Unconventional Policies, External Adjustment, and the ZLB

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May, 2017

Abstract

We study the implications of unconventional policies for external adjustment in a two-country model. In the model, the foreign country relies on Quantitative Easing (QE) and the home country on Foreign Exchange (FX) intervention. In the cooperative equilibrium, there is a moderate use of unconventional policies and the real exchange rate plays its traditional role of shock absorber. In the Nash equilibrium, central bank's balance sheets experience a larger expansion relative to the cooperative equilibrium, moderating real exchange rate fluctuations at the expense of larger macroeconomic volatility in the country that experiences a negative shock. At the zero lower bound (ZLB) we find that in response to a negative shock, the recession becomes more protracted. In that scenario, the cooperative equilibrium features expansionary unconventional policies in the foreign country and a larger exchange rate adjustment, while at the Nash equilibrium the exchange rate displays low volatility. These results suggest that international policy cooperation is key in facilitating external adjustment during times of crisis.

JEL Classification: E52; F41; F42; F44.

Keywords: Foreign Exchange Intervention, Quantitative Easing, International Policy Coordination

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1 Introduction

In recent decades central banks in both advanced and emerging economies have increasingly relied on unconventional policies with the objective of pursuing domestic macroeconomic stabilization. As figure 1 shows, central banks' balance sheets have expanded dramatically during the last twenty years in both advanced and emerging economies. In the aftermath of the Asian crisis, central banks in emerging markets engaged in a build up of Foreign Exchange (FX) reserves over more than a decade. In advanced economies, central banks have expanded their balance sheets by conducting Quantitative Easing (QE) in the aftermath of the global financial crisis once the interest rates reached the zero lower bound (ZLB). While from the point of view of domestic macroeconomic stabilization purposes, both QE and FX intervention could be useful policy tools in times of crisis, from the global perspective, scaling-up the central banks' balance sheet could lead to substantial international spillovers (both negative and positive), making more difficult to achieve internal and external balance in the recipient countries of policy spillovers.

As illustrated in Figure 1, the expansion of central banks balance sheets through unconventional policies coincided with large adjustments of the current account in advanced and emerging economies. During the period of FX reserves accumulation (1997-2007), emerging economies experienced an increase in their current account balance. Similarly, in the aftermath of the global financial crisis (2007-2015), advanced economies experienced a reduction of their current account deficits at a time when central banks were deploying QE measures. The real exchange rate also adjusted in a way consistent with the current account dynamics. In this context, there are several policy questions related to the recent period of policy activism among major central banks: What are global effects of unconventional policies? How unconventional policies should be implemented during times of crisis? Are the effect from unconventional policies on the external sector desirable? How big are the gains from international policy cooperation? How the ZLB affects the optimal implementation of unconventional policies? In this paper we answer these questions using a two-country model where central banks conduct QE and FX intervention policies.

We develop a two-country model DSGE which extends the work from Christiano et al. (2005), Smets and Wouters (2007), and Chen et al. (2012) to a two country setting and assumes that each country deploys different unconventional policy tools. The home country relies on FX intervention to stabilize the business cycle, while the foreign country deploys QE with the same goal. In the model, we simulate a scenario in which the foreign country experiences a negative demand shock resulting in a decline of 1 percent of GDP. Then we evaluate the macroeconomic outcomes under the Nash and cooperative equilibrium in normal times (positive nominal interest rates) and at the ZLB.

In normal times the cooperative equilibrium features a moderate use of unconventional policy instruments, and the real exchange rate plays the traditional role of shock absorber in the economy that faces a negative shock. In the Nash equilibrium, both countries engage actively in deploying unconventional policies with a limited adjustment of the real exchange rate. At the ZLB, a negative demand shock generates a much larger recession as the nominal interest rate does not adjust in response to domestic economic conditions. In addition, since in the ZLB scenario there is a higher real interest rate (as the nominal rate does not go below the zero bound), the resulting real exchange rate appreciation aggravates the recession. In this situation, the cooperative equilibrium requires a more aggressive use of QE and larger real exchange rate depreciation in the foreign country.

We also find that the largest welfare gains occur when unconventional policies are implemented under cooperation, and the combination of QE and FX intervention allows the economy that experiences a negative shock to depreciates its currency in order to absorb the shock. The Nash equilibrium delivers welfare gains close to the cooperative equilibrium, a result similar to the one obtained by Obstfeld and Rogoff (2002). The intuition for this result is that when a country optimally deploys unconventional policy tools generate positive spillovers from output stabilization (expenditure shifting effect) and negative spillovers from movements in the exchange rate (expenditure switching effect). In the Nash equilibrium, the rest of the world is capable of offsetting the negative policy spillovers and in equilibrium both countries benefit from greater macroeconomic stability. We also show that in a scenario were unconventional policies are deployed unilaterally, without offsetting policy measures from the rest of the world, welfare in the world economy could be reduced.

Our paper is related to several strands of the literature. One strand is related to the gains from cooperation. Obstfeld and Rogoff (2002) concluded that implementing monetary policy focusing solely on domestic objectives (Nash equilibrium) yields global outcomes that are close to the cooperative equilibrium, hence the gains from policy coordination are small. Similarly, Jeanne (2014) studied capital account policies to address financial distortions associated with over-borrowing and found that the gains from multilateral coordination are small. The other strand is related to the effects on unconventional policies. Chen et al. (2012) quantify the effects of QE in the US in an estimated DSGE model. Alpanda and Kabaca (2015) estimate the international spillovers from QE in the US. Gabaix and Maggiori (2015) study the spillovers from FX intervention in a two-country model.

Our paper contributes to the literature by analyzing the interaction of QE and FX intervention in the global economy both in normal times at the ZLB. It illustrates the international spillovers of unconventional policies and characterizes the optimal policies both at the Nash and the cooperative equilibrium.

The rest of the paper is organized as follows. Section 2 describes the two-country model. Section 3 explains the calibration strategy. Section 4 show the results of optimal unconventional policies in normal times. Section 5 show 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

In this section we present the two-country model used for to analyzing the global effects QE and FX intervention. Our model is an extension of Christiano et al. (2005), Smets and Wouters (2003, 2007), which includes several nominal and real rigidities, but extended to a two-country framework as in Chari et al. (2002), Rabanal and Tuesta (2010), and Lama and Rabanal (2015), among others.

In the model we assume local currency pricing. We also consider an incomplete asset market structure for international bonds, that is, agents only have access to non-contingent international bonds denominated in the foreign country currency. The main innovation relative to standard two-country models is that we incorporate unconventional policies in the model, namely QE and FX intervention. In order for these unconventional policies to have real effects, we need to assume additional frictions that generate imperfect asset substitution between short-term and long-term bonds and between domestic and foreign assets. For QE, we follow Chen et al. (2012) and assume segmented asset markets in the spirit of Alvarez et al. (2002).

and Maggiori (2015) and assume imperfect substitution between foreign and domestic bonds, modeled as a risk premium that is increasing on the stock of bonds.

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 that 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 goods producers, and final goods producers in the home country. The description for the foreign country is analogous, and we use an asterisk to denote variables and parameters for the foreign country.

