,t} \tag{A.14}$$

$$\left(\widehat{\frac{P^*_{H,t}}{P^*_t}}\right) = \left(\widehat{\frac{P_{H,t}}{P_t}}\right) - \hat{\mathcal{E}}_{R,t} \tag{A.15}$$

$$\hat{Y}^*_{H,t} = -\theta\left(\widehat{\frac{P_{H,t}}{P_t}}\right) + \theta\hat{\mathcal{E}}_{R,t} + \hat{Z}^*_t \tag{A.16}$$

$$\hat{\mathcal{E}}_{R,t} = \widehat{\Delta\mathcal{E}}_t - \hat{\Pi}_t + \hat{\mathcal{E}}_{R,t-1} \tag{A.17}$$

$$\hat{W}_t = \sigma\hat{C}_t + \chi\hat{L}_t \tag{A.18}$$

$$\hat{C}_t = E_t\left(\hat{C}_{t+1}\right) + \sigma^{-1}\left[E_t\left(\hat{\Pi}_{t+1}\right) - \hat{R}_t\right] \tag{A.19}$$

$$\hat{R}_t = \hat{R}^*_t + E_t\left(\widehat{\Delta\mathcal{E}}_{t+1}\right) - \mu_T\hat{b}_{F,t} \tag{A.20}$$

$$\hat{\Lambda}_{t,t+1} = \sigma(\hat{C}_t - \hat{C}_{t+1}) \tag{A.21}$$

$$\hat{r}_t = \hat{R}_t - \hat{\Pi}_{t+1} \tag{A.22}$$

$$\hat{r}_{P,t} = \frac{\bar{r}_s}{\bar{r}_P}\hat{r}_{S,t+1} - \frac{\bar{r}}{\bar{r}_P}\hat{r}_t \tag{A.23}$$

$$\bar{\upsilon}\hat{\upsilon}_t = (1-\zeta)\,\beta\bar{r}_P\left(\hat{\Lambda}_{t,t+1} + \hat{r}_{P,t}\right) + \beta\zeta\bar{x}\bar{\upsilon}\left(\hat{\Lambda}_{t,t+1} + \hat{x}_{t+1} + \hat{\upsilon}_{t+1}\right) \tag{A.24}$$

$$\hat{x}_t = \hat{h}_t + \hat{\phi}_t - \hat{\phi}_{t-1} \tag{A.25}$$

$$\hat{h}_t = \frac{\bar{r}_P}{\bar{h}}\bar{\phi}\left(\hat{r}_{P,t-1} + \hat{\phi}_{t-1}\right) + \frac{\bar{r}}{\bar{h}}\hat{r}_{t-1} \tag{A.26}$$

$$\hat{\eta}_t = \beta\zeta\bar{h}\left(\hat{\Lambda}_{t,t+1} + \hat{h}_{t+1} + \hat{\eta}_{t+1}\right) \tag{A.27}$$

$$\hat{Q}_t + \hat{K}_{t+1} = \hat{\phi}_t + \hat{N}_t \tag{A.28}$$

$$\hat{\phi}_t = \frac{1}{\lambda - \bar{\upsilon}}\left(\frac{\bar{\eta}}{\bar{\phi}}\hat{\eta}_t + \bar{\upsilon}\hat{\upsilon}_t\right) \tag{A.29}$$

$$\hat{N}_t = \frac{\omega\bar{K}}{\bar{N}}\left(\hat{Q}_t + \hat{K}_t\right) + \zeta\bar{h}\left(\hat{h}_t + \hat{N}_{t-1}\right) \tag{A.30}$$

$$(1-\omega)\,\hat{Q}_t + \hat{K}_{t+1} = \zeta\bar{r}_S\left(\hat{r}_{S,t} + \hat{Q}_{t-1} + \hat{K}_t\right) - \frac{\bar{b}_H}{\bar{K}}\left(\zeta\hat{b}_{H,t-1} - \frac{\hat{b}_{H,t} - \hat{r}_t}{\bar{r}}\right) + \omega\hat{K}_t \tag{A.31}$$

$$\hat{K}_{t+1} = (1-\delta)\,\hat{K}_t + \frac{\bar{I}}{\bar{K}}\hat{I}_t \tag{A.32}$$

