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Unconventional Policies and Exchange Rate Dynamics

by Gustavo Adler, Ruy Lama, and Juan Pablo Medina

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Prepared by Gustavo Adler, Ruy Lama, and Juan Pablo Medina[1]

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Abstract

We study exchange rate dynamics under cooperative and self-oriented policies in a two-country DSGE model with unconventional monetary and exchange rate policies. The cooperative solution features a large exchange rate adjustment that cushions the impact of negative shocks and a moderate use of unconventional policy instruments. Self-oriented policies (Nash equilibrium), however, entail limited exchange rate movements and an aggressive use of unconventional policies in both countries. Our results highlight the role of international policy cooperation in allowing the exchange rate to play the traditional role of shock absorber.

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Author's E-Mail Address: gadler@imf.org; rlama@imf.org; juan.medina@uai.cl.

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[1] Mr. Adler is Deputy Division Chief in IMF Research department, Mr. Lama is a Senior Economist in ICD, and Mr. Medina is a professor of economics at Universidad Adolfo Ibañez. We thank Maury Obstfeld, Jonathan Ostry, Steve Phillips, David Cook, Menzie Chinn, Nelson Mark, Yin-Wong Cheung, Machiko Narita, and participants at the conference "Exchange Rate Models for a New Era: Major and Emerging Market Currencies" for useful feedback on previous versions of the paper. Any remaining errors are our own.

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1 Introduction

Over the last two decades, central banks in both advanced and emerging economies resorted to unconventional policies with the objective of stabilizing their business cycles, leading to a steep expansion of their balance sheets. As shown in Figure 1, since the mid-1990s central banks in emerging market economies amassed a large stock of foreign assets as a result of Foreign Exchange (FX) interventions. In advanced economies, central banks expanded their balance sheets by conducting Quantitative Easing (QE) in response to the global financial crisis, once interest rates reached the zero lower bound (ZLB). From the standpoint of each economy, QE and FX intervention can be useful policy tools for macroeconomic stabilization purposes. Yet, from a global perspective, a scaling-up of central banks' balance sheets could lead to substantial international spillovers, making more difficult to achieve internal and external balance in recipient countries.

As illustrated in Figure 1, the expansion of central banks balance sheets through unconventional policies coincided with notable adjustments in current accounts and real exchange rates. During the period of sustained FX reserves accumulation (1997-2007), emerging market economies experienced an increase in their current account balances. Similarly, in the aftermath of the global financial crisis (2007-2015), the current account deficits in advanced economies narrowed while central banks were deploying QE measures. Real exchange rates also adjusted in a way consistent with current account dynamics. In a context of policy activism by major central banks, a number of policy questions arise: What are the effects of unconventional policies on the exchange rate and the current account? Are these desirable from a global standpoint? How big are the welfare gains from international policy cooperation? Does the ZLB affect the optimal implementation of unconventional policies? In this paper, we answer these questions using a two-country model in which central banks conduct optimal QE and FX intervention policies.

We develop a DSGE model extending the work from Christiano et al. (2005), Smets and Wouters (2007), and Chen et al. (2012) to a two-country setting and assuming that each country deploys different unconventional policy tools. The home country relies on FX intervention while the foreign country deploys QE policies. We simulate a crisis scenario in which the foreign country experiences a negative demand shock resulting in a decline of GDP by 1 percentage point. We then analyze exchange rate dynamics and macroeconomic outcomes under self-oriented (Nash) and cooperative equilibria in normal times (positive nominal interest rates) as well as at the ZLB.

In normal times, the cooperative equilibrium entails a moderate use of unconventional policy instruments and the real exchange rate plays its traditional role of shock absorber. In the Nash equilibrium, both countries engage actively in unconventional policies, leading to a limited adjustment of the real exchange rate. At the ZLB, a negative demand shock generates a much larger output contraction as the short-term policy rate is unable to adjust to domestic economic conditions. In this case, the cooperative equilibrium entails a more aggressive use of unconventional policies and a larger real exchange rate depreciation in the foreign country. The Nash equilibrium at the ZLB features limited exchange rate adjustment as in the normal times scenario. The welfare gains from international policy cooperation are found to be quantitatively small as in Obstfeld and Rogoff (2002).

This paper is related to two strands of the literature. One strand concerns to the gains from international policy cooperation. Obstfeld and Rogoff (2002) concluded that policies aimed at maximizing domestic welfare (Nash equilibrium) yield global outcomes that are close to the cooperative equilibrium. Similarly, Jeanne (2014) studied capital account policies to address financial distortions associated with over-borrowing and found that the gains from international coordination are small. Dedola et al. (2013) also confirm this result in a two-country model with unconventional policies.

The second strand relates to the real and financial effects of unconventional policies. This literature, developed after the implementation of unconventional policies in the US and other advanced economies, focused mainly on event-study analysis to estimate the effects of these policies on long-term rates and term premiums.[1] Some empirical studies have also focused on estimating the international spillover effects of unconventional policies on foreign bond yields, exchange rates and the current account.[2] Other papers have relied on structural models for analyzing the macroeconomic effects of unconventional policies. For instance, Chen et al. (2012) quantified the macroeconomic effects of QE in the US in an estimated DSGE model. Similarly, Alpanda and Kabaca (2015) estimated the international spillovers from QE in the US. Furthermore, Gabaix and Maggiori (2015) studied the spillover

[1]See Gagnon et al. (2011), D'Amico and King (2010), Krishnamurthy and Vissing-Jorgensen (2011), and Bomfim and Meyer (2010)

[2]See Bayoumi et al. (2016), Bowman et al. (2015), Chen et al. (2014), Chen et al. (2012), Fratzscher et al. (2013), Gagnon et al. (2017), Glick and Leduc (2013,2015), Neely (2015), Rogers et al. (2014), among a long list of recent papers.

effects from FX intervention in a two-country model.

Two are the main contributions of our paper. First, from a modeling perspective, we characterize cooperative and non-cooperative global outcomes with asymmetric unconventional policies (QE and FX intervention) at the ZLB. Second, we show that exchange rate dynamics depend crucially on the degree of international policy cooperation. In particular, cooperative unconventional policies result in a large exchange rate adjustment that speeds up the recovery in the country affected by a negative shock. This issue is also of interest from a policy perspective, since large exchange rate movements do not necessarily imply a "beggar-thy-neighbor" policy, but could also reflect a desirable process of external adjustment that improves global welfare.

The rest of the paper is organized as follows. Section 2 describes the two-country model. Section 3 explains the calibration strategy. Section 4 shows the results of optimal unconventional policies in normal times. Section 5 presents the results at the ZLB. Section 6 discusses the welfare analysis. Section 7 concludes with a discussion of the key findings.

2 A Two-country Model

This section presents the two-country model used for analyzing the global effects of unconventional policies. Our model extends the work of Christiano et al. (2005), and Smets and Wouters (2003, 2007), to a two-country setting as in Chari et al. (2002), Rabanal and Tuesta (2010), and Lama and Rabanal (2015), among others.

The model features local currency pricing and incomplete asset markets. The main innovation relative to standard two-country models is the presence of asymmetric unconventional policy tools, namely QE and FX intervention. These unconventional policies operate through portfolio balance effects, which arise by assuming imperfect asset substitution between short-term and long-term bonds and between domestic and foreign bonds, following Chen et al. (2012) and Gabaix and Maggiori (2015).

The two countries are denoted by home and foreign and have equal size. Each country produces a continuum of intermediate tradable goods, indexed by $h \in [0, 1]$ in the home country and by $f \in [0, 1]$ in the foreign country. These intermediate goods are used in the production of the final good, which is sold domestically within each country. Final goods are used for domestic consumption, investment, and government spending. Next, we describe the problem for households, intermediate, capital, and final goods producers in the home country. The description for the foreign country is analogous. An asterisk denotes variables and parameters of the foreign country.

2.1 Households

There is a continuum of households in each country. As in Chen et al. (2012), asset markets are segmented with two distinct groups of households: unrestricted (denoted by u) and restricted (denoted by r). A fraction ω_u of households are unrestricted and fraction $1-\omega_u$ are restricted. Households from group $j = u, r$ derive utility from consumption C_t^j and disutility from hours worked L_t^j. Households supply differentiated labor services indexed by i, but have full risk-sharing within each type of household. The supply of labor services for unrestricted household is $L_t^u(i)$ for $i \in [0, \omega_u)$ and $L_t^r(i)$ for $i \in [\omega_u, 1]$. The life-time utility function for a household j is given by:

$$E_t[\sum_{s=0}^{\infty} \beta_j^s \chi_{t+s} U(C_{t+s}^j, L_{t+s}^j(i))], \tag{1}$$

where $U(\bullet)$ is the period utility function, $\beta_j \in [0,1]$ is the discount factor, and χ_t is a preference shock.