2.1 Households

There is continuum of households in each country. We follow Chen et al. (2012), and assume asset market segmentation that takes the form of two groups of households: one unrestricted (denoted by u) and one restricted (denoted by r). Household of group $j = u, r$ obtains 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. A fraction ω_u of households are unrestricted and fraction $1-\omega_u$ are restricted. 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 different type of bonds. First, they can trade short-term domestic bonds B_t, which are one-period securities purchased at period t that pays the nominal return R_t in period $t+1$. Second, households can trade long-term bonds, which are perpetuities with a price $P_{L,t}$ at period t and pay an exponentially decaying coupons 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, they can trade short-term foreign bonds D_t that pays 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 a debt-elastic risk premium for the short-term bond. Finally, households can also trade 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 a debt-elastic risk premium for long-term bonds. Following Woodford (2001), the return and price of the long-term bonds satisfy:

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

Unrestricted households can trade short-term or long-term bonds, but they need to pay a transaction cost η_t per-unit of long-term bond purchased. Unrestricted households can also trade foreign bonds, either short-term or long-term. In contrast, restricted households only trade long-term domestic bonds . Thus, the budget constraint differs depending on whether the household is unrestricted or restricted. One consequence of the specification of the long-term bonds is that the price in period t of a bond issued in $t-s$ is a function of the coupon size κ and the current price $P_{L,t}$. With that result, the budget constraint of each group of households can be written in a compact way. For unrestricted households, the budget constraint is

$$\begin{pmatrix} P_tC_t^u + B_t^u + S_tD_t^u + \\ (1+\eta_t)(P_{L,t}B_{L,t}^u + S_tP_{L,t}^*D_{L,t}^u) \end{pmatrix} = \begin{pmatrix} R_{t-1}B_{t-1}^u + S_tR_{t-1}^*\Theta_tD_{t-1}^u + \\ P_{L,t}R_{L,t}B_{L,t-1}^u + S_tP_{L,t}^*R_{L,t}^*\Theta_{L,t}D_{L,t-1}^u + \\ W_t^u(i)L_t^u(i) + \Pi_t^u - T_t^u \end{pmatrix} \tag{2}$$

For restricted households their budget constraint is:

$$P_tC_t^r + P_{L,t}B_{L,t}^r = P_{L,t}R_{L,t}B_{L,t-1}^r + W_t^r(i)L_t^r(i) + \Pi_t^r - T_t^r \tag{3}$$

In these budget constraints, (2) and (3), P_t is the price of the final consumption good, S_t is the nominal exchange rate (units of domestic currency per one 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 to household 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.

The optimal consumption-saving decision for households are obtained by maximizing (1) subject to (2) in the case of unrestricted households and maximizing (1) subject to (3) in the case of restricted households.

2.2 Wage setting and labor supply

As in Erceg et al. (2000), we assume that perfectly competitive labor agencies combine differentiated labor services of each households, $L_t^j(i)$, into a homogenous labor composite L_t according to a Dixit-Stiglitz aggregator:

$$L_t = \left[\int_0^{\omega_u} \left(L_t^u(i)\right)^{\frac{\sigma_w - 1}{\sigma_w}} di + \int_{\omega_u}^1 \left(L_t^r(i)\right)^{\frac{\sigma_w - 1}{\sigma_w}} di \right]^{\frac{\sigma_w}{\sigma_w - 1}} \tag{4}$$

Profit maximization of labor agencies provides the demand for labor service of type i:

$$L_t^j(i) = \left(\frac{W_t^j(i)}{W_t} \right)^{-\sigma_w} L_t \tag{5}$$

Using the zero profit condition for labor agencies, we get an expression for the aggregate wage index W_t as:

$$W_t = \left[\int_0^{\omega_u} \left(W_t^u(i)\right)^{1-\sigma_w} di + \int_{\omega_u}^1 \left(W_t^r(i)\right)^{1-\sigma_w} di \right]^{\frac{1}{1-\sigma_w}} \tag{6}$$

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. Consider an unrestricted household resetting its wage in period t in a value $\widetilde{W}_t$. The household will choose $\widetilde{W}_t$ in order to maximize:

$$E_t \left\{ \sum_{s=0}^{\infty} (\beta_u \theta_w)^s \chi_{t+s} U(C_{t+s|t}^u, C_{t+s-1|t}^u, L_{t+s|t}^u) \right\} \tag{7}$$

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

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

2.3 Capital good producers

Firms in this sector invest and rent capital to intermediate good producers. The investment good is defined in terms of the final good. The representative capital-producer firm solves the following problem for choosing the optimal investment and capital stock:

$$\max_{K_{t+s},I_{t+s}} E_t \left\{ \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left(R_{K,t+s} K_{t+s} - P_{t+s} I_{t+s} \right) \right\} \tag{8}$$

subject to the law of motion of capital accumulation:

$$K_{t+1} = (1-\delta) K_t + S\left(\frac{I_t}{I_{t-1}} \right) I_t \tag{9}$$

where $R_{K,t}$ is the rental rate of capital, δ is the depreciation rate of capital, and function $S(.)$ characterizes the adjustment cost for investment.[1] Capital good producers are own by unrestricted households. Thus, the discount factor for future profits, $\Lambda_{t,t+s}$, corresponds to marginal rate of substitution of consumption between period t and $t+s$ of unrestricted households:

$$\Lambda_{t,t+s} = (\beta_u)^s \frac{\lambda^u_{t+s}}{\lambda^u_t} \tag{10}$$

where λ^u_t 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 for the final goods is given by:

$$Y_t = \left[(\alpha_Y)^{1/\eta_Y} (Y_{H,t})^{\frac{\eta_Y - 1}{\eta_Y}} + (1-\alpha_Y)^{1/\eta_Y} (Y_{F,t})^{\frac{\eta_Y - 1}{\eta_Y}} \right]^{\frac{\eta_Y}{\eta_Y - 1}} \tag{11}$$

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 domestically produced and imported intermediate goods in both countries. The price of home-produced goods is $P_{H,t}$ and of foreign-produced

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

goods is $P_{F,t}$. The optimal basket of home-produced and foreign-produced goods satisfies:

$$Y_{H,t} = \alpha_Y \left(\frac{P_{H,t}}{P_t} \right)^{-\eta_Y} Y_t, Y_{F,t} = (1 - \alpha_Y) \left(\frac{P_{F,t}}{P_t} \right)^{-\eta_Y} Y_t \tag{12}$$

where the price of final goods is:

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

2.5 Intermediate good producers

In each country, there is a continuum of intermediate differentiated goods producers, each producing a type of good that are imperfect substitutes using capital and labor. The differentiated goods are sold to the composite intermediate goods producers that have the following technology:

$$Y_{H,t} = \left[\int_0^1 (Y_{H,t}(h))^{\frac{\epsilon_p - 1}{\epsilon_p}} \, dh \right]^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{14}$$

$$Y_{F,t} = \left[\int_0^1 (Y_{F,t}(f))^{\frac{\epsilon_p - 1}{\epsilon_p}} \, df \right]^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{15}$$

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.

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

$$Y_t(h) = (A_t L_t(h))^{1-\alpha} (K_{t-1}(h))^{\alpha} \tag{16}$$

where $L_t(h)$ is the labor input used, $K_{t-1}(h)$ is the capital rented, A_t is a country-specific Total Factor Productivity (TFP) component, and α is the share of capital in the production function. TFP evolves as a zero-mean, AR(1) process in logs.

From cost minimization provide expressions for the marginal cost and for the capital-labor ratio:

$$MC_{H,t} = \left(\frac{W_t}{(1 - \alpha) A_t} \right)^{1-\alpha} \left(\frac{R_{K,t}}{\alpha} \right)^{\alpha} \tag{17}$$

$$\frac{W_t L_t(h)}{R_{K,t} K_{t-1}(h)} = \frac{1-\alpha}{\alpha} \tag{18}$$

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-type price-setting restriction. We assume local currency pricing (LCP) for goods that are shipped internationally. 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. Additionally, we assume that each firm that cannot reoptimize its price in a given period, it will adjust it based on the last period's inflation rate in each destination market with weight coefficient $\lambda_H \in [0, 1]$. Therefore, the coefficients of the two Phillips curves for each country (for domestic inflation and export inflation) have the same coefficients (θ_H, λ_H). In the case of the foreign country, foreign inflation and export inflation are governed by parameters θ_F^* and λ_F^*.

