Unconventional Monetary Policy Spillover and EME Vulnerability

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Abstract

This paper develops a structural two-country DSGE model to study the spillover of both conventional and unconventional monetary policies from advanced economies to Emerging Market Economies (EMEs). I contrast the effects of conventional monetary policy, forward guidance, and quantitative easing (QE). The model reveals that both conventional and unconventional expansionary monetary policies tend to decrease asset prices while simultaneously boosting output and inflation. In contrast, QE has a comparatively mild impact on exchange rates and exerts opposing effects on capital outflows in comparison to the other policies. Additionally, I explore the optimal foreign exchange rate regime from the perspective of EME countries to minimize their vulnerability to spillover effects. My analysis highlights that under an exchange rate peg, EME nations are more significantly influenced by monetary policy spillovers from advanced economies. However, the implementation of capital controls emerges as an effective strategy for mitigating the vulnerabilities arising from foreign monetary policy spillovers.

Keywords: Unconventional monetary policy, International spillover, Financial friction,Foreign exchange rate regime

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By downplaying the adverse effects of cross-border monetary transmission of unconventional policies, we are overlooking the elephant in the post-crisis room.–Rajan (2015)

1 Introduction

Past decades featured two underlying trends in international financial landscape: firstly, financial globalization strengthens the connection between economic conditions in different countries and opens avenue for spillover effects of domestic policies. Secondly, Federal Reserve, together with other major central banks, adopted unconventional monetary policies (UMPs) when nominal interest rate hits zero lower bound (ZLB) to stimulate their economies. These measures are aimed at impacting medium and long term interest rate through asset purchasing (quantitative easing, or QE), communicating with market (forward guidance, or FG) and other means. While they were firstly proposed as temporary measure against economic crisis, "in an era of low inflation, low growth, and low interest rates, UMPs will likely remain an important contingency tool." (Bhattarai and Neely, 2022) Meanwhile, US still holds a central role in global monetary system, and its monetary policies have powerful spillover effect to the rest of the world (Miranda-Agrippino and Rey, 2015). Starting from QE1 in 2008, foreign policy makers argued that QE policies have neglected its spillover effects overseas, especially to the vulnerable emerging market economies (EMEs). However, there still lacks deep and systematic inquiries into the issue, especially how various monetary policy tools, including conventional monetary policies, QE, and FG, differ in their spillover effect, and how their spillover is impacted by exchange rate regime of EMEs. In this paper, we attempt to provide insights into these questions.

Firstly, we study the effects of US (both conventional and unconventional) monetary policy shocks on a panel of EMEs. To this end, we aggregate the US monetary policy shocks, including both conventional and UMPs, identified by high frequency methods in Swanson (2023) to compile a consecutive monthly series, and estimate a local projection regression with the shocks on a panel of EME macroeconomics indicators.

Then, we develop a two-country DSGE model to study the spillover effects of various monetary policies. Compared to standard two-country New Keynesian DSGE model, our model has three features. Firstly, we augment both countries with financial intermediaries (or banks) à la Gertler and Karadi (2011) that issue deposit to household and hold firm bonds. There are several constraints built in the model: firms have to issue bonds due to a "loan in advance" constraint; banks are restricted by an incentive constraint; and households can only hold asset indirectly through depositing in banks. As is standard to UMP literature, these constraints allow central banks to impact real economy from its bond purchasing activities, or QE. Secondly, we assume that all the firm bonds are perpetual bonds with a constant decaying rate. Following Sims and Wu (2020), we think the yield rate of long-term bond as long-term interest rate, on which QE has direct impact. Meanwhile, bank deposit of household is the short-term asset whose (nominal) interest rate is determined by central bank subject to zero lower bond (ZLB). FG is modelled as a shock to the desired nominal short-term interest rate when ZLB is already binding. Within the framework we are able to incorporate both conventional and unconventional monetary policies. Lastly, we consider a core-periphery asymmetric international financial landscape as in Banerjee et al. (2016) and Devereux et al. (2020). Specifically, we posit that banks in EMEs partially fund their assets by borrowing from core country banks. We allow the central bank in the core country to implement both conventional and unconventional monetary policies. In contrast, the EME central bank is limited to conventional monetary policies, with the options of pegging the exchange rate and imposing capital controls.

We have three major findings from model quantification. When we standardize the three shocks (conventional, QE, and FG) to generate the same stimulative impact on domestic output, we find that their spillover effects on EME are different. While the spillover effects of conventional and FG shocks are qualitatively similar, the effects of QE are substantially different. While domestically stimulative conventional and FG shocks will firstly decrease the output, inflation and deposit rate of EME before their bumping back, stimulative QE shocks will lead to an instant increase of these variables. The magnitude of peak positive response for QE is also higher than that for the other two shocks.

However, when it comes to real exchange rate, the result is reversed: FG and conventional monetary policies generate almost identical core country currency depreciation after a stimulative shocks, but QE has basically no effects on real exchange rate. Compensating for the stable exchange rate, there will be a large capital out flow from emerging countries after the initial temporary capital inflow under a stimulative QE shock, which is not observed in the IRFs to other two policies. This result agrees on both the view that UMPs do not have significant impact on exchange rate (Curcuru et al., 2023) and the concern that QE may bring about more volatility to EMEs (Rajan, 2015).

Finally, speaking of different policies adopted by EMEs, we find that pegging exchange rate will magnify the spillover effect of all MP shocks on EME output, consumption and other macroeconomic variables. While there is no substantial difference in spillover effects under core country's conventional monetary policy shocks, capital control policies stand out effectively decreasing the volatility of the economy when faced with UMP (both FG and QE) shocks compared to the baseline case.

Related Literature This paper is related and aimed to contributing to three strands of literature. Firstly, we contribute to the empirical studies on the spillover effects of UMPs in advanced economies on EMEs. There is a large empirical literature evaluating the impact of US UMPs on international financial markets, including the exchange rate between dollar and EME currency, and the yield rate of EME bonds (e.g. Bowman et al. (2015), Curcuru et al. (2023)). They analyzed the change of daily financial variables within a short window around monetary policy announcement events (e.g. FOMC). And the literature mostly agrees on that there is no significant difference between conventional MP and UMP, or between the change in short term rate and change in term premium. A smaller literature analyzed the impact of UMP shocks on macroeconomic indicators of EME like output and inflation using data of monthly frequency. To bridge the discrete nature of monetary policy announcement events and the requirement of consecutive monthly panel data, Bhattarai et al. (2021) firstly estimate QE shocks from a VAR on US monthly data with standard restrictions on covariance matrix. Bluwstein and Canova (2018) employed a mixed-frequency VAR to estimate the spillover effects of ECB UMP shocks on other countries. We combine linear projection and high-frequency identified both conventional and UMP shocks on a panel cross country data, allowing us to consistently comparing effects of various policies, and utilizing the panel feature to increase the efficiency of estimation.

Secondly, we also add to the recent effort to provide a model-based evaluation of UMP spillover effects. Jones et al. (2022) studied spillover effects of FG by literally modelling it as a shock to the duration of ZLB. Alpanda and Kabaca (2020) studied the spillover effects of QE by highlighting the portfolio balancing channel due to imperfect substitution among different types of assets. Lastly, Kyriazis (2022) built a two-country HANK model to study the spillover effect of QE on inequality. We contribute to this list by building up a two-country DSGE model with standard financial sectors á la Gertler and Karadi (2011) and asymmetric arrangements on international financial market. We also incorporate both policies into core country's central bank toolbox. Upon the unified framework we are able to compare the effects of conventional monetary policies, QE, and FG.

Lastly, as financial linkages between household, banks and wholesale firms are key to transmitting UMP shocks, we also speak to the recent thriving literature on the role of financial intermediaries on transmission of shocks in an international context. Bruno and Shin (2015) empirically evaluated the impact of US monetary policies on the liquidity and leverage of international banks. Gabaix and Maggiori (2015) studied the determination of exchange rate in an imperfect international financial market. Morelli et al. (2022) studied the role of global banks balanced sheet in sovereign debt default. In a recent paper, Du et al. (2023) explicitly measures the shadow cost of intermediary that break covered interest parity (CIP). In our model quantification, we keep track of the change in bank balanced sheets, and link them to the changes in macroeconomic variables beyond financial market in a standard model-based approach.

2 Empirical Results

3 Model

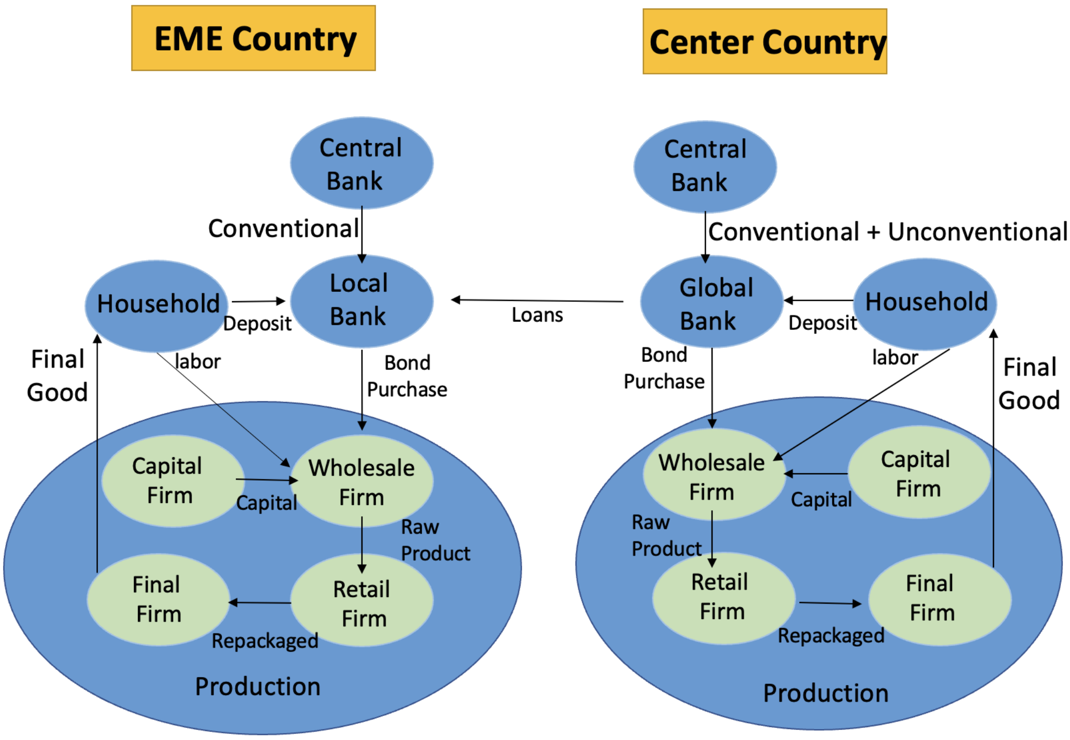
In this section, we follow Banerjee et al. (2016) to build a two-country DSGE model with long-term corporate debt, constrained financial intermediaries, asymmetric international financial market, and nominal rigidities. We use superscript 'c' to denote the center economy and 'e' to denote the periphery emerging market economy (EME). The structure of model is displayed in 1. There are four key ingredients of the model. Firstly, in each country there are banks and wholesale firms à la Gertler and Karadi (2011). Banks raise fund from household deposit and purchase long-term bond of wholesale firms, Return rates to household deposit and corporate bond correspond to short-term and long-term interest rates in reality. Secondly, the international financial market is asymmetric as banks in EME are partly funded by inter-bank loan from banks in center country. Thirdly, we assume that central bank in center country is subject to zero lower bond in setting short-term (deposit) rate but can use unconventional monetary policy tools, and lastly, we have standard price and wage rigidity with retail firms and labor unions subject to Calvo pricing constraints. Below we will firstly introduce the common setup shared by both countries, and then spell out the different setup of banks in two countries due to asymmetric financial market.

