Sharing the Burden: Monetary and Fiscal Responses to a World Liquidity Trap[†]

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This paper analyzes optimal policy responses to a global liquidity trap. The key feature of this environment is that relative prices respond perversely. A fall in demand in one country causes an appreciation of its terms of trade, exacerbating the initial shock. At the zero bound, this country cannot counter this shock. Then it may be optimal for the partner country to raise interest rates. The partner may set a positive policy interest rate, even though its “natural interest rate” is below zero. An optimal policy response requires a mutual interaction between monetary and fiscal policy. (JEL E12, E32, E44, E52, E62, F44, G01)

This paper is concerned with global policy responses to a world liquidity trap. Following the global financial crisis, many countries experienced depressed aggregate demand and policy interest rates close to zero. The incidence was not uniform across countries or regions, however, suggesting that policy responses should differ among countries. In normal times, with positive interest rates, an active monetary policy can be used to perfectly offset shocks to aggregate demand. In the standard New Keynesian model the “divine coincidence” means that monetary policy can simultaneously deliver zero inflation and a zero output gap. In such a setting, monetary policymakers may act independently—there is no need for international policy cooperation across countries. But in the face of large negative demand shocks, one or more countries may find that optimal policy is constrained by the zero lower bound on interest rates. This leads policy choices to become interdependent across countries. This paper explores how optimal policy should be designed in such an environment.

A key question is how the adjustment to a global recession should be allocated across countries that experience the downturn at different levels of severity.¹

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¹ For most of the paper, the focus is on optimal cooperative monetary policy, although, as discussed below, a later section briefly analyzes the outcome under noncooperative policy.

We focus on an environment where two trading partners are well integrated through financial markets (as we assume throughout the paper) but less than perfectly integrated in goods markets. For normal, cyclical shocks, monetary policy can be used to offset the shock in each country, and there is no need for either international cooperation, or the use of other policy tools, such as fiscal policy. But for very large shocks that push desired policy rates below zero, the propagation of shocks depends critically on the degree of trade integration. With highly open trade linkages, all countries face a similar macroeconomic response to a shock in a single country due to risk sharing in financial markets. In particular, a liquidity trap in one country is mirrored in all other countries. This implies that policy responses should be uniform across countries: interest rates should be as low as possible in all countries and all should engage in an equal fiscal expansion.

However, the benchmark of fully open trade does not closely approximate the current configuration of the world economy, where large but relatively closed economies, such as Japan and the United States, are stuck in a liquidity trap. In these countries, exports make up substantially less than 20 percent of GDP. When home bias in consumption baskets limits trade linkages between countries, a negative demand shock in one country (in the paper we call this the “home” country) will push down the desired real interest rate in that country more than those of its trading partners.² This is the scenario we examine in the paper.

The key feature of the environment with home bias in trade is that a shock that precipitates a liquidity trap generates a perverse response of the terms of trade. Under normal monetary policy, a fall in demand in the one country will reduce domestic real interest rates and lead to a compensating terms of trade deterioration, channelling more world demand toward the country directly affected by the shock, thus mitigating the effects of the shock. But when the interest rate is at the zero bound, this same shock generates a terms of trade appreciation, since it tends to raise domestic real interest rates by pushing down inflation expectations. Hence, the response of the terms of trade exacerbates the effect of the shock. Typically, in order to alleviate a terms of trade appreciation, a country could engage in expansionary monetary policy. When interest rates are zero, the home country cannot do this. But instead, the foreign country can raise its interest rate. We find that, such an interest rate increase will in general form part of an optimal policy response. Strikingly, we find that the optimal policy is for the foreign country to tighten monetary policy, even when, using the standard criterion from the closed economy logic, it should still be in a liquidity trap (where its natural interest rate is below zero).³ The rise in the foreign interest rate acts so as to weaken the appreciation of the home terms of trade caused by the original demand shock, limiting the degree of world expenditure-switching away from the home economy.

²Though the paper is primarily a theoretical analysis, it may be relevant to the current situation. In the aftermath of the recession of 2008–2009, the European Central Bank kept the main policy rate above zero while other central banks such as the Federal Reserve and the Bank of Japan took the interest rates to zero.

³Following the literature, we define the natural interest rate as the rate that would obtain in a world flexible price equilibrium with zero inflation. An alternative “conditional natural interest rate,” defined as the flexible price equilibrium in one country alone, is also described below.

Specifically, we find the optimal response of policy interest rates in a global liquidity trap are piecewise functions of the degree of trade-openness as measured by the parameter of “home bias” in preferences. When preferences are identical, trade is fully open, and a global liquidity trap is associated with zero policy rates in all countries. At a critical threshold level of home bias, foreign policy interest rates are raised above their own natural rate, even when that is negative. As the degree of home bias rises, foreign rates rise more and more and are always set above the natural interest rate. Interestingly, optimal monetary policy when one country is in a liquidity trap leads to deflation in both countries, regardless of the degree of home bias. This contrasts with standard closed economy logic, which focuses on implementing price stability whenever possible.

Throughout the paper we focus on discretionary policymaking, assuming that neither country can credibly commit to policy responses that would not necessarily be “ex post optimal” following the cessation of the liquidity trap shock. The general features of the case of policy commitment have been explored in the closed economy by Krugman (1998); Eggertsson and Woodford (2003); and Jung, Teranishi, and Watanabe (2005) and in open economies by Nakajima (2008) and Fujiwara et al. (2010). They involve a commitment to a monetary policy in the future that is more expansionary than would be optimal under discretionary policymaking. This offers a lever of policymaking that is not available under discretion. The main point of our paper is to show that in a multi-country setting, even under policy discretion, a liquidity trap in one country can be alleviated by policy actions in another country, and that this may form part of an optimal policy response, even if under conventional measures there should be a liquidity trap in all countries. Thus, we identify an additional degree of flexibility in monetary policymaking, even without the option of credible commitment to future policy.⁴

We extend the model to allow for the choice of fiscal policy response as well as asymmetric monetary response. Again, the results critically depend on the degree of trade integration. With fully open trade, both countries are in a liquidity trap, and the optimal policy is to have an identical fiscal expansion in both countries. But when trade is limited, we find that the optimal policy response is to have a large fiscal expansion in the home country, coupled with a small fiscal expansion, but a positive interest rate in the foreign country. The results indicate that monetary and fiscal policy should be used in a mutually supportive way in responding to a global liquidity trap shock. If monetary policy were set in a conventional way, so that the partner policy rate was set equal to its own natural rates, except when the latter variables were below zero, then all the burden of adjustment would be on fiscal policy. In this case, in order to facilitate expenditure adjustment and expenditure switching, a policy response would require a large source country fiscal expansion and partner country fiscal contraction. The benefit of adjusting partner country interest rates optimally is that it relieves, but does not eliminate, the need for fiscal responses in each country.

⁴In the conclusion, we discuss how the results would be qualified in the case of full commitment in policymaking.

The main results are derived in a setting with cooperative monetary policy, following standard approaches to optimal policy in open economies (e.g., Clarida, Galí, and Gertler 2002; Benigno and Benigno 2003). But a later section shows that the main result of the paper, namely that monetary policy in the least-hit country tends to be tighter than the conventional monetary rule, in fact extends to a setting of noncooperative monetary policy choice. We derive this result in an example that follows the noncooperative monetary policy framework of Clarida, Galí, and Gertler (2002). Our result shows that even with noncooperative monetary policy, the foreign country will set its interest rate above the natural interest rate. The key reason is that if the foreign economy did not raise its interest rate, it would experience excessive inflation and a large positive output gap arising from the home terms of trade appreciation. There is a difference between noncooperative and cooperative policy however. The interest rate response under noncooperative policy is less contractionary than in the cooperative outcome.

The paper builds on a substantial recent literature on monetary and fiscal policy in a liquidity trap. In particular, with the experience of Japan in mind, Krugman (1998); Eggertsson and Woodford (2003, 2006); Jung, Teranishi, and Watanabe (2005); Svensson (2003); Auerbach and Obstfeld (2005); and many other writers explore how monetary and fiscal policy could be usefully employed even when the authorities have no further room to reduce short-term nominal interest rates. Recently, a number of authors have revived this literature in light of the very similar problems recently encountered by the economies of Western Europe and North America. Papers by Christiano, Eichenbaum, and Rebelo (2009); Devereux (2010); Eggertsson (2011); and Cogan et al. (2009) have explored the possibility for using government spending expansions, tax cuts, and monetary policy when the economy is in a liquidity trap. Bodenstein, Erceg, and Guerrieri (2009) is an example of a fully specified two-country DSGE model to examine the international transmission of standard business cycle shocks when one country is in a liquidity trap.

Some recent papers consider international dimensions of optimal policy in a liquidity trap. Jeanne (2009) examines whether either monetary policy or fiscal policy can implement an efficient equilibrium in a “global liquidity trap” in a model of one-period ahead pricing similar to that of Krugman (1998). Fujiwara et al. (2010a) use numerical results to describe optimal monetary policy responses to asymmetric interest rate shocks. The present paper develops optimal natural interest rates as a function of demand shocks and characterizes optimal policies analytically. Nakajima (2008) and Fujiwara et al. (2010b) examine optimal policy responses to technology shocks in a model without home bias. We focus on the role of home bias in creating asymmetries in optimal policies amongst countries differentially affected by a demand contraction in the tradition of Eggertsson (2009) and Woodford (2011). Cook and Devereux (2011b) and Fujiwara and Ueda (2012) examine the fiscal policy multiplier in an open economy at the lower bound. In addition, a key contribution of our paper is the unified examination of the interaction between monetary policy and fiscal policy, which are not considered jointly by the above papers.

The rest of the paper is organized as follows. The next section develops the basic model. Section II examines the solution under sticky prices. Then in Section III we analyze the impact of demand shocks at the zero lower bound. Section IV examines

the optimal policymaking problem in a global cooperative agreement, including the possibility of using both monetary and fiscal policy. Section V illustrates a numerical analysis of optimal policy. Section VI develops the results in a noncooperative monetary policy framework. Some conclusions are then offered.

I. A Two Country Model

Assume that there are two countries in the world economy. In each country, households consume both private and government goods, and supply labor. Denote the countries as “home” and “foreign,” with foreign variables denoted with an asterisk superscript. The population of each country is normalized to unity. Each country produces a range of differentiated goods. Complete asset markets allow full insurance of consumption risk across countries. Households also hold their own country’s nominal government bonds. Firms produce private goods, while governments produce government goods that are distributed uniformly across households. Firm’s production and supply is constrained by sticky prices. Governments have access to lump sum taxation.

A. Households

Utility of a representative infinitely lived home household evaluated from date 0 is

$$(1) \quad U_t = E_0 \sum_{i=0}^{\infty} \beta^i (U(C_t, \xi_t) - V(N_t) + J(G_t)),$$

where U , V , and J represent the utility of the composite home consumption bundle C_t , disutility of labor supply N_t , and utility of the government supplied public good G_t , respectively, with $\beta < 1$. The variable ξ_t represents a shock to preferences (a “demand” shock). We assume $U_{12} > 0$.

Composite consumption is defined as

$$C_t = \Phi C_{Ht}^{v/2} C_{Ft}^{1-v/2}, \quad v \geq 1,$$

where $\Phi = \left(\frac{v}{2}\right)^{\frac{v}{2}} \left(1 - \left(\frac{v}{2}\right)\right)^{\frac{v}{2}}$, C_H is the consumption of the home country composite good by the home household, and C_F is consumption of the foreign composite good. If $v > 1$, then there is a home bias for domestic goods. The case $v > 1$ is most realistic for thinking about policy in large open economies.