2.6 Macroeconomic policies

We assume that the central bank in each country follows a Taylor rule that reacts to the deviations of GDP and inflation from the steady state:

$$R_t = R\left[(P_t/P_{t-1})^{\gamma_\pi}(GDP_t/\overline{GDP})^{\gamma_y}\right] exp(\epsilon_{m,t}) \tag{19}$$

where R is the long-run value for the interest rate, $\epsilon_{m,t}$ is an iid monetary policy shock.

The central bank can also intervene in the FX market according to the following rule:

$$\frac{F_t}{\bar{F}} = \left[(P_t/P_{t-1})^{\theta_\pi}(GDP_t/\overline{GDP})^{\theta_y}\right] exp(\epsilon_{fx,t}) \tag{20}$$

where F_t is the stock of FX reserves denominated in the foreign currency, $\bar{F}$is the steady-state value of reserves, $\theta_\pi$and θ_y the coefficients on inflation and GDP for the FX intervention rule, and $\epsilon_{fx,t}$ is iid FX reserve shock.

The presence of long-term bonds and FX reserves modifies the consolidated budget constraint of the government. The total 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. Thus, the government budget constraint is:

$$B_t + P_{L,t}B_{L,t} - S_tF_t = R_{t-1}B_{t-1} + (1+\kappa P_{L,t})B_{L,t-1} - S_tR^*_{t-1}F_{t-1} + P_tG_t - T_t \tag{21}$$

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 for FX interventions.

We assume that macroeconomic policies also control the supply of long-term bonds, following a simple rule for their market value in real terms:

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

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

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

$$\frac{T_t}{P_t} - G_t = \Psi\left(\frac{P_{L,t-1}B_{L,t-1}}{P_{t-1}}\right)^{\phi_T} \tag{23}$$

where $\phi_T > 0$ and Ψ is just a constant to obtain the primary balance at the steady state.[2]

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:

$$Y_t = \omega_u C_t^u + (1-\omega_u)C_t^r + G_t + I_t. \tag{24}$$

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

[2]For the spillover analysis we consider an AR(1) processes for QE and FX intervention with a persistency coefficient of 0.9.

$$Y_t(h) = Y_{H,t}(h) + Y_{H*,t}(h) \tag{25}$$

$$Y_t(f) = Y^F_{F,t}(f) + Y_{F*,t}(f) \tag{26}$$

where $Y_t(h), Y_{H,t}(h)$, $Y_{H^*,t}(h)$ are production of the intermediate home good of type h, the domestic and demand foreign 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:

$$GDP_t = \int_0^1 Y_t(h)dh \tag{27}$$

The equilibrium for the labor market is given by:

$$L_t = \int_0^1 L_t(h)dh \tag{28}$$

For capital goods market clearing condition is:

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

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

$$B_t = \omega_u B^u_t, B_{L,t} = \omega_u B^u_{L,t} + (1-\omega_u) B^r_{L,t} \tag{30}$$

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:

$$\begin{pmatrix} S_t D_t + S_t P^*_{L,t} D_{L,t} \\ +S_t F_t \end{pmatrix} = \begin{pmatrix} S_t P_{H^*,t} Y_{H^*} - P_{F,t} Y_{F,t} + S_t R^*_{t-1} \Theta_t D_{t-1} \\ +S_t P^*_{L,t} R^*_{L,t} \Theta_{L,t} D_{L,t-1} + S_t R^*_{t-1} F_t \end{pmatrix} \tag{31}$$

Imperfect substitution between FX reserves and foreign short-term bond is controlled by Θ_t, whereas the imperfect substitution between FX reserves and foreign long-term bonds is captured by the term $\Theta_{L,t}$. These terms are endogenous risk premiums that generate imperfect asset substitutability between domestic and foreign bonds, and allows FX intervention to have real effects in the economy. We model the debt-elastic risk premium following

Schmitt-Grohé and Uribe (2003), and making it a function of the aggregate levels of foreign short and long term bonds:

$$\Theta_t = \Theta\left(D_t, D_{L,t}\right), \text{ and } \Theta_{L,t} = \Theta_L\left(D_t, D_{L,t}\right) \tag{32}$$

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

Following Chen et al. (2012), the formulation of the relation between transaction costs and the quantity of long-term debt is modeled as:

$$(1+\eta_t) = \Theta_\eta\left(P_{L,t}B_{L,t}, S_t P^*_{L,t}B^*_{L,t}\right) exp(\varepsilon_{\eta,t}) \tag{33}$$

We assume that the 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. It is important to 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.

The corresponding model equations for the foreign country will be similar to the ones for the home country and all foreign country's variables are denoted by an asterisk.

3 Calibration

We calibrate the model to a quarterly frequency using standard parameter values from the literature. Table 1 shows the parameter values used in the model simulation. We set the discount factor to β_u for unrestricted households and β_r 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, in annual basis. We calibrate κ to imply a duration of 30 quarters for long-term bonds, similar to the average duration in the secondary market for 10-year US Treasury bills. The degree of bond market segmentation in the model is chosen to have a half of unrestricted households in each country.

We set the elasticity of substitution across types of labor, σ_w, and across types of goods, ε_p, equal to 6 and 11, respectively, as it is standard in the DSGE literature. We set the steady-state ratio of government expenditures over GDP, 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 elasticity of the investment adjustment cost is $\mu_S = 2.5$, which is consistent with the value used in Christiano et al. (2005). The capital share in intermediate good production, α, is equal to 0.36. The Calvo price-setting parameters for price rigidities are set to $\theta_H = \theta_F^* = 0.75$, consistent with an average price duration of 4 quarters. For wage rigidity, parameter θ_w and θ_w^* are set to 0.75, which is consistent with a average wage rate duration of 4 quarters.

Households' preferences are represented by the following functional form:

$$U = log(C_t - \psi \frac{L_t^{1+\varphi}}{1+\varphi}),$$

We assume that the Frisch elasticity of the 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 $\gamma_y = 0.5$, without smoothing $\gamma_R = 0$. 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 equilibrium.[3]

We set values for the parameters Θ_1, Θ_2, $\Theta_{L,1}$, $\Theta_{L,2}$, $\Theta_{\eta,1}$ and $\Theta_{\eta,2}$ in order to target some statistics that controls the effectiveness of FX intervention and QE in both countries. Thus, consistent with the evidence of Bayoumi et al. (2016) the calibration reproduces that an increase in FX reserves of 1 percent of GDP increases the current account balance by 0.4 percent of GDP. At the same time, consistent with the average effect of QE in the term premium documented by Chen et al (2012), our calibration generate a reduction of 10 basis point in the term premium for long-term bond purchases of 1 percent of GDP.

Finally, we set the steady state stock of long and short-term bonds equal to 15 percent of annual GDP. We assume a trade balance equal to zero at

[3]In the Nash equilibrium each country optimizes the coefficient of the unconventional policy rules in order to maximize the welfare of the restricted and unrestricted households. In the cooperative equilibrium each country choose the coefficients to maximize the aggregate welfare of the world economy.

the steady state. This assumption implies that in the steady state the stock of Net Foreign Assets to GDP is equal to zero. Finally, we assume that the logarithm of the preference shock χ_t follows an AR(1) process with a persistency coefficient of 0.95.

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
$G/GDP, G^*/GDP^*$	0.25	Government consumption-to-GDP
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^*	0.0125	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 growth 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

Table 1: Baseline Calibration (cont.)