Households can trade four types of bonds. First, short-term domestic bonds B_t, which are one-period securities purchased at period t that pay the nominal return R_t in period $t+1$. Second, long-term domestic bonds which are perpetuities with a price $P_{L,t}$ at period t and pay an exponentially decaying coupon κ^s at period $t+s+1$, for $\kappa \in (0,1]$. The long-term bond has a return $R_{L,t}$ in period t. Third, short-term foreign bonds D_t that pay a nominal return of foreign currency of $R_t^* \Theta_t$, where R_t^* is the foreign short-term interest rate and Θ_t is the risk premium for the short-term bonds. Finally, foreign long-term bonds $D_{L,t}$ that pay a nominal return in foreign currency of $R_{L,t}^* \Theta_{L,t}$, where $R_{L,t}^*$ is the foreign long-term bond return and $\Theta_{L,t}$ is the risk premium for long-term bonds. Following Woodford (2001), the return and price of the long-term bonds satisfy:

$$P_{L,t} = \frac{1}{R_{L,t} - \kappa}, P_{L,t}^* = \frac{1}{R_{L,t}^* - \kappa^*}. \tag{2}$$

Unrestricted households can trade the four type of bonds, but they need to pay a transaction cost η_t per-unit of long-term bonds purchased. In contrast, restricted households can only trade long-term domestic bonds. Thus, households budget constraints differ depending on whether they are restricted or unrestricted . For unrestricted households, the budget constraint is:

$$\begin{pmatrix} P_tC_t^u + B_t^u + S_tD_t^u + \\ (1+\eta_t)(P_{L,t}B_{L,t}^u + S_tP_{L,t}^*D_{L,t}^u) \end{pmatrix} = \begin{pmatrix} R_{t-1}B_{t-1}^u + S_tR_{t-1}^*\Theta_tD_{t-1}^u + \\ P_{L,t}R_{L,t}B_{L,t-1}^u + S_tP_{L,t}^*R_{L,t}^*\Theta_{L,t}D_{L,t-1}^u + \\ W_t^u(i)L_t^u(i) + \Pi_t^u - T_t^u \end{pmatrix}. \tag{3}$$

For restricted households their budget constraint is:

$$P_tC_t^r + P_{L,t}B_{L,t}^r = P_{L,t}R_{L,t}B_{L,t-1}^r + W_t^r(i)L_t^r(i) + \Pi_t^r - T_t^r. \tag{4}$$

WhereP_t is the price of the final consumption good, S_t is the nominal exchange rate (in units of domestic currency per unit of foreign currency), $W_t^j(i)$ is the wage set by a household of type $j = u, r$ who supplies labor of type i, Π_t^j are the profits distributed to household of type j from ownership of intermediate goods producers, capital producers and financial intermediaries, and T_t^j are lump-sum taxes for household of type j.

Households first order conditions are obtained from maximizing (1) subject to (3) in the case of unrestricted households, and maximizing (1) subject to (4) in the case of restricted households.

2.2 Wage setting and labor supply

As in Erceg et al. (2000), the model assumes perfectly competitive labor agencies that combine differentiated labor services from each household, $L_t^j(i)$, into a homogeneous labor composite L_t according to a Dixit-Stiglitz aggregator:

$$L_t = \left[\int_0^{\omega_u} (L_t^u(i))^{\frac{\sigma_w - 1}{\sigma_w}} di + \int_{\omega_u}^1 (L_t^r(i))^{\frac{\sigma_w - 1}{\sigma_w}} di\right]^{\frac{\sigma_w}{\sigma_w - 1}}. \tag{5}$$

The demand for labor services of type i is obtained from the profit-maximization condition of labor agencies:

$$L_t^j(i) = \left(\frac{W_t^j(i)}{W_t}\right)^{-\sigma_w} L_t. \tag{6}$$

From the zero-profit condition for labor agencies, we obtain the aggregate wage index W_t:

$$W_t = \left[\int_0^{\omega_u} (W_t^u(i))^{1-\sigma_w} di + \int_{\omega_u}^1 (W_t^r(i))^{1-\sigma_w} di\right]^{\frac{1}{1-\sigma_w}}. \tag{7}$$

Unrestricted households set wages in a staggered fashion as in Calvo (1983). In each period, a fraction θ_w of unrestricted households can re-optimize their nominal wage. The unrestricted household resets the wage in period t at the value $\widetilde{W}_t$. The household will choose $\widetilde{W}_t$ in order to maximize:

$$E_t \left\{ \sum_{s=0}^{\infty} (\beta_u \theta_w)^s \chi_{t+s} U(C^u_{t+s|t}, C^u_{t+s-1|t}, L^u_{t+s|t}) \right\}, \tag{8}$$

subject to (5) and where $x_{t+s|t}$ denotes the variable x in period $t+s$ for unrestricted households that choose their wage in period t.

For simplicity, restricted households are assumed to set wages equal to the average wage set by unrestricted households. Given the demand for each type of labor services, this implies that labor supply of restricted households coincides with the average labor supply from unrestricted households.

2.3 Capital good producers

Capital good producers invest and rent capital to intermediate good producers. The investment good is defined in terms of the final good. The representative capital-producing firm chooses optimal investment and capital stock by solving the following problem:

$$\max_{K_{t+s}, I_{t+s}} E_t \left\{ \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left(R_{K,t+s} K_{t+s} - P_{t+s} I_{t+s} \right) \right\}, \tag{9}$$

subject to the law of motion of capital accumulation:

$$K_{t+1} = (1-\delta) K_t + S\left(\frac{I_t}{I_{t-1}} \right) I_t, \tag{10}$$

where $R_{K,t}$ is the rental rate of capital, δ is the depreciation rate of capital, and the function $S(.)$ characterizes the investment adjustment costs.[3] Capital good producers are owned by unrestricted households. Thus, the discount factor $(\Lambda_{t,t+s})$ corresponds to marginal rate of substitution of consumption between period t and $t+s$ of unrestricted households:

$$\Lambda_{t,t+s} = (\beta_u)^s \frac{\lambda^u_{t+s}}{\lambda^u_t}, \tag{11}$$

[3]The investment adjustment cost function satisfies: $S(1) = 1$, $S'(1) = 0$, $S''(1) = -\mu_S < 0$. See Altig et al. (2005).

where λ_t^u is the marginal utility of consumption of unrestricted households in period t.

2.4 Final good producers

A continuum of final goods producers purchase a composite of intermediate home-produced goods, $Y_{H,t}$, and a composite of intermediate foreign-produced goods, $Y_{F,t}$, to produce a homogeneous final good. The technology of the final goods production function is given by:

$$Y_t = \left[(\alpha_Y)^{1/\eta_Y} (Y_{H,t})^{\frac{\eta_Y - 1}{\eta_Y}} + (1 - \alpha_Y)^{1/\eta_Y} (Y_{F,t})^{\frac{\eta_Y - 1}{\eta_Y}} \right]^{\frac{\eta_Y}{\eta_Y - 1}}, \tag{12}$$

where α_Y denotes the fraction of the home-produced goods that are used for the production of the final good, and η_Y denotes the elasticity of substitution between domestic and imported intermediate goods. The price of domestic and imported inputs is denoted by $P_{H,t}$ and $P_{F,t}$, respectively. The optimal basket of home-produced and foreign-produced goods satisfies:

$$Y_{H,t} = \alpha_Y \left(\frac{P_{H,t}}{P_t} \right)^{-\eta_Y} Y_t, Y_{F,t} = (1 - \alpha_Y) \left(\frac{P_{F,t}}{P_t} \right)^{-\eta_Y} Y_t, \tag{13}$$

where the price of final goods is:

$$P_t = \left[\alpha_Y (P_{H,t})^{1-\eta_Y} + (1 - \alpha_Y) (P_{F,t})^{1-\eta_Y} \right]^{\frac{1}{1-\eta_Y}}. \tag{14}$$

2.5 Intermediate good producers

In each country, there is a continuum of intermediate differentiated good producers. The differentiated goods are sold to the composite intermediate goods producers with the following technology:

$$Y_{H,t} = \left[\int_0^1 (Y_{H,t}(h))^{\frac{\epsilon_p - 1}{\epsilon_p}} dh \right]^{\frac{\epsilon_p}{\epsilon_p - 1}}, \tag{15}$$

$$Y_{F,t} = \left[\int_0^1 (Y_{F,t}(f))^{\frac{\epsilon_p - 1}{\epsilon_p}} df \right]^{\frac{\epsilon_p}{\epsilon_p - 1}}, \tag{16}$$

where $Y_{H,t}(h)$ is the amount of differentiated home good h for the composite $Y_{H,t}$, $Y_{F,t}(f)$ is the amount of differentiated foreign good f for the composite $Y_{F,t}$, and ϵ_p is the elasticity of substitution across types of differentiated goods. $Y^*_{H,t}$, and $Y^*_{F,t}$ are defined similarly for the foreign country.

The technology of production for each differentiate home good h in the home country is given by

$$Y_t(h) = (A_t L_t(h))^{1-\alpha}(K_{t-1}(h))^{\alpha}, \tag{17}$$

where $L_t(h)$ is the labor input, $K_{t-1}(h)$ is the capital rented, A_t is a country-specific level of total factor productivity (TFP), and α is the share of capital in the production function. TFP evolves according to a zero-mean, AR(1) process in logs.

The marginal cost and the capital-labor ratio are obtained from the the cost-minimization problem of intermediate good producers:

$$MC_{H,t} = \left(\frac{W_t}{(1-\alpha)A_t}\right)^{1-\alpha}\left(\frac{R_{K,t}}{\alpha}\right)^{\alpha}, \tag{18}$$

$$\frac{W_t L_t(h)}{R_{K,t}K_{t-1}(h)} = \frac{1-\alpha}{\alpha}. \tag{19}$$

Once intermediate good firms have solved the cost minimization problem and have chosen the optimal capital-output ratio, intermediate good producers choose the price that maximizes discounted profits subject to a Calvo price-setting restriction. We assume local currency pricing (LCP) for goods that are traded across countries. With probability $1-\theta_H$ a firm can choose optimally the price for the domestic market and a price for the foreign market, each price quoted in the destination market currency. Hence, there is price stickiness in each country's imports prices in terms of local currency, and the law of one price does not holds in the short-run.