Consumption aggregates, C_H and C_F are composites, defined over a range of home and foreign differentiated goods, with elasticity of substitution $\theta > 1$ between goods. Price indices for home and foreign consumption are

$$P_H = \left[\int_0^1 P_H(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}, \quad P_F = \left[\int_0^1 P_F(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}},$$

while the aggregate CPI price index for the home country is $P = P_H^{v/2} P_F^{1-v/2}$ and for the foreign country is $P_t^* = P_F^{*v/2} P_H^{*1-v/2}$.

Demand for each differentiated good $j = H, F$ is

$$\frac{C_j(i)}{C_j} = \left(\frac{P_j(i)}{P_j} \right)^{-\theta}.$$

The law of one price holds for each good so $P_j(i) = S_t P_j^*(i)$, where S_t is the nominal exchange rate (home price of foreign currency).

In each country, government spending falls only on the domestic good. Thus, government spending is assumed to have full home bias. In addition, we assume that government demand for each variety of home goods has price elasticity θ , the same as that for private spending.

The household's implicit labor supply at nominal wage W_t is

$$(2) \quad U_C(C_t, \xi_t) W_t = P_t V'(N_t).$$

Optimal risk sharing implies

$$(3) \quad U_C(C_t, \xi_t) = U_C(C_t^*, \xi_t^*) \frac{S_t P_t^*}{P_t} = U_C(C_t^*, \xi_t^*) T_t^{v-1},$$

where T represents the level of the terms of trade (equal to $\frac{P_F}{P_H}$). Nominal bonds pay interest, R_t . Then the Euler equation is

$$(4) \quad \frac{U_C(C_t, \xi_t)}{P_t} = \beta R_t E_t \frac{U_C(C_{t+1}, \xi_{t+1})}{P_{t+1}}.$$

Foreign household preferences and choices can be defined exactly symmetrically. The foreign representative household has weight $v/2$, $(1 - v/2)$ on the foreign (home) composite good in preferences.

B. Firms

Each firm i employs labor to produce a differentiated good

$$Y_t(i) = N_t(i).$$

Profits are $\Pi_t(i) = P_{Ht}(i) Y_t(i) - W_t N_t(i) \frac{\theta - 1}{\theta}$ indicating a subsidy financed by lump sum taxation to eliminate steady-state, first-order inefficiencies. Each firm re-sets its price according to Calvo pricing with probability of adjusting prices equal to $1 - \kappa$. Firms that adjust their price set a new price given by $\tilde{P}_{Ht}(i)$:

$$(5) \quad \tilde{P}_{Ht}(i) = \frac{E_t \sum_{j=0}^{\infty} m_{t+j} \kappa^j \frac{W_{t+j}}{A_{t+j}} Y_{t+j}(i)}{E_t \sum_{j=0}^{\infty} m_{t+j} \kappa^j Y_{t+j}(i)},$$

where the stochastic discount factor $m_{t+j} = \frac{P_t}{U_C(C_t, \xi_t)} \frac{U_C(C_{t+j}, \xi_{t+j})}{P_{t+j}}$. In the aggregate, the price index for the home good then follows the process given by

$$(6) \quad P_{Ht} = \left[(1 - \kappa) \tilde{P}_{Ht}^{1-\theta} + \kappa P_{Ht-1}^{1-\theta} \right]^{\frac{1}{1-\theta}}.$$

The behavior of foreign firms and the foreign good price index may be described analogously.

C. Market Clearing

Equilibrium in the market for good i is

$$Y_{Ht}(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}} \right)^{-\theta} \left[\frac{\nu}{2} \frac{P_t}{P_{Ht}} C_t + \left(1 - \frac{\nu}{2} \right) \frac{S_t P_t^*}{P_{Ht}} C_t^* + G_t \right],$$

where G_t represents total home government spending. Aggregate market clearing in the home good is

$$(7) \quad Y_{Ht} = \frac{\nu}{2} \frac{P_t}{P_{Ht}} C_t + \left(1 - \frac{\nu}{2} \right) \frac{S_t P_t^*}{P_{Ht}} C_t^* + G_t.$$

Here, $Y_{Ht} = V_t^{-1} \int_0^1 Y_{Ht}(i) di$ is aggregate home country output, where we have defined $V_t = \int_0^1 \left(\frac{P_{Ht}(i)}{P_{Ht}} \right)^{-\theta} di$. It follows that home country employment (employment for the representative home household) is given by $N_t = \int_0^1 N(i) di = Y_{Ht} V_t$.

The aggregate market-clearing condition for the foreign good is

$$(8) \quad Y_{Ft} = \frac{\nu}{2} \frac{P_t^*}{P_{Ft}^*} C_t^* + \left(1 - \frac{\nu}{2} \right) \frac{P_t}{S_t P_{Ft}^*} C_t^* + G_t^*,$$

where $N_t^* = \int_0^1 N_t^*(i) di = Y_{Ft} V_t^*$, and $V_t^* = \int_0^1 \left(\frac{P_{Ft}^*(i)}{P_{Ft}^*} \right)^{-\theta} di$.

An equilibrium in the world economy with positive nominal interest rates may be described by equation (3), and then equations (2), (4), (5), and (6) for the home and foreign economy, as well as (7) and (8). For given values of V_t and V_t^* , given monetary rules (to be discussed below) and given government spending policies, these equations determine an equilibrium sequence for the variables $C_t, C_t^*, W_t, W_t^*, S_t, P_{Ht}, P_{Ft}^*, \tilde{P}_{Ht}, \tilde{P}_{Ft}^*, R_t, R_t^*$, and N_t, N_t^* .

II. Demand Shocks and Natural Interest Rates

A. Defining Natural Interest Rates

Define $\sigma \equiv -\frac{U_{CC}\bar{C}}{U_C}$ as the inverse of the elasticity of intertemporal substitution in consumption: $\phi \equiv -\frac{V''\bar{H}}{V'}$ as the elasticity of the marginal disutility of hours worked and $\sigma_g \equiv -\frac{J''\bar{G}}{J'}$ as the elasticity of marginal utility of public goods. In addition, we assume that $\sigma_g = \sigma > 1$, consistent with empirical evidence (see Yogo 2004). Finally, $\varepsilon_t = \frac{U_C \xi}{U_C} \ln(\xi_t)$ is the measure of a positive demand shock in the home country. Define $c_y = \frac{C}{Y}$ as the steady-state share of consumption in output.

We assume that any preference shock is unanticipated, and reverts back to 0 with probability $1 - \mu$ in each period. Because there are no predetermined state variables in the model, this implies that all variables in the world economy will inherit the same persistence as the shock itself, in expectation. Thus, for any variable x_t , we may write $E_t(x_{t+1}) = \mu x_t$. After the shock expires, all variables will then revert to their zero initial equilibrium.

We first derive a measure of Wicksellian, or “natural,” interest rates for each country, defined as the interest rates that would hold in a purely flexible price equilibrium of the world economy, where there are no monopolistic distortions, and, in addition, where governments choose an optimal fiscal spending rule with access to lump-sum taxes. In this case, the government spending rate for the home economy will be determined by

$$(9) \quad V'(N_t) = J'(G_t).$$

Note that natural interest rates are equivalently defined as the value of the nominal rate less expected PPI inflation, (i.e., $r_t - E_t \pi_{Ht+1}$ for the home economy) in a flexible price economy. That is, the PPI-based real interest rate that would hold with flexible prices.

For any variable x_t , define the world average and world relative level, $x_t^W = \frac{x_t + x_t^*}{2}$ and $x_t^R = \frac{x_t - x_t^*}{2}$. In a competitive equilibrium with optimal government spending in both countries as in (9), the natural interest rates of the home and foreign economy are defined as

$$(10) \quad \tilde{r}_t = \bar{r} + \left(\frac{\phi c_y}{\phi + \sigma} \varepsilon_t^W + \frac{\phi c_y(\nu - 1)}{\Delta} \varepsilon_t^R \right) (1 - \mu)$$

$$(11) \quad \tilde{r}_t^* = \bar{r} + \left(\frac{\phi c_y}{\phi + \sigma} \varepsilon_t^W - \frac{\phi c_y(\nu - 1)}{\Delta} \varepsilon_t^R \right) (1 - \mu),$$

where $\bar{r}$ is the rate of time preference, and $\sigma > D \equiv (\sigma \nu(2 - \nu) + (1 - \nu)^2) > 1$, and $\Delta = \phi D + \sigma > 0$. The natural rates are critical variables for our analysis, since

they govern the degree to which monetary policy can be efficiently employed to stabilize the economy. In particular, our model has the characteristic that when (10) and (11) are both positive, then monetary policy can perfectly achieve the joint target of zero inflation and zero output gaps, since home and foreign policy rates can simply be set to equal (10) and (11), respectively (subject to the conditions for determinacy being met—see footnote 6 below). In addition, as seen below, there will then be no need to have fiscal gaps differ from zero.

In the no home-bias case, $v = 1$, the natural interest rate for both economies is the same. In that case demand shocks have no effect on the terms of trade so financial market integration equalizes PPI based real interest rates across countries. However, the case $v = 1$ is not particularly realistic. For most economies, and particularly for large open economies, the lion's share of demand will come from the domestic economy, making the home bias case most relevant.

We look at the case of a large *home* country negative preference shock, $\varepsilon_t < 0$, assuming foreign preference shocks are zero, $\varepsilon_t^* = 0$. Thus $\varepsilon_t^W = \varepsilon_t^R = \frac{\varepsilon_t}{2}$. Home consumers are affected by preference shocks which affect their propensity to save. We can then write the home natural interest rate as

$$(12) \quad \tilde{r}_t = \bar{r} + \left(\frac{\Delta + (\phi + \sigma)(v - 1)}{(\phi + \sigma)\Delta} \right) (1 - \mu)\phi c_y \frac{\varepsilon_t}{2}.$$

Foreign consumers are indirectly affected by the shock, since integrated financial markets and terms of trade movements lead to international linkages between interest rates.

$$(13) \quad \tilde{r}_t^* = \bar{r} + \left(\frac{\Delta - (\phi + \sigma)(v - 1)}{(\phi + \sigma)\Delta} \right) (1 - \mu)\phi c_y \frac{\varepsilon_t}{2}$$

Therefore, a negative home preference shock that pushes home natural interest rates down will also push foreign natural rates down as long as there is any trade at all, i.e., $1 \leq v < 2$. Moreover, a sufficiently large home preference shock could push both countries natural rates below zero.

We may rewrite the natural interest rate expressions in shorthand as $\tilde{r}(\varepsilon_t, v)$ and $\tilde{r}^*(\varepsilon_t, v)$. We define $\varepsilon_H(v)$ and $\varepsilon_F(v)$, respectively, as the size of the shock such that $\tilde{r}(\varepsilon_H, v) = 0$, and $\tilde{r}^*(\varepsilon_F, v) = 0$. Clearly, for $v \geq 1$, $\varepsilon_H \geq \varepsilon_F$. Figure 1 illustrates the two functions $\tilde{r}(\varepsilon_t, v)$ and $\tilde{r}^*(\varepsilon_t, v)$. For $v = 1$, they coincide, while for $v = 2$, the foreign natural real interest rate is simply $\bar{r}$. The point v_F is where the foreign country's natural interest rate is exactly zero. As the countries move from being more open to more closed, the impact of the shock on the home country natural interest rate rises, while the impact on the foreign natural real interest rate falls.

In the discussion below, we will focus mostly on a “large” negative shock, such that $\varepsilon_t < \varepsilon_H(1)$. This means that whatever is v , the home natural interest rate is always below zero.