Parameter	Value	Description
Θ_1	0.035	Derivative of short-term portfolio cost w.r.t. short-term foreign bonds
Θ_2	0.035	Derivative of short-term portfolio cost w.r.t. long-term foreign bonds
$\Theta_{L,1}$	0.040	Derivative of long-term portfolio cost w.r.t. short-term foreign bonds
$\Theta_{L,2}$	0.060	Derivative of long-term portfolio cost w.r.t. long-term foreign bonds
$\Theta_{\eta,1}$	0.011	Elasticity of home transaction costs to home long-term bonds
$\Theta_{\eta,2}$	0.005	Elasticity of home transaction costs to foreign long-term bonds
$\Theta^*_{\eta,1}$	0.011	Elasticity of foreign transaction costs to foreign long-term bonds
$\Theta^*_{\eta,2}$	0.005	Elasticity of foreign transaction costs to home long-term bonds
$\bar{B}/GDP, \bar{B}^*/GDP^*$	0.15	Short-term bonds-to-GDP
$\bar{P}_L\bar{B}_L/GDP, \bar{P}^*_L\bar{B}^*_L/GDP^*$	0.15	Long-term bonds-to-GDP

4 Unconventional Policies in Normal Times

Figure 2 and 3 illustrate the transmission mechanism and international spillovers of QE and FX intervention in normal times, when the short-term nominal rate is set by the Taylor rule. In Figure 2 we simulate the purchase of 1 percent of GDP in domestic long-term bonds in the foreign country. The effects in the foreign country, shown in the second column, are as expected. As a result of a reduction in the term premium there is a boost in aggregate demand. While the term premium goes down, the short-term nominal interest rate goes up, as the Taylor rule calls for higher nominal interest rates in response to higher output and inflation. In addition, the compression of the term-premium induces capital outflows resulting in real exchange rate depreciation and a modest improvement in the current account balance. The first column illustrates the effects on the home country. There are two opposing forces affecting the home economy. On the one hand, as world demand increases, GDP in the home country is expected to increase (reflecting the expenditure shifting effect). On the other hand, as capital flows to the recipient country, the exchange rate appreciates resulting in lower output, inflation, and nominal short-term interest rate (reflecting the expenditure switching effect). For our parametrization the expenditure shifting effect initially dominates, and eventually the expenditure switching effect gains traction and leads to lower output.

Figure 3 illustrates a scenario where the central bank in the home country conduct an expansion of FX reserves by 1 percent of GDP. From the domestic point of view, the effects are similar to QE. An increase in reserves leads to a real exchange rate depreciation, higher output, current account, and nominal interest rate. Notice that in the case sterilized FX intervention, the spillovers are mainly driven by the flow of capital to the rest of the world. Since FX is a policy that increases national savings, it does not lead to an increase in world demand. FX intervention only shifts demand from one country to another through changes in the real exchange rate. The effects to the foreign economy are illustrated in the second column. As the real exchange rate appreciates, the economy experiences a loss of competitiveness, a deterioration in the current account, lower output and a lower nominal short-term interest rate.

Figure 4 shows the global outcomes of QE and FX intervention under the cooperative and Nash equilibrium. We assume a baseline scenario (blue line) of a decline in aggregate demand of 1 percent in the foreign country triggered by a negative preference shock (χ_t) and that no unconventional policies are in place. In this scenario 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. The recession in the foreign country generate spillovers to the home country, leading to a decline in output of 0.5 percent, a decline in interest rates, and small appreciation and deterioration of the current account balance.

Next, we consider the case of the cooperative equilibrium (green line). In this scenario both countries implement unconventional policies optimally with the objective of maximizing global welfare. In terms of the equilibrium dynamic of QE and FX intervention, two things are noticeable. First, there is an expansion of the balance sheet 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 leads to a real exchange rate depreciation of 4 percent and to an increase in the current account balance of 0.6 percent of GDP in the foreign country. The resulting external adjustment leads to a shallower recession and more stable nominal interest rates. While these policies are optimal for the world economy, the home country experiences a larger decline in output as their policies are designed to increase global welfare. The resulting equilibrium indicates some degree of risk-sharing across the home and foreign economy.

Finally, we consider the model dynamics under the Nash equilibrium (red line). In that situation, both QE and FX intervention are used more intensively as each country maximizes their own welfare, taking as given the reaction function and spillovers from the other country. In particular, in the foreign country now the central bank's balance sheet expands by 5 percent of GDP and the home country accumulates FX reserves by 3 percent of GDP. In the equilibrium we observe the combination of unconventional policies stabilizes the current account and generates a small appreciation in the foreign country. In this scenario, as a result of the combination of unconventional policies measures, the home country can be largely insulated from the external shock and spillovers, but the foreign country experiences a slower recovery. Hence, the limited movement of the exchange rate prevented the needed external adjustment in the economy that experiences the negative shock.

To summarize, this section characterizes the global outcomes of optimal unconventional policies in the Nash and cooperative equilibrium. The key distinctive feature that distinguishes both equilibria is the process of external adjustment. In the cooperative equilibrium, the country that faces a negative shock experiences a large real exchange rate depreciation and fast external adjustment. In the Nash equilibrium, as both countries engage in competitive devaluations, the equilibrium outcome is a small external adjustment.

5 Unconventional Policies at the ZLB

In this section, we extend our analysis to the scenario where the nominal short-term interest rate in the foreign country reaches the ZLB. Under the ZLB, in response to a negative shock the nominal interest rate does not adjust below the zero bound, inducing a higher real interest rate, amplifying the effects on output.

For a better understanding of the outcomes in the Nash and cooperative equilibria at the ZLB, we first show how the transmission mechanism of unconventional policies and the propagation of the demand shock changes at the ZLB.

Figure 5 show the dynamics in the home and foreign country in response to a 1 percent asset purchases or QE at the ZLB (red line) in the foreign country. The first thing to notice is that the effect on output more than doubles, now becoming 0.3 percent of GDP. Since the nominal interest rates remain at zero while there is an expansion in aggregate demand, there is a decline in the real rates that generates an additional boost in output. The decline in the real interest rate induces a real exchange rate depreciation and an improvement in the current account balance. In the home country the increase in world demand, leads to a greater expansionary effect in the short term but after four quarters the contractionary effect induced by the expenditure switching effect leads to a decline in output. The increase in activity induces a higher short-term nominal interest rate, a real exchange rate appreciation, and a decline in the current account balance.

Figure 6 illustrates the transmission mechanism of FX intervention at the ZLB. The domestic effects of FX intervention at the ZLB, are easier to understand if we first analyze the policy spillovers on the foreign country. The accumulation of FX reserves by 1 percent of GDP in the home country induces capital inflows for the same amount in the foreign country. As the real exchange rate appreciates, output and inflation declines. Since the nominal interest cannot go below the zero bound, the decline in inflation raises the real interest rate, inducing an additional contraction in output. The current account balance is not significantly different from the case in normal times as the effect from the appreciation on the current account is offset by the import compression as a result of lower demand. Output in the home country declines relative to the normal times scenario, as global demands decline at the ZLB. In addition lower interest rate triggers a depreciation and additional capital outflows. In sum, FX intervention at ZLB leads to lower output in the foreign country, as a result of higher interest rate, but also to lower output in the home country as global demands decline.

Figure 7 shows the effects of a negative demand shock at the ZLB (red line) in the absence of unconventional policies. 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 scenario of normal times, inducing a real exchange rate appreciation and a decline in the current account balance. The negative spillover to the rest of the world is also magnified relative to scenario in normal times. As the real interest rate is higher in the foreign country, capital flows out of the home country generating a real exchange rate depreciation and a small improvement in the current account balance.

Figure 8, show the model dynamics under the Nash and cooperative equilibrium at 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 to stabilize the foreign economy. That equilibrium is achieved with a larger balance sheet expansion in the foreign country central bank relative to the 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 the current account which results in lower output growth in the foreign country. In sum, under the ZLB we obtain a similar result from the one observed in the normal times scenario. Under the cooperative equilibrium the foreign economy experiences a significant external adjustment while under Nash equilibrium the external adjustment is limited as countries compete to maximize their share of global demand.

6 Welfare Gains from International Policy Cooperation

Table 2 shows the welfare gains from implementing unconventional policies in the home and foreign country. We consider four possible scenarios. The first two sections show the welfare gains from optimal unconventional policies under the Nash and cooperative equilibrium, and the last two sections of table 2 table show the case where each country uses unconventional policy measures unilaterally (i.e., only QE in the foreign country, or only FX intervention in the home country).