2.6 Macroeconomic policies

The short-term interest rate follows a Taylor-type rule that reacts to deviations of GDP and inflation from the steady state:

$$\frac{R_t}{\bar{R}} = \left[(P_t/P_{t-1})^{\gamma_\pi}(GDP_t/\overline{GDP})^{\gamma_y}\right], \tag{20}$$

where $\bar{R}$ and $G\bar{D}P$ are the steady state interest rate and GDP, respectively.

FX intervention is conducted according to the following rule:

$$\frac{F_t}{\bar{F}} = \left[(P_t/P_{t-1})^{\theta_\pi}(GDP_t/\overline{GDP})^{\theta_y}\right], \tag{21}$$

where F_t is the stock of FX reserves denominated in the foreign currency, $\bar{F}$ is the steady-state value of reserves, and θ_π and θ_y the coefficients on inflation and GDP for the FX intervention rule.

The government also controls the real supply of long-term bonds $(P_{L,t}B_{L,t}/P_t)$ following a simple rule:

$$\frac{P_{L,t}B_{L,t}}{P_t} = \left(\bar{P}_L\bar{B}_L\right)\left[(P_t/P_{t-1})^{\phi_\pi}(GDP_t/\overline{GDP})^{\phi_y}\right], \tag{22}$$

where $\bar{P}_L\bar{B}_L$ is the steady state value for the real market value of long-term bonds, and ϕ_π and ϕ_y the coefficients on inflation and GDP in the QE rule.

The government budget constraint is given by:

$$B_t + P_{L,t}B_{L,t} - S_tF_t = R_{t-1}B_{t-1} + (1+\kappa P_{L,t})B_{L,t-1} - S_tR^*_{t-1}F_{t-1} + P_tG_t - T_t, \tag{23}$$

where G_t is government consumption in final goods and T_t are total lump-sum taxes to households (net of transfers for seigniorage and profits from FX intervention and QE policies). The government budget constraint states that the market value of the government debt net of FX reserves should be equal to the total deficit of the government. Total deficit is the cost of servicing bonds maturing in that period, minus income from FX reserves plus government spending net of taxes.

In order to ensure a sustainable path of public debt, we include a fiscal reaction function for the primary balance of the government as a function of the long-term bonds:

$$\frac{T_t}{P_t} - G_t = \Psi\left(\frac{P_{L,t-1}B_{L,t-1}}{P_{t-1}}\right)^{\phi_T}, \tag{24}$$

where $\phi_T > 0$ and $\Psi > 0$.

2.7 Aggregation and equilibrium conditions

Markets clear for final and intermediate goods, labor, capital and financial assets. For the final good, the market-clearing condition is:

$$Y_t = \omega_u C^u_t + (1-\omega_u)C^r_t + G_t + I_t. \tag{25}$$

The market-clearing conditions for the domestic and foreign intermediate goods ($h \in [0,1]$, $f \in [0,1]$) are given by:

$$Y_t(h) = Y_{H,t}(h) + Y_{H*,t}(h), \tag{26}$$

$$Y_t(f) = Y^F_{F,t}(f) + Y_{F*,t}(f), \tag{27}$$

where $Y_t(h), Y_{H,t}(h)$, $Y_{H^*,t}(h)$ are production of the intermediate home good of type h, and the domestic and foreign demand of that type, respectively. Similarly, $Y_t(f)$, $Y^F_{F,t}(f)$, $Y_{F*,t}(f)$ are defined for the intermediate foreign good of type f.

We define GDP_t as aggregate the total production of home intermediate goods:

$$GDP_t \equiv \int_0^1 Y_t(h)dh. \tag{28}$$

The equilibrium for the labor market is given by:

$$L_t = \int_0^1 L_t(h)dh. \tag{29}$$

For capital goods market clearing condition is:

$$K_t = \int_0^1 K_t(h)dh. \tag{30}$$

The equilibrium conditions for domestic short-term and long-term bonds are:

$$B_t = \omega_u B^u_t, B_{L,t} = \omega_u B^u_{L,t} + (1-\omega_u)B^r_{L,t}. \tag{31}$$

Defining the aggregated holding of foreign short-term and long-term bonds as $D_t = \omega_u D^u_t$ and $D_{L,t} = \omega_u D^u_{L,t}$, the balance of payment identity is given by:

$$\begin{pmatrix} S_t D_t + S_t P^*_{L,t} D_{L,t} \\ +S_t F_t \end{pmatrix} = \begin{pmatrix} S_t P_{H^*,t} Y_{H^*} - P_{F,t} Y_{F,t} + S_t R^*_{t-1} \Theta_t D_{t-1} \\ +S_t P^*_{L,t} R^*_{L,t} \Theta_{L,t} D_{L,t-1} + S_t R^*_{t-1} F_t \end{pmatrix}. \tag{32}$$

Imperfect substitutability is modeled through an endogenous risk premium on short-term and long-term foreign debt, denoted by Θ_t and $\Theta_{L,t}$, respectively. We model risk premiums by extending the work of Schmitt-Grohé and Uribe (2003), and defining them as a function of the aggregate levels of foreign short and long term bonds:

$$\Theta_t = \Theta\left(D_t, D_{L,t}\right), \ \Theta_{L,t} = \Theta_L\left(D_t, D_{L,t}\right) \tag{33}$$

Let denote Θ_1 and Θ_2 the partial derivatives of $\Theta(\cdot)$ with respect to D_t and $D_{L,t}$ and $\Theta_{L,1}$ and $\Theta_{L,2}$ the same partial derivatives for $\Theta_L(\cdot)$.

Following Chen et al. (2012), transaction costs are modeled as:

$$(1+\eta_t) = \Theta_\eta\left(P_{L,t}B_{L,t}, S_t P^*_{L,t} B^*_{L,t}\right). \tag{34}$$

We assume that transactions costs depend on the stock of long-term bonds in the home and in the foreign country. The elasticities of the transaction cost in the home country with the respect to the stock of long-term bonds at home and at abroad are denoted by $\Theta_{\eta,1}$ and $\Theta_{\eta,2}$, respectively. Note that parameters Θ_1, Θ_2, $\Theta_{L,1}$, $\Theta_{L,2}$, $\Theta_{\eta,1}$ and $\Theta_{\eta,2}$ control simultaneously the effects of QE and FX intervention in both countries.

2.8 Transmission Mechanism of Unconventional Policies

In this sub-section, we describe the transmission mechanism of FX intervention and QE. Both unconventional policies operate through portfolio balance effects that arise from imperfect asset substitutability across different asset classes. In the case of FX intervention, we assume imperfect substitution between domestic and foreign short-term bonds, while for QE the imperfect substitutability arises between short and long term domestic bonds. For a better understanding of the transmission channels, it is useful to consider the benchmark case of "Wallace neutrality", where open market operations are neutral under the assumption of frictionless financial markets.[4] In that case, if a central bank purchases an asset A in exchange for an asset B, households offset the central bank operations by purchasing an asset B in exchange for asset A. Households fully reverse the transactions conducted by the central bank with the goal of hedging income risks associated with the change in central bank's portfolio. Since in the aggregate there is no change in the overall net wealth of the private sector, open market operations do not entail real effects in the economy. Next, we explore how this result is modified when

[4]See Wallace (1981) and Curdia and Woodford (2011).

we depart from the assumption of frictionless markets and assume imperfect asset substitutability. Figure 2 summarizes the transmission mechanisms of unconventional policies to real and nominal variables under imperfect asset substitution.

2.8.1 Foreign Exchange Intervention

The key margin that allows the FX intervention to have real effects is the endogenous risk premium in foreign debt (33). When the central bank conducts FX intervention, it purchases short-term foreign bonds and sells short-term domestic bonds. In a frictionless financial market, the optimal response of households to sterilized intervention would be to purchase domestic bonds and to issue foreign bonds. When we assume an endogenous risk premium, the cost of borrowing will increase with the size of foreign debt, preventing a full offset of central banks' transactions by households. As a result, FX intervention implies an increase in Net Foreign Asset position in the economy (foreign assets minus liabilities), a nominal exchange rate depreciation, higher inflation, current account, and output.

2.8.2 Quantitative Easing

Quantitative Easing is modeled following the approach by Chen et al. (2012). As in the case of FX intervention, we introduce a financial friction that induces a portfolio balance effect. More specifically, we assume that financial transaction costs (34) depend on the private sector's holdings of long-term bonds. We model an expansionary QE policy as a central bank's purchase of domestic long-term bonds, which reduces the supply available to the private sector (23). By assuming a positive elasticity of the transaction costs with respect to the aggregate stock of long-term debt, an expansionary QE policy lowers transaction costs and the term premium, generating an expansion in consumption, investment, output, and inflation. Moreover, through the interest rate parity conditions QE will result in a nominal exchange rate depreciation as a result of a widening of long-term interest rate differentials.

3 Calibration

The model is calibrated to a quarterly frequency using standard parameter values from the literature (see Table 1). The discount factor is set to $\beta_u = 0.995$ for unrestricted households and $\beta_r = 0.993$ for restricted households in order to obtain steady state values for the short-term and long-term real interest rates equal to 2% and 2.75%, respectively, on annual basis. We calibrate κ to match a duration of 30 quarters for long-term bonds, consistent with the average duration in the secondary market of 10-year US Treasury bills. The degree of asset market segmentation is such that half of the households in each country are unrestricted.