3.1 Long-term Bond

As a prelim we introduce a tractable way to model long-term bond that is pioneered by Woodford (2001) and widely used in the literature. We consider long-term bonds as perpetuities with fixed decaying coupon payments, and let $\kappa \in [0, 1]$ denote the decay parameter for coupon payments. One unit of bond issued in period t obligates the issuer to a coupon payment of one dollar in t+1, κ dollars in t+2, κ^2 dollars in t+3, and so on. Let $CF_{m,t}$ denote the new nominal issuance of the bonds at time t, and $F_{m,t-1}$ denote the total coupon liability due in period t, we have:

$$F_{m,t-1} = CF_{m,t-1} + \kappa CF_{m,t-2} + \kappa^2 CF_{m,t-3}..... \tag{3.1}$$

Figure 1: **Model Structure**



Thus, we can use $F_{m,t-1}$ as the only and sufficient state variable when considering long-term debt, and the issuance in the period t could be represented as:

$$CF_{m,t} = F_{m,t} - \kappa F_{m,t-1}$$

Moreover, let Q_t denote the price of bond newly issued in period t, then clearly in the same period, the price of bonds issued at time $t-j$ will be $\kappa^j Q_t$. Combine these prices with equation 3.1 we have

$$Q_t F_{m,t} = Q_t CF_{m,t} + \kappa Q_t CF_{m,t-1} + \kappa^2 Q_t CF_{m,t-2} + ...$$

One unit of long-term debt $F_{m,t}$ is worth Q_t in the current period, yields one unit of currency and decays to κ in the next period. Therefore, the rate of return for the long-term bond, $R_{F,t+1}$, could be written as:

$$R_{F,t+1} = \frac{1 + \kappa Q_{t+1}}{Q_t} \tag{3.2}$$

3.2 Household

There is a unit measure of households in the world, with a fraction of m living in EME country and the rest $1-m$ living in center country. Each country produces a country-specific output, and packs the outputs from two countries with a CES aggregator to a final output for consumption and investment. Home bias is present in this aggregator. Households in different countries trade a one period risk-free asset denoted in center country's currency. Besides the difference in home bias of final goods and currency denotion of the asset, the household problem is identical in two countries. And we introduce the setup of a representative EME household below. The EME household supplies labor $L^e_{s,t}$, deposits in domestic banks with amount D^e_t and trade in asset market at amount B^e_t. She receives income from labor, deposits, dividend payment of domestic firm profits, pays lump sum transfer to fund government consumption, and spends the rest to purchase final good as consumption. The preference is given by:

$$E_t \sum_{j=0}^{\infty} \beta^j \left(\ln(C^e_{t+j} - bC^e_{t+j-1}) - \frac{\chi^e \cdot (L^e_{s,t+j})^{1+\zeta}}{1+\zeta} \right)$$

where $\beta \in$ (0,1) is a discount factor and $b \in$ [0,1) is a measure of internal habit formation. χ is a scaling parameter and ζ is the inverse Frisch elasticity. Consumption C^e_t is the consumption of final good, which is a CES aggregator of domestic ($C^e_{e,t}$) and foreign goods ($C^e_{c,t}$):

$$C^e_t = \left(\upsilon^{e\frac{1}{\eta}} C_{et}^{e1-\frac{1}{\eta}} + (1-\upsilon^e)^{\frac{1}{\eta}} C_{ct}^{e1-\frac{1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

where $\eta > 0$ is the elasticity of substitution between home and foreign goods, and $\upsilon^e \geq \frac{1}{2}$ indicates the presence of home bias. And price index, measured by the price of final good in EME country, P^e_t, is:

$$P^e_t = \left(\upsilon^e P_{et}^{1-\eta} + (1-\upsilon^e) P_{ct}^{1-\eta} \right)^{\frac{1}{1-\eta}}$$

where P_{et} and P_{ct} denote price for goods produced in EME country and center country.

The budget constraint of a representative EME household is:

$$P^e_t C^e_t + S_t P^c_t B^e_t + P^e_t D^e_t = MRS^e_t L^e_{s,t} + R^c_{d,t-1} S_t P^c_{t-1} B^e_{t-1} + R^e_{d,t-1} P^e_{t-1} D^e_{t-1} + M^e_t$$

where MRS_t is the price of labor received by household from labor unions, M^e_t encompasses all the lump sum transfer including firms' profits, cash injection to bank, government expenditure, and central bank's purchase of bond. $R^c_{d,t}$ is the deposit rate in center country, $R^e_{d,t}$ is the deposit rate in EME country. S_t is the nominal exchange rate (price of center country currency). We can rewrite the budget constraint in real term as:

$$C^e_t + RER_t B^e_t + D^e_t = mrs^e_t L^e_{s,t} + RER_t R^c_{d,t-1} B^e_{t-1} \Pi_t^{c-1} + R^e_{d,t-1} D^e_{t-1} \Pi_t^{e-1} + M^e_t / P^e_t \quad (3.3)$$

where RER_t is the real exchange rate i.e. $RER_t = \frac{S_t P_t^c}{P_t^e}$.

As households manipulate their consumption, labor, and asset holdings to maximize their discounted utility subject to the budget constraint, we have the following FOCs:

$$
\begin{aligned}
B_t^e &: E_t \Lambda_{t,t+1}^e \frac{R_{d,t}^c}{\Pi_{t+1}^c} \frac{RER_{t+1}}{RER_t} = 1 \\
D_t^e &: E_t \Lambda_{t,t+1}^e \frac{R_{d,t}^e}{\Pi_{t+1}^e} = 1 \\
L_{s,t}^e &: \chi^e {L_{s,t}^e}^{\zeta} = mrs_t^e \mu_t^e
\end{aligned}
$$

where μ_t^e is the marginal utility of consumption, $\Lambda_{t,t+1}^e$ is the stochastic discount factor, defined as $\Lambda_{t,t+1}^e = \beta \frac{\mu_{t+1}^e}{\mu_t^e}$, and inflation $\Pi_{t+1}^e = \frac{P_{t+1}^e}{P_t^e}$. Essentially, as EME households could purchase two different assets, they have two Euler equations, from which we can drive the Uncovered Interest Rate Parity in real term:

$$
RER_t = \frac{R_{d,t}^c / \Pi_{t+1}^c}{R_{d,t}^e / \Pi_{t+1}^e} RER_{t+1}
$$

3.3 Production

In both countries there are four important entities in production, each subject to some special constraint and is introduce below. As the setup is the same for both countries, we will drop the superscript c or e in this subsection.

3.3.1 Wholesale Firm

In each period, the representative wholesale firm produces output $Y_{m,t}$ using physical capital K_t and labor L_t with the following production function:

$$
Y_{m,t} = A_t (u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} \tag{3.4}
$$

where A_t is TFP level and u_t is capital utilization rate. Capital is owned by the wholesale firm and follows the standard law of motion:

$$
K_{t+1} = \widehat{I}_t + (1 - \delta(u_t)) K_t \tag{3.5}
$$

where $\delta(u_t)$ is the utilization rate-dependent depreciation rate of capital which takes the following functional form:

$$
\delta(u_t) = \delta_0 + \delta_1 (u_t - 1) + \frac{\delta_2}{2} (u_t - 1)^2
$$

and $\widehat{I}_t$ is the efficient investment purchased by wholesale firm from the capital producer (which is specified below). We impose a loan-in-advance constraint on wholesale firm such that $\psi \in (0, 1)$ proportion of the investment must be funded by the issuance of new long-term debt, such that:

$$\psi P_t^k \widehat{I}_t \leq Q_t CF_{m,t} = Q_t(F_{m,t} - \kappa F_{m,t-1}) \tag{3.6}$$

where P_t^k is the price of capital (investment). Wholesale firms issue debt, invest in capital, hire labor $L_{d,t}$ at price W_t, and sell their output at price $P_{m,t}$. The nominal profit earned in the current period:

$$\Pi_{m,t} = P_{m,t} A_t (u_t K_t)^\alpha L_{d,t}^{1-\alpha} - W_t L_{d,t} - P_t^k \widehat{I}_t - F_{m,t-1} + Q_t(F_{m,t} - \kappa F_{m,t-1}) \tag{3.7}$$

Competitive in factor market, wholesale firms take prices of investment, labor, and bond as given, manipulate $L_{d,t}$, u_t, $\hat{I}_t$, and $F_{m,t}$ to maximize the present value of real profit, which is discounted by the price level P_t (specified below) and the stochastic discount factor of households, $\Gamma_{t,t+1}$, subject to the constraints in (3.5) and (3.6). The first order conditions in real terms are:

$$\begin{aligned}
w_t &= (1-\alpha) p_{m,t} A_t (u_t K_t)^\alpha L_{d,t}^{-\alpha} \\
p_t^k M_{1,t} \delta'(u_t) &= \alpha p_{m,t} (u_t K_t)^{\alpha-1} L_{d,t}^{1-\alpha} \\
p_t^k M_{1,t} &= E_t \Lambda_{t,t+1} [\alpha p_{m,t+1} A_{t+1} K_{t+1}^{\alpha-1} u_{t+1}^\alpha L_{d,t+1}^{1-\alpha} + (1 - \delta(u_{t+1})) p_{t+1}^k M_{1,t+1}] \\
Q_t M_{2,t} &= E_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} [1 + \kappa Q_{t+1} M_{2,t+1}] \\
\frac{M_{1,t} - 1}{M_{2,t} - 1} &= \psi
\end{aligned}$$

where $w_t = W_t / P_t$ is the real wage, $p_{m,t} = P_{m,t} / P_t$ is the relative price of wholesale output, and $p_t^k = P_t^k / P_t$ is the relative price of new capital. $M_{1,t} = 1 + \psi \nu_{2,t}$, and $M_{2,t} = 1 + \nu_{2,t}$ are two auxiliary variables and $\nu_{2,t}$ is the Lagrangian multiplier of loan-in-advance constraint (3.6).

3.3.2 Capital Producer

A representative capital producer transfers final output 1 on 1 to "raw" investment I_t, which is then used to generate efficient new physical capital $\widehat{I}_t$ subject to an adjustment cost $S(\cdot)$:

$$\widehat{I}_t = [1 - S(I_t / I_{t-1})] I_t \tag{3.8}$$

And the profit of the current period is

$$\Pi_{k,t} = P_t^k \left[1 - S\left(I_t/I_{t-1}\right)\right] I_t - P_t I_t$$

Similarly, capital producers manipulate their input to maximize the present value of real profit. And the FOC to the optimization problem is:

$$\begin{aligned} 1 =& p_t^k \left[1 - S\left(I_t/I_{t-1}\right) - S'\left(I_t/I_{t-1}\right) \cdot \left(I_t/I_{t-1}\right)\right] \\ &+ E_t \Lambda_{t,t+1} p_{t+1}^k S'\left(I_{t+1}/I_t\right) \cdot \left(I_{t+1}/I_t\right)^2 \end{aligned} \tag{3.9}$$

where $p_t^k = \frac{P_t^k}{P_t}$ is the relative price of capital. In this paper we will consider the standard quadratic investment adjustment cost as follows:

$$S(I_t/I_{t-1}) = \frac{\psi_K}{2}(I_t/I_{t-1} - 1)^2$$

3.3.3 Retailer and Labor Union

We follow the standard practice to model sticky price and wage setting by introducing a unit measure of retailers and labor unions into the model, who repackage the wholesale output and household labor supply into a unique variety which is then aggregated with a CES aggregator for downstream use. Details of these setups are presented in the appendix.