$$\hat{Q}_t = \mu_I\left(\hat{I}_t - \hat{I}_{t-1} + \hat{A}_{I,t}\right) - \beta\mu_I\left(\hat{I}_{t+1} - \hat{I}_t + \hat{A}_{I,t+1}\right) \tag{A.33}$$

$$\hat{R}_t = \rho_R\hat{R}_{t-1} + (1-\rho_R)\left(\gamma_P\hat{\Pi}_t + \gamma_Y\hat{Y}_t\right) + \hat{\mu}_t \tag{A.34}$$

$$\hat{Y}_t = \frac{\bar{Y}_H}{\bar{Y}}\hat{Y}_{H,t} + \frac{\bar{Y}_M^*}{\bar{Y}}\hat{Y}_{H,t}^* \tag{A.35}$$

$$\hat{Z}_t = \frac{\bar{C}}{\bar{Z}}\hat{C}_t + \frac{\bar{I}}{\bar{Z}}\hat{I}_t + \frac{\bar{G}}{\bar{Z}}\hat{G}_t \tag{A.36}$$

$$\hat{A}_t = \rho_A\hat{A}_{t-1} + \hat{\varepsilon}_{A,t} \tag{A.37}$$

$$\hat{A}_{I,t} = \rho_{AI}\hat{A}_{I,t-1} + \hat{\varepsilon}_{AI,t} \tag{A.38}$$

$$\hat{\mu}_t = \rho_M\hat{\mu}_{t-1} + \hat{\varepsilon}_{M,t} \tag{A.39}$$

$$\hat{R}_t^* = \rho_{MF}\hat{R}_{t-1}^* + \hat{\varepsilon}_{M,t}^* \tag{A.40}$$

$$\hat{Z}_t^* = \rho_Z\hat{Z}_t^* + \hat{\varepsilon}_{Z,t}^* \tag{A.41}$$

$$\bar{G}\hat{G}_t = m\,(1-\zeta)\left[\bar{r}_S\bar{K}\left(\hat{r}_{S,t} + \hat{Q}_{t-1} + \hat{K}_t\right) - \bar{b}_H\hat{b}_{H,t-1}\right] + m\bar{W}\bar{L}\left(\hat{W}_t + \hat{L}_t\right) \tag{A.42}$$

$$\bar{Y}_H^*\left[\left(\widehat{\frac{P_{H,t}}{P_t}}\right) + \hat{Y}_{H,t}^*\right] - \bar{Y}_F\left[\left(\widehat{\frac{P_{F,t}}{P_t}}\right) + \hat{Y}_{F,t}\right] = \left(\bar{Y}_H^* - \bar{Y}_F + \bar{b}_F\right)\left[(1+\mu_T)\,\hat{b}_{F,t} - \hat{R}_t^* - \widehat{\Delta\mathcal{E}}_{t+1} + \hat{\Pi}_{t+1}\right] - \bar{b}_F\hat{b}_{F,t-1} \tag{A.43}$$

A.4 Derivation of the Sticky Price Dynamics

A.4.1 Optimal Relative Price

The optimization problem of the home intermediate good producer is given by

$$\underset{\tilde{P}_{H,t}}{max}\sum_{\tau=0}^{\infty}\beta^{\tau}\xi^{\tau}E_t\left\{D_{t,t+\tau}\left[\bar{\Pi}^{\tau}\tilde{P}_{H,t}\left(\tfrac{\tilde{P}_{H,t+\tau}}{P_{H,t+\tau}}\right)^{-\varepsilon}Y_{t+\tau}-\Phi(Y_{H,t+\tau|t}+Y^*_{H,t+\tau|t})\right]\right\}.$$

Also, from the demand functions of home purchased goods and exported goods, the equation (5), and the law of one price ($\mathcal{E}_{t+\tau}P^*_{H,t+\tau}=P_{H,t+\tau}$),

$$\frac{\partial Y_{H,t+\tau|t}}{\partial \tilde{P}_{H,t}} = -\varepsilon\left(\frac{\Pi^{\tau}}{\Pi_{H,t+\tau}}\right)^{-\varepsilon}\left(\frac{\tilde{P}_{H,t}}{P_{H,t}}\right)^{-\varepsilon}\frac{Y_{H,t+\tau}}{\tilde{P}_{H,t}} \quad (A.44)$$

$$\frac{\partial Y^*_{H,t+\tau|t}}{\partial \tilde{P}_{H,t}} = -\varepsilon\left(\frac{\Pi^{\tau}}{\Pi_{H,t+\tau}}\right)^{-\varepsilon}\left(\frac{\tilde{P}_{H,t}}{P_{H,t}}\right)^{-\varepsilon}\frac{Y^*_{H,t+\tau}}{\tilde{P}_{H,t}} \quad (A.45)$$

where $\Pi_{H,t+\tau}=P_{H,t+\tau}/P_{H,t}$.