FIGURE 1. NATURAL INTEREST RATES

B. The World and Relative Economy

We derive a sticky price log-linear approximation of the model in terms of inflation and output gaps in a similar manner to Clarida, Galí, and Gertler (2002) and Engel (2011).^{5, 6}

⁵We linearize around an efficient, flexible price allocation with zero inflation. When policy rates are unconstrained, and there is an optimal subsidy in place that offsets monopoly distortions, price stability is the cooperative optimal policy under both commitment and discretion, as in Benigno and Benigno (2003). This is true even in the case of home bias in preferences, as shown by Engel (2011). Intuitively, if policy is determined relative to an initial steady state without monopoly distortions, and there are no mark-up shocks, optimal cooperative policy will close all gaps, whether under discretion or commitment. A policy of price stability can be implemented by setting nominal interest rates equal to natural interest rates as defined in (10) and (11). Note that in order to implement this policy, it is necessary that there be an interest rate feedback rule on inflation or other endogenous variables, in order to avoid indeterminacy (see e.g., Galí 2008). For related discussion on determinacy issues in open economies, see Benigno and Benigno (2008).

⁶One important caveat to the result that price stability is optimal is that this outcome treats the possibility of future constraints on monetary policy as a zero-probability event. Adam and Billi (2006, 2007), and Nakov (2008) show that if there is a positive probability of hitting the zero lower bound the flexible price equilibrium might not be optimal, even when interest rates are not constrained by the lower bound.

Let $\hat{x}_t$ be the percentage deviation of a given variable x_t from the efficient flexible price equilibrium. Thus, $\hat{x}_t$ is interpreted as a “gap” variable. Define $s \equiv \frac{\sigma}{c_y}$, and $s > s_D \equiv \frac{s}{D} > 1$. In order to explore the implications of the zero lower bound constraint, we begin with the standard forward looking inflation equations and open economy IS relationships, expressed in terms of world averages and world relatives. The world average equations are:

$$(14) \quad \pi_t^W = k(\phi + s)\hat{n}_t^W - ks \cdot \widehat{cg}_t^W + \beta E_t \pi_{t+1}^W$$

$$(15) \quad sE_t(\hat{n}_{t+1}^W - \hat{n}_t^W) - sE_t(\widehat{cg}_{t+1}^W - \widehat{cg}_t^W) = E_t(r_t^W - \tilde{r}_t^W - \pi_{t+1}^W)$$

The world “relative” variables are written as

$$(16) \quad \pi_t^R = k(\phi + s_D)\hat{n}_t^R - ks_D \widehat{cg}_t^R + \beta E_t \pi_{t+1}^R$$

$$(17) \quad s_DE_t(\hat{n}_{t+1}^R - \hat{n}_t^R) - s_DE_t(\widehat{cg}_{t+1}^R - \widehat{cg}_t^R) = E_t(r_t^R - \tilde{r}_t^R - \pi_{t+1}^R),$$

where $\widehat{cg}_t^W \equiv (1 - c_y)\hat{g}_t^W$ and $\widehat{cg}_t^R \equiv (1 - c_y)\hat{g}_t^R$. The coefficient k depends on the degree of price rigidity. Note that, approximated around the steady state, up to a first order, $\hat{n}_t \approx \hat{y}_t$, $\hat{n}_t^* \approx \hat{y}_t^*$, so the labor gap for each country will stand in for the output gap.

If one or both countries have a natural real interest rate below zero then the monetary and fiscal authorities cannot achieve perfect price and output stability by setting the nominal interest rate equal to the natural interest rate and keeping the fiscal gaps, $\hat{g}_t^W$ and $\hat{g}_t^R$ equal to zero, because at least one policy rate will be constrained by the zero bound.

Note that the systems of equations (14)–(15) for the world average economy are identical to the canonical New Keynesian closed economy model. These equations are separable from the relative equations (16)–(17), and do not depend on the home bias parameter ν . The equations governing the relative economy (16)–(17) are also in the form of the canonical New Keynesian closed economy. The only difference between the two systems is in the parameterization of the inverse elasticity of consumption: s , in the case of the average economy; and, s_D , in the case of the relative world economy. Note that $s_D < s$, so the world average level of demand is less sensitive to the average interest rate than the relative level of demand is sensitive to the relative interest rate. This reflects the expenditure switching effect of terms of trade changes. When worldwide interest rates are relatively low, then (for intertemporal substitution reasons) world demand will be relatively high. Analogously, when the relative interest rate is low, demand will be relatively high in the low interest rate country. But, in order to satisfy interest rate parity, a relatively low real interest rate country must have an anticipated terms of trade appreciation. This implies a current terms of trade depreciation, leading world aggregate demand to move toward the low interest rate country through the expenditure switching channel.

As mentioned above, a maintained assumption of the model is that $\sigma > 1$. In the case $\sigma = 1$, we would have $D = 1$ and $s = s_D = c_y^{-1}$, and the equations governing world averages (14)–(15) become identical *in form* to the equations governing world relatives (16)–(17). In this case, the determination of home and foreign inflation and output gaps completely dichotomize. Then, in fact, the conventional closed-economy rule for monetary policy in a liquidity trap obtains. Optimal policy for each policymaker is characterized in the same way as in the closed economy (see (25)). Nonetheless, it is still true, even in this case, that the demand shock in the two countries is correlated. Since capital markets are integrated, shocks to natural interest rates move together across countries unless the two economies are completely closed to trade (i.e., $v = 2$).

III. Negative Demand Shocks and the Terms of Trade

The expenditure switching effects implicit in (16)–(17) are key to understanding the response to shocks that create liquidity traps. For $v > 1$, demand shocks affecting the home country will affect the terms of trade, because they alter the world demand for home goods relative to foreign goods. First, we look at the terms of trade response when policy is unconstrained, and policy interest rates can be immediately adjusted to equal natural interest rates.

With small shocks, so that $\varepsilon_t > \varepsilon_H(v)$, then policy rates can adjust to close output gaps, so that all deviations from the flexible price optimum are zero. This policy is implemented through perfect price stabilization, $\pi_{F,t} = \pi_{H,t} = \pi_t^R = 0$. A negative demand shock is matched by a decline in policy rates in both countries precisely equal to the fall in the natural rates $\tilde{r}(\varepsilon, v)$ and $\tilde{r}^*(\varepsilon, v)$.

In all versions of the model, up to a first order, the interest rate parity condition implies (here, $\hat{\tau}_t$ is the response of the terms of trade)

$$(18) \quad r_t - E_t \pi_{H,t+1} = r_t^* - E_t \pi_{F,t+1} + E_t(\hat{\tau}_{t+1} - \hat{\tau}_t),$$

which implies that

$$(19) \quad r_t^R - E_t \pi_{t+1}^R = E_t(\hat{\tau}_{t+1} - \hat{\tau}_t).$$

Thus, relative (PPI-based) real interest rates are proportional to expected terms of trade depreciation.

Now imposing the fact that under the first-best optimum policy $\pi_t^R = 0$, and also $E_t \hat{\tau}_{t+1} = \mu \hat{\tau}_t$, (19) implies

$$(20) \quad \hat{\tau}_t = -\frac{1}{2} \frac{\tilde{r}_t^R}{1 - \mu} = -\frac{(v - 1)}{\Delta} \phi c_y \varepsilon_t.$$

When $v = 1$, there are no terms of trade response. However, in the realistic case of home bias, $v > 1$, in the first-best optimum, the home policy rate falls by more than the foreign policy rate. This requires an *expected* terms of trade appreciation, which, given $\mu < 1$, implies an immediate home terms of trade depreciation.

To illustrate the dynamics of our model, we now compare the efficient response of the terms of trade (20) to the responses under more constrained monetary policies. First, we examine the case when the central bank stabilizes inflation imperfectly using a Taylor rule. Second, we examine the terms of trade response when the home country policy rate is constrained by the zero lower bound. For now, we assume fiscal gaps are closed so as to facilitate comparison with (20).

A. Demand Shocks under a Taylor Rule

Now assume that, instead of offsetting the movement in natural interest rates, policy interest rates are set according to a Taylor rule:

$$(21) \quad r_t = \bar{r} + \chi \pi_{Ht}, \quad r_t^* = \bar{r} + \chi \pi_{Ft},$$

with $\chi > 1$. In this case, we can write the terms of trade as proportional to relative inflation:

$$(22) \quad \hat{\tau}_t = -2 \frac{\tilde{r}_t^R - \mu \pi_t^R}{1 - \mu} = -2 \frac{\chi - \mu}{1 - \mu} \pi_t^R.$$

Cook and Devereux (2011b) show that under home bias, with policy following (21), a negative home demand shock $\varepsilon_t < 0$, leads to sharper home deflation $\pi_t^R < 0$ and a more negative output gap, $\hat{n}_t^R < 0$. The deeper deflation in the home country spurs a sharper cut in interest rates in the home country, resulting in a terms of trade depreciation. The terms of trade response in terms of the fundamental shocks may be written as

$$(23) \quad \hat{\tau}_t = - \frac{(\chi - \mu) k(\phi + s_D)(v - 1)}{\Delta_1^D \Delta} \phi c_y \varepsilon_t,$$

where $\Delta_1^D > 0$ (see the Appendix for a definition of expressions). When $\varepsilon_t < 0$, the terms of trade must depreciate. Hence, when policy interest rates follow a Taylor rule, a negative demand shock in one country is associated with a depreciation in that country's terms of trade, which cushions the impact of the shock on inflation and the output gap.⁷

B. Demand Shocks in a Liquidity Trap

Finally, we look at the response of the terms of trade in a liquidity trap. More specifically, assume that $\tilde{r}(\varepsilon_t, v) < 0$ and $r_t = 0$. In the next section, it is shown that this will always be an optimal policy for the home economy when $\tilde{r}(\varepsilon_t, v) < 0$. We

⁷It is straightforward to see that as $\chi \rightarrow \infty$, the Taylor rule achieves perfect price stabilization, ensuring efficient terms of trade depreciation and closing all gaps.

examine the terms of trade response conditional on the policy decision of the foreign monetary authority, so $r_t^R = -\frac{r_t^*}{2}$. Then, using (19), we have

$$\hat{\tau}_t = 2\frac{\mu}{1-\mu}\pi_t^R + \frac{r_t^*}{1-\mu}.$$

From (14)–(17), we derive

$$\pi_t^R = \frac{k(\phi + s_D)}{\Delta_2^D} \left[\tilde{r}_t^R + \frac{r_t^*}{2} \right],$$

where $\Delta_2^D > 0$. Then we have

$$\begin{aligned} (24) \quad \hat{\tau}_t &= \frac{1}{1-\mu} \left[\frac{\mu k(\phi + s_D)}{\Delta_2^D} 2\tilde{r}_t^R + \frac{s_D(1-\beta\mu)(1-\mu)}{\Delta_2^D} r_t^* \right] \\ &= \left[\frac{\mu k(\phi + s_D)(v-1)}{\Delta_2^D \Delta} \phi c_y \varepsilon_t + \frac{s_D(1-\beta\mu)}{\Delta_2^D} r_t^* \right]. \end{aligned}$$

First, look at the case $r_t^* = 0$, so that both policy rates are at the zero bound. Then from (24), when $\varepsilon < 0$, the terms of trade *appreciates*. A fall in demand during a liquidity trap causes a persistent fall in inflation, which, given no adjustment in the nominal interest rate, causes a rise in the real interest rate. By condition (19), this requires an anticipated terms of trade depreciation for the home country. Since the shock is temporary, an anticipated terms of trade depreciation can only be satisfied by an immediate exchange rate *appreciation*. Thus, relative to the outcome under the full, flexible price equilibrium, or that under a Taylor rule when policy rates are constrained by the zero bound, relative prices move in the “wrong direction.”⁸ We note from (24) however that the terms of trade is increasing in r_t^* . Thus, the foreign central bank can limit the terms of trade depreciation by increasing its own policy rate.