3.4 Banks

3.4.1 EME Banks

There is a unit measure of banks in EME countries that channel household deposit to wholesale bonds, and we follow Gertler and Karadi (2011) in modelling this sector. Let $i \in [0, 1]$ index a typical bank, it purchases domestic corporate bond $F_{i,t}^e$ and finance itself with net worth $N_{i,t}^e$, domestic deposit $D_{i,t}^e$, and inter bank loan from center country $V_{i,t}$. The balance sheet is described by the following condition:

$$Q_t^e F_{i,t}^e = N_{i,t}^e + S_t V_{i,t} + D_{i,t}^e$$

Divide both sides by P_t^e, and notice that we will discount $V_{i,t}$ by P_t^c, we could obtain the balanced sheet in real terms:

$$Q_t^e f_{i,t}^e = n_{i,t}^e + RER_t v_{i,t} + d_{i,t}^e \tag{3.10}$$

As bank accumulates the profit, the real net worth evolves as follows:

$$n_{i,t}^{e} = \frac{R_{f,t}^{e}}{\Pi_{t}^{e}} Q_{t-1}^{e} f_{i,t-1}^{e} - RER_{t} \frac{R_{v,t-1}}{\Pi_{t}^{c}} v_{i,t-1} - \frac{R_{d,t-1}^{e}}{\Pi_{t}^{e}} d_{i,t-1}^{e} \tag{3.11}$$

where $R_{F,t}^{e}$, $R_{v,t-1}$, and $R_{d,t-1}^{e}$ are respectively the nominal interest rate on long-term bond, inter bank loan, and deposit. In the equilibrium, the cost of inter bank loan will be higher than that of domestic deposit. We follow Devereux et al. (2020) to impose an ad hoc constraint such that domestic deposit cannot be larger than a fraction $\frac{\psi_D - 1}{\psi_D}$ of total liabilities, with $\psi_D \geq 1$. So the ratio of the domestic liability to foreign liability satisfies the following equation:

$$d_{i,t} = (\psi_D - 1) RER_t v_{i,t} \tag{3.12}$$

In law of motion of the net worth, we can substitute out deposit, so combing (3.10), (3.11) and (3.12) to get:

$$n_{i,t}^{e} = \left(\frac{R_{f,t}^{e}}{\Pi_{t}^{e}} - \frac{RER_{t}}{RER_{t-1}} \frac{\widetilde{R}_{v,t-1}}{\psi_D} \right) Q_{t-1}^{e} f_{i,t-1}^{e} + \frac{RER_{t}}{RER_{t-1}} \frac{\widetilde{R}_{v,t-1}}{\psi_D} n_{i,t-1}^{e}$$

where $\widetilde{R}_{v,t-1} = \left(\frac{R_{v,t-1}}{\Pi_{t}^{c}} + \frac{R_{d,t-1}^{e}}{\Pi_{t}^{e}} (\psi_D - 1) \right)$ is the average cost of fund. We assume that each period the bank has a probability σ to survive and continue operation, otherwise it quit the market and reimburse all of its net worth to households. Thus, the value function of bank, $J_{i,t}^{e}$ is given by the following recursive equation:

$$J_{i,t}^{e} = \max_{f_{i,t}^{e}, n_{i,t}^{e}} \; E_t \Lambda_{t,t+\tau}^{e} \left[(1-\sigma) n_{i,t+1}^{e} + \sigma J_{i,t+1}^{e} \right]$$

We also assume that the banker may risk absconding with θ_t^e share of the existing asset, and the following incentive compatibility constraint is imposed:

$$J_{i,t}^{e} \geq \theta_t^e Q_t^e f_{i,t}^{e} \tag{3.13}$$

Note that θ_t^e is a stochastic process and same across all EME banks. By solving the Bellman equation, we can get the first order condition to the bonds holding and envelope condition:

$$f_{i,t}^{e} : E_t \Lambda_{t,t+1}^{e} \Omega_{t+1}^{e} \left(\frac{R_{f,t+1}^{e}}{\Pi_{t+1}^{e}} - \frac{RER_{t+1}}{RER_t} \frac{\widetilde{R}_{v,t}}{\psi_D} \right) = \theta_t^e \lambda_t^e \tag{3.14}$$

$$n_{i,t}^{e} : E_t \Lambda_{t,t+1}^{e} \Omega_{t+1}^{e} \left(\frac{RER_{t+1}}{RER_t} \frac{\widetilde{R}_{v,t}}{\psi_D} \right) = (1-\lambda_t^e) \alpha_t^e \tag{3.15}$$

where λ_t^e is the Lagrange multiplier of the incentive constraint, which is positive when incentive constraint binds, indicating excess return of long-term corporate bond compared to short-term asset. Ω_{t+1}^e is the auxiliary variable satisfying:

$$\Omega_{t+1}^e = 1 - \sigma + \sigma \alpha_{t+1}^e$$

where α_t^e is the derivative of the the value function $J_{i,t}^e$ to the bank net worth $N_{i,t}^e$. Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) show that the value function is linear in net worth, so that:

$$J_{i,t}^e = \alpha_t^e N_{i,t}^e$$

This linearity allows us to aggregate continuum of banks as if the sector is inhibited with a unit measure of representative banks. Thus, we will drop the subscript i in the following expression. In each period, a fraction of $1-\sigma$ banks will quit, but the same measure of new bank will be born with initial net worth bequeathed from household. We assume that the fund infusion will be equal to δ_T of the existing asset. Therefore, the net worth of a representative bank will evolve according to the following equation:

$$N_t^e = \sigma \left[\left(\frac{R_{f,t}^e}{\Pi_t^e} - \frac{RER_t}{RER_{t-1}} \frac{\widetilde{R}_{v,t-1}}{\psi_D} \right) Q_{t-1}^e f_{t-1}^e + \frac{RER_t}{RER_{t-1}} \frac{\widetilde{R}_{v,t-1}}{\psi_D} N_{t-1}^e \right] + \delta_T Q_t^e f_{t-1}^e \tag{3.16}$$

3.4.2 Global Banks

We call banks in center country as "global banks". The basic setup of the global bank is same as EME banks except the inter bank loan is now an asset instead of liability. We assume that the inter bank loan is issued by all global banks proportional to their sizes. For a global bank indexed by $j \in [0,1]$, its balance sheet in real terms looks like the follows:

$$\frac{m}{1-m} v_{j,t} + Q_t^c f_{j,t}^c = n_{j,t}^c + d_{j,t}^c \tag{3.17}$$

And its net worth evolves as follows:

$$n_{j,t}^c = \left(\frac{R_{f,t}^c}{\Pi_t^c} - \frac{R_{d,t-1}^c}{\Pi_t^c} \right) Q_{t-1}^c f_{j,t-1}^c + \left(\frac{R_{v,t-1}}{\Pi_t^c} - \frac{R_{d,t-1}^c}{\Pi_t^c} \right) \frac{m}{1-m} v_{j,t-1} + \frac{R_{d,t-1}^c}{\Pi_t^c} n_{j,t-1}^c \tag{3.18}$$

Similarly, the bank operation is subject to no-absconding incentive constraint, but for global banks the asset includes both deposit and inter bank loans:

$$J_{i,t}^c \geq \theta_t^c \left(Q_t^c f_{i,t}^c + \frac{m}{1-m} v_t \right) \tag{3.19}$$

So the first-order conditions and envelope condition of the bank's problem are:

$$\begin{aligned} f_{j,t}^c &: E_t \Lambda_{t,t+1} \Omega_{t+1}^c \Pi_{t+1}^{c\ -1} \left(R_{f,t+1}^c - R_{d,t}^c \right) = \theta_t^c \lambda_t^c \\ V_{j,t}^c &: E_t \Lambda_{t,t+1} \Omega_{t+1}^c \Pi_{t+1}^{c\ -1} \left(R_{v,t} - R_{d,t}^c \right) = \theta_t^c \lambda_t^c \\ n_{j,t}^c &: E_t \Lambda_{t,t+1} \Omega_{t+1}^c \Pi_{t+1}^{c\ -1} R_{d,t}^c = \left(1 - \lambda_t^c\right) \alpha_t^c \end{aligned}$$

where λ_t^c is the Lagrange multiplier of the incentive constraint, and Ω_{t+1}^c is the auxiliary variable satisfying:

$$\Omega_{t+1}^c = 1 - \sigma + \sigma \alpha_{t+1}^c$$

The aggregate net worth across all global banks can be written as:

$$\begin{aligned} n_t^c =& \sigma \left[\left(\frac{R_{f,t}^c}{\Pi_t^c} - \frac{R_{d,t-1}^c}{\Pi_t^c} \right) Q_{t-1}^c f_{t-1}^c + \left(\frac{R_{v,t-1}}{\Pi_t^c} - \frac{R_{d,t-1}^c}{\Pi_t^c} \right) \frac{m}{1-m} v_{t-1} + \frac{R_{d,t-1}^c}{\Pi_t^c} n_{t-1}^c \right] \\ &+ \delta_T Q_t^c f_{t-1}^c \end{aligned} \tag{3.20}$$

3.5 Monetary Policy

We consider different monetary policy tools available to central banks in two countries. We follow Sims and Wu (2020) to incorporate conventional monetary policy, forward guidance and quantitative easing in a unified framework for center country's central bank. For EME central bank, we assume that the central bank could choose between a simple Taylor-rule conventional monetary policy regime (without ZLB) and a fixed exchange rate regime, and allow it to have capital control by imposing cost on adjustment in inter bank loan.

3.5.1 Center Country Central Bank

Central bank in center country will determine the domestic deposit rate $R_{d,t}^c$ as its conventional monetary policy. The desired policy rate, $R_{tr,t}^c$, follows an endogenous feedback rule similar to Taylor (1993):

$$\begin{aligned} \ln R_{tr,t}^c =& \rho_r \ln R_{tr,t-1}^c + (1-\rho_r) \ln R_{tr,ss}^c \\ &+ (1-\rho_r) \left[\phi_\pi \ln \Pi_t^c + \phi_y (\ln Y_t^c - \ln Y_{t-1}^c) \right] - s_r \, \varepsilon_{r,t} \end{aligned} \tag{3.21}$$

where $R_{tr,ss}^c$ is steady state values of policy rate, Π_t^c is the gross inflation rate and Y_t^c is the output. $0 < \rho_r < 1$, ϕ_π and ϕ_y are parameters satisfying Taylor principle. The policy rate adjusts in response to deviation of inflation from target and output growth from trend. $\varepsilon_{r,t}$

is conventional monetary policy shock which is independently and identically distributed (IID) with mean 0 and standard deviation 1. A positive shock represent expansionary conventional monetary policy. s_r is the standard deviation of conventional monetary policy shock. In the model, the actual deposit rate is deterined by desired policy rate as follows:

$$R^c_{d,t} = max\{1, R^c_{tr,t}\}$$

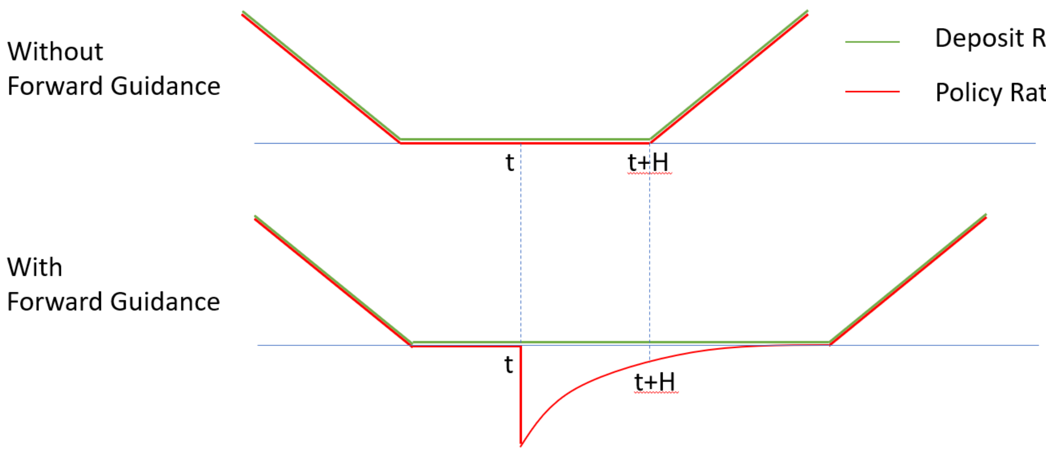
So during normal time, short run deposit rate is equal to the policy rate, while when zero lower bound binds, $R^c_{tr,t}$ can turn to negative and $R^c_{d,t}$ is equal to 0.