In normal times and no unconventional policies (A.1) there are welfare losses derived from the negative demand shock. The losses are greater for the foreign country, where the shock is originated.[4] 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 country are able to partially stabilize their economies, but also to offset some of the negative policy spillovers. In the cooperative equilibrium, there is a trade-off between the welfare in the two countries. While the foreign country is better off, as the exchange rate depreciation cushions the external 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 are sharing the risks associated with a recession (a negative shock in the home country would imply the opposite exchange rate adjustment). To summarize, the fourth row (A.4.) shows that there are welfare gains from cooperation, but these gains are relatively small.

At the ZLB, the welfare costs of the negative demand shock are much larger for both the home and foreign country. In the Nash equilibrium, both economies are highly effective in stabilizing their economies and the welfare losses are significantly reduced. At the ZLB not only unconventional policies contribute directly to the stabilization of the business cycle, but since the nominal interest rates are at the zero bound, the increase in output and inflation, induces a reduction in the real rate that provides and additional boost in demand that helps insulate the economy from the negative shock. As in the scenario of normal times, the welfare gains from cooperation are

[4]We computed the welfare costs as a percent of steady state consumption as in Lucas (1987). Table 2 expresses the welfare losses relative to the World's welfare loss in the baseline scenario in normal times (0.02 percent of steady consumption).

small.

In the case of unilateral policy actions (Section C) in normal times, we observe limited gains from the use of unconventional policies. The global welfare costs increase under a temporary intervention of 1 percent of GDP of QE and FX intervention. At the ZLB, we find that a unilateral accumulation of FX reserves increases welfare costs but QE reduces the welfare costs marginally.

To summarize, optimal unconventional policies implemented in a self-oriented fashion (Nash equilibrium) yield a welfare gain that closely mimics the one obtained under the cooperative equilibrium, a result consistent with Obstfeld and Rogoff (2002). Interestingly, discretionary unilateral policy interventions either reduce welfare or have modest welfare gains for the world economy. Countries could achieve superior outcomes if they implement optimal unconventional policies simultaneously.

7 Concluding Remarks

In this paper we have analyzed the implications on unconventional policies for external adjustment in normal times and at the ZLB. In normal times, the cooperative equilibrium features a moderate use of unconventional policy instruments and the real exchange rate plays the traditional role of shock absorber and depreciates in response to a negative shock. In the Nash equilibrium, central bank's balance sheets experience a larger expansion relative to the cooperative equilibrium, moderating the fluctuations of the real exchange rate as countries compete for their share of global demand. At the ZLB, we find that in response to the same shock, the recession becomes deeper which in turn requires a more expansionary QE policy and a larger external adjustment. Consistent with the findings in the literature of international policy coordination, we find that the gains from policy cooperation are small both in normal times and at the ZLB.

There are important avenues for future research. For example, we could consider additional frictions such as foreign-currency liabilities and learning-by-doing externalities that will call for more aggressive unconventional policies in times that there are real exchange rate appreciation pressures. Also we could explicitly model the quasi-fiscal costs associated with the unconventional policies, such that their use could be restricted after some thresholds are reached.

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Appendix A: Effects of Quantitative Easing

Several papers find evidence that large scale asset purchases (LSAP) programs or QE have indeed been effective in reducing long-term rates. For example, Gagnon et al. (2011) estimates that the ten-year term premium reduced in a range between 30 and 100 basis points for the LSAP through March 2010. Since this asset purchases correspond to roughly 12 percent of GDP, 1 percent of asset purchase will imply a reduction in term premium between 2.5 and 8.3 basis points. Other studies, like D'Amico and King (2010) find much higher effects for 1 percent of GDP of QE, above 20 basis points. Chen et al (2012) provide a set of results, one based on prior of the key parameters of the model and one based on the posterior distribution of the estimation of the model. They also consider the effects in the absence of a commitment to the zero lower bound. They assume a reduction 30 basis point in the term premium with a 4 percent of GDP of QE.

Table 1: QE effects on long-term premium

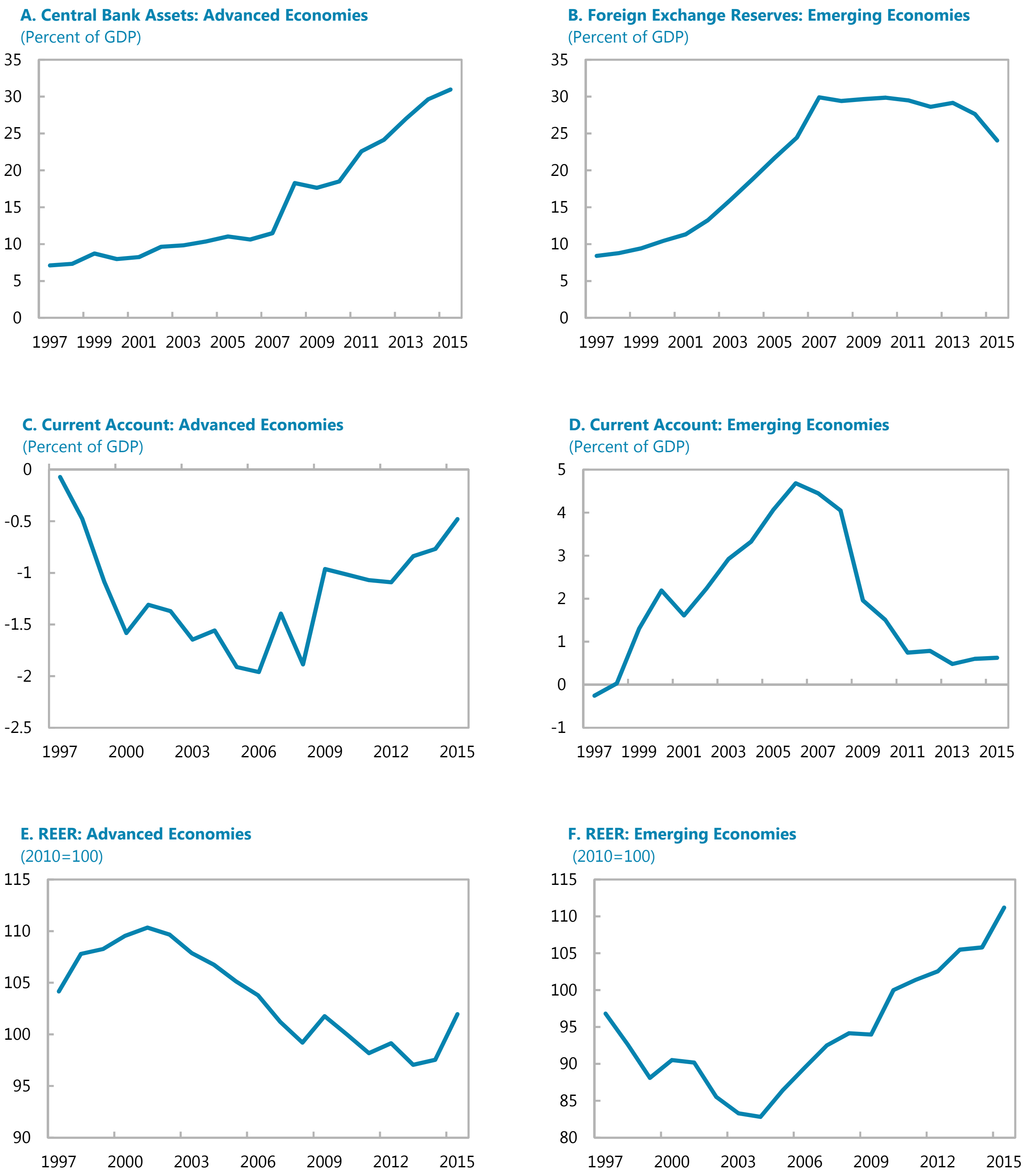
Paper	term premium
Gagnon et al (2011)	-4.4bp to -9.8bp
D'Amico and King (2010)	-22.5bp
D'Amico et al. (2011)	-13.5
Hamilton and Wu (2010)	-4.5bp
Baumeister and Benati (2011)	-15bp
Abrahams et al. (2015)	-10bp