The elasticity of substitution across types of labor, σ_w, and across types of goods, ε_p, is 6 and 11, respectively. The steady-state ratio of government expenditures over GDP, is set equal to 0.25. The home bias in the final good is set to $\alpha_Y = \alpha_Y^* = 0.7$ and the elasticity of substitution between home and foreign goods is $\eta_Y = \eta_Y^* = 0.9$.

The depreciation rate δ is set equal to 0.025 per quarter, which implies an annual depreciation of capital equal to 10 percent. The investment adjustment cost parameter is set to $\mu_S = 2.5$, which is consistent with the value used in Christiano et al. (2005). The capital share in intermediate good production function, α, is equal to 0.36. The Calvo price-setting parameters are set to $\theta_H = \theta_F^* = 0.75$, consistent with an average price duration of 4 quarters. The wage rigidity parameters θ_w and θ_w^* are set to 0.75, consistent with an average wage rate duration of 4 quarters.

Households' preferences are represented by the following functional form:

$$U = log(C_t^j - \psi \frac{L_t^{j1+\varphi}}{1+\varphi}) \;\; (j = u, r)$$

The Frisch elasticity of labor supply is set to $1/\varphi = 1$ as in Galí and Monacelli (2005). We set the coefficients from the Taylor-type rule consistent with Taylor (1993), that is $\gamma_\pi = 1.5$ and $\gamma_y = 0.5$. The fiscal rule parameter, ϕ_T is set at 1.5. as in Chen et al. (2012). The parameters for the QE and FX intervention rules θ_π, θ_π, ϕ_π, and ϕ_π are obtained from maximizing welfare under the Nash and cooperative equilibria.[5] The logarithm of the preference shock χ_t follows an AR(1) process with a persistency coefficient of 0.95.

[5] In the Nash equilibrium, each country optimizes the coefficients of the unconventional policy rules in order to maximize its own welfare. In the cooperative equilibrium, each country chooses the coefficients to maximize the world's aggregate welfare.

We calibrate the elasticities of the risk premium and transactions costs Θ_1, Θ_2, $\Theta_{L,1}$, $\Theta_{L,2}$, $\Theta_{\eta,1}$ and $\Theta_{\eta,2}$ to replicate the effects of QE and FX intervention on long-term rates, current account and exchange rates within the range of recent empirical studies. For QE, our calibrated elasticities target three empirical features of the data. First, a 1 percent of GDP of long-term bond purchase (QE) implies a reduction of 15 basis points in the domestic term premium. This is consistent with the average of the empirical effects of QE in the term premium documented for US by Chen et al. (2012).

Second, the international spillover of a 1 percent of GDP of long-term bond purchases generates a reduction of 9 basis points in the foreign-country term premium, in line with the estimates from Bowman et al (2015), Chen et al. (2012), and Neely (2015).

Third, a 1 percent of GDP of QE depreciates the exchange rate by 0.4 percent. This magnitude is consistent with the estimates by Chen et al. (2012), Glick and Leduc (2013, 2015) and Neely (2015), who find that, during QE1 long-term rates in US declined by 90-100 basis points and the exchange rate depreciated in the range of 3.5 to 8 percent.

For FX intervention, a 1 percent of GDP accumulation of FX reserves depreciates the exchange rate by 2 percent, improving the current account around 0.4 percent of GDP. The magnitude of the exchange rate depreciation is similar to the one obtained by Blanchard et al. (2015), who find evidence suggesting that FXI is effective in stemming appreciation pressures arising from global flow shocks. At the same time, Bayoumi et al. (2016) and Gagnon et al. (2017) find that an increase in FX reserves of 1 percent of GDP increases the current account balance in range around 0.5 percent.

Table 1: Baseline Calibration

Parameter	Value	Description
β_u, β_u^*	0.995	Discount factor for unrestricted HH
β_r, β_r^*	0.993	Discount factor for restricted HH
κ, κ^*	0.973	Decaying coupons for long-term bonds
ω_u, ω_u^*	0.50	Fraction of unrestricted HH
σ_w, σ_w^*	6	Elasticity of substitution across labor varieties
$\varepsilon_p, \varepsilon_p^*$	11	Elasticity of substitution across labor varieties
α_Y, α_Y^*	0.70	Home bias in final goods
η_Y, η_Y^*	0.90	Elasticity of substitution b/w home and foreign goods
δ, δ^*	0.025	Capital depreciation rate
μ_S, μ_S^*	2.5	Elasticity of investment adjust cost
α, α^*	0.36	Capital share in intermediate good production
θ_H	0.75	Price rigidity in home goods
θ_F^*	0.75	Price rigidity in foreign goods
θ_w	0.75	Wage rigidity
$1/\varphi$	1.0	Labor Supply Elasticity
γ_π, γ_π^*	1.5	Inflation Coefficient - Taylor Rule
γ_y, γ_y^*	0.5	Output Gap Coefficient - Taylor Rule
ρ_{fx}, ρ_{fx}^*	0.9	Persistency of FXI
ρ_B, ρ_B^*	0.9	Persistency of Long-term bond supply
ϕ_T, ϕ_T^*	1.5	Fiscal rule coefficient
Θ_1	0.035	Elasticity of risk premium (short-term debt) w.r.t. short-term foreign bonds
Θ_2	0.035	Elasticity of risk premium (short-term debt) w.r.t. long-term foreign bonds
$\Theta_{L,1}$	0.040	Elasticity of risk premium (long-term debt) w.r.t. short-term foreign bonds
$\Theta_{L,2}$	0.060	Elasticity of risk premium (long-term debt) w.r.t. long-term foreign bonds
$\Theta_{\eta,1}$	0.011	Elasticity of home transaction costs w.r.t. home long-term bonds
$\Theta_{\eta,2}$	0.005	Elasticity of home transaction costs w.r.t. foreign long-term bonds
$\Theta_{\eta,1}^*$	0.011	Elasticity of foreign transaction costs w.r.t. foreign long-term bonds
$\Theta_{\eta,2}^*$	0.005	Elasticity of foreign transaction costs w.r.t. home long-term bonds

4 Unconventional Policies in Normal Times

In this section, we analyze the implications of unconventional policies in normal times, when the short-term nominal interest rate is set by a Taylor-type rule. The first sub-section illustrates the transmission mechanism and international spillovers of QE and FX intervention, assuming they follow an exogenous process.[6] The second sub-section, characterizes the cooperative and Nash equilibria and unconventional policies are set according to the optimized policy rules (21) and (22).

4.1 Spillovers from Unconventional Policies

Figure 3 shows the model dynamics of a purchase of 1 percent of GDP of domestic long-term bonds (QE) in the foreign country (second column). By reducing the term premium, QE boosts aggregate demand. While the term premium falls, the short-term nominal interest rate goes up, as the Taylor rule calls for higher nominal interest rates in response to an increase in output and inflation. In addition, the compression of the term-premium induces capital outflows, resulting in a real exchange rate depreciation and a modest improvement in the current account balance. The first column shows the corresponding effects on the home country.

Two opposing forces drive the outcomes in the home economy. On the one hand, as the world demand increases, GDP in the home country expands (reflecting an expenditure shifting effect). On the other hand, as foreign capital flows into the home country, the exchange rate appreciates resulting in lower output, inflation, and nominal short-term interest rate (reflecting an expenditure switching effect). For our parametrization, the expenditure shifting effect (increase in global demand) initially dominates, while the expenditure switching effect (real exchange rate appreciation) eventually gains traction leading to lower output after two quarters.

Figure 4 illustrates the scenario in which the central bank in the home country conducts FX intervention of 1 percent of GDP. From the domestic standpoint, the effects are similar to QE. An increase in FX reserves leads to a real exchange rate depreciation, higher output, current account, and nominal interest rate. Notice, however, that FX intervention operates mainly

[6] For the spillover analysis we consider AR(1) processes for the stock of long-term bonds (QE) and the stock of foreign bonds (FX intervention) with a persistency coefficient of 0.9.

through the expenditure switching effect, which affects negatively the foreign economy (second column). As the real exchange rate appreciates in the foreign economy, we observe a decline in the foreign current account, output and nominal short-term interest rate.

4.2 Cooperative and Nash Equilibria

Figure 5 shows the macroeconomic outcomes of unconventional policies under the cooperative and Nash equilibria when the foreign country experiences a negative demand shock. In this scenario, we assume policy rules for QE and FX intervention as stated in equations (21) and (22), and the coefficients are optimized according to the type of equilibrium (See footnote 5). We start the analysis with the baseline scenario (blue line), which assumes a decline in GDP of 1 percent in the foreign country triggered by a negative preference shock (χ_t) and that no unconventional policies are in place. The decline in aggregate demand generates a reduction in the short-term interest rate, a small real exchange rate depreciation, and a modest improvement in the current account in the foreign country. The recession in the foreign country generate spillovers to the home country, leading to a decline in domestic output, interest rates, current account balance, and a small appreciation.

In the scenario of cooperative equilibrium (green line in figure 5), both countries implement unconventional policies optimally, with the objective of maximizing global welfare. In terms of the QE and FX reserves dynamics, two features are notable. First, there is an expansion of QE in the foreign country of about 1 percent of GDP. Second, there is a decline in FX reserves in the home country of 2 percent of GDP. The combination of these policies generates a real exchange rate depreciation of 4 percent and an increase in the current account balance of 0.6 percent of GDP in the foreign country. As a result, the foreign country experiences a smaller decline in output and more stable path of nominal interest rates. While these policies are optimal for the world economy, the home country experiences a larger output decline as unconventional policies in the cooperative equilibrium are designed to share the costs of the recession.