3.5.2 Forward Guidance

Forward guidance entails promises from a central bank about the future path of its policy rate. Some degree of forward guidance has been used as a communications tool by central banks and gained more attention recently due to the ZLB constraint on short term policy rates.

Following the idea of Sims and Wu (2020), forward guidance is modelled as a decrease of desired policy rate $R^c_{tr,t}$ by the Taylor rule during ZLB. So forward guidance will not affect on current deposit rate $R^c_{d,t}$ during ZLB, but it will keep $R^c_{d,t} = 1$ longer when it tends to come back to positive. The advantage of modeling in this way is that because of the decay due to interest smoothing ($0 < \rho_r$ <1),the change in the expected path of future deposit rate is smaller to a more standard forward guidance shock, or leave the model immune from the "forward guidance puzzle".

Figure 2: **Forward Guidance**



As shown in Figure 2, ZLB continuously binds until period t + H. If there's no forward guidance policy, deposit rate will immediately turn to positive at time t+H. While in the lower graph when central bank conducts forward guidance, policy rate becomes negative and since it follows AR(1) as (3.21), the policy rate gradually converge back to 0. So there's a period that policy rate remains negative so that it takes longer for deposit rate to be positive again.

To simulate the scenario, we use the Occbin toolkit developed by Guerrieri and Iacoviello (2015) to add ZLB, which is now incorporated in Dynare 5. We firstly impose big liquidity shocks to make policy rate negative and ZLB binding, and plot the impulse response by the difference of all variables between whether there's a forward guidance shock.

3.5.3 Quantitative Easing

Following Gertler et al. (2013), QE is interpreted as the central bank directly purchase of private issued bonds. Note that the center country corporate bond market clearing condition is:

$$f^c_{w,t} = f^c_t + f^c_{cb,t}$$

where $f^c_{w,t}$ is the total private bonds issued by wholesale firm in center country, $f_{cb,t}$ is the private bonds held by the central bank. f^c_t is the private bonds held by global bank.

Center country's QE policy shock is interpreted as central bank increasingly hold private bonds by the QE shock $\varepsilon_{f,t}$ which is drawn from standard normal distributions (with s_f denoting standard deviation of the shock). Central banks' bond holding $f_{cb,t}$ follows an AR(1) process:

$$f_{cb,t} = (1-\rho_f)f_{cb} + \rho_f f_{cb,t-1} + s_f \varepsilon_{f,t}$$

where f_{cb} is the steady state private bonds holding of the central bank. ρ_f is parameter constrained to lie between zero and one. When global banks are constrained by the incentive constraint (3.19), central bank's purchase of long term bonds not only ease the constraint, but also will push up the price of the long term bonds, which will also ease the loan-in-advance constraint in (3.6) faced by the wholesale firm. This results in higher investment and aggregate demand.

3.5.4 EME Central Bank

We assume that EME central bank is not subject to ZLB and does not conduct unconventional monetary policies. But it has two options regarding conventional monetary policies: firstly, it could set deposit rate with a standard Taylor rule as follows:

$$\ln R^e_{tr,t} = \rho_r \ln R^e_{tr,t-1} + (1-\rho_r)\ln R^e_{tr,ss} + (1-\rho_r)\left[\phi_\pi \ln \Pi^e_t + \phi_y(\ln Y^e_t - \ln Y^e_{t-1})\right] \tag{3.22}$$

and $R^e_{d,t} = R^e_{tr,t}$ always hold. Secondly, it could also manipulate the domestic short-term (deposit) interest rate to peg the nominal exchange rate between center and EME currencies. In this case, we will replace Taylor rule (3.22) with the following equation

$$RER_{t+1}\Pi^e_{t+1} = RER_t\Pi^c_{t+1} \tag{3.23}$$

3.5.5 Capital Control

Finally, we also allow EME country to conduct capital control policies, which is prevalent in many EMEs in reality. Following Chang et al. (2015), we model capital control as an ad-hoc adjustment cost imposed on EME household's portfolio choices and EME banks' inter bank loans. The new budget constraint of household and net worth movement are as follows:

$$\begin{aligned} &C^e_t + (RER_tB^e_t + D^e_t)\left(1 + \frac{\kappa_b}{2}\left(\frac{D^e_t}{RER_tB^e_t + D^e_t} - \frac{D^e_{ss}}{RER_{ss}B^e_{ss} + D^e_{ss}}\right)^2\right) \\ &= mrs^e_tL^e_{s,t} + RER_tR^c_{d,t-1}B^e_{t-1}\Pi^{c-1}_t + R^e_{d,t-1}D^e_{t-1}\Pi^{e-1}_t + M^e_t/P^e_t \end{aligned} \tag{3.24}$$

$$N^e_{i,t} = \frac{R^e_{f,t}}{\Pi^e_t}Q^e_{t-1}f^e_{i,t-1} - \widetilde{R}_{v,t-1}RER_tV_{i,t-1}\left(1 + \frac{\kappa_v}{2}\left(V_{i,t-1} - V_{ss}\right)^2\right)$$

where D^e_{ss}, B^e_{ss}, RER_{ss}, are steady state EME deposit, foreign bond holding and real exchange rate. κ_b is the coefficient controlling effectiveness of capital control; V_{ss} is the steady state amount of inter bank loan, and κ_v is the effectiveness of capital control. So it becomes costly for EME bank to adjust inter bank loan from global bank.

4 Quantitative Analysis

In this section, we firstly calibrate parameters of the model, and then compare the spillover effects of different monetary policy shocks from center country, as well as the results reflecting vulnerability under different policy regimes of EME country

4.1 Calibration

The model is solved via a linear approximation around the non-stochastic steady state with Dynare 5.4 where Occbin toolbox is incorporated to handle the ZLB constraint. Details are listed in Table 1.

Many parameters are common in macroeconomic models, and are calibrated externally following convention, especially those in Sims and Wu (2020) and Devereux et al. (2020). Three groups of parameters are calibrated internally to facilitate the computation of steady state:

Table 1: Calibrated Parameters

Parameter	Value or Target	Description
Household Preference		
β	0.995	Discount factor
b	0.7	Habit formation
η	1	Inverse Frisch elasticity
χ^e, χ^c	$L = 1$	Labor disutility scaling
ν	0.9	Degree of openness
η_p	1.5	Elasticity of substitution in final good aggregation
Bank		
σ	0.9	Intermediary survival probability
ψ_D	1.5	Fraction of domestic deposit in EME bank
δ_T	0.04	Fraction of transfer to new banks
Production		
κ	$1 - 40^{-1}$	Bond duration
ψ	0.81	Loan in advance constraint
α	0.33	Capital Intensity of Production function
ψ_K	2	Capital adjustment cost
Price and Wage Rigidity		
ϵ_p	11	Elasticity of substitution goods
ϵ_w	11	Elasticity of substitution labor
ϕ_p	0.75	Calvo price goods
ϕ_w	0.75	Calvo price wage
Monetary Policy		
ρ_r	0.8	AR(1) Taylor rule
ϕ_π	1.2	Taylor rule inflation
ϕ_y	0.25	Taylor rule output growth
Exogenous Shocks		
s_r	0.0025	SD MP shock
ρ_f	0.99	AR(1) QE
s_f	0.0025	SD QE shock
Others		
g	0.2	Government spending ratio to output
m	0.3	EME population

firstly, we manipulate δ_1 to keep steady state capital utilization rate to 1 in both countries. Secondly, we calibrate the steady state incentive constraint coefficient θ in both countries to target a steady state term premium of 3% in annual interest rate. Lastly, labor scaling factors χ's are calibrated to match steady state labor supply in both countries to be 1.

4.2 Monetary Policy Spillover

We experiment on the parameterized model by firstly looking at the impulse response functions (IRFs) of various variables to three monetary policy shocks from center country central bank. Conventional MP and QE shocks are modelled as an exogenous shock on Taylor rule and central bank's bond holding on period 5. We follow the approach of Sims and Wu (2020) to obtain IRFs of forward guidance shocks, which involves firstly imposing a large liquidity shock on center country to drive it to ZLB, and then applying a conventional MP shock in the 5th period. IRFs of forward guidance shock is determined by calculating the difference in IRFs between scenarios with only the liquidity shock and those with both the liquidity and MP shocks. We rescale the magnitude of IRFs by firstly standardizing the immediate response of deposit interest rate in center county to conventional monetary policy shock to be 1, and then manually modifying the size of IRFs of other two shocks to match the IRF of center country output. The comparison of three policies is depicted in Figure 3. Generally speaking, IRFs of conventional MP and FG shocks are similar while the IRFs of QE shocks are quite different. Intuitively, conventional and FG policies impact the economy by managing the aggregate demand through interest rate, but QE policies alleviate the credit constraints of wholesale firms and shed a direct impact on supply side. There are three things that are worth noting. Firstly, after we standardize the instant IRF of domestic output, it turns out that QE will generate a much larger spillover impact on output and investment in the EME country. If we follow the advice of Bernanke (2020) to adopt QE as a conventional policy tool for center country, it will also bring about stronger spillover effect to EMEs. Secondly, stimulative conventional MP and FG shocks ought to lower deposit rate in both center country and EME, while stimulative QE shocks will increase the deposit rate. Last but not least, while stimulative conventional MP and FG shocks will substantially decrease the real exchange rate i.e. a depreciation of real value in center country's currency, while the QE shocks have basically no impact on real exchange rate.

4.3 Foreign Exchange Rate Regime

Next we turn to the spillover effects of center country's monetary policies under different institutions of EME, namely a simple Taylor rule, pegging the real exchange rate, and capital control. Details of these institutions are already introduced above, and the IRFs of EME variables under different institutions are depicted in figure 4 - 6. There are two important observations. Firstly, pegging real interest rate will lead to much more volatile scenarios for almost all EME variables under all three center country's MP shocks compared to other two regimes. Secondly, imposing capital control in EME does not necessarily help mitigate the spillover effects of center country's MP shocks help mitigate the spillover effects of center country's conventional MP and QE shocks, especially under FG shocks.