Using the equations (A.44) and (A.45), the first order condition of the optimization is derived as

$$\sum_{\tau=0}^{\infty}\beta^{\tau}\xi^{\tau}E_t\left\{D_{t,t+\tau}\left(\frac{\Pi^{\tau}}{\Pi_{H,t+\tau}}\right)^{-\varepsilon}\left[(1-\varepsilon)\bar{\Pi}^{\tau}Y_{t+\tau}+\varepsilon P_{t+\tau}MC_{t+\tau}\left(\frac{Y_{H,t+\tau|t}}{\tilde{P}_{H,t}}+\frac{Y^*_{H,t+\tau}}{\tilde{P}_{H,t}}\right)\right]\right\} = 0$$

$$\sum_{\tau=0}^{\infty}\beta^{\tau}\xi^{\tau}E_t\left\{D_{t,t+\tau}Y_{t+\tau}\left(\frac{\Pi^{\tau}}{\Pi_{H,t+\tau}}\right)^{-\varepsilon}\left[\bar{\Pi}^{\tau}\left(\frac{\tilde{P}_{H,t}}{P_t}\right)-\frac{\varepsilon}{\varepsilon-1}\Pi_{t+\tau}MC_{t+\tau}\right]\right\} = 0$$

where $\Pi_{t+\tau}=P_{t+\tau}/P_t$. This yields the equation (12).

A.4.2 Dynamics of Optimal Relative Price

Denote $\Pi_{s,r}=P_r/P_s$. The equation (11) can be rewritten by,

$$\frac{\tilde{P}_{H,t}}{P_t}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}E_t\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi^{\varepsilon}_{H,t,t+\tau}Y_{H,t+\tau}\right)=\frac{\varepsilon}{\varepsilon-1}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}E_t\left(D_{t,t+\tau}\bar{\Pi}^{-\epsilon\tau}\Pi^{\varepsilon}_{H,t,t+\tau}\Pi_{t,t+\tau}Y_{H,t+\tau}MC_{t+\tau}\right). \quad (A.46)$$

Ignoring the expectation term, at $t+1$ the optimal price would satisfy

$$\frac{\tilde{P}_{H,t+1}}{P_{t+1}}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t+1,t+1+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi^{\varepsilon}_{H,t+1,t+1+\tau}Y_{H,t+1+\tau}\right)$$

$$=\frac{\varepsilon}{\varepsilon-1}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t+1,t+1+\tau}\bar{\Pi}^{-\epsilon\tau}\Pi^{\varepsilon}_{H,t+1,t+1+\tau}\Pi_{t,t+\tau}Y_{H,t+1+\tau}MC_{t+1+\tau}\right). \quad (A.47)$$

By the definition, $D_{t,t+1}D_{t+1,t+\tau}=D_{t,t+\tau}$. Multiplying $\tilde{\beta}D_{t,t+1}\bar{\Pi}^{1-\varepsilon}\Pi^{\varepsilon}_{H,t+1}$ to the left hand side of the equation (A.47) yields

$$\frac{\tilde{P}_{H,t+1}}{P_{t+1}}\left(\tilde{\beta}D_{t,t+1}\bar{\Pi}^{1-\varepsilon}\Pi^{\varepsilon}_{H,t,t+1}Y_{t+1}+\tilde{\beta}^2D_{t,t,t+2}\bar{\Pi}^{2(1-\varepsilon)}\Pi^{\varepsilon}_{t,t+2}Y_{t+2}+\cdots\right) \quad (A.48)$$

and using the law of iterated expectation, the equation (A.48) can be rewritten by

$$\frac{\tilde{P}_{H,t+1}}{P_{t+1}}\sum_{\tau=0}^{\infty}\left(\tilde{\beta}^{\tau}D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{H,t+\tau}\right)-\frac{\tilde{P}_{H,t+1}}{P_{t+1}}Y_t. \tag{A.49}$$