Cook and Devereux (2011b) show that when $r_t^* = 0$, a negative demand shock causes the output gap in the home economy to fall by more when the economy is in a liquidity trap than under a Taylor rule.

⁸While our model is obviously not designed to match the historical data, the incidence of real exchange rate appreciation in a liquidity trap is not inconsistent with the experience of Japan and the United States in the wake of the financial crisis of October 2008. The Bank of Japan and United States Federal Reserve Bank cut their policy rates so that by December 2008 the uncollateralized call money rate and the Fed Funds rate were effectively at a lower bound. Simultaneously, both countries' real exchange rates appreciated sharply, despite expansionary monetary policy. The CPI based Real Effective Exchange Rate for the United States and Japan appreciated by 15 percent and 30 percent, respectively, between June and November 2008. Of course, other factors were at work, including the “flight to safety” in global financial markets, and the reversal of the foreign exchange “carry trade.” A full analysis of the impact of the episode on real exchange rates would require a careful decomposition of these separate effects.

IV. Optimal Policy in a Liquidity Trap

We continue to assume that the demand shock satisfies $\varepsilon < \varepsilon_H(1)$. Then either one or both countries will be constrained by the zero lower bound on nominal interest rates. The affect of these shocks is obviously going to depend on the policy response, both the current and anticipated future responses. As discussed in the introduction, our focus is exclusively on discretionary policymaking. We return to this issue in the conclusions.

A natural benchmark for comparison is the conventional policy described in the closed-economy literature on the zero lower bound. This may be described as

$$(25) \quad r_t = \max(0, \tilde{r}_t), \quad r_t^* = \max(0, \tilde{r}_t^*).$$

Under this conjectured policy, each country will set its policy rate to target the natural interest rate, if this is feasible. Otherwise, policy interest rates will be zero. This is an intuitive extension of the optimal discretionary monetary rule in the closed-economy literature on the zero bound (e.g., Eggertsson and Woodford 2003; Jung, Teranishi, and Watanabe 2005). In the analysis below, however, we see that policy (25) is the optimal rule in the two-country model only under very special circumstances.

In this section, we focus on optimal *cooperative* monetary and fiscal policy responses. Focusing on the cooperative problem is a desirable first approach, since it sets out a benchmark for choosing a policy so as to maximize world welfare in response to a negative demand shock that undermines the normal mechanism of monetary policy.⁹ In Section VI, we extend the results to a noncooperative setting, and show that under some parameterizations, optimal monetary policy has features that are qualitatively similar to those described in this section.

In order to analyze optimal policy, we first need to define an objective function. As shown in Cook and Devereux (2011a), a second-order approximation to an equally weighted world social welfare can also be constructed in world averages and world differences. Welfare for any period t is written as

$$(26) \quad V_t = -(\hat{n}_t^R)^2 \cdot \frac{A}{2} - (\hat{n}_t^W)^2 \frac{B}{2} - (\widehat{c}g_t^R)^2 \cdot \frac{F}{2} - (\widehat{c}g_t^W)^2 \cdot \frac{H}{2} - J(\hat{n}_t^R)(\widehat{c}g_t^R) \\ - L(\hat{n}_t^W)(\widehat{c}g_t^W) - \frac{\theta}{4k}(\pi_t^W + \pi_t^R)^2 - \frac{\theta}{4k}(\pi_t^W - \pi_t^R)^2,$$

where $A, B, F, H, J, L > 0$ are defined in the Appendix. Thus, the social welfare function faced by the policymaker depends upon output gaps, inflation rates, fiscal gaps, and the interaction between these variables.

⁹The cooperative approach to fiscal policy in a global liquidity trap is not necessarily unrealistic. In the immediate aftermath of the financial crash of 2008, the G20 group agreed on a joint policy response to the crisis that assigned target levels of fiscal stimulus to each member country.

Given this, cooperative policy under discretion may be characterized by the solution to the following optimization problem:

$$\begin{aligned}
 & \max_{\hat{n}_t^R, \hat{n}_t^W, c g_t^R, c g_t^W, \pi_t, \pi_{t+1}^R, r_t, r_t^*} L_t \\
 & = V_t + \lambda_{1t} [\pi_t^W - k(\phi + s)\hat{n}_t^W + ks \cdot \widehat{c g}_t^W - \beta E_t \pi_{t+1}^W] \\
 & \quad + \lambda_{2t} [\pi_t^R - k(\phi + s_D)\hat{n}_t^R + ks_D \widehat{c g}_t^R - \beta E_t \pi_{t+1}^R] \\
 & \quad + \psi_{1t} \left[s E_t (\hat{n}_{t+1}^W - \hat{n}_t^W) - s E_t (\widehat{c g}_{t+1}^W - \widehat{c g}_t^W) - E_t \left(\frac{r_t + r_t^*}{2} - \tilde{r}_t^W - \pi_{t+1}^W \right) \right] \\
 & \quad + \psi_{2t} \left[s_D E_t (\hat{n}_{t+1}^R - \hat{n}_t^R) - s_D E_t (\widehat{c g}_{t+1}^R - \widehat{c g}_t^R) - E_t \left(\frac{r_t - r_t^*}{2} - \frac{\tilde{r}_t^R}{2} - \pi_{t+1}^R \right) \right] \\
 & \quad + \gamma_{1t} r_t + \gamma_{2t} r_t^*.
 \end{aligned}$$

The policy optimum involves the choice of the output gaps, government spending gaps, inflation rates, and the foreign interest rate to maximize this Lagrangian. The first two constraints are the inflation equations in average and relative terms. The second two constraints are the average and relative “IS” equations. The final two constraints are the nonnegativity constraint on the two policy interest rates.

The first-order conditions of the maximization are

$$(27) \quad -A\hat{n}_t^R - J(\widehat{c g}_t^R) = \lambda_2 k(\phi + s_D) + s_D \psi_2$$

$$(28) \quad -B\hat{n}_t^W - L(\widehat{c g}_t^W) = \lambda_1 k(\phi + s) + s \psi_1$$

$$(29) \quad F\widehat{c g}_t^R + J(\hat{n}_t^R) = ks_D \lambda_2 + s_D \psi_2$$

$$(30) \quad H\widehat{c g}_t^W + L(\hat{n}_t^W) = ks \lambda_1 + s \psi_1$$

$$(31) \quad k\lambda_1 = \theta \pi_t^W$$

$$(32) \quad k\lambda_2 = \theta \pi_t^R$$

$$(33) \quad \psi_{2t} + \psi_{1t} = \gamma_{1t}$$

$$(34) \quad \psi_{1t} - \psi_{2t} = \gamma_{2t}$$

$$(35) \quad \gamma_{1t} \geq 0, \quad r_t \geq 0, \quad \gamma_{1t} r_t = 0$$

$$(36) \quad \gamma_{2t} \geq 0, \quad r_t^* \geq 0, \quad \gamma_{2t} r_t^* = 0.$$

These equations, in conjunction with (14)–(17), give the conditions determining average and relative output gaps; $\hat{n}_t^R$, $\hat{n}_t^W$, inflation rates; π_t^R , π_t^W , fiscal gaps; $\widehat{cg}_t^R$, $\widehat{cg}_t^W$, the Lagrange multipliers; λ_{1t} , λ_{2t} , ψ_{1t} , ψ_{2t} , and the value of either r_t , or γ_{1t} and r_t^* , or γ_{2t} , under optimal policy.

A. Optimal Monetary Policy

First, we focus on monetary policy alone. Assume that all fiscal gaps are zero, $\widehat{cg}_t^R = \widehat{cg}_t^W = 0$, and the only instrument available is the policy interest rate in each country. The key question is whether (25), the conventional interpretation of optimal monetary policy under the zero lower bound, is a correct description of optimal monetary policy. Conditions (33) and (34) together with the comparative slackness conditions (35) and (36), are the key equations of interest. They say that if the sum of the multipliers on the world and relative IS curves is positive, then the home country interest rate is at the zero bound (i.e., $\gamma_{1t} > 0$), while condition (34) says that if the difference between the multipliers is positive, then the foreign country is at the zero bound, (i.e., $\gamma_{2t} > 0$).

In the Appendix, we show that, using (27)–(36) together with (14)–(17), we can derive a two-equation relationship between the policy rates and the multipliers ψ_{1t} and ψ_{2t} . This is given by

$$(37) \quad \Omega_D \left(\frac{r_t - r_t^*}{2} - \tilde{r}_t^R \right) = \psi_2 \quad \Omega \left(\frac{r_t + r_t^*}{2} - \tilde{r}_t^W \right) = \psi_1,$$

where $\Omega_D \geq \Omega > 0$ are defined in the Appendix. There, we show that $\Omega_D > \Omega$ when $\nu < 2$.

From (37), we can now characterize the jointly optimal monetary policy in terms of the properties of the policy interest rates r_t and r_t^* . The key question is to see the conditions under which either the home, the foreign, or both nonnegativity conditions on interest rates are binding, i.e., what determines when the zero lower bound is reached for each country? Note that since $\varepsilon < \varepsilon_H(\nu)$, it must be that $\tilde{r}(\varepsilon, \nu) < 0$, so clearly the unconstrained optimal policy is not a feasible solution.

B. Characteristics of the Optimal Policy

It is clear in the special case of no home bias, $\nu = 1$, $r_t = r_t^* = 0$ is a solution. From (33), the home policy interest rate is zero whenever $\psi_1 + \psi_2 > 0$; and from (34), the foreign rate is zero when $\psi_1 - \psi_2 > 0$. In the case $\nu = 1$, $\tilde{r}_t^R = 0$, and $\tilde{r}_t^W < 0$. Setting $r_t = r_t^* = 0$ in (37), we find that $\psi_1 > 0$ and $\psi_2 = 0$, so that both constraints are binding.

In the more general case, conditions (37) and the characteristics of the natural interest rates (10) and (11) may be used to establish the following proposition.

PROPOSITION 1: For $\varepsilon < \varepsilon_H(1)$, the optimal policy is characterized by the conditions: a) $r_t = 0$, b) there exists a critical value $\bar{v}$, such that (i) for $1 \leq v \leq \bar{v}$, $r_t^* = 0$, (ii), for $v > \bar{v}$, r_t^* satisfies

$$r_t^* = \tilde{r}^*(\varepsilon_t, v) - \frac{(\Omega_D - \Omega)}{\Omega_D + \Omega} \tilde{r}(\varepsilon_t, v) > 0,$$

with $r_t^* > \tilde{r}^*(\varepsilon_t, v)$, and $\bar{v} < v_F$.

PROOF:

See Appendix.

This proposition makes it clear that the sense in which the two countries are in a liquidity trap is critically determined not by the fact that their respective natural interest rates are negative, but by the strength of the shock and the size of the trade flows between the countries. Figure 2 illustrates the behavior of the foreign interest rate for various values of v (the calibration assumptions for this figure are described in Section V). For a shock that would be large enough to drive the world natural interest rate below zero in the fully open world economy (i.e., $\varepsilon < \varepsilon_H(1)$), the foreign country will also set the interest rate at the zero bound, if it is sufficiently open to trade with the home country ($v \leq \bar{v}$). But no matter how big the shock, there is always a $\bar{v}$ such that, for $v \geq \bar{v}$, the foreign country will keep its policy interest rate above zero, and also above its natural interest rate. And there is always an interval $[\bar{v}, v_F]$ for which the foreign policy rate is above zero, even though its natural interest rate is below zero. An interesting feature of this figure is that for some range of v , the foreign country may set its interest rate above the nonstochastic steady-state rate. Thus, the interest rate in an optimal monetary regime may not only be higher than the natural interest rate, but also higher than the rate that would apply if the foreign economy were *completely closed*, and unaffected by the negative demand shock emanating from the home country.¹⁰

The key intuition behind the optimal monetary policy rule comes from the benefits of tempering the home country terms of trade appreciation that occurs in a global liquidity trap. As we discussed above, when $v > 1$, the home terms of trade exacerbate the negative demand effects of the liquidity shock on the home country, drawing world demand away from home goods rather than cushioning the impact of the fall in demand. The only way in which the home monetary authority could limit this is to reduce its interest rate; but of course at the zero bound, it cannot engage in any further interest rate reduction. But the foreign country can limit the home terms of trade appreciation by increasing its own interest rate. For higher and higher values of v , this is of direct benefit to the foreign country, since in those circumstances,

¹⁰ Note also that if $\sigma = 1$, that $\Omega = \Omega_D$, and the optimal foreign interest rate would equal the natural interest rate, if this is positive. In this case, the policy decisions for the two country's dichotomize, and the optimal policy is simply (25). We note that Fujiwara et al. (2009) also find numerical examples of an economy facing a natural interest rate shock raising its policy rate above its natural rate when a trading partner is at the zero lower bound.