Figure 3: IRFs under Different Monetary Policy Tools

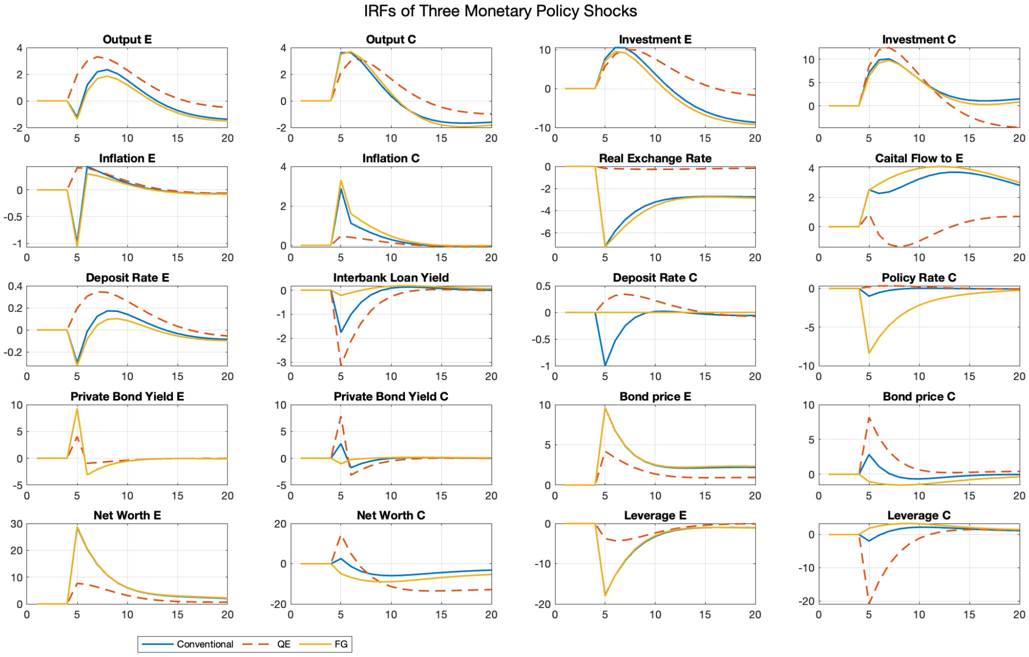


Figure 4: Regimes comparison with Conventional MP Shock

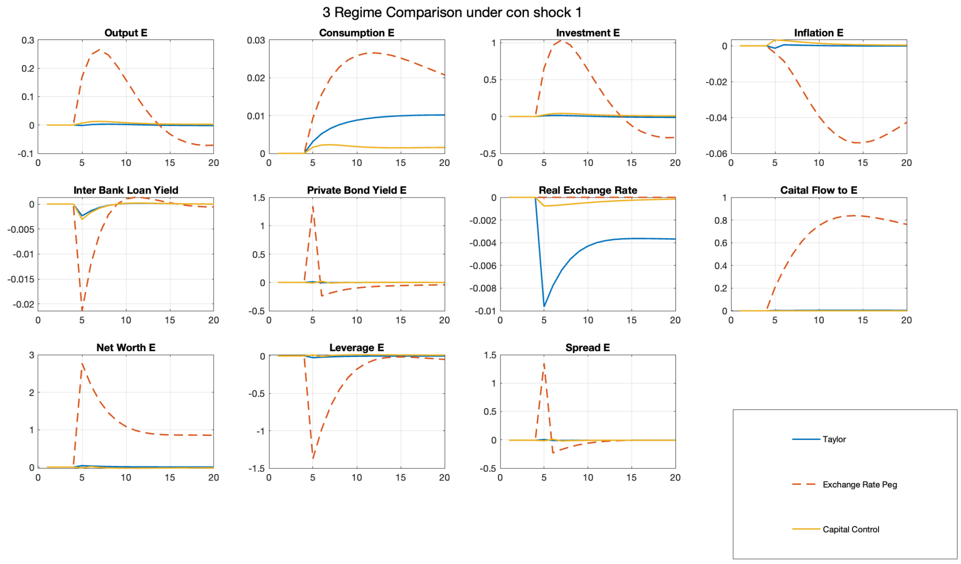
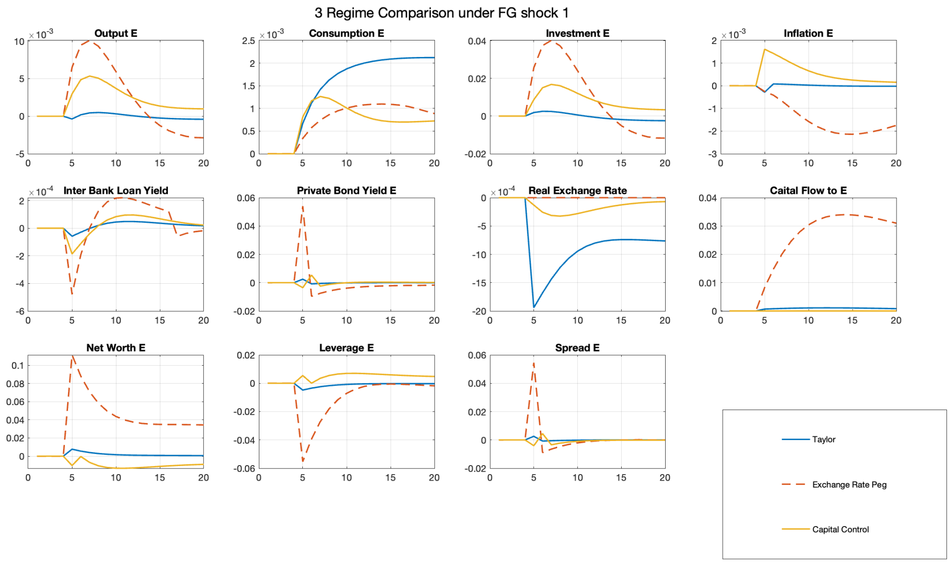


Figure 5: Regimes comparison with Forward Guidance



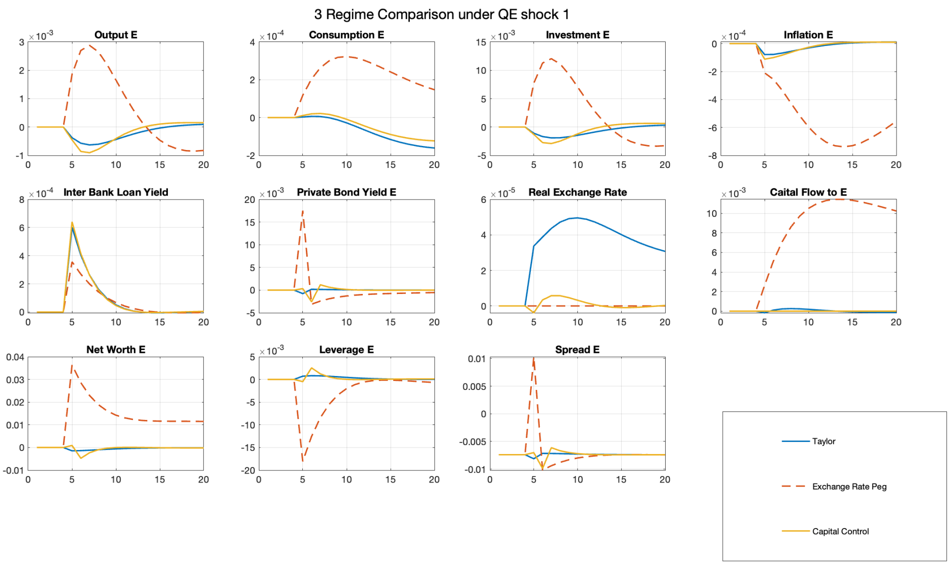
5 Conclusion

In this paper, we explore the spillover effects of three types of monetary policy shocks through the lens of empirical methods and DSGE model. In the first part, we combine the high-frequency identified shocks of conventional MP, QE, and FG with a panel data of macroeconomic indicators of EME countries to run a linear projection.

We build a two-country new Keynesian DSGE model with financial intermediaries in both countries that are linked by asymmetric setup of inter-bank loans, which opens new avenues for spillover effects other than the classical trade channel. Employing the model, we find that the spillover effect of QE shock is substantially different from the other two, as it has a stronger impact on output and investment, the opposite impact on deposit rate, and basically no impact on real exchange rate. In an era of normalizing QE policies, these findings shed light on the international impact of such policy paradigm transition.

We also compare the spillover effects under different policy regimes in EME country. We find that pegging real exchange rate will lead to large volatility, and capital control policy not necessarily helps mitigate the spillover effects.

Figure 6: Regimes comparison with QE



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A Setup of Sticky Price and Sticky Wage

We follow the standard practice to model sticky price and wage setting à la Calvo (1983). In each country there is a unit measure of retail firms each transfers the wholesale output 1 on 1 to a unique variety of goods that is aggregated with CES aggregator to be the (country-specific) final good. The continuum of firms are faced with a Calvo-type price rigidity when setting price for their goods. For an individual firm $\omega \in [0,1]$ in country $r = c, e$, we have its demand $Y_{r,t}(\omega)$ as a function of its own price $P_t(\omega)$, aggregate price level (of all its monopolistic competitors in the country) $P_{r,t}$ and aggregate demand $Y_{r,t}$

$$Y_{r,t}(\omega) = \left(\frac{P_{r,t}(\omega)}{P_{r,t}}\right)^{-\epsilon_p} Y_{r,t} \tag{A.1}$$

where $\epsilon_p > 1$ is the elasticity of substitution among varieties, and $P_{r,t} = (\int_0^1 P_{r,t}(\omega)^{1-\epsilon_p} d\omega)^{\frac{1}{1-\epsilon_p}}$ is the price index. The profit of a retail firm is:

$$\Pi_{r,t}(\omega) = P_{r,t}(\omega)Y_{r,t}(\omega) - P_{m,t}Y_{m,t}(\omega)$$

Substitute in the demand curve (A.1), we will have:

$$\Pi_{r,t}(P^*_{r,t}(\omega)) = P^*_{r,t}(\omega)^{1-\epsilon_p} P^{\epsilon_p}_{r,t} Y_{r,t} - P_{m,t}P^*_{r,t}(\omega)^{-\epsilon_p} P^{\epsilon_p}_{r,t} Y_{r,t}$$

In each period, each individual firm cannot change its price in the last period unless it got a lottery of probability $(1 - \phi_p)$. Given the chance, the firm will sets its nominal price P^*_{rt} to maximize the discounted real value of profit:

$$\max_{P^*_{rt}} E_t \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \frac{\Pi_{r,t+j}(P^*_{r,t})}{P_{t+j}}$$

The first order condition for this problem indicates that:

$$P^*_{rt} = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{E_t \sum_j \phi_p^j \Lambda_{t,t+j} p_{m,t+j} P^{\varepsilon_p}_{r,t+j} Y_{r,t+j}}{E_t \sum_j \phi_p^j \Lambda_{t,t+j} P^{\varepsilon_p}_{r,t+j} P^{-1}_{t+j} Y_{r,t+j}}$$

Following Sims and Wu (2020), we use the following notation to define the infinite summation on RHS as:

$$\text{Numerator: } X_{1,t} = p_{mt} P^{\varepsilon_p}_{rt} Y_{rt} + \phi_p \Lambda_{t,t+1} X_{1,t+1}$$
$$\text{Denominator: } X_{2,t} = P^{\varepsilon_p}_{rt} P^{-1}_t Y_{rt} + \phi_p \Lambda_{t,t+1} X_{2,t+1}$$