Also, using the same method, the right hand side can be rewritten by

$$\frac{\varepsilon}{\varepsilon-1}\frac{\bar{\Pi}}{\Pi_{t,t+1}}\left[\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{-\epsilon\tau}\Pi_{H,t,t+\tau}^{\varepsilon}\Pi_{t,t+\tau}Y_{H,t+\tau}MC_{t+\tau}\right)-MC_tY_t\right]. \tag{A.50}$$

From the equality of (A.48) and (A.50), we can get the following equation.

$$\begin{aligned}&\tfrac{\tilde{P}_{H,t+1}}{P_{t+1}}\sum_{\tau=0}^{\infty}\left(\tilde{\beta}^{\tau}D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{H,t+\tau}\right)-\tfrac{\tilde{P}_{H,t+1}}{P_{t+1}}Y_t\\ &=\frac{\varepsilon}{\varepsilon-1}\left(\frac{\bar{\Pi}}{\Pi_{t,t+1}}\right)\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{-\epsilon\tau}\Pi_{H,t,t+\tau}^{\varepsilon}\Pi_{t,t+\tau}Y_{H,t+\tau}MC_{t+\tau}\right)-\frac{\varepsilon}{\varepsilon-1}\left(\frac{\bar{\Pi}}{\Pi_{t,t+1}}\right)MC_tY_t\end{aligned} \tag{A.51}$$

which can be transformed by

$$\begin{aligned}&\tfrac{\tilde{P}_{H,t+1}}{P_{t+1}}\left\{1-Y_t\left[\sum_{\tau=0}^{\infty}\left(\tilde{\beta}^{\tau}D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{H,t+\tau}\right)\right]^{-1}\right\}\\ &=\frac{\varepsilon}{\varepsilon-1}\left(\frac{\bar{\Pi}}{\Pi_{t,t+1}}\right)\frac{\tilde{P}_{H,t}}{P_t}-\frac{\varepsilon}{\varepsilon-1}\left(\frac{\bar{\Pi}}{\Pi_{t,t+1}}\right)MC_tY_t\left[\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{H,t+\tau}\right)\right]^{-1}.\end{aligned} \tag{A.52}$$

Defining $F_t=Y_t^{-1}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{H,t+\tau}\right)$, the following equation is derived.

$$\frac{\tilde{P}_{H,t}}{P_t}=F_t^{-1}\frac{\varepsilon}{\varepsilon-1}MC_t+\left(1-F_t^{-1}\right)\left(\frac{\Pi_{t+1}}{\bar{\Pi}}\right)\left(\frac{\tilde{P}_{H,t+1}}{P_{t+1}}\right). \tag{A.53}$$

This recursive form can be represented by a log-linearized equation of (A.53), which is

$$\left(\widehat{\frac{\tilde{P}_{H,t}}{P_t}}\right)=\bar{F}^{-1}\widehat{MC}_t+\left(1-\bar{F}^{-1}\right)\left(\widehat{\frac{\tilde{P}_{H,t+1}}{P_{t+1}}}+\hat{\Pi}_{t+1}\right). \tag{A.54}$$

Also, from the definition of the variable F_t,

$$F_{t+1}=Y_{t+1}^{-1}\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t+1,t+1+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+1,t+1+\tau}^{\varepsilon}Y_{t+1+\tau}\right) \tag{A.55}$$

and multiplying $\tilde{\beta}Y_t^{-1}Y_{t+1}D_{t,t+1}\bar{\Pi}^{1-\varepsilon}\Pi_{H,t+1}^{\varepsilon}$ to both sides of (A.55) yields

$$\left(\tilde{\beta}Y_t^{-1}Y_{t+1}\bar{\Pi}^{1-\varepsilon}\Pi_{H,t+1}^{\varepsilon}D_{t,t+1}\right)F_{t+1}=Y_t^{-1}\sum_{\tau=1}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{t+\tau}\right). \tag{A.56}$$