Finally, we consider the model dynamics under the Nash equilibrium (red line in figure 5). In that situation, both QE and FX intervention are used more intensively as each country maximizes its own welfare, taking as given the reaction function from the other country. In particular, the foreign country implements a QE policy of 5 percent of GDP and the home country accumulates FX reserves by 3 percent of GDP. In equilibrium, we observe that the combination of unconventional policies stabilizes the current account and generates a small appreciation in the foreign country. In this scenario, the home country is largely insulated from the external shock and spillovers from unconventional policies. However, the foreign country experiences a slower recovery. Hence, under the Nash equilibrium there is limited exchange rate adjustment that aggravates the recession in the economy that experiences the negative shock.

In sum, this sub-section characterizes the he Nash and cooperative equilibria of unconventional policies. The key distinctive feature that distinguishes both equilibria is the process of external adjustment. In the cooperative equilibrium, the foreign country is insulated from a negative shock by experiencing an exchange rate depreciation and a fast external adjustment. In the Nash equilibrium, as both countries engage in competitive devaluations, the final outcome is a small external adjustment that worsens the recession in the country affected by the negative shock.

5 Unconventional Policies at the ZLB

In this section, we analyze the implications of unconventional policies when the foreign country reaches the ZLB.[7] The first sub-section discusses the transmission mechanism and spillovers of unconventional policies, assuming that they follow an exogenous process. The second sub-section, characterizes the cooperative and Nash equilibria of unconventional policies.

5.1 Spillovers from Unconventional Policies at the ZLB

Figure 6 shows the model dynamics in response to a QE stimulus of 1 percent of GDP at the ZLB (red line) in the foreign country (second column). The first thing to notice is that the effect of QE on output is 0.3 percent on impact, two times larger than in the normal times scenario. Since the nominal interest rate remains at zero while there is an expansion in aggregate demand, there is a decline in the real rates (as inflation raises), which generates an additional boost in output. The decline in the real interest rate induces a real exchange

[7]In this scenario we assume that only the foreign country is at the ZLB, while the short-term policy rate in the home country follows a Taylor rule. We solve the model at the ZLB, by following the algorithm proposed by Laseen and Svensson (2009).

rate depreciation and an improvement in the current account balance. In the home country, the increase in world demand leads to a short-term output expansion, but after four quarters the exchange rate appreciation reduces output. The increase in activity induces a higher real interest rate, a real exchange rate appreciation, and a decline in the current account balance in the home country.

Figure 7 illustrates the transmission mechanism of FX intervention in the home country when the foreign country is at the ZLB. The domestic effects of FX intervention in this scenario are better understood if we first analyze the policy spillovers on the foreign country (second column). An accumulation of FX reserves by 1 percent of GDP in the home country induces capital flows into the foreign country. As the real exchange rate appreciates, output and inflation declines. Because the nominal interest in the foreign country cannot go below the ZLB, the decline in inflation raises the real interest rate, inducing an additional contraction in output. The current account balance response does not change significantly as the negative effect from the appreciation is offset by the positive effect of import compression. Output in the home country (first column) declines relative to the normal times scenario, as foreign demand declines at the ZLB. Furthermore, lower interest rates in the home country trigger a larger depreciation. In sum, FX intervention at the ZLB leads to lower output in the foreign country, as a result of higher real interest rates, but also to lower output in the home country as a consequence of negative spillovers.

Finally, figure 8 presents the effects of a negative demand shock when the foreign country is at the ZLB (red line). As expected, the impact of the negative shock on output in the foreign country is exacerbated at the ZLB. As the nominal interest rate does not adjust in response to the negative shock, the real rates are higher relative to the normal times scenario, inducing a real exchange rate appreciation and a decline in the current account balance. The negative policy spillover to the rest of the world is also magnified relative to normal times. As the real interest rate increases in the foreign country, there is a real exchange rate depreciation and a small improvement of the current account balance in the home country.

5.2 Cooperative and Nash Equilibria at the ZLB

Figure 9 shows the model dynamics under the Nash and cooperative equilibria when the foreign country hits the ZLB. Since the recession in the foreign country is deeper at the ZLB, the cooperative equilibrium requires a larger real exchange depreciation and external adjustment in order to stabilize output in the foreign economy. This external adjustment is supported with an expansionary QE policy in the foreign country relative to normal times and a larger sale of FX reserves in the home country. In the Nash equilibrium, both countries compete in the use of unconventional policies, resulting in a limited adjustment of the real exchange rate and lower output growth in the foreign country. In sum, under the ZLB international policy spillovers are magnified. However, we obtain qualitatively similar results to the ones obtained in the normal times scenario. Under the cooperative equilibrium the foreign economy experiences a significant external adjustment while under Nash equilibrium there is limited external adjustment as both countries engage in competitive devaluations.

6 Welfare Gains from International Policy Cooperation

Table 2 reports the welfare implications from cooperative and self-oriented unconventional policies both in normal times and at the ZLB.

In normal times (section A) and no unconventional policies, welfare losses associated with the negative demand shock are sizable and greater for the foreign country, where the shock is originated.[8] In the Nash equilibrium, when both countries implement optimal unconventional policies in a self-oriented fashion, the welfare losses are lower as the home and foreign countries can partially stabilize their economies. In the cooperative equilibrium, there is a trade-off between the welfare gains in the two countries. While the foreign country is better off as the exchange rate depreciation cushions the negative shock, the home country is worse off than in the Nash equilibrium. Notice that the world's welfare is higher in the cooperative equilibrium as both countries share optimally the costs associated with the recession. To summarize, the fourth row shows that the welfare gains from cooperation. Consistent with the literature, these gains are quantitatively small.

At the ZLB in the foreign country (section B), the welfare costs of a negative demand shock become significantly larger for both the home and foreign

[8]We compute the welfare costs as a percent of steady state consumption as in Lucas (1987).

country. In the Nash equilibrium, both economies are highly effective in stabilizing their economies with unconventional policies, and the welfare losses associated with the recession are reduced significantly. Output is largely stabilized not only in response to the deployment of unconventional policies, but also as a consequence of the amplification effects of the ZLB. An increase in inflation as a result of expansionary unconventional policies reduces the real interest rate at the ZLB, providing an additional demand boost. Similar to the scenario in normal times, the welfare gains from cooperation remain quantitatively small.

Overall, these results show that unconventional policies implemented in a self-oriented fashion (Nash equilibrium) yield welfare gains that are close to the ones obtained under the cooperative equilibrium, a result consistent with Obstfeld and Rogoff (2002). Interestingly, the welfare gains from international cooperation remain small at the ZLB.

7 Conclusions

This paper has analyzed exchange rate dynamics under cooperative and self-oriented unconventional policies. We show that the cooperative equilibrium features a moderate use of unconventional policy instruments and the real exchange rate plays its traditional role of shock absorber, depreciating in response to a negative shock. In the Nash equilibrium, central banks deploy more intensively unconventional policies and the real exchange rate is largely stabilized. At the ZLB, however, we find that the intensity of unconventional policies and exchange rate adjustment are magnified. We also show find that the welfare gains from international policy cooperation are small.

There are promising avenues for future research. For example, considering additional features such as a high exchange rate pass-through or foreign currency liabilities in the corporate sector could increase the costs of exchange rate movements, potentially leading to more aggressive unconventional policies in the cooperative equilibrium. The degree of business cycle synchronization could also play an important role in determining the optimal use of unconventional policies and their impact on exchange rate dynamics. For instance, as business cycles become more synchronized, optimal unconventional policies under cooperative and self-oriented policies could become more alike, reducing the scope for exchange rate adjustment.