We define $x_{1,t} = X_{1,t}/P_{rt}^{\varepsilon_p}$, and $x_{2t} = X_{2,t}/(P_{rt}^{\varepsilon_p} P_t^{-1})$ (note that, these "real term" auxiliary variables are discounted by different factors, where P_t stands for price of final good, which will be P_t^e or P_t^c in the full model). Then we can rewrite the above equations as follows:

$$
\begin{aligned}
x_{1,t} &= p_{m,t} Y_{r,t} + \phi_p \Lambda_{t,t+1} (\Pi_{t+1}^{ppi})^{\epsilon_p} x_{1,t+1} \\
x_{2,t} &= Y_t + \phi_p \Lambda_{t,t+1} (\Pi_{t+1}^{ppi})^{\epsilon_p} \Pi_{t+1}^{-1} x_{2,t+1} \\
p_{rt}^* &= \frac{\epsilon_p}{\epsilon_p - 1} \frac{x_{1,t}}{x_{2,t}}
\end{aligned}
$$

where $\Pi_{t+1}^{ppi} = \frac{P_{r,t+1}}{P_{rt}}$ denotes the PPI inflation, which is the change of nominal country-specific output price, and $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ is the inflation of final good price index in country r. Note that given the monopolistic competition nature of technology, there will be a loss due to firm markup. Following the convention of literature, we assume that the government sets a fixed rate subsidy to retail firms funded by lump sum transfer to eliminate that markup. Thus, the last line of equation will be

$$
p_{rt}^* = \frac{x_{1,t}}{x_{2,t}}
$$

in equilibrium. The country-specific good price index P_{rt}, and its dispersion v_{pt}^r evolves as follows:

$$
\begin{aligned}
P_{rt}^{1-\varepsilon_p} &= (1-\phi_p)(P_{rt}^*)^{1-\varepsilon_p} + \phi_p P_{r,t-1}^{1-\varepsilon_p} \\
\Rightarrow 1 &= (1-\phi_p)(\frac{p_{rt}^*}{p_{rt}}) + \phi_p (\Pi_t^{ppi})^{\varepsilon_p - 1} \\
v_{pt}^r &= \int_0^1 (\frac{P_{rt}(\omega)}{P_{rt}})^{-\varepsilon_p} d\omega = (1-\phi_p)(\frac{P_{rt}^*}{P_{rt}})^{-\varepsilon_p} + \int_0^{\phi_p} (\frac{P_{r,t-1}(\omega)}{P_{rt}})^{-\varepsilon_p} d\omega \\
\Rightarrow v_{pt}^r &= (1-\phi_p)(\frac{p_{rt}^*}{p_{rt}})^{-\varepsilon_p} + \phi_p (\Pi_t^{ppi})^{\varepsilon_p} v_{p,t-1}^r
\end{aligned}
$$

A new term emerges: $p_{r,t}$, which is the relative price of country-specific good to the country's final good bundle, and a key complication and departure from closed economy NK model.

Similarly, we assume that there is a unit measure of labor unions that purchase labor from household at price MRS_t and repackage it to a unique variety of labor service which is aggregated in a CES aggregator to form a composite labor hired by wholesale firms at price W_t, and all the labor unions draw a lottery to determine whether they can change their individual prices (wages). To save notations, we do not include $W_t^{\varepsilon_w}$ in the discount factors for auxiliary variables, instead we take $F_{1,t} = f_{1,t}/P_t^{\varepsilon_w}$ and $f_{2,t} = F_{2,t}/P_t^{\varepsilon_w - 1}$. In the end of the day, we will have the following FOCs in real terms:

$$w_t^* = \frac{f_{1t}}{f_{2t}} \quad \text{with proper subsidy}$$
$$f_{1t} = mrs_t w_t^{\epsilon_w} L_{dt} + \phi_w \Lambda_{t,t+1} (\Pi_{t+1})^{\epsilon_w} f_{1,t+1}$$
$$f_{2t} = w_t^{\epsilon_w} L_{dt} + \phi_w \Lambda_{t,t+1} (\Pi_{t+1})^{\epsilon_w - 1} f_{1,t+1}$$

where ϵ_w is the elasticity of substitution among labor varieties. Similarly, we have the following intertemporal movement of wage level and dispersion:

$$1 = (1-\phi_w)(\frac{w_t^*}{w_t})^{1-\varepsilon_w} + \phi_w \Pi_t^{\varepsilon_w - 1} (\frac{w_t}{w_{t-1}})^{\varepsilon - 1}$$
$$v_{wt}^r = (1-\phi_p)(\frac{w_t^*}{w_t})^{-\varepsilon_w} + \phi_w (\frac{w_t}{w_{t-1}})^{\varepsilon_w} v_{w,t-1}^r$$

B Full list of equations used in the simulation

Essentially, below we have

Households Define SDF:

$$\Lambda_t^e = \beta \frac{\mu_t^e}{\mu_{t-1}^e} \tag{B.1}$$
$$\Lambda_t^c = \beta \frac{\mu_t^c}{\mu_{t-1}^c} \tag{B.2}$$

Marginal Utility:

$$\mu^e = (C_t^e - b\ C_{t-1}^e)^{-1} - \beta\ b\ (C_{t+1}^e - C_t^e)^{-1} \tag{B.3}$$
$$\mu^c = (C_t^c - b\ C_{t-1}^c)^{-1} - \beta\ b\ (C_{t+1}^c - C_t^c)^{-1} \tag{B.4}$$

Labor supply:

$$\chi^e {L_{s,t}^e}^\zeta = mrs_t^e \mu_t^e \tag{B.5}$$
$$\chi^c {L_{s,t}^c}^\zeta = mrs_t^c \mu_t^c \tag{B.6}$$

Euler Equation, EME country has two Euler equation since households in EME country can choose either depositing in local bank or purchasing bond from center country:

$$1 = R_{d,t}^e \Lambda_{t+1}^e (\Pi_{t+1}^e)^{-1} \tag{B.7}$$
$$1 = R_{d,t}^c \Lambda_{t+1}^e RER_{t+1} / (RER_t \Pi_{t+1}^c) \tag{B.8}$$
$$1 = R_{d,t}^c \Lambda_{t+1}^c {\Pi_{t+1}^c}^{-1} \tag{B.9}$$

Banks For financial intermediaries, FOC to bonds holding of EME country:

$$\Lambda^e_{t+1}\Omega^e_{t+1}\left(\frac{R^e_{f,t+1}}{\Pi^e_{t+1}} - \frac{RER_{t+1}}{RER_t}\frac{\widetilde{R}_{v,t}}{\psi_D}\right) = \theta^e_t\lambda^e_t \tag{B.10}$$

Envelop condition(FOC to net worth) of the intermediaries is:

$$\Lambda^e_{t+1}\Omega^e_{t+1}\left(\frac{RER_{t+1}}{RER_t}\frac{\widetilde{R}_{v,t}}{\psi_D}\right) = (1-\lambda^e_t)\alpha^e_t \tag{B.11}$$

Define the auxiliary variable Ω is:

$$\Omega^e_{t+1} = 1 - \sigma + \sigma\alpha^e_{t+1} \tag{B.12}$$

Incentive constraint faced by intermediary is:

$$(\alpha^e_t N^e_t - \theta^e_t Q^e_t f^e_t)\lambda^e_t = 0 \tag{B.13}$$

Net worth evolvement is:

$$N^e_t = \sigma\left[\left(\frac{R^e_{f,t}}{\Pi^e_t} - \frac{RER_t}{RER_{t-1}}\frac{\widetilde{R}_{v,t-1}}{\psi_D}\right)Q^e_{t-1}f^e_{t-1} + \frac{RER_t}{RER_{t-1}}\frac{\widetilde{R}_{v,t-1}}{\psi_D}N^e_{t-1}\right] + \delta_T Q^e_t f^e_{t-1} \tag{B.14}$$

Balance sheet of local bank is:

$$Q^e_t f^e_t = N^e_t + RER_t V_t + D^e_t \tag{B.15}$$

Definition of $\widetilde{R}_{v,t}$ is:

$$\widetilde{R}_{v,t} = \left(\frac{R_{v,t}}{\Pi^c_{t+1}} + \frac{R^e_{d,t}}{\Pi^e_{t+1}}(\psi_D - 1)\right) \tag{B.16}$$

Leverage ratio is defined as:

$$\phi^e_t = \frac{Q^e_t f^e_t}{N^e_t} \tag{B.17}$$

First order conditions to bond holding f^c_t and interbank loan holding V^c_t

$$\Lambda^c_{t+1}\Omega^c_{t+1}{\Pi^c_{t+1}}^{-1}\left(R^c_{f,t+1} - R^c_{d,t}\right) = \theta^c_t\lambda^c_t \tag{B.18}$$

$$\Lambda^c_{t+1}\Omega^c_{t+1}{\Pi^c_{t+1}}^{-1}\left(R_{v,t} - R^c_{d,t}\right) = \theta^c_t\lambda^c_t \tag{B.19}$$

Envelop condition of global bank is:

$$\Lambda^c_{t+1}\Omega^c_{t+1}{\Pi^c_{t+1}}^{-1}R^c_{d,t} = (1-\lambda^c_t)\,\alpha^c_t \tag{B.20}$$

Net worth movement of global bank is:

$$\begin{aligned} N^c_t =& \sigma\left[\left(\frac{R^c_{f,t}}{\Pi^c_t} - \frac{R^c_{d,t-1}}{\Pi^c_t}\right)Q^c_{t-1}f^c_{t-1} + \left(\frac{R_{v,t-1}}{\Pi^c_t} - \frac{R^c_{d,t-1}}{\Pi^c_t}\right)\frac{m}{1-m}V_{t-1} + \frac{R^c_{d,t-1}}{\Pi^c_t}N^c_{t-1}\right] \\ & + \delta_T Q^c_t f^c_{t-1} \end{aligned} \tag{B.21}$$

Incentive constraint global bank is facing is:

$$\left(\alpha_t^c N_t^c - \theta_t^c \left(Q_t^c f_t^c + \frac{m}{1-m} V_t\right)\right) \lambda_t^c = 0 \tag{B.22}$$

Definition for auxiliary variable Ω_t^c is:

$$\Omega_t^c = 1 - \sigma + \sigma \alpha_t^c \tag{B.23}$$

Balance sheet for global bank is:

$$\frac{m}{1-m} V_t + Q_t^c f_t^c = N_t^c + D_t^c \tag{B.24}$$

Define the leverage ratio of global bank:

$$\phi_t^c = \left(\frac{m}{1-m} V_t + Q_t^c f_t^c\right) / N_t^c \tag{B.25}$$

Domestic deposit constraint:

$$D_t^e = (\psi_D - 1) RER_t V_t \tag{B.26}$$

Wholesale Firms Wholesale firm FOCs on labor:

$$w_t^e = (1-\alpha) p_{m,t}^e A_t^e (u_t^e K_{t-1}^e)^\alpha {L_{d,t}^e}^{-\alpha} \tag{B.27}$$

$$w_t^c = (1-\alpha) p_{m,t}^c A_t^c (u_t^c K_{t-1}^c)^\alpha {L_{d,t}^c}^{-\alpha} \tag{B.28}$$

First order condition to capital utilization for wholesales firms are:

$$p_t^{k,e} M_{1,t}^e (\delta_1 + \delta_2 (u_t^e - 1)) = \alpha p_{m,t}^e A_t^e (u_t^e K_{t-1}^e)^{\alpha-1} {L_{d,t}^e}^{1-\alpha} \tag{B.29}$$

$$p_t^{k,c} M_{1,t}^c (\delta_1 + \delta_2 (u_t^c - 1)) = \alpha p_{m,t}^c A_t^c (u_t^c K_{t-1}^c)^{\alpha-1} {L_{d,t}^c}^{1-\alpha} \tag{B.30}$$