Substracting (A.56) from F_t yields

$$\begin{aligned} Y_t^{-1}\left[\sum_{\tau=0}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{t+\tau}\right)-\sum_{\tau=1}^{\infty}\tilde{\beta}^{\tau}\left(D_{t,t+\tau}\bar{\Pi}^{(1-\varepsilon)\tau}\Pi_{H,t+\tau}^{\varepsilon}Y_{t+\tau}\right)\right] &= 1 \\ F_t-\tilde{\beta}Y_t^{-1}\bar{\Pi}^{1-\varepsilon}\left(D_{t,t+1}\Pi_{H,t+1}^{\varepsilon}Y_{t+1}F_{t+1}\right) &= 1 \end{aligned}$$

which means the steady state value of F_t $(=\bar{F})$ can be derived by

$$\bar{F}=\frac{1}{1-\tilde{\beta}}=\frac{1}{1-\beta\xi}. \tag{A.57}$$

Eventually putting (A.57) and the expectation term into the equation (A.54) yields the equation (13).

A.5 Data Description

Table 6: List of Data Sources

Data	Source (code)
Output (GDP)	Datastream: KOGDP...D
Inflation (CPI)	Bank of Korea
Real Exchange Rate	Datastream: KOQCC011H
Investment	Bank of Korea
Government Spending	Datastream: KOCNGOV.D
Consumption	Datastream: KOCNPER.D
Import/Output	The World Bank Data
Export/Output	The World Bank Data
World GDP	The World Bank Data
Net Foreign Assets	The World Bank Data
Certificate Deposit rate	Datastream: KODPNNCD
Loan-Deposit Spread	The World Bank Data
Bank Balance Sheet	Financial Supervisory Service (FSS Korea)
Bailout and Recovery	Financial Services Commission (FSC Korea)

A.6 Bayesian Estimation Results

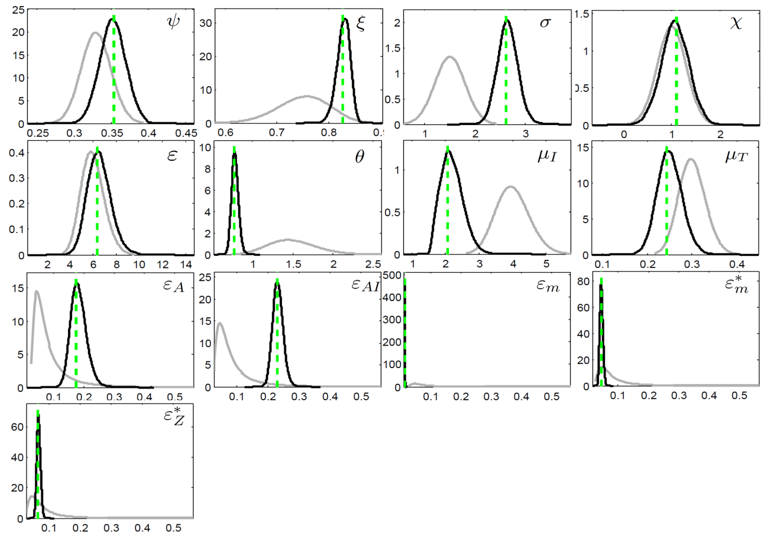

Figure 8: Prior and Posterior Distributions of Estimated Parameters

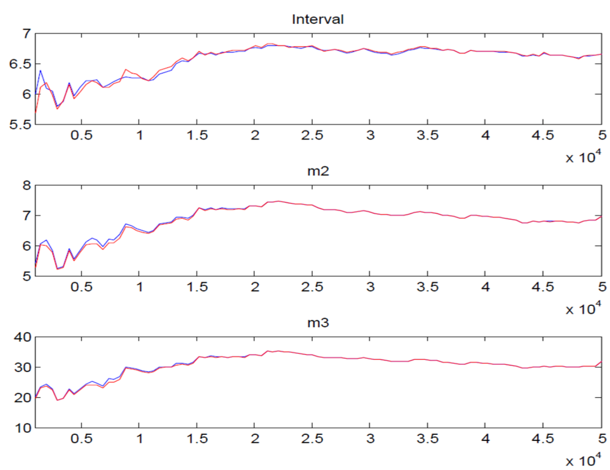

Figure 9: Multivariate MH Convergence Diagnosis