Table 2. Welfare Gains from Unconventional Policies

	Home Country	Foreign Country	World
A. Nash and Cooperative Equilibrium in Normal Times 2/			
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. Nash and Cooperative Equilibrium 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
C. Unilateral Unconventional Policies in Normal Times			
1. Baseline Scenario	-0.25	-1.75	-1.00
2. QE	-0.75	-1.55	-1.42
3. FXI	-0.53	-1.88	-1.21
D. Unilateral Unconventional Policies at the ZLB			
1. Baseline Scenario (No QE,FXI)	-0.58	-4.85	-2.42
2. QE	-1.02	-3.65	-2.34
3. FXI	-0.89	-5.87	-3.27

1/ Percent of steady state consumption
2/ Welfare gain relative to the baseline 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



Source: Haver Analytics. IMF Staff Estimates.

Figure 2. Spillovers from Quantitative Easing

Home Country | Foreign Country

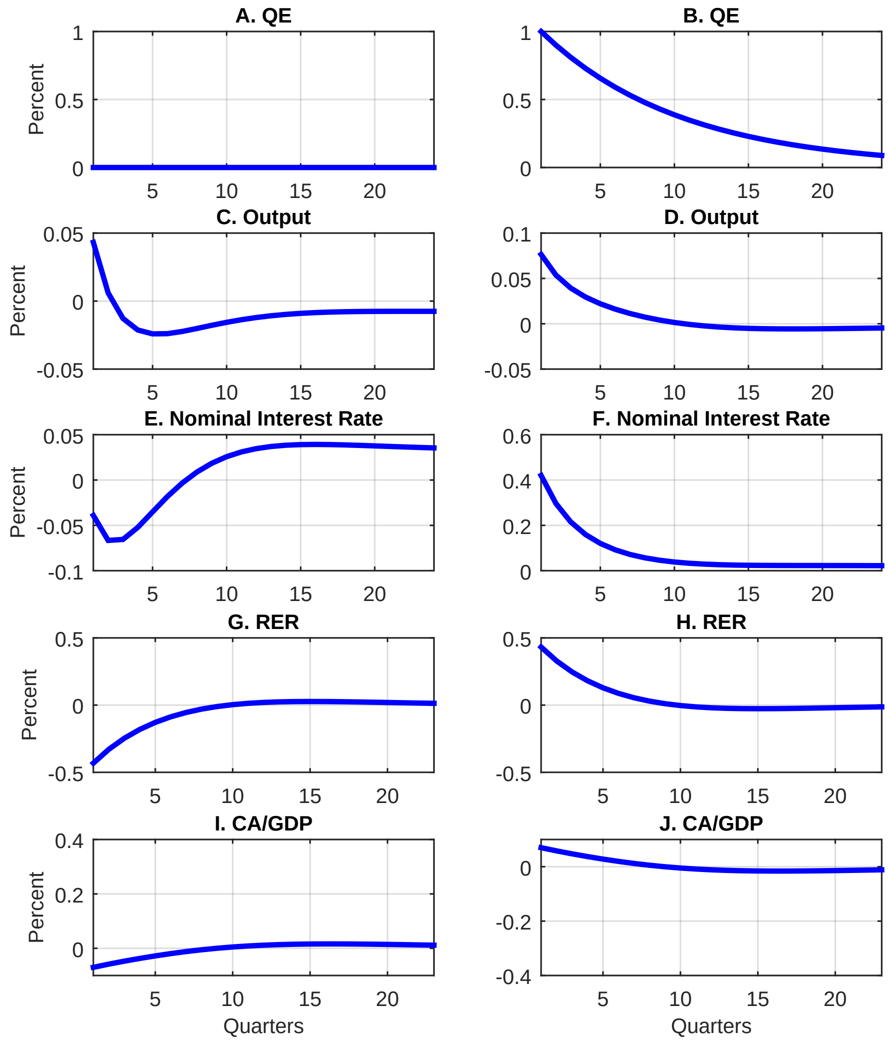


Figure 3. Spillovers from Foreign Exchange Intervention