First order condition to capital for wholesale firms are:

$$\begin{aligned} p_t^{k,e} M_{1,t}^e =& \Lambda_{t+1}^e [\alpha p_{m,t+1}^e A_{t+1}^e {K_t^e}^{\alpha-1} {u_{t+1}^e}^{\alpha} {L_{d,t+1}^e}^{1-\alpha} \\ &+ (1 - \delta(u_{t+1}^e)) p_{t+1}^{k,e} M_{1,t+1}^e] \end{aligned} \tag{B.31}$$

$$\begin{aligned} p_t^{k,c} M_{1,t}^c =& \Lambda_{t+1}^c [\alpha p_{m,t+1}^c A_{t+1}^c {K_t^c}^{\alpha-1} {u_{t+1}^c}^{\alpha} {L_{d,t+1}^c}^{1-\alpha} \\ &+ (1 - \delta(u_{t+1}^c)) p_{t+1}^{k,c} M_{1,t+1}^c] \end{aligned} \tag{B.32}$$

where $\delta(u_t)$ satisfies $\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \frac{\delta_2}{2}(u_t - 1)^2$. First order condition to the bonds issued is:

$$Q_t^e M_{2,t}^e = \Lambda_{t+1}^e {\Pi_{t+1}^e}^{-1} [1 + \kappa Q_{t+1}^e M_{2,t+1}^e] \tag{B.33}$$

$$Q_t^c M_{2,t}^c = \Lambda_{t+1}^c {\Pi_{t+1}^c}^{-1} [1 + \kappa Q_{t+1}^c M_{2,t+1}^c] \tag{B.34}$$

and $M_{1,t}$, $M_{2,t}$ satisfy

$$\frac{M_{1,t}^e - 1}{M_{2,t}^e - 1} = \psi \tag{B.35}$$

$$\frac{M_{1,t}^c - 1}{M_{2,t}^c - 1} = \psi \tag{B.36}$$

Production functions for wholesale firms are:

$$Y^e_{m,t} = A^e_t(u^e_t K^e_{t-1})^\alpha {L^e_{d,t}}^{1-\alpha} \tag{B.37}$$

$$Y^c_{m,t} = A^c_t(u^c_t K^c_{t-1})^\alpha {L^c_{d,t}}^{1-\alpha} \tag{B.38}$$

Loan in advance constraints faced by the wholesale firms are:

$$\psi p^{k,e}_t \widehat{I}^e_t = Q^e_t(f^e_{m,t} - \kappa f^e_{m,t-1}{\Pi^e_t}^{-1}) \tag{B.39}$$

$$\psi p^{k,c}_t \widehat{I}^c_t = Q^e_t(f^c_{m,t} - \kappa f^c_{m,t-1}{\Pi^c_t}^{-1}) \tag{B.40}$$

Capital Producers Capital investment with adjustment cost:

$$\widehat{I}^e_t = \left(1 - \frac{\psi_k}{2}\left(\frac{I^e_t}{I^e_{t-1}} - 1\right)^2\right) I^e_t \tag{B.41}$$

$$\widehat{I}^c_t = \left(1 - \frac{\psi_k}{2}\left(\frac{I^c_t}{I^c_{t-1}} - 1\right)^2\right) I^c_t \tag{B.42}$$

First order condition for capital producing firm:

$$\begin{aligned} 1 =& p^{k,e}_t \left(1 - \frac{\psi_k}{2}\left(\frac{I^e_t}{I^e_{t-1}} - 1\right)^2 - \psi_k\left(\frac{I^e_t}{I^e_{t-1}} - 1\right)\frac{I^e_t}{I^e_{t-1}}\right) \\ &+ \Lambda_{t+1} p^{k,e}_{t+1}\psi^e_k \left(\frac{I^e_t}{I^e_{t-1}} - 1\right)\left(\frac{I^e_t}{I^e_{t-1}}\right)^2 \end{aligned} \tag{B.43}$$

$$\begin{aligned} 1 =& p^{k,c}_t \left(1 - \frac{\psi_k}{2}\left(\frac{I^c_t}{I^c_{t-1}} - 1\right)^2 - \psi_k\left(\frac{I^c_t}{I^c_{t-1}} - 1\right)\frac{I^c_t}{I^c_{t-1}}\right) \\ &+ \Lambda_{t+1} p^{k,c}_{t+1}\psi^c_k \left(\frac{I^c_t}{I^c_{t-1}} - 1\right)\left(\frac{I^c_t}{I^c_{t-1}}\right)^2 \end{aligned} \tag{B.44}$$

Capital accumulation for two countries are:

$$K^e_t = \widehat{I}^e_t + (1 - \delta(u^e_t))K^e_{t-1} \tag{B.45}$$

$$K^c_t = \widehat{I}^c_t + (1 - \delta(u^c_t))K^c_{t-1} \tag{B.46}$$

Stickiness Routines Wage setting,EME country:

$$w^{*e}_t = \frac{f^e_{1,t}}{f^e_{2,t}} \tag{B.47}$$

$$f^e_{1,t} = mrs^e_t(w^e_t)^{\epsilon_w} L^e_{d,t} + \phi_w \Lambda^e_{t+1}(\Pi^e_{t+1})^{\epsilon_w} f^e_{1,t+1} \tag{B.48}$$

$$f^e_{2,t} = (w^e_t)^{\epsilon_w} L^e_{d,t} + \phi_w \Lambda^e_{t+1}(\Pi^e_{t+1})^{\epsilon_w - 1} f^e_{2,t+1} \tag{B.49}$$

Center country:

$$w^{*c}_t = \frac{f^c_{1,t}}{f^c_{2,t}} \tag{B.50}$$

$$f^c_{1,t} = mrs^c_t w^{c\epsilon_w}_t L^c_{d,t} + \phi_w \Lambda^c_{t+1}(\Pi^c_{t+1})^{\epsilon_w} f^c_{1,t+1} \tag{B.51}$$

$$f^c_{2,t} = w^{c\epsilon_w}_t L^c_{d,t} + \phi_w \Lambda^c_{t+1}(\Pi^c_{t+1})^{\epsilon_w - 1} f^c_{2,t+1} \tag{B.52}$$

Retail firms price setting problem for EME country is:

$$p_t^{*e} = \frac{x_{1,t}^e}{x_{2,t}^e} \tag{B.53}$$

$$x_{1,t}^e = p_{m,t}^e Y_t^e + \phi_p \Lambda_{t+1}^e (\Pi_{t+1}^{ppi,e})^{\epsilon_p} x_{1,t+1}^e \tag{B.54}$$

$$x_{2,t}^e = Y_t^e + \phi_p \Lambda_{t+1}^e (\Pi_{t+1}^{ppi,e})^{\varepsilon_p} (\Pi_{t+1}^e)^{-1} x_{2,t+1}^e \tag{B.55}$$

Center country price setting problem is identical to EME country:

$$p_t^{*c} = \frac{x_{1,t}^c}{x_{2,t}^c} \tag{B.56}$$

$$x_{1,t}^c = p_{m,t}^c Y_t^c + \phi_p \Lambda_{t+1}^c (\Pi_{t+1}^{ppi,c})^{\epsilon_p} x_{1,t+1}^c \tag{B.57}$$

$$x_{2,t}^c = Y_t^c + \phi_p \Lambda_{t+1}^c (\Pi_{t+1}^{ppi,c})^{\varepsilon_p} (\Pi_{t+1}^c)^{-1} x_{2,t+1}^c \tag{B.58}$$

Inflation dynamics with resetting price:

$$1 = (1-\phi_p)\left(\frac{p_{et}^*}{p_{et}}\right)^{1-\epsilon_p} + \phi_p (\Pi_t^{ppi,e})^{\epsilon_p - 1} \tag{B.59}$$

$$1 = (1-\phi_p)\left(\frac{p_{ct}^*}{p_{ct}}\right)^{1-\epsilon_p} + \phi_p (\Pi_t^{ppi,c})^{\epsilon_p - 1} \tag{B.60}$$

Price dispersion dynamics is:

$$v_{p,t}^e = (1-\phi_p)(\frac{p_{et}^*}{p_{et}})^{-\epsilon_p} + \phi_p (\Pi_t^{ppi,e})^{\epsilon_p} v_{p,t-1}^e \tag{B.61}$$

$$v_{p,t}^c = (1-\phi_p)(\frac{p_{ct}^*}{p_{ct}})^{-\epsilon_p} + \phi_p (\Pi_t^{ppi,c})^{\epsilon_p} v_{p,t-1}^c \tag{B.62}$$

Aggregate output with dispersion:

$$Y_{m,t}^e = Y_t^e v_{p,t}^e \tag{B.63}$$

$$Y_{m,t}^c = Y_t^c v_{p,t}^c \tag{B.64}$$

Wage dynamics is:

$$w_t^{e\,1-\epsilon_w} = (1-\phi_w)(w_t^{*e})^{1-\epsilon_w} + \phi_w (\Pi_t^e)^{\epsilon_w - 1} w_{t-1}^e{}^{1-\epsilon_w} \tag{B.65}$$

$$w_t^{c\,1-\epsilon_w} = (1-\phi_w)(w_t^{*c})^{1-\epsilon_w} + \phi_w (\Pi_t^c)^{\epsilon_w - 1} w_{t-1}^c{}^{1-\epsilon_w} \tag{B.66}$$

Wage dispersion:

$$v_{w,t}^e = (1-\phi_w)\left(\frac{w_t^{*e}}{w_t^e}\right)^{-\epsilon_w} + \phi_w (\Pi_t^e)^{\epsilon_w}\left(\frac{w_t^e}{w_{t-1}^e}\right)^{\epsilon_w} v_{w,t-1}^e \tag{B.67}$$

$$v_{w,t}^c = (1-\phi_w)\left(\frac{w_t^{*c}}{w_t^c}\right)^{-\epsilon_w} + \phi_w (\Pi_t^c)^{\epsilon_w}\left(\frac{w_t^c}{w_{t-1}^c}\right)^{\epsilon_w} v_{w,t-1}^c \tag{B.68}$$

Labor market clearing condition:

$$L_{s,t}^e = L_{d,t}^e v_{w,t}^e \tag{B.69}$$

$$L_{s,t}^c = L_{d,t}^c v_{w,t}^c \tag{B.70}$$

CPI inflation and PPI inflation are connected by:

$$p_{et}\ \Pi_t^e = p_{e,t-1}\ \Pi_t^{ppi,e} \tag{B.71}$$

$$P_{ct}\ \Pi_t^c = p_{c,t-1}\ \Pi_t^{ppi,c} \tag{B.72}$$

Monetary Policies For central bank, we first consider EME country follows taylor rule with flexible exchange rate and free capital flow:

$$\begin{aligned}\ln R^c_{tr,t} =& \rho_r \ln R^c_{tr,t-1} + (1-\rho_r)\ln R^c_{tr,ss} \\ & + (1-\rho_r)\left[\phi_\pi \ln \Pi_t^c + \phi_y(\ln Y_t^c - \ln Y_{t-1}^c)\right] - s_r\,\varepsilon_{r,t}\end{aligned} \tag{B.73}$$

$$\ln R^e_{tr,t} = \rho_r \ln R^e_{tr,t-1} + (1-\rho_r)\ln R^e_{tr,ss} + (1-\rho_r)\left[\phi_\pi \ln \Pi_t^e + \phi_y(\ln Y_t^e - \ln Y_{t-1}^e)\right] \tag{B.74}$$