FIGURE 2. POLICY RATES

it is more likely that the movement in the terms of trade causes an expansion in the foreign output gap. We can write the home terms of trade as follows

$$\hat{\tau}_t = 2 \frac{\mu}{1 - \mu} \frac{k(\phi + s_D)}{\Delta_2^D} \left(\tilde{r}_t^W + \frac{r_t^*}{2} \right) + \frac{r_t^*}{(1 - \mu)}.$$

For $1 \leq v < \bar{v}$, then $\tau_t < 0$, and the terms of trade appreciate. But as $\bar{v} \leq v \leq 2$, the appreciation is mitigated by a rise in the foreign policy rate.

So far we have focused on large negative demand shocks, defined as $\varepsilon < \varepsilon_H(1)$. In this case, there is always a region $[1, \hat{v}]$, such that both countries are in a liquidity trap. Figure 3 illustrates an opposite case, where the negative demand shock is smaller. In this case, $\varepsilon < \varepsilon_H(1)$. Then, with fully open trade, neither country is in a liquidity trap. But if the shock is still sufficiently large so that $\varepsilon < \varepsilon_H(\hat{v})$, for some $\hat{v} \in [1, 2]$, then the home country is in a liquidity trap for values of $v \geq \hat{v}$. Then, in this case, Proposition 1 applies as before. For $1 < v \leq \hat{v}$, both countries can close all gaps by adjusting policy interest rates. For $v > \hat{v}$, the home economy is constrained by the zero bound. Now the foreign economy raises its interest

FIGURE 3. POLICY RATES

rate above its natural interest rate. Interestingly, this is a case where more open trade *reduces* policy interdependence. With fully open trade, due to the spreading of demand shocks through the two countries, each country can act independently to adjust its policy rate. But with more restricted trade, the home economy is more affected by the negative shock, and the inability to adjust interest rates in a downward direction leads to a reliance on tighter foreign monetary policy to adjust to the shock. Paradoxically, policy interdependence is more important, the *less interdependence* there is in trade flows.

Proposition 1 compares the optimal monetary policy to the conventional policy given by (25). We have established that the optimal policy will never target $\tilde{r}^*(\varepsilon_r, v)$. But an alternative policy conjecture would be that the foreign monetary authority targets the interest rate that would obtain in a zero-inflation, flexible price equilibrium for the *foreign* economy alone, taking the zero-bound interest rate in the home economy as given. We could refer to this as a policy that targets the *conditional* natural interest rate in the foreign economy (conditional on the home economy being

in a liquidity trap).¹¹ How would such a policy compare to the optimal policy of Proposition 1? The following proposition demonstrates that an unconstrained foreign central bank will implement a monetary policy that is more contractionary than that which would implement the conditional natural interest rate policy.

PROPOSITION 2: *If the foreign central bank follows an optimal policy as in Proposition 1, then both home and foreign inflation will be negative, and the home output gap will be negative.*

PROOF:

See Appendix.

The tighter rule foreign monetary policy minimizes the terms of trade appreciation of the home country, and reduces the inflationary forces affecting the foreign economy. In fact, the foreign central bank will temper the appreciation to such an extent that it imports deflation—i.e., the inflation rate under the optimal policy rule is negative. In Section VI, however, we show that a policy rule targeting the conditional natural interest rate for the foreign economy still implies a higher interest rate than the conventional rule (25).

C. Characteristics of the Conventional Policy

We can obtain more insight into the motivation for the foreign country to raise interest rates by looking at the alternative, where the foreign country set $r_t^* = \tilde{r}^*(\varepsilon, v)$, when $v > v_F$.

PROPOSITION 3: *If the foreign central bank nonoptimally closes the interest gap, $r_t^* = \tilde{r}_t^*$, there would be a contraction and deflation in the home economy, $\hat{n}_t < 0$, $\pi_{Ht} < 0$ and would result in expansion and inflation in the foreign economy, $\hat{n}_t^* > 0$, $\pi_{Ft} > 0$.*

PROOF:

See Appendix.

When $r_t^* = \tilde{r}^*(\varepsilon, v)$, the only shock to system (14)–(17) is to the home natural interest rate $\tilde{r}(\varepsilon, v)$, and the shock enters the same way in both the average and relative systems. It is then possible to show that $\hat{n}^W$ and $\hat{n}^R$ fall—both world average output and relative home output fall. But, as discussed above, home bias in preferences leads the relative elasticities of response to a given real interest rate shock to exceed the average elasticity. Thus, we can show that $\hat{n}^R < \hat{n}^W$. This implies that $\hat{n} < 0$, and $\hat{n}^* > 0$. A similar argument applies to inflation, so we may show that $\hat{\pi}^R < \hat{\pi}^W$, and $\hat{\pi} < 0$ and $\hat{\pi}^* > 0$.

¹¹ We thank a referee for drawing this case to our attention.

Thus, in the region $v > v_F$, where the foreign central bank actually has the capacity to close its interest rate gap, it finds such a policy excessively expansionary and inflationary. This suggests that features of the optimal policy of Proposition 1 are in the interest of the foreign country even if it were to ignore the preferences of the home country. We follow up this logic in Section VI.

D. Optimal Monetary and Fiscal Policy

So far we've assumed fiscal gaps are all closed. But recognizing the zero lower bound gives a role for active fiscal policy, which involves having nonzero fiscal gaps.¹²

Our characterization of monetary policy in the model with optimal fiscal policy is analogous to the previous section. We may use (27), (28), (31), (32), and (34) in conjunction with (14) and (17) to compute a solution for γ_2 as

$$(38) \quad \gamma_2 = \psi_1 - \psi_2 = \Gamma\left(\frac{r_t^*}{2} - \tilde{r}_t^W\right) - \Gamma_D\left(\frac{r_t^*}{2} + \tilde{r}_t^R\right),$$

where $\Gamma(v)$ and $\Gamma_D(v)$ (defined in the Appendix) satisfy the condition that $\Gamma_D(v) \geq \Gamma(v)$, with $\Gamma_D(2) = \Gamma(2)$.

Equation (38) satisfies the same properties as Proposition 1 in the previous subsection. In an economy without home bias, when $v = 1$, then $r_t^* = 0$, $\tilde{r}_t^R = 0$, and so $\gamma_2 > 0$, ensuring that the foreign zero-bound constraint is binding. In that case, it can immediately be seen that the home and foreign fiscal gaps are equal, and positive. Alternatively, in the case with no trade, $v = 2$, then (38) gives the solution $r_t^* = \bar{r}$, and the foreign fiscal gap is zero.

As before, there is a critical value for v , denoted $\bar{v}$, such that for $v \geq \bar{v}$, then $r_t^* > 0$. In this case, since $\gamma_2 = 0$, we may derive the optimal value of r_t^* from (38) itself. In summary, we may then define the behavior of the foreign policy interest rate in the same way as before. Thus,

$$(39) \quad \text{For } 1 \leq v \leq \bar{v}, \quad r_t^* = 0$$

$$\text{For } \bar{v} < v < 2, \quad r_t^* = \tilde{r}_t^*(\varepsilon, v) - \frac{(\Gamma_D - \Gamma)}{(\Gamma_D + \Gamma)} \tilde{r}_t(\varepsilon, v).$$

The monetary policy response on the part of the foreign country is augmented by positive fiscal gaps on the part of one or both governments. Though optimal

¹²Cook and Devereux (2011a) show that fiscal multipliers depend on the degree of trade integration but always exceed the closed-economy multiplier. Fujiwara and Ueda (2012) show that the fiscal multiplier in a global liquidity trap exceeds one in the case of no home bias (even under the local currency pricing case not considered here). Cook and Devereux (2011a, 2011b) examine *optimal* fiscal policy when both economies are in a liquidity trap. In the no home bias case, both countries must have identical and positive optimal fiscal gaps since the natural rates are equalized across countries. Home bias complicates this conclusion in two ways. First, it creates an asymmetry in the response of the economies to a shock, and thus creates differences in the fiscal response. Second, it allows for the possibility that the less-affected foreign economy adjusts its policy rate. Hence, in general, the stance of monetary policy will affect the optimal fiscal gaps chosen by each country.

fiscal policy will affect optimal monetary policy, the qualitative characterization is unchanged; with sufficiently low trade integration, the optimal foreign interest rate exceeds the natural interest rate, even when optimal fiscal policy is implemented.

We can also show that the optimal policy response of the foreign monetary authority cannot change the qualitative response of home fiscal policy to the liquidity trap.

PROPOSITION 4: *When $r_t = 0$, the optimal home fiscal gap will always be positive, regardless of optimal r_t^* .*

PROOF:

See Appendix.

Fully characterizing the qualitative response of foreign fiscal policy when monetary policy can also adjust is algebraically complex. We now turn to a numerical illustration. We show that fiscal policy is very sensitive to the optimal implementation of monetary policy.

V. Numerical Analysis of Optimal Policy

To evaluate the economy quantitatively, we adopt some parameters from Cook and Devereux (2011b). Let $\beta = 0.99$, so each period is a quarter, and thus $\bar{r} = 0.01$. The Frisch labor supply elasticity is set at $\phi = 1$. Price stickiness is $\kappa = 0.85$, so that $k = 0.027$, as in Christiano, Eichenbaum, and Rebelo (2009). Let the share of government in output be 20 percent, so that $c_y = 0.8$. We assume the inverse of the intertemporal demand elasticity σ , is equal to two. The persistence of the demand shock is set at 0.8 ($\mu = 0.8$) implying an expected length of the slump to be 5 quarters. We set the elasticity of substitution between individual good varieties within a country, θ , equal to five. Finally, we set the preference shock in the home country ε so that at $v = 1$ (the case without any home bias), the natural interest rate at the quarterly frequency would fall from 1 percent to -1.7 percent, with persistence μ .

Figure 4 illustrates the response of home and foreign output gaps, home and foreign government spending gaps, home and foreign inflation, the foreign country optimal policy rate, as well as the foreign natural interest rate, and the home country terms of trade, for different values of v , when the optimal fiscal and monetary policy response is chosen. The figure takes account of condition (39), so that, at each value of v , the nonnegativity constraint on r_t^* is tested, and if it is not binding, the optimal foreign policy rate is chosen to satisfy (39). The first thing to note is that at $v = 1$, then clearly the zero bound is binding in both countries, and all variables respond in the same way in the two countries. The output gap falls by over 7 percent in both countries, and this is coupled with a fall in the rate of inflation by equal amounts. Since both countries are affected equally, and interest rates are zero, adjusting the fiscal gaps is the only possible policy response to the shock. The figure shows a positive response of the fiscal gap in each country. Thus, fiscal policy should behave countercyclically, and equally so in each country for a world without home bias in preferences.