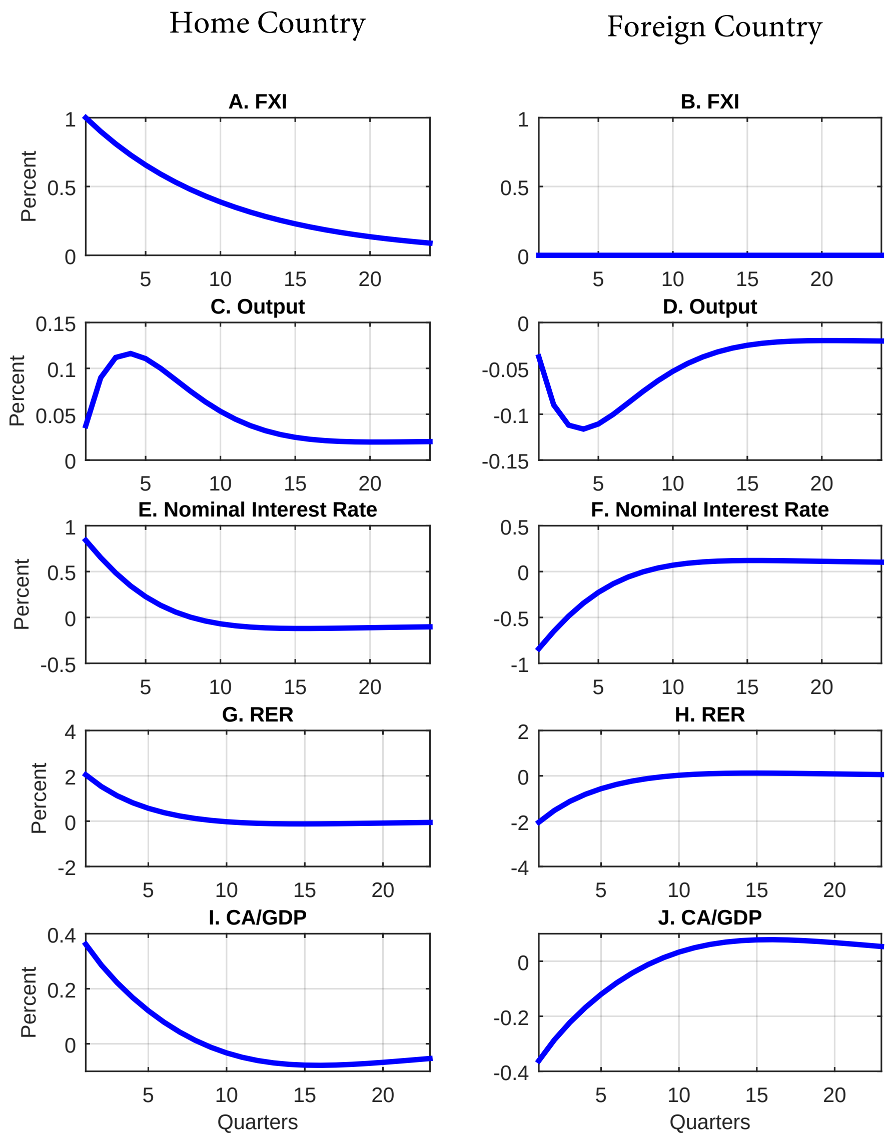


Figure 4. Cooperative and Nash Equilibrium in Normal Times

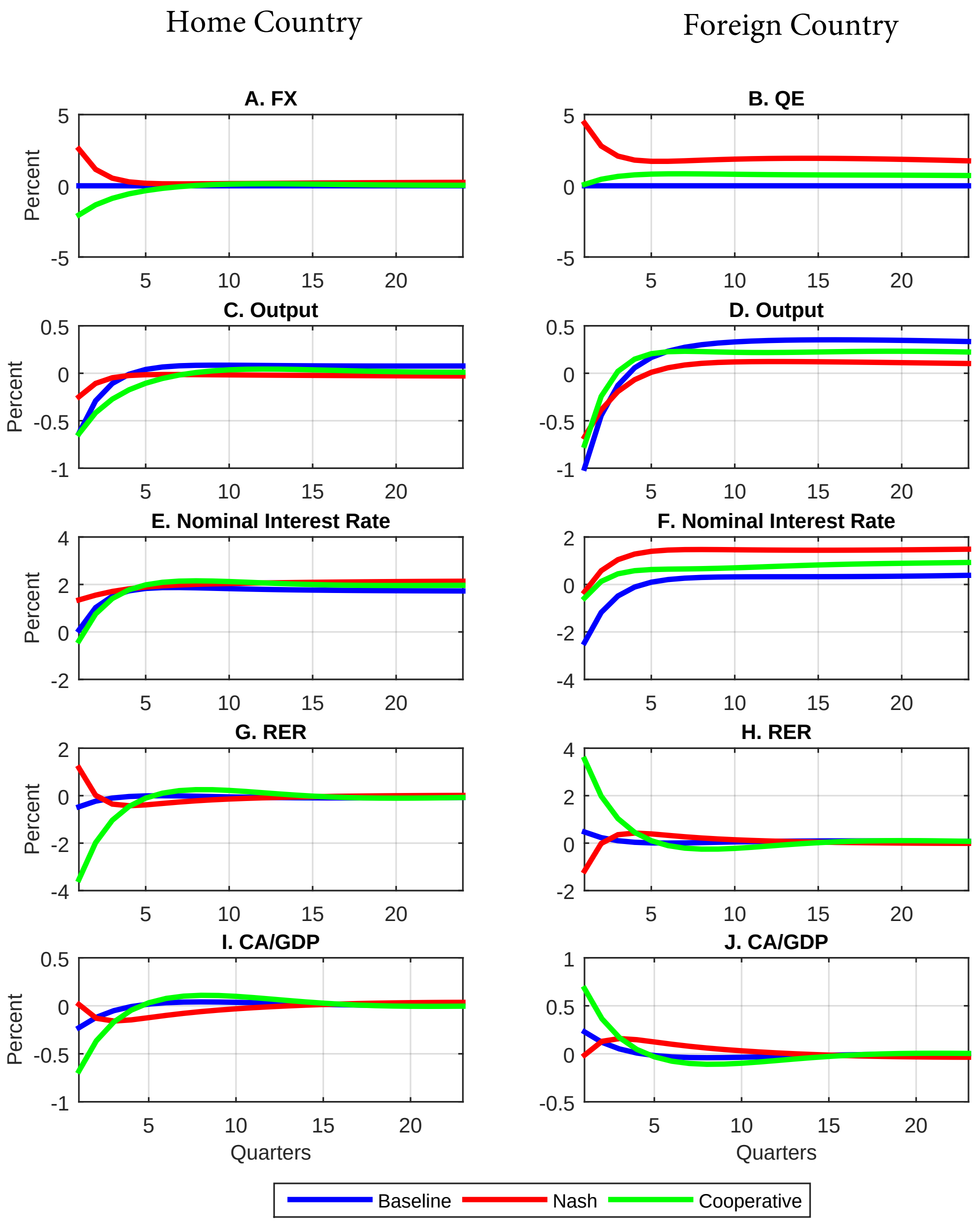


Figure 5. Spillovers from Quantitative Easing at the ZLB

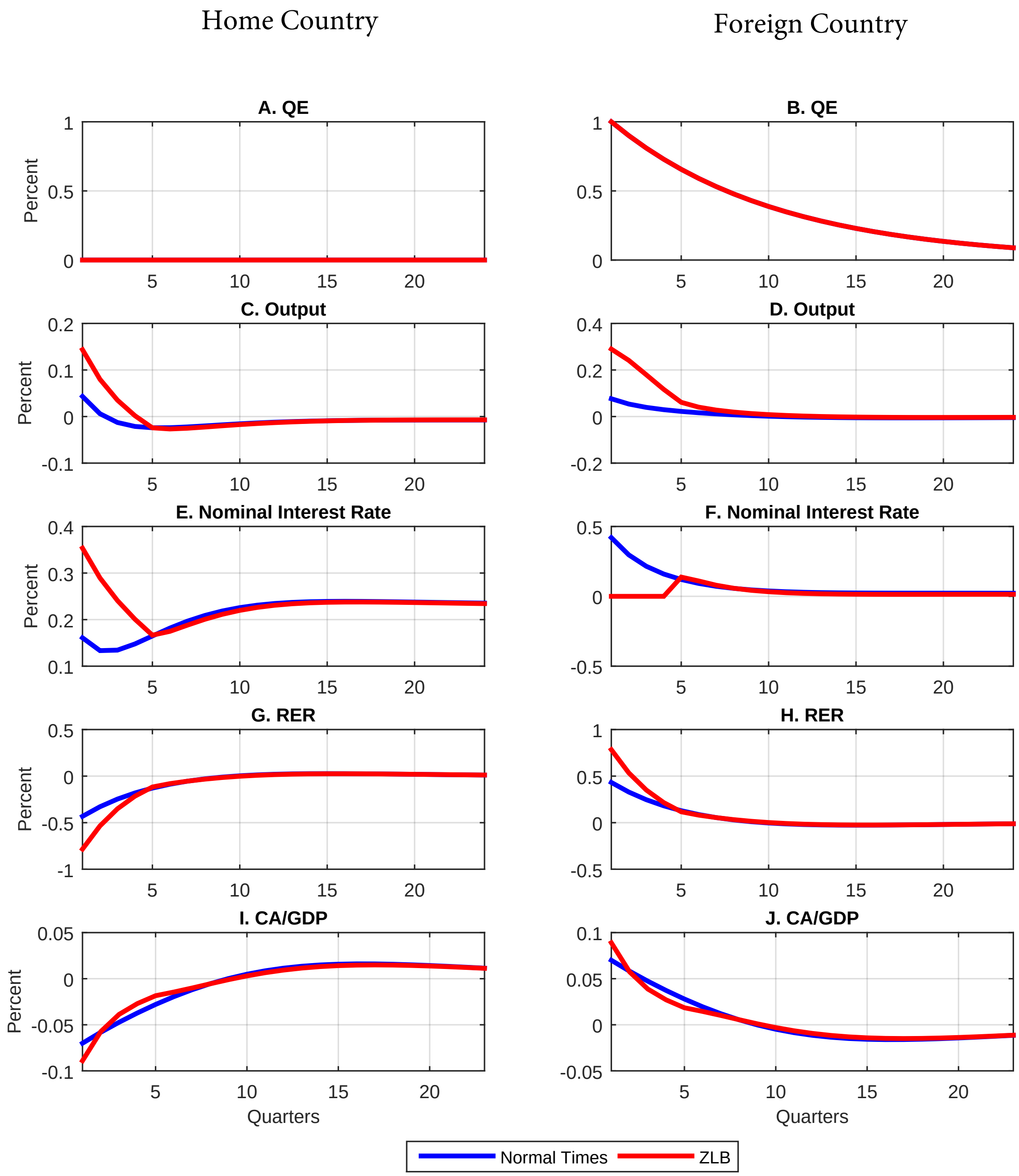


Figure 6. Spillovers from Foreign Exchang Intervention at the ZLB

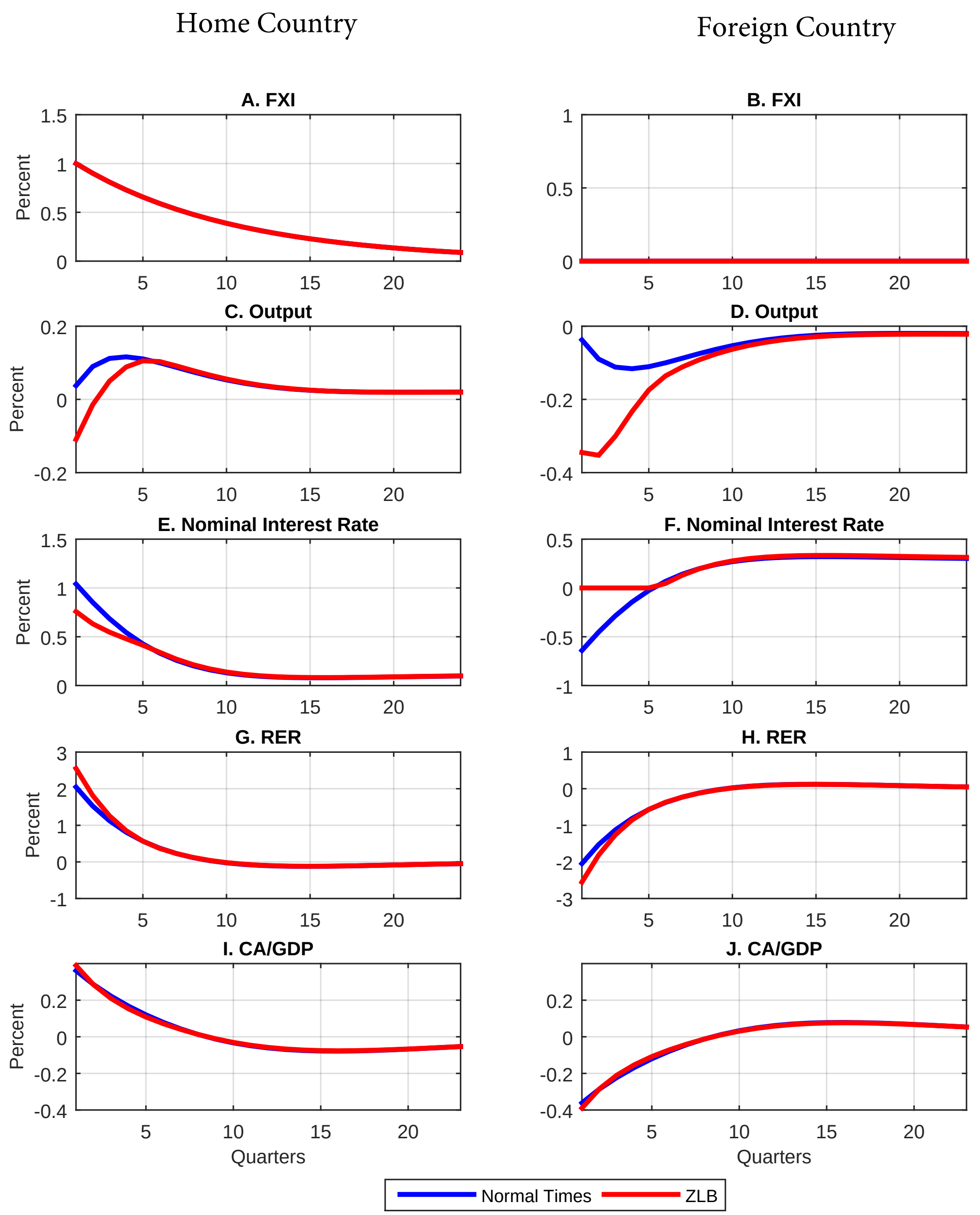
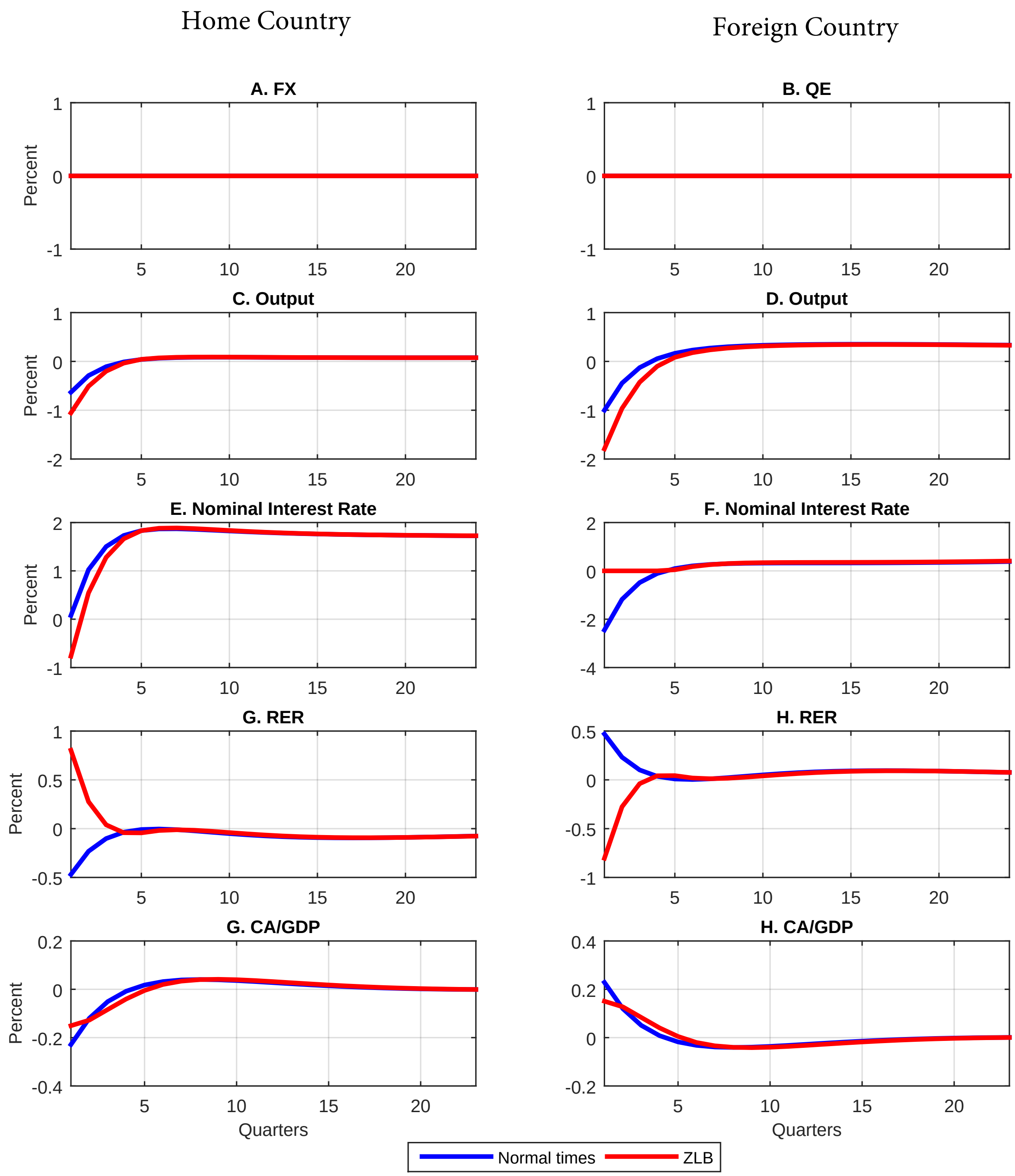


Figure 7. Negative Demand Shock at the ZLB



Figuer 8. Cooperative and Nash Equilibrium at the ZLB