Private holdings of central bank:

$$f^e_{cb,t} = (1-\rho_f) f^{ss}_{cb} + \rho_f f^e_{cb,t-1} + s_f \varepsilon^e_{f,t} \tag{B.75}$$

$$f^c_{cb,t} = (1-\rho_f) f^{ss}_{cb} + \rho_f f^c_{cb,t-1} + s_f \varepsilon^c_{f,t} \tag{B.76}$$

Deposit rate is equal to policy rate without binding ZLB:

$$R^e_{d,t} = R^e_{tr,t} \tag{B.77}$$

$$R^c_{d,t} = R^c_{tr,t} \tag{B.78}$$

Market Clearing, Long-Term bonds, and Others Define private bond rate with the bond price:

$$R^e_{f,t} = \frac{1+\kappa Q_t^e}{Q^e_{t-1}} \tag{B.79}$$

$$R^c_{f,t} = \frac{1+\kappa Q_t^c}{Q^c_{t-1}} \tag{B.80}$$

Define long-term bonds:

$$R^e_{L,t} = \frac{1}{Q_t^e} + \kappa \tag{B.81}$$

$$R^c_{L,t} = \frac{1}{Q_t^c} + \kappa \tag{B.82}$$

Amount of government spending with total output is:

$$G_t^e = g p_t^e Y_t^e \tag{B.83}$$

$$G_t^c = g p_t^c Y_t^c \tag{B.84}$$

Aggregate price indexes:

$$1 = \nu^e {p_{et}}^{1-\eta_p} + (1-\nu^e)\left(p_{ct} RER_t\right)^{1-\eta_p} \tag{B.85}$$

$$1 = \nu^c {p_{ct}}^{1-\eta_p} + (1-\nu^c)\left(\frac{p_{et}}{RER_t}\right)^{1-\eta_p} \tag{B.86}$$

Private bond market clearing condition:

$$f_{w,t}^e = f_t^e + f_{cb,t}^e \tag{B.87}$$

$$f_{w,t}^c = f_t^c + f_{cb,t}^c \tag{B.88}$$

Aggregate demand for domestic and foreign goods:

$$Y_t^e = \nu^e {p_{et}}^{-\eta_p}(C_t^e + I_t^e + G_t^e) + (1-\nu^c)\left(\frac{1-m}{m}\right)\left(\frac{p_{et}}{RER_t}\right)^{-\eta_p}(C_t^c + I_t^c + G_t^c) \tag{B.89}$$

$$Y_t^c = (1-\nu^e)\left(\frac{m}{1-m}\right)(p_{ct}RER_t)^{-\eta_p}(C_t^e + I_t^e + G_t^e) + \nu^c {p_{ct}}^{-\eta_p}(C_t^c + I_t^c + G_t^c) \tag{B.90}$$

Exogenous Variables Productivity follows AR(1) process that:

$$\log A_t^e = \rho_A \log A_{t-1}^e + s_A \varepsilon_{A,t}^e \tag{B.91}$$

$$\log A_t^c = \rho_A \log A_{t-1}^c + s_A \varepsilon_{A,t}^c \tag{B.92}$$

Liquidity condition follows AR(1) process that:

$$\log\, \theta_t^e = (1-\rho_\theta)\log\, \theta_{ss} + \rho_\theta \log\, \theta_{t-1}^e + s_\theta \varepsilon_{\theta,t}^e \tag{B.93}$$

$$\log\, \theta_t^c = (1-\rho_\theta)\log\, \theta_{ss} + \rho_\theta \log\, \theta_{t-1}^c + s_\theta \varepsilon_{\theta,t}^c \tag{B.94}$$

C Steady State

In the steady state, we assume that $A^e = A^c = 1$. As there is no shock, price rigidity makes no difference, and all the stickiness routines could be pinned down as

$$p_e^* = p_m^e = p_e; \quad p_c^* = p_m^c = p_c; \quad mrs_t^e = w_t^e; \quad mrs_t^c = w_t^c$$
$$v_p^e = v_p^c = v_w^e = v_w^c = 1; \quad Y_{me} = Y_e; Y_{ce} = Y_c; L_d^e = L^e; L_d^c = L^c$$

Also note that as capital level is constant, we have

$$\hat{I}^e = I^e = \delta_0 K^e; \quad \hat{I}^c = I^c = \delta_0 K^c; \quad p_k^e = p_k^c = 1$$

The short term interest rate, in this model the deposit rate, will be pinned down by discount factor:

$$R_d^e = (\beta)^{-1}; \quad R_d^e = (\beta)^{-1}$$

Target term spread in both countries Suppose that we target term spreads in both countries to be a specific value. As short term interest rate is already pinned down by discounting factors, we will then know the long term debt interest rate R_f^e, R_f^c in both countries, bond price Q^e, Q^c, and thus the inter bank loan rate $R_v = R_f^c$ and the average cost of fund for EME bank $\tilde{R}$. From EME bank aggregate net worth evolution, we have

$$N^e = \sigma((R_f^e - \frac{\tilde{R}}{\psi_d})Q^e f^e + \frac{\tilde{R}}{\psi_d}N^e) + \delta_T Q^e f^e$$

From the definition of leverage ratio we have $Q^e f^e = \phi^e N^e$. Plug this in the equation above and divide both sides by N^e, we have

$$\phi^e = (\frac{\tilde{R}}{\psi_d}\sigma - \delta_T)^{-1}\sigma(\frac{\tilde{R}}{\psi_d} + R_f^e)$$

That is, once we pin down the term premium (thus determine R_f^e, R_f^c and R_v), the leverage ratio of EME bank is determined. Then recall that from EME bank's problem we have

$$\begin{aligned}
\beta\Omega^e(R_f^e - \frac{\tilde{R}}{\psi_D}) &= \theta^e\lambda^e \\
\beta\frac{\tilde{R}}{\psi_d} &= (1-\lambda^e)\alpha^e \\
\frac{\alpha^e}{\theta^e} &= \phi^e \\
\Omega^e &= 1 - \sigma + \sigma\alpha^e
\end{aligned}$$

We could solve out three auxiliary variables Ω^e, λ^e, α^e, and a parameter θ^e which is backed out from targeting credit spread in EME. With $D^e = (\psi_D - 1)RER \cdot V$ and bank balance sheet, we can also express the other three items on balance sheet as linear functions of net worth:

$$D^e = \frac{(\phi^e - 1)N^e}{\psi_D}; \quad RER \cdot V = \frac{(\psi_D - 1)(\phi^e - 1)N^e}{\psi_D}; Q^e f^e = \phi^e N^e$$

And similarly, we have the set of four equations for center country bank. Combine these four equations with the one above, we can express everything in terms of Now we turn to centre country bank. We do the similar things to the net worth evolution equation:

$$N^c = \sigma[(R_f^c - R_d^c)\phi^c N^c + R_d^c N^c] + \delta_T Q^c f^c$$

from which we can pin down ϕ^c from the targeting spread. Finally, the long-term bond price $Q^e(Q^c)$ could also be pinned down as

$$Q^e = (R_d^e + spread - \kappa)^{-1}$$

Target Labor Supply We also internally calibrate χ^e and χ^c to target steady state labor supply level to 1 in both countries. We will come back to this after finishing the description of the main component of steady state.

Target capital utilization rate We normalize the utilization rate of capital to 1 in both countries in the steady state. Take EME as example, plugging steady state values into (B.29) and (B.31), we have

$$\begin{aligned}
M_1^e\delta_1 &= \alpha p^e(K^e)^{\alpha-1} \\
M_1^e &= \beta(\alpha p^e(K^e)^{\alpha-1} + (1-\delta_0)M_1^e) \\
\Rightarrow \delta_1 &= \delta_0 + \frac{1}{\beta} - 1
\end{aligned}$$

Therefore, we utilize the above equation to set the value of δ_1. Moreover, (B.33) we have

$$Q^e M_2^e = \beta(1 + \kappa Q^e M_2^e) \Rightarrow M_2^e = \frac{\beta}{Q^e(1-\kappa\beta)}$$

From (B.34), we have:

$$M_1^e = \psi(M_2^e - 1) + 1$$

Take the value of M_1^e into (B.31), we have

$$\alpha\beta p^e (K^e)^{\alpha-1} = M_1^e[\underbrace{1(1-\delta_0)\beta}_{\delta_1\beta}] \Rightarrow K^e = (\frac{\alpha\beta p^e}{\delta_1\beta M_1^e})^{\frac{1}{1-\alpha}}$$

In the steady state, the investment just offsets the depreciation of capital:

$$I^e = \delta_0 K^e$$

Trade Balance We have already represented I^e, K^e, and hence Y^e and G^e as functions of the price of EME output real price p^e. The same applies to centre countries. Similar to Devereux et al. (2020), we will search numerically for 5 variables $(C^e, C^c, p^e, p^c, RER)$ to satisfy 5 equations in the steady state. Four of them are already given in the equilibrium:

$$\begin{aligned}
Y_t^e &= \nu^e {p_{et}}^{-\eta_p}(C_t^e + I_t^e + G_t^e) + (1-\nu^c)\left(\frac{1-m}{m}\right)\left(\frac{p_{et}}{RER_t}\right)^{-\eta_p}(C_t^c + I_t^c + G_t^c) \\
Y_t^c &= (1-\nu^e)\left(\frac{m}{1-m}\right)(p_{ct}RER_t)^{-\eta_p}(C_t^e + I_t^e + G_t^e) + \nu^c {p_{ct}}^{-\eta_p}(C_t^c + I_t^c + G_t^c) \\
1 &= \nu^e {p_{et}}^{1-\eta_p} + (1-\nu^e)(p_{ct}RER_t)^{1-\eta_p} \\
1 &= \nu^c {p_{ct}}^{1-\eta_p} + (1-\nu^c)\left(\frac{p_{et}}{RER_t}\right)^{1-\eta_p}
\end{aligned}$$

The last equation, however, is subject to our discretion. In two country models, there could be multiple steady states with different current account balances. In this paper, we follow the common choice in the literature to focus the equilibrium with balanced international trade i.e. the value of goods exported will be equal to the value of goods imported. Note that this condition will also clears the international financial market. Given that the EME banks borrow loans from centre country banks, paying them interest, the EME household then needs to lend to centre country household on the international market to offset that current account deficit. We consider the trade from EME's perspective i.e. all prices are discounted by price index of EME composite good. The export of EME country is valued at

$$Export = \underbrace{p_e}_{price}\underbrace{(1-\nu^c)(1-m)(\frac{p_c}{RER})^{-\eta_p}(C^c + I^c + G^c)}_{quantity}$$

And the import of the centre country's output is

$$Import = \underbrace{RERp_c}_{price}\underbrace{(1-\nu^e)m(p_c RER)^{-\eta_p}(C^e + I^e + G^e)}_{quantity}$$

Note that compared to the good market clearing conditions, here we modify the term related to m to account for the relative size of the two countries. Hence the last equation is

$$p_e(1-\nu^c)(1-m)(\frac{p_c}{RER})^{-\eta_p}(C^c + I^c + G^c) = RERp_c(1-\nu^e)m(p_c RER)^{-\eta_p}(C^e + I^e + G^e)$$

After this system of equations, all the other variables are solved recursively. Specifically, as we target labor supply to be 1 in both countries, we will back out the parameter values of the labor scaling factor χ^e and χ^c.