FIGURE 4. OPTIMAL POLICY

Now, as ν rises above unity, we know that the impact of the shock on the foreign natural interest rate becomes muted, while the opposite occurs for the home natural interest rate. The negative response of the foreign output gap is then reduced, while that of the home output gap is increased. As ν rises, holding the foreign policy rate constant, the foreign output gap may actually increase. This is due to the sharp

terms of trade appreciation of the home country, leading to an expenditure switching toward foreign output. A similar dynamic occurs in the response of the inflation rates in the two countries—home inflation becomes more and more negative as v rises, while the negative response of foreign inflation becomes less and less. The optimal response of fiscal policy gaps is illustrated in panel B of the figure. As v rises, home fiscal policy becomes more aggressive, while the foreign fiscal policy becomes more restrained.

Panel D illustrates the optimal response of the foreign country policy rate, alongside the foreign country natural interest rate. Note that at $v = 1$, the foreign policy rate is stuck at zero, while the natural interest rate is at -0.017 . As v rises, the response of the foreign natural interest rate becomes less, as is obvious from the formula (39). Eventually, as v rises to 2, the foreign country would be entirely unaffected by the shock, and the foreign natural interest rate would rise to 0.01, the steady-state natural interest rate. But the key feature of panel D is that the foreign country will raise its policy rate above zero for values of $\tilde{r}_t^* < 0$. The foreign country will not follow a policy of offsetting the movement in the foreign natural interest rate to the greatest extent that it can, so long as the policy rate is above the zero bound. Rather, it chooses to raise policy rates, even though $\tilde{r}_t^* < 0$. Panel D also shows that, above $\bar{v}$, there is always a range where the foreign country sets its policy rate *above the steady-state natural rate of interest*.

So an optimal cooperative policy response to a liquidity trap can be characterized by expansionary fiscal policy in all countries, but contractionary monetary policy in the least affected country. Since the impact of the home country shock on foreign output is positive in any case, when v is sufficiently greater than unity, the rise in the foreign policy rate has the additional benefit that it helps to minimize the response of the foreign output gap to the home country shock. The figure shows that the tightening of the policy rate in the foreign country as v rises reduces the degree to which the home terms of trade appreciates in response to the initial savings shock.

We note that, when an optimal foreign monetary policy is used, the foreign country has a very small fiscal gap. While it is optimal for the foreign country to follow an expansionary fiscal policy, quantitatively, the size of the fiscal expansion is much less than that of the home country.

Figure 5 provides further illustration of the key interaction between monetary and fiscal policy in responding to the liquidity trap in the home country. The figure contrasts the optimal policy for fiscal and monetary policy to that where fiscal policy is set optimally, but monetary policy is set according to the conventional rule (25). Thus, the foreign country sets the policy rate equal to zero when the natural interest rate is negative, and equal to the natural interest rate when it is above zero. The figure shows that the response of fiscal policy under this alternative (nonoptimal) monetary rule is substantially different when $v > 1$. The key feature of this policy is that it is excessively expansionary for the foreign economy, relative to the optimal rule. As v rises, the foreign economy experiences a boom, which is countered by a *contractionary* fiscal policy. At the same time, the suboptimal adjustment in the foreign country leads to an excessive contraction in the home economy, which then requires a much greater fiscal expansion than would take place under the optimal policy. This comparison makes clear that the *optimal* foreign monetary policy adjustment

FIGURE 5. OPTIMAL AND CONSTRAINED POLICY

in effect reduces the extent to which the home country has to engage in expansionary fiscal policy in response to the liquidity trap. It does so precisely by tempering the sharp terms of trade appreciation of the home economy. Note from panel E that under the nonoptimal monetary rule (25), the terms of trade appreciate much more for the home economy than it would under the optimal policy. In addition, under this

nonoptimal rule, the foreign economy experiences inflation, while the deflation in the home economy is substantially greater than it would be under the optimal policy.

VI. Monetary Policy in a Noncooperative Setting

Our analysis has so far been based on an optimal cooperative policy. But we suggested above that even in a noncooperative setting, the foreign policymaker may wish to follow a tighter policy than implied by the conventional monetary policy rule (25). In this section, we briefly analyze the optimal foreign monetary policy in a noncooperative equilibrium, following the approach of Clarida, Gali, and Gertler (2002). We show that a noncooperative monetary policy may indeed display interest rate responses above those implied by (25). That is, a tight monetary policy may actually be followed by the foreign monetary authority, purely for its own benefit.

We illustrate these results in a restricted version of the main model. Specifically, we ignore the role of government spending on public goods, focusing on a version of (1) where all output goes to private goods.¹³ The equilibrium for inflation and output gap determination, conditional on the path of the natural interest rates, is identical to that of previous sections. The difference now is that optimal monetary policy is chosen to minimize a domestically orientated loss function.

A number of complicating factors arise in specifying noncooperative policy making in a multi-country DSGE environment. First, as is well-known, in a dynamic strategic setting there is generally a large number of equilibria indexed by threats, or trigger strategies (e.g., Chari and Kehoe 1990). We narrow the focus down from this by concentrating on discretionary policymaking for each authority, so that all expectations of future variables are taken as given (as in the previous section). Secondly, as discussed in Clarida, Gali, and Gertler (2002); Corsetti and Pesenti (2001); and Benigno and Benigno (2003), in a noncooperative setting, a benevolent monetary authority will attempt to manipulate the home terms of trade in favor of the domestic country, since the competitive equilibrium suffers from the “distortion” that the terms of trade are below the level that is optimal from the point of view of a domestic policymaker. This introduces a second distortion in addition to that of monopoly pricing, which is inherent in the underlying monopolistic competitive framework of this model. Clarida, Gali, and Gertler (2002) deal with this by assuming an optimal subsidy is in place, which just balances the incentive to eliminate the monopoly pricing distortion against the incentive to manipulate the terms of trade in the country’s favor. We follow this procedure here.¹⁴ Online Appendix B defines the optimal subsidy necessary to attain this balance. A final complication introduced by non-cooperative policymaking is the nature of the strategy space. Clearly, in a strategic policy-making environment, the strategies used are not irrelevant to the outcome. In our analysis, we again follow Clarida, Gali, and Gertler (2002) in assuming that

¹³The results for fiscal spending policies can be easily added to the analysis but offer little additional insight relative to those of the cooperative equilibrium.

¹⁴An alternative, more general approach is in Benigno and Benigno (2006).

each monetary authority chooses its own output gap, taking the output gap of the other monetary authority as given.

Online Appendix B derives the loss function of the monetary authority in a non-cooperative setting where there is an optimal subsidy in place, and policymakers choose their own output gaps. Our analysis differs from that of Clarida, Galí, and Gertler (2002) primarily due to the existence of home bias in preferences. In addition, as in the analysis above, we focus exclusively on a discretionary equilibrium where the home government is constrained by the zero bound. This means that the home strategy is redundant during the period of the liquidity trap. Moreover, after the liquidity trap shock elapses, the optimal noncooperative policy outcome is simply to close all gaps, as in the cooperative policymaking problem described above.¹⁵ Hence, we can simply focus on the problem of the foreign government in choosing an output gap to minimize its own loss, subject to the foreign inflation and IS equations. Then we can chart out the foreign policy interest rate that implements this policy, subject to the zero lower bound.

The foreign period loss function is described as (see online Appendix B):

$$v_t^{NC*} = \frac{(\hat{n}_t - \hat{n}_t^*)^2(2 - \nu)\nu(1 - \nu)^2(1 - \sigma)^2}{8\delta_1 D^2} - \frac{(1 - \sigma)}{2}(\delta_1 \hat{n}_t^* + \delta_2 \hat{n}_t)^2 \\ + \frac{(1 + \phi)}{2} \hat{n}_t^{*2} + \frac{\theta}{2k} \pi_t^{*2} + ((1 - \sigma)\tilde{c}_t^* - (1 + \phi)\tilde{n}_t^*) \hat{n}_t^*.$$

This depends on foreign and home output gaps, foreign PPI inflation, and a cross term involving the foreign output gap and flexible price consumption and output.¹⁶

Appendix B describes the problem for the foreign policymaker in a noncooperative equilibrium. Although the policymaker's loss function depends on the home country output gap, this is taken as given by the foreign policymaker.

Figure 6 illustrates the results of the noncooperative policy for the foreign policy rate, and compares this to the cooperative policy rate from Proposition 1. In addition, we report the policy rate implied by the foreign monetary authority targeting the *conditional* natural interest rate defined in Section II. The first thing to note is that the noncooperative policy rate is always below the cooperative rate of Proposition 1. Thus, in following a fully self-oriented policy, foreign monetary policy is not as tight as that under cooperation. Nevertheless, as conjectured above, it is still the case that the foreign monetary authority follows a tighter rule than that implied by the conventional zero lower bound rule (25). The policy rate under a noncooperative policy is always above the foreign natural interest rate, and is positive in regions even where the latter rate is negative. Thus, the general feature of the policy response of Section IV prevails.¹⁷

¹⁵ This follows because we have eliminated the incentive to engage in strategic manipulation of the terms of trade, so the Nash equilibrium will be to replicate the flexible price equilibrium.

¹⁶ In the cooperative loss function, all cross terms such as this cancel out.

¹⁷ An important caveat pertains to the interpretation of Figure 6. As in Clarida, Galí, and Gertler (2002), the steady state of the noncooperative equilibrium differs from that of the cooperative equilibrium due to the tax-subsidy policy designed to counterbalance the monopoly pricing distortion against the terms of trade distortion. By contrast,

FIGURE 6. NONCOOPERATIVE AND CONDITIONAL NATURAL RATES

Figure 6 also indicates that the noncooperative policy rate is above the rate implied by the conditional natural rate of interest defined in Section IV above. Under the conditional natural rate targeting policy, the foreign monetary authority keeps inflation equal to zero, which translates into a significant positive output gap for the foreign economy (since it still experiences a terms of trade deterioration). By contrast, the efficient trade-off under the noncooperative outcome is to raise the policy rate higher, generating a deflation, and achieving a lower (positive) output gap.¹⁸ Figure A1 in the online Appendix illustrates that the noncooperative outcome involves a smaller output gap and a small negative inflation rate, whereas the conditional natural rate targeting has a zero inflation rate and a significantly larger output gap. Thus, in general the noncooperative outcome differs from that where the foreign policymaker targets the foreign conditional natural interest rate.

the cooperative equilibrium is approximated around an undistorted steady state. Hence, the response of the interest rate in the noncooperative case is based on a different approximation point (see Benigno and Benigno 2006, for a discussion). Thus, the two responses are not strictly speaking quantitatively comparable, and therefore, Figure 6 should be interpreted in a qualitative way. The key point of Figure 6 remains however; the foreign policymaker, acting noncooperatively, will set an interest rate higher than the foreign natural interest rate, in general.

¹⁸Note that because the two countries are interdependent when $\sigma > 1$, it is not possible for the foreign monetary authority to choose a zero inflation and zero output gap response to the home country shock, except when $v = 2$.

VII. Conclusions

The experience of major recessions in many of the world's largest economic regions, together with low or zero interest rates, has reduced confidence in the ability of monetary policy to respond to economic shocks, and suggests that only fiscal policy can be used as a countercyclical device. This paper shows that in a world economy, where countries are affected in different ways by "liquidity trap" shocks, monetary and fiscal policy may be used in mutually supportive ways, and in some cases the standard prescriptions for monetary policy response to a liquidity trap may fail to apply. A relatively tight monetary policy in the least hit country facilitates an efficient redirection of world spending, and reduces the extent to which fiscal expansion must be used to raise world expenditure. The key useful feature of monetary policy in our model is that it tempers the perverse response of relative prices to shocks that occur in a liquidity trap. The underlying message of the paper is that in a liquidity trap, the relative price response may exacerbate rather than ameliorate the impact of negative demand shocks.