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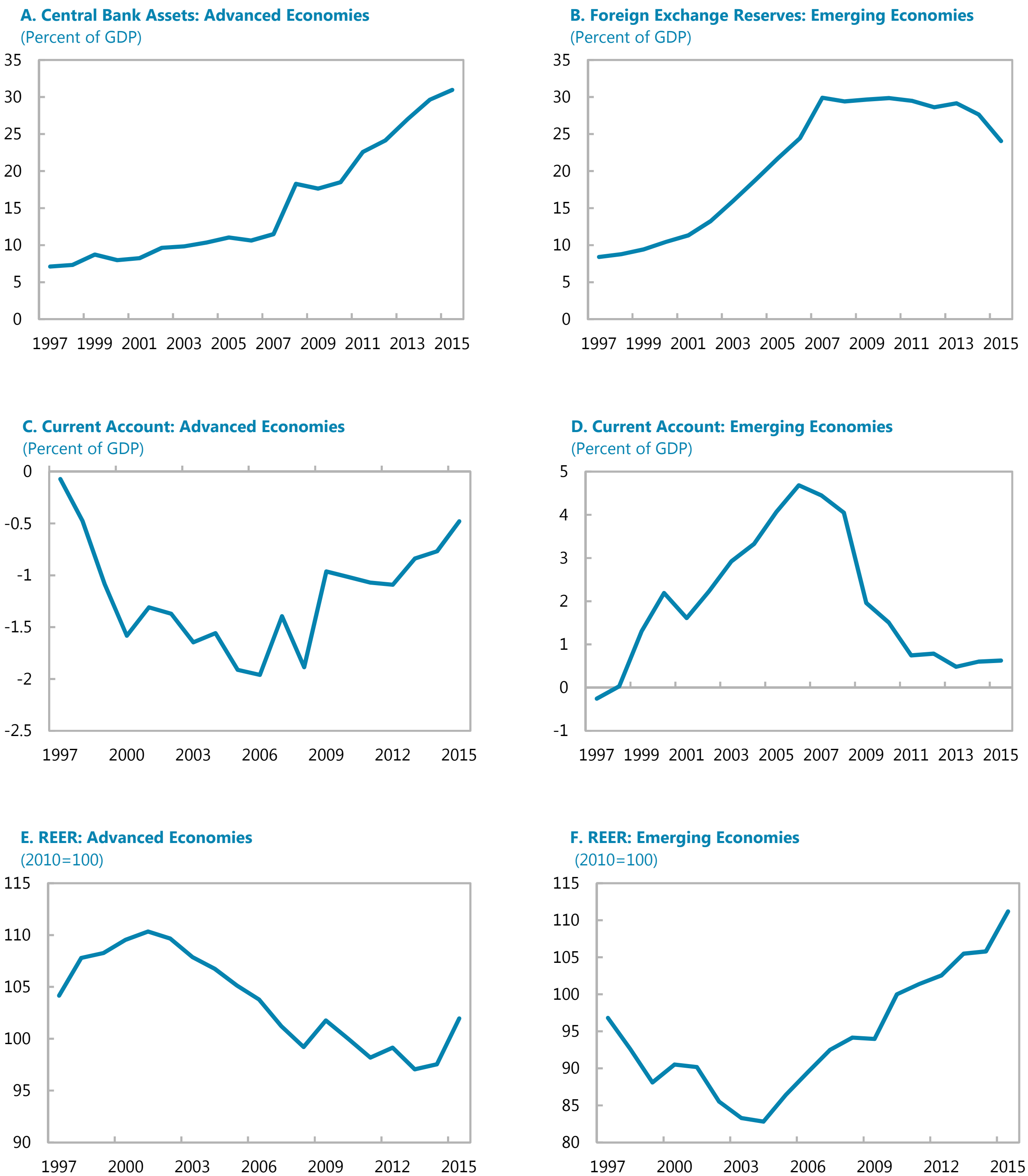
Table 2. Welfare Gains from Unconventional Policies 1/

	Home Country	Foreign Country	World
A. Unconventional Policies in Normal Times			
1. Baseline Scenario	-0.25	-1.75	-1.00
2. Nash Equilibrium	-0.18	-1.35	-0.74
3. Cooperative Equilibrium	-0.27	-1.09	-0.68
4. Gains from Cooperation (3-2)	-0.09	0.26	0.07
B. Unconventional Policies at the ZLB			
1. Baseline Scenario at ZLB	-0.58	-4.85	-2.70
2. Nash Equilibrium	-0.02	-0.45	-0.20
3. Cooperative Equilibrium	-0.03	-0.21	-0.16
4. Gains from Cooperation (3-2)	-0.01	0.24	0.04

1/ Normalized to 1 in the scenario of a negative demand shock and no unconventional policies.
Under that scenario the world economy welfare loss is 0.02 percent of steady state consumption.

Figure 1. Unconventional Policies and External Adjustment



Sources: Haver Analytics; IMF Staff Estimates. Advanced Economies variables correspond to a weighted average of Australia, Canada, France, Germany, Italy, Japan, United Kingdom, and United States. Emerging Economies variables correspond to a weighted average of Argentina, Brazil, China, India, Indonesia, Korea, Mexico, Saudi Arabia, South Africa, and Turkey.