Much of the literature on the macroeconomics of liquidity traps focuses on the optimal policy response in a setting where the monetary authority has the ability to credibly commit to a policy plan in the aftermath of the liquidity trap. Jung, Teranishi, and Watanabe (2005) and Eggertsson and Woodford (2003) find that in a liquidity trap in a closed economy, central banks should commit to keeping interest rates at zero for some time after the liquidity trap shocks expire. As stated in the introduction, the focus of our paper is to show that even without credible commitment, in a multi-country setting, monetary policy may not be ineffective in response to a liquidity trap shock, even when under conventional measures, all countries should be in a liquidity trap. Optimal monetary policy may involve a compensating (and, surprisingly, contractionary) policy response in the least hit country, even if this country acts purely for its own benefit. In particular, we showed that this result obtained in environments where there is sufficient home bias, and inter-temporal substitution exceeding unity.

How would our results change with credible commitment in policy? One of the implications of our model is that without home bias, each country is hit identically by a liquidity trap shock. In that case, the optimal monetary response is identical in the two countries, and requires no relative price adjustment. It then follows that the world economy responds to the shock as in a closed economy, and the optimal policy *with commitment* would exactly mimic that of Jung, Teranishi, and Watanabe (2005) or Eggertsson and Woodford (2003). Nakajima (2008) and Fujiwara et al. (2010) develop models of optimal monetary policy in multi-country models with policy commitment (but without home bias); under different types of shocks than we have here—they focus on asymmetric technology shocks. They find that international coordination would implement similar optimal policy conditions to those found in Eggertsson and Woodford (2003). In our model, where countries are asymmetrically affected by the liquidity trap shock, due to home bias in preferences, credible commitment would allow the home country to use the promise of future monetary expansion to alleviate the impact of the shock. By doing so, it could increase expected inflation and limit the immediate terms of trade appreciation. This would

reduce the degree to which an optimal monetary policy requires a tightening of policy rates in the foreign country. Nevertheless, because the linear quadratic objective function generally implies using all policy margins at least to some degree, it is very likely that at least qualitatively, the overall optimal monetary response in an environment of policy commitment would have the general features described in the present paper. We defer a full analysis of the commitment case for future research.

APPENDIX

A. Parameter Derivations

Here, we define the parameters used in the loss function, which is taken from that used in Cook and Devereux (2011).

$$A \equiv \left\{ \frac{(1 + \phi c_y)}{c_y^2} + \frac{(\sigma - D)}{D} \left(1 + \frac{(1 - c_y^2)}{c_y^2 D} \right) \right\} = \frac{(s_{DD} + \phi)}{c_y}$$

$$s_{DD} \equiv \frac{(D - 1)(1 - c_y^2)}{c_y D} + \frac{(\sigma)}{D} \left(\frac{1 + c_y^2(D - 1)}{c_y D} \right) < s_D$$

$$B \equiv \frac{(\sigma + \phi c_y)}{c_y^2} = \frac{(s + \phi)}{c_y},$$

$$H \equiv \frac{1}{(1 - c_y)} \frac{\sigma}{c_y^2} = \frac{1}{(1 - c_y)} \frac{s}{c_y} \quad L \equiv \frac{-\sigma}{c_y^2} = \frac{s}{c_y}$$

$$J \equiv \left[-\frac{1}{c_y^2} - \frac{(\sigma - D)}{c_y^2 D^2} (1 + (v - 1)(D - 1)c_y^2) \right]$$

$$F \equiv \frac{((1 - c_y) + c_y \sigma)}{(1 - c_y)c_y^2} + \frac{(\sigma - D)}{c_y^2 D^2} (1 + (v - 1)(D - 1)c_y^2)$$

$$\Delta_1 \equiv s(1 - \beta\mu)(1 - \mu) + (\chi - \mu)k(\phi + s) > 0,$$

$$\Delta_1 > \Delta_1^D = s_D(1 - \beta\mu)(1 - \mu) + (\chi - \mu)k(\phi + s_D) > 0$$

$$\Delta_2 \equiv s(1 - \beta\mu)(1 - \mu) - \mu k(\phi + s) > 0$$

$$\Delta_2 > \Delta_2^D = s_D(1 - \beta\mu)(1 - \mu) - \mu k(\phi + s_D) > 0.$$

The assumption that $\Delta_2 > 0$ and $\Delta_2^D > 0$ is necessary for determinacy of the model when the zero lower bound is binding, and requires a limit on the persistence of the shock, μ .

$$\Psi = [B(1 - \beta\mu) + \theta k(\phi + s)^2]$$

$$\Psi_D = [A(1 - \beta\mu) + \theta k(\phi + s_D)^2]$$

$$\Omega_D \equiv \frac{\Psi_D}{\Delta_2^D s_D} \quad \Omega \equiv \frac{\Psi}{\Delta_2 s}$$

$$g^R = -\frac{[f(\phi + s_D) + (1 - \beta\mu)JA]}{[\Delta_2^D FJ + \Delta_3^D JA + f\phi s_D(1 - \mu)]}$$

$$g^W = \frac{[f(\phi + s) + (1 - \beta\mu)BL]}{[\Delta_2 HL + \Delta_3 BL] + \phi f(1 - \mu)s}$$

$$\Delta \equiv \phi c_y D + \phi(1 - c_y) + \sigma$$

$$\Gamma_D \equiv \Omega_D + \frac{(J\Delta_2^D + A\Delta_3^D)(1 - \beta\mu) + (\phi + s_D)\theta k\phi s_D(1 - \mu)}{\Delta_3^D s_D} g^R$$

$$\Gamma \equiv \Omega + \frac{(L\Delta_2 + B\Delta_3)(1 - \beta\mu) + (\phi + s)\theta k\phi s(1 - \mu)}{\Delta_3 s} g^W.$$

The expressions are in Section VC and are defined as follows:

$$\Gamma_D \equiv \Omega_D + \frac{(J\Delta_2^D + A\Delta_3^D)(1 - \beta\mu) + (\phi + s_D)\theta k\phi s_D(1 - \mu)}{\Delta_3^D s_D} g^R,$$

$$\Gamma \equiv \Omega + \frac{(L\Delta_2 + B\Delta_3)(1 - \beta\mu) + (\phi + s)\theta k\phi s(1 - \mu)}{\Delta_3 s} g^W,$$

$$g^R = -\frac{[f(\phi + s_D) + (1 - \beta\mu)JA]}{[\Delta_2^D FJ + \Delta_3^D JA + f\phi s_D(1 - \mu)]}$$

$$g^W = \frac{[f(\phi + s) + (1 - \beta\mu)BL]}{[\Delta_2 HL + \Delta_3 BL] + \phi f(1 - \mu)s}.$$

B. Derivations of Conditions under Closed Fiscal Gaps

To derive the conditions governing optimal monetary policy, combine (31) and (32) with (27) and (28). We obtain the relationship between world and relative output gaps, inflation rates, and the multipliers ψ_{2t} and ψ_{1t} . Since the underlying demand shock is either a constant (negative) number or zero, the solution for all

variables during the period of the shock will be time invariant. Hence, we can drop the time notation. Thus,

$$(40) \quad -A\hat{n}^R = \theta\pi^R(\phi + s_D) + s_D\psi_2$$

$$(41) \quad -B\hat{n}^W = \theta\pi^W(\phi + s) + s\psi_1.$$

Then, solving the conditions (14)–(17) using the fact that the shock to the natural interest rates will revert to zero with probability $1 - \mu$ per period, we have:

$$(42) \quad \pi^R(1 - \beta\mu) = k(\phi + s_D)\hat{n}^R$$

$$(43) \quad s_D(\mu - 1)\hat{n}^R = \frac{r - r^*}{2} - \tilde{r}^R - \mu\pi^R$$

$$(44) \quad \pi^W(1 - \beta\mu) = k(\phi + s)\hat{n}^W$$

$$(45) \quad s(\mu - 1)\hat{n}^W = \frac{r + r^*}{2} - \tilde{r}^W - \mu\pi^W.$$

From (42) and (43), we can derive the partial solution for the relative output gap as

$$(46) \quad \Delta_2^D \hat{n}^R = -\left(\frac{r - r^*}{2} - \tilde{r}^R\right)(1 - \beta\mu).$$

Likewise, the world output gap that solves (44) and (45) is

$$(47) \quad \Delta_2 \hat{n}^W = -\left(\frac{r + r^*}{2} - \tilde{r}^W\right)(1 - \beta\mu).$$

Now using (42) in (27) we get:

$$(48) \quad -[A(1 - \beta\mu) + \theta k(\phi + s_D)^2]\hat{n}_t^R \equiv -\Psi_D \hat{n}_t^R = s_D\psi_2(1 - \beta\mu)$$

and (44) in (28) we get

$$(49) \quad -[B(1 - \beta\mu) + \theta k(\phi + s)^2]\hat{n}_t^W \equiv -\Psi \hat{n}_t^W = s\psi_1(1 - \beta\mu).$$

C. Proof of Propositions

PROPOSITION 1:

PROOF:

To prove the proposition, initially assume that a) holds, so that $r_t = 0$. Then from (34) and (37), we may write

$$(50) \quad \gamma_2 = \psi_1 - \psi_2 = \Omega\left(\frac{r^*}{2} - \tilde{r}_t^W(\varepsilon, \nu)\right) + \Omega_D\left(\frac{r^*}{2} + \tilde{r}_t^R(\varepsilon, \nu)\right).$$

Define the right-hand side of (50) as $J(\varepsilon, \nu)$. If $J(\varepsilon, \nu) > 0$, then $r^* = 0$ must hold. Assuming this is the case, we have

$$(51) \quad J(\varepsilon, \nu) = -\Omega \tilde{r}_t^W(\varepsilon, \nu) + \Omega_D \tilde{r}_t^R(\varepsilon, \nu).$$

By the definition of $\tilde{r}_t^W(\varepsilon, \nu)$ and $\tilde{r}_t^R(\varepsilon, \bar{\nu})$, it must be that $\tilde{r}_t^R(\varepsilon, 1) = 0$, so that $J(\varepsilon, 1) = -\Omega \tilde{r}_t^W(\varepsilon, 1) > 0$, while $\tilde{r}_t^W(\varepsilon, 2) > \tilde{r}_t^R(\varepsilon, 2)$, so that $J(\varepsilon, 2) = -\Omega \tilde{r}_t^W(\varepsilon, 2) + \Omega_D \tilde{r}_t^R(\varepsilon, 2) < 0$, since from the definitions above, we know that $\Omega = \Omega_D$ when $\nu = 2$. Hence, by continuity, there exists a value $\bar{\nu}$ defined by the condition $J(\varepsilon, \bar{\nu}) = -\Omega \tilde{r}_t^W(\varepsilon, \bar{\nu}) + \Omega_D \tilde{r}_t^R(\varepsilon, \bar{\nu}) = 0$.¹⁹

Taking ν such that $1 \leq \nu \leq \bar{\nu}$, and setting $r_t = r_t^* = 0$ in (37) and (34) implies that $J(\varepsilon, \nu) > 0$, which confirms the conjecture that both zero bound constraints are strictly binding, so both policy rates are zero. At $\nu = \bar{\nu}$, $J(\varepsilon, \bar{\nu}) = 0$, and the home constraint is strictly binding, while for foreign constraint it is just binding. For $\bar{\nu} < \nu \leq 2$, $J(\varepsilon, \nu) < 0$. Then the home country constraint is binding, but the foreign constraint is not binding. Then for $\nu \geq \bar{\nu}$, given that the foreign constraint is not binding, we set $\gamma_{2t} = 0$ in (34), which implies that $\psi_1 = \psi_2$. Using this condition, we set $r_t = 0$ in (37) and solve for the equilibrium foreign country interest rate as

$$(52) \quad r_t^* = \tilde{r}^*(\varepsilon, \nu) - \frac{(\Omega_D - \Omega)}{\Omega_D + \Omega} \tilde{r}(\varepsilon, \nu) > 0.$$

Note that for $\nu \geq \bar{\nu}$, this is strictly positive, since from the definition of $J(\varepsilon, \nu)$, we have $r_t^* = -\frac{2}{\Omega_D + \Omega} J(\varepsilon, \nu) > 0$, for $\nu \geq \bar{\nu}$.

Moreover, the critical value $\bar{\nu}$ must satisfy $\bar{\nu} < \nu_F$. This is because, given the definition of the natural interest rates, it must be that $\tilde{r}_t^W(\varepsilon, \nu_F) = \frac{\tilde{r}_t(\varepsilon, \nu_F)}{2}$, and $\tilde{r}_t^R(\varepsilon, \nu_F) = \frac{\tilde{r}_t(\varepsilon, \nu_F)}{2}$. Hence, $J(\varepsilon, \nu_F) = -(\Omega - \Omega_D) \frac{\tilde{r}_t(\varepsilon, \nu_F)}{2} < 0$, since $\Omega_D > \Omega$. Therefore, the foreign policy rate is strictly positive, for $\nu \geq \bar{\nu}$, even in the range $[\bar{\nu}, \nu_F]$, for which the foreign natural interest rate is strictly negative.

This establishes part b) of the proposition. To show that part a) holds, assume that $r_t = 0$. Then for $\nu \leq \bar{\nu}$,

$$\gamma_1 = \psi_1 + \psi_2 = -\Omega \tilde{r}_t^W(\varepsilon, \nu) - \Omega_D \tilde{r}_t^R(\varepsilon, \nu) > 0,$$

¹⁹We have not shown that $\bar{\nu}$ is unique. However, in extensive simulation over different parameter settings, we did not find any instances of non-uniqueness.

so that $r_t = 0$ is confirmed. For $\bar{v} < v \leq 2$, using (52), we have

$$\begin{aligned}
 \gamma_1 &= \psi_1 + \psi_2 = -\Omega \frac{(\tilde{r}_t(\varepsilon, v) + \tilde{r}_t^*(\varepsilon, v))}{2} - \Omega_D \frac{(\tilde{r}_t(\varepsilon, v) - \tilde{r}_t^*(\varepsilon, v))}{2} \\
 &\quad + (\Omega - \Omega_D) \frac{r_t^*}{2} \\
 &= -(\Omega + \Omega_D) \frac{\tilde{r}_t(\varepsilon, v)}{2} - (\Omega - \Omega_D) \frac{\tilde{r}_t^*(\varepsilon, v)}{2} \\
 &\quad + (\Omega - \Omega_D) \left(\frac{\tilde{r}_t^*(\varepsilon, v)}{2} - \frac{(\Omega_D - \Omega)}{(\Omega_D + \Omega)} \tilde{r}_t(\varepsilon, v) \right) \\
 &= -2 \frac{\Omega \Omega_D}{(\Omega_D + \Omega)} \tilde{r}_t(\varepsilon, v) > 0,
 \end{aligned}$$

where the second line equality follows from use of (52), and the third line follows by cancellation and rearrangement. Hence, $r_t = 0$ is satisfied for $\bar{v} < v \leq 2$.

PROPOSITION 2:

PROOF:

If $\gamma_2 = 0$,

$$\psi_1 = \psi_2 \equiv \psi.$$

Multiply both sides of (48) by D to equalize the right side with the right side of (49):

$$(53) \quad D\Psi_D \hat{n}_t^R = \Psi \hat{n}_t^W.$$

Add (46) and (47) and premultiply by $D\Psi_D$ to get

$$D\Psi_D \Delta_2 \hat{n}_t^W + \Delta_2^D D\Psi_D \hat{n}_t^R = (1 - \beta\mu) D\Psi_D \tilde{r}_t.$$

Insert the optimal monetary condition

$$[D\Psi_D + \Delta_2^D \Psi] \hat{n}_t^W = (1 - \beta\mu) D\Psi_D \tilde{r}_t.$$

So $\hat{n}_t^W < 0$. From (53), we have $\hat{n}_t^R < 0$ so $\hat{n}_t < 0$. From (44) and (42), we have $\pi_t^W < 0$ and $\pi_t^R < 0$, so $\pi_t < 0$. Insert (44) and (42) into (53):

$$\begin{aligned}
 &[(1 - \beta\mu)B + \theta k(\phi + s)^2] \frac{(1 - \beta\mu)}{k(\phi + s)} \pi_t^W \\
 &= D[(1 - \beta\mu)A + \theta k(\phi + s_D)^2] \frac{(1 - \beta\mu)}{k(\phi + s_D)} \pi_t^R.
 \end{aligned}$$

Cancel $\frac{(1 - \beta\mu)}{k}$ and $B = \frac{(\phi + s)}{c_y}$ so the left-hand side is

$$\frac{\left[\frac{(1 - \beta\mu)}{c_y}(\phi + s) + \theta k(\phi + s)^2 \right]}{(\phi + s)} \pi_t^W = \left[\frac{(1 - \beta\mu)}{c_y} + \theta k(\phi + s) \right] \pi_t^W.$$

Multiply both sides by $(\phi + s_D)$:

$$\begin{aligned} & \left[\frac{(1 - \beta\mu)}{c_y}(\phi + s_D) + \theta k(\phi + s)(\phi + s_D) \right] \pi_t^W \\ &= D \left[\frac{(1 - \beta\mu)}{c_y}(\phi + s_{DD}) + \theta k(\phi + s_D)^2 \right] \pi_t^R. \end{aligned}$$

Define

$$\begin{aligned} \Pi_1 &\equiv \left[\frac{(1 - \beta\mu)}{c_y}(\phi + s_D) + \theta k(\phi + s)(\phi + s_D) \right] \\ \Pi_2 &\equiv D \left[\frac{(1 - \beta\mu)}{c_y}(\phi + s_D) + \theta k(\phi + s_D)^2 \right], \end{aligned}$$

so

$$\Pi_1 \pi_t^W = \Pi_2 \pi_t^R.$$

Calculate

$$\begin{aligned} \Pi_2 - \Pi_1 &= \frac{(1 - \beta\mu)}{c_y}(D - 1)\phi + \frac{(1 - \beta\mu)}{c_y}(Ds_{DD} - s_D) \\ &\quad + \theta k(\phi + s_D)[D(\phi + s_D) - (\phi + s)] \\ &= \frac{(1 - \beta\mu)}{c_y}(D - 1)\phi + \frac{(1 - \beta\mu)}{c_y}(Ds_{DD} - s_D) \\ &\quad + \theta k(\phi + s_D)[(D - 1)\phi + (Ds_D - s)] \\ &= \frac{(1 - \beta\mu)}{c_y}(D - 1)\phi + \frac{(1 - \beta\mu)}{c_y}(Ds_{DD} - s_D) \\ &\quad + \theta k(\phi + s_D)[(D - 1)\phi] > 0. \end{aligned}$$

Hence, the fall in inflation of the home country is less than the world average decline. Therefore inflation must also fall in the foreign country.

PROPOSITION 3:

PROOF:

Note that $r_t = 0$. $\frac{r_t^*}{2} = \frac{\tilde{r}_t^*}{2}$, so $r_t^W - \tilde{r}_t^W = r_t^R - \tilde{r}_t^R = \frac{\tilde{r}_t}{2} < 0$. Write (46) and (47):

$$(54) \quad \Delta_2 \hat{n}_t^W = \Delta_2^D \hat{n}_t^R = (1 - \beta\mu) \frac{\tilde{r}_t}{2} < 0.$$

Since $\Delta_2 > \Delta_2^D > 0$, $\hat{n}_t^R < \hat{n}_t^W < 0$. Since the average level of output drops by less than the relative level, $\hat{n}_t < 0$ and $\hat{n}_t^* > 0$. Add both sides of (44) and (42):

$$(55) \quad (1 - \beta\mu)\pi_t = k(\phi + s)\hat{n}_t^W + k(\phi + s_D)\hat{n}_t^R < 0.$$

Since both $\hat{n}_t^R, \hat{n}_t^W < 0$, $\pi_t < 0$. Subtract (42) from (44) and subtract the world Phillips curve:

$$(1 - \beta\mu)\pi_t^* = k(\phi + s)\hat{n}_t^W - k(\phi + s_D)\hat{n}_t^R.$$

Multiply both sides of the equation by $\Delta_2^D \Delta_2$. We can write $\Delta_2^D \Delta_2 \hat{n}_t^W = \Delta_2^D (1 - \beta\mu) \frac{r_t}{2}$ and $\Delta_2^D \Delta_2 \hat{n}_t^R = \Delta_2 (1 - \beta\mu) \frac{r_t}{2}$

$$\begin{aligned} \Delta_2^D \Delta_2 (1 - \beta\mu)\pi_t^* &= k(\phi + s)\Delta_2^D \Delta_2 \hat{n}_t^W - k(\phi + s_D)\Delta_2^D \Delta_2 \hat{n}_t^R \\ &= [\phi(\Delta_2^D - \Delta_2) + (s\Delta_2^D - s_D\Delta_2)] k(1 - \beta\mu) \frac{\tilde{r}_t}{2} \end{aligned}$$

Note $(s\Delta_2^D - s_D\Delta_2) = (s_D - s)\mu\phi k$, so

$$\Delta_3^D \Delta_3 (1 - \beta\mu)\pi_t^* = (1 - \beta\mu)k\phi[(\Delta_2^D - \Delta_2) + (s_D - s)\mu k] \frac{\tilde{r}_t}{2} > 0,$$

since $(\Delta_2^D - \Delta_2) < 0$ and $(s_D - s) < 0$.

PROPOSITION 4:

PROOF:

First, take (28), (30), and (32). Combine these with (14) and (15) to get the relationship between the world average fiscal gap and the interest rate gap as follows:

$$(56) \quad \begin{aligned} [(\Delta_2 HL + \Delta_3 BL) + \phi f(1 - \mu)s] \widehat{cg}_t^W \\ = [f(\phi + s) + (1 - \beta\mu)BL] \left(\frac{r_t^*}{2} - \tilde{r}_t^W \right), \end{aligned}$$

where $\Delta_3 = \Delta_2 + k\phi > 0$, $HL \equiv H + L > 0$, $BL \equiv B + L > 0$ and $f \equiv \phi\theta k > 0$. Since $r_t^* \geq 0$, from this, it is clear that when the world average natural rate falls below zero, the world average fiscal gap must increase. When at least one of the policy rates is constrained by the zero lower bound, the world output gap is negative,

and inflation is negative. Then fiscal spending, by creating anticipated inflation, can reduce real interest rates, stimulate private demand, and reduce the current world output gap. We may use a similar procedure to compute the relationship between the relative fiscal gap and the relative interest rate gap. This gives us the condition

$$(57) \quad [\Delta_2^D FJ + \Delta_3^D JA + f\phi s_D(1 - \mu)] \widehat{c}g_t^R \\ = -[f(\phi + s_D) + (1 - \beta\mu)JA] \left(\frac{r_t^*}{2} + \tilde{r}_t^R \right),$$

where $\Delta_3^D = \Delta_2^D + k\phi > 0$, $FJ \equiv F + J > 0$, and $JA \equiv J + A > 0$. With the condition that $\Gamma_D \geq \Gamma$, this ensures that $r_t^* - \tilde{r}_t^* \leq \tilde{r}_t$. Hence, the *relative* fiscal gap is always nonnegative. It follows then that the home country fiscal gap will always be positive.

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