Figure 2. Transmission Mechanism of Unconventional Policies

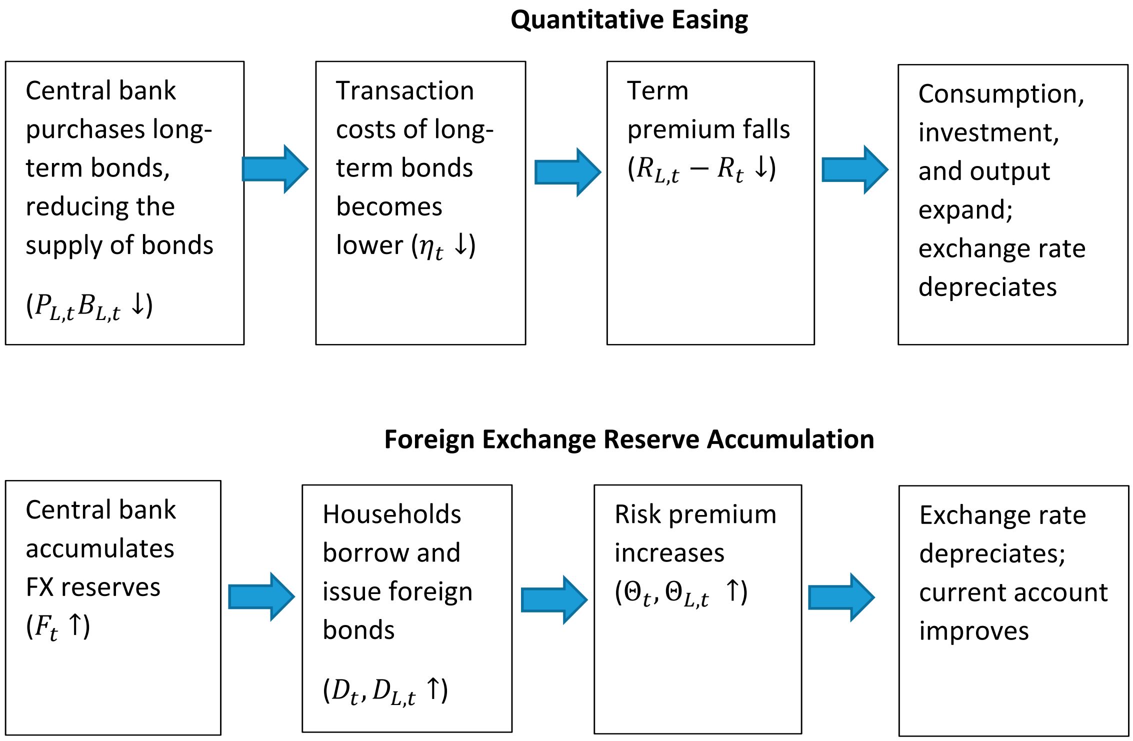


Figure 3. Spillovers from Quantitative Easing

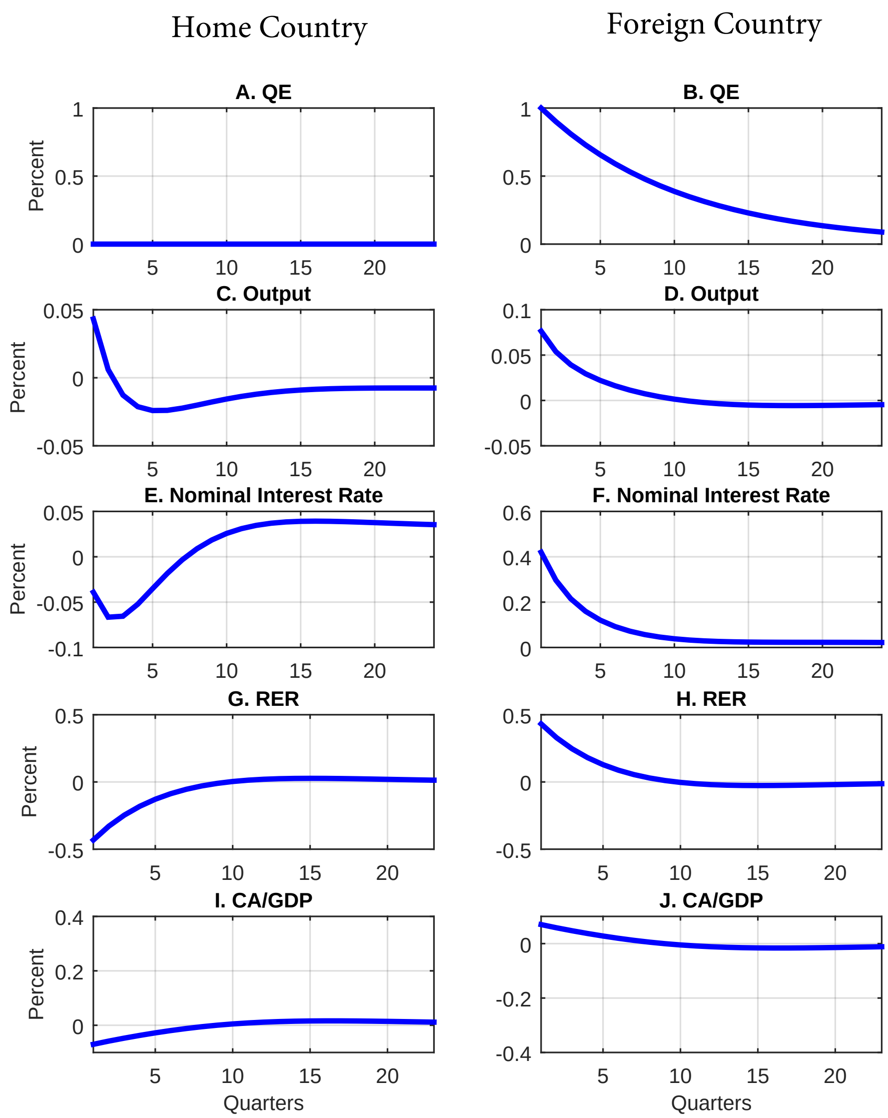


Figure 4. Spillovers from Foreign Exchange Intervention

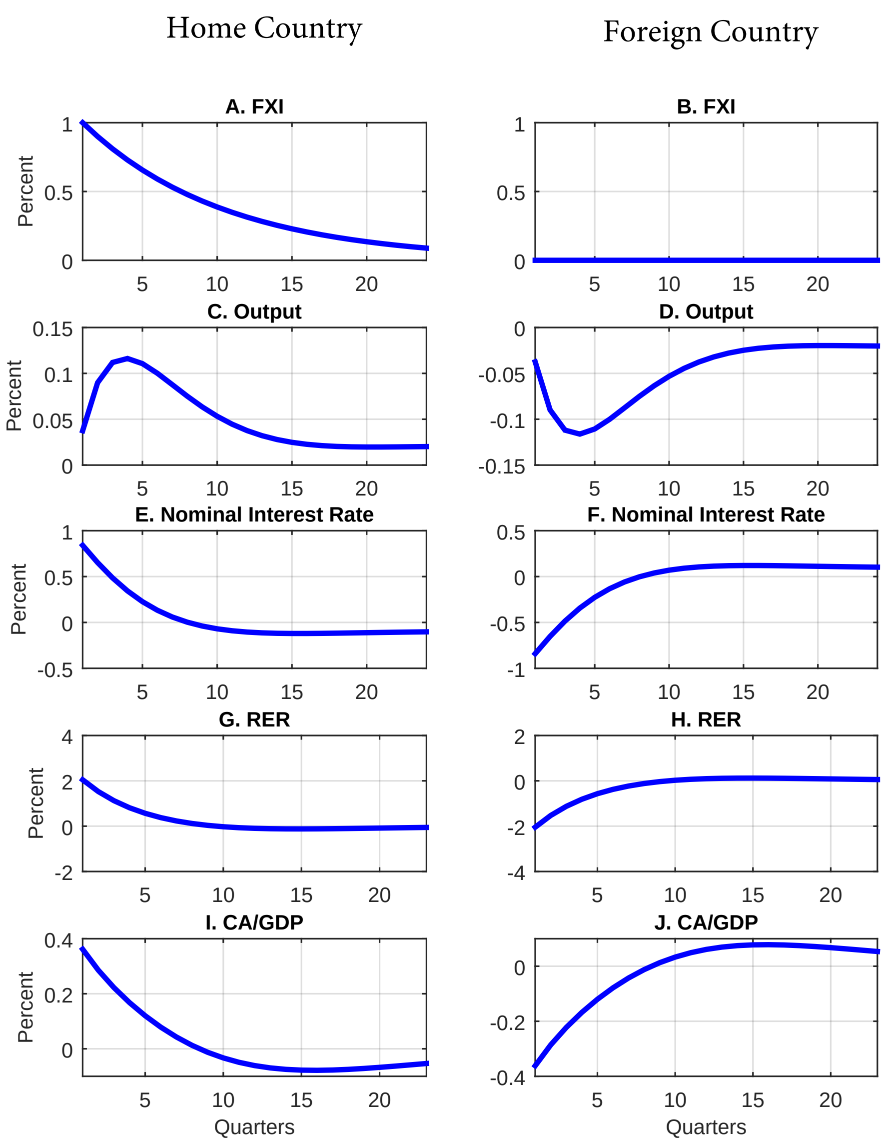


Figure 5. Cooperative and Nash Equilibria in Normal Times

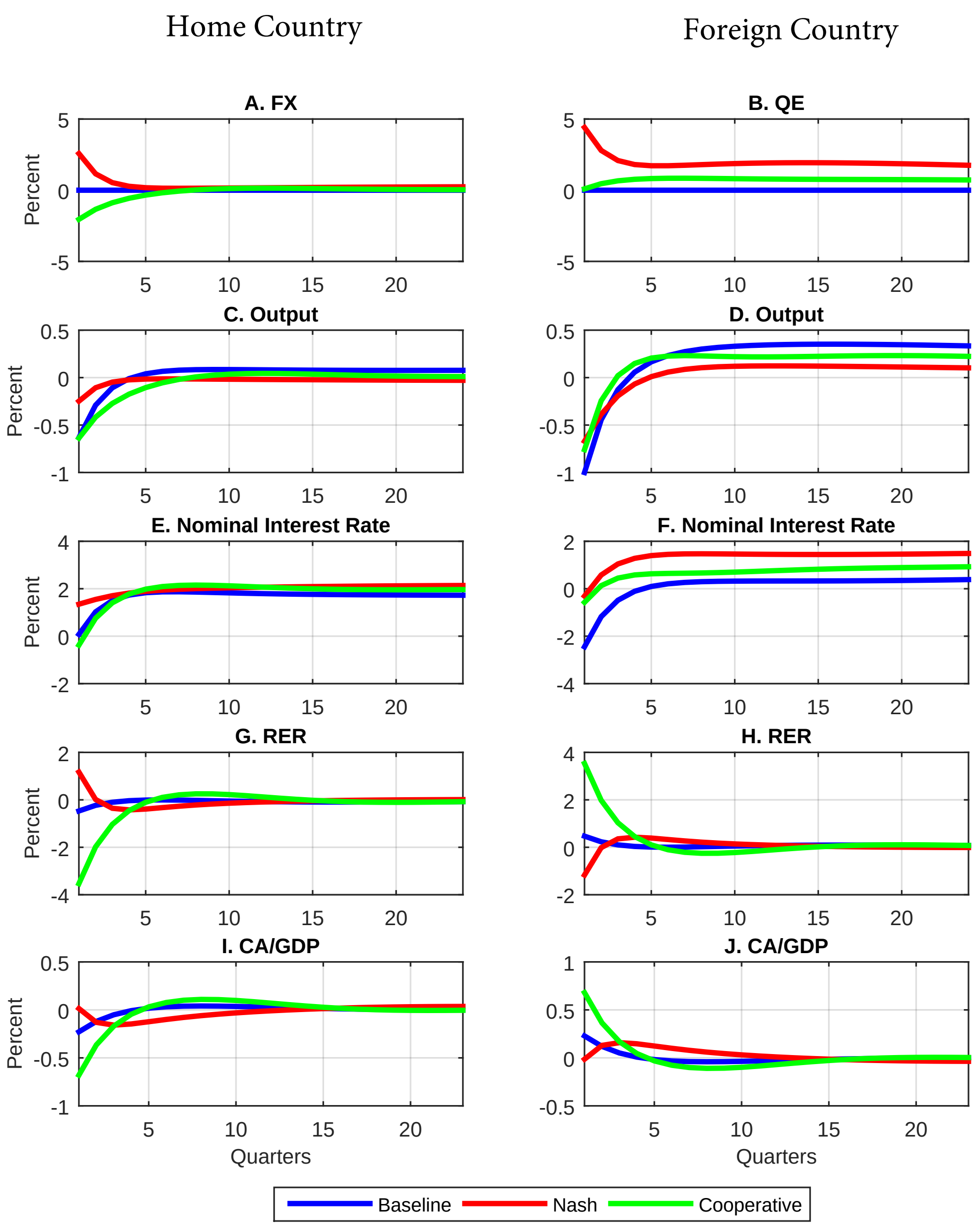


Figure 6. Spillovers from Quantitative Easing at the ZLB

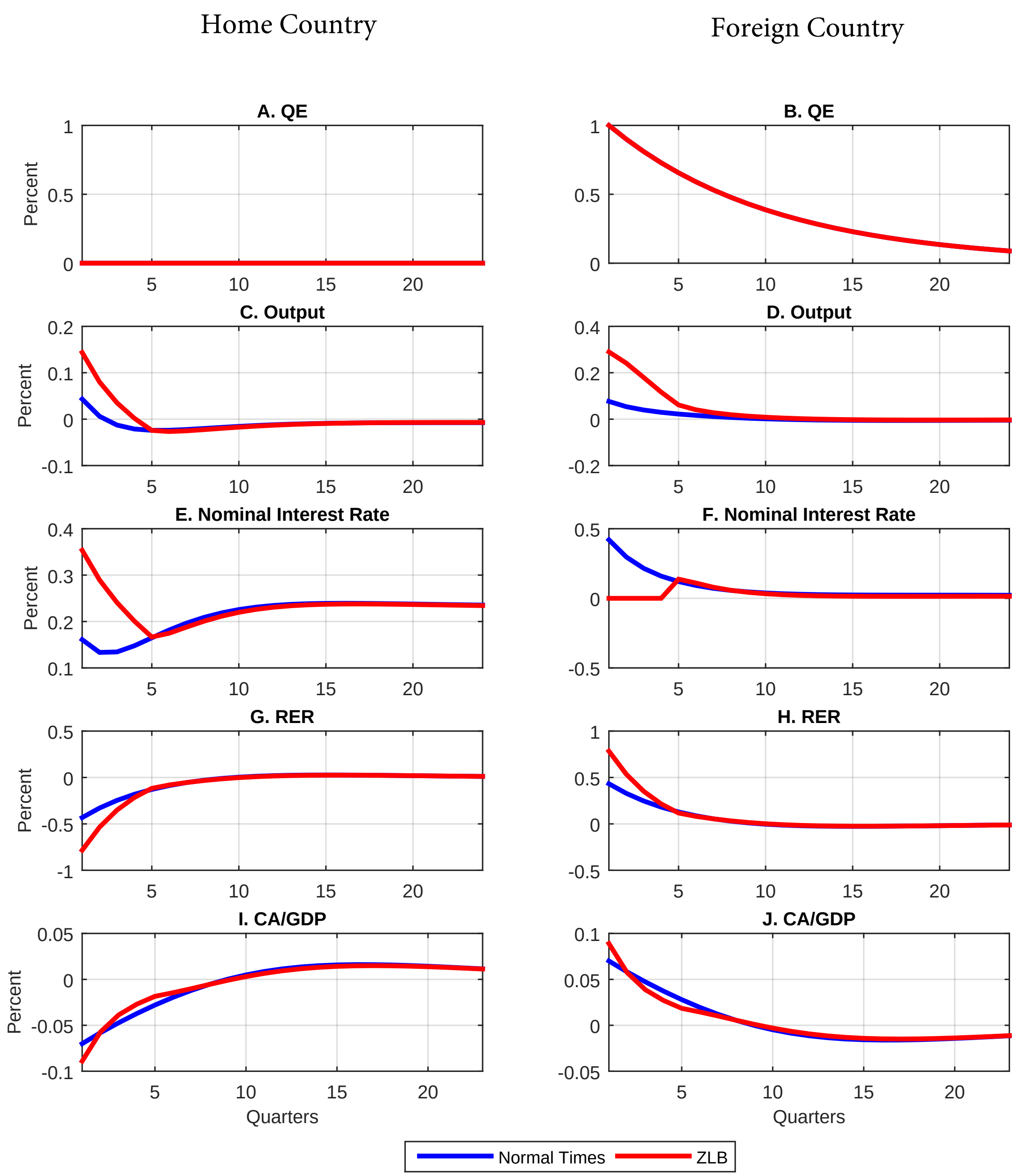


Figure 7. Spillovers from Foreign Exchange Intervention at the ZLB

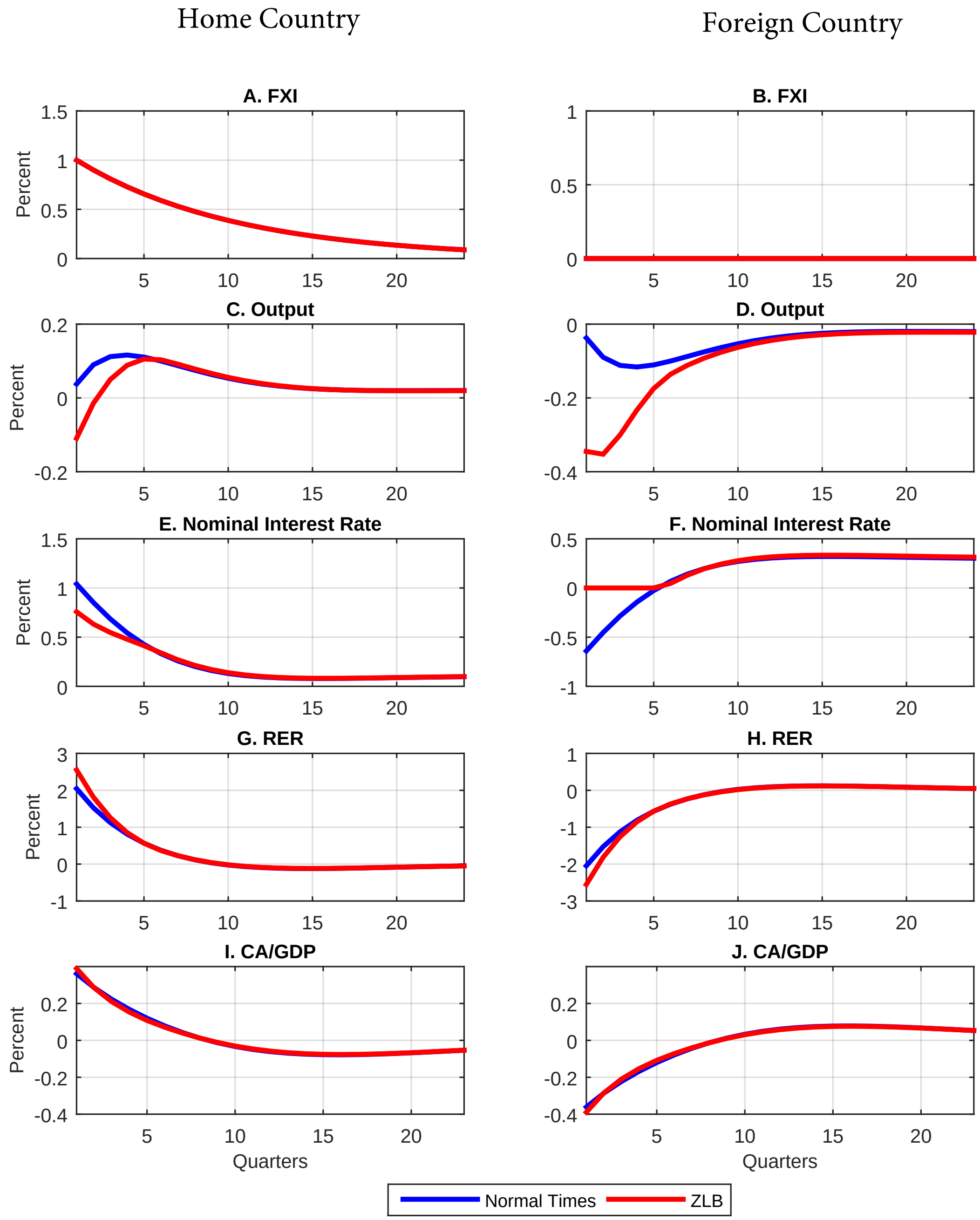


Figure 8. Negative Demand Shock at the ZLB

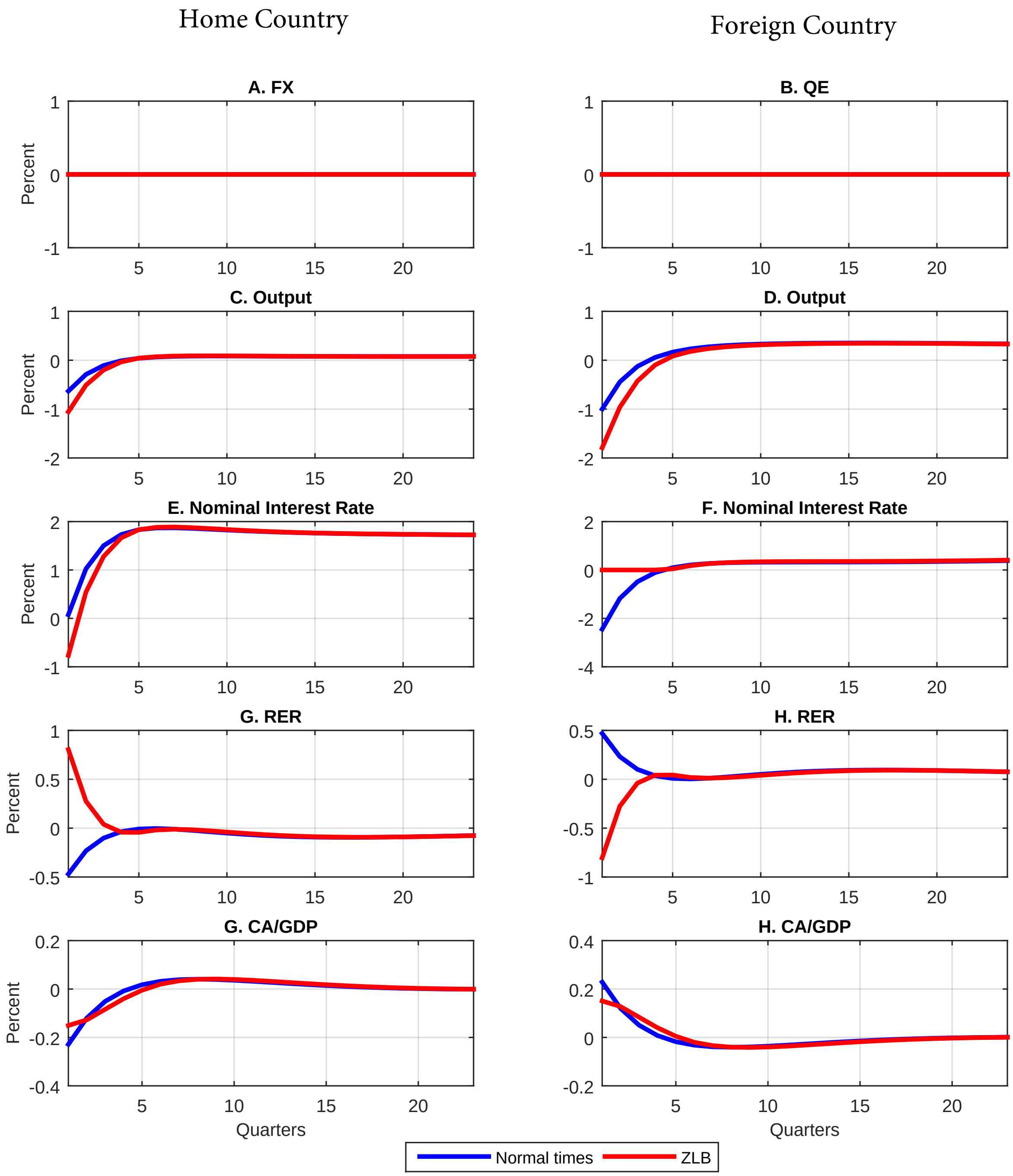


Figure 9. Cooperative and Nash Equilibria at the ZLB