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ABSTRACT

The effects of foreign shocks when interest rates are at zero*

In a two-country DSGE model, the effects of foreign demand shocks on the home country are greatly amplified if the home economy is constrained by the zero lower bound for policy interest rates. This result applies even to countries that are relatively closed to trade such as the United States. Departing from many of the existing closed-economy models, the duration of the liquidity trap is determined endogenously. Adverse foreign shocks can extend the duration of the trap, implying more contractionary effects for the home country; conversely, large positive shocks can prompt an early exit, implying effects that are closer to those when the zero bound constraint is not binding.

JEL Classification: F32 and F41

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1 Introduction

For large and relatively closed economies such as the United States and the euro area, foreign shocks are often perceived as having small effects on domestic output. Thus, researchers, policymakers, and forecasters frequently abstract from the open economy dimension in analyzing business cycle fluctuations in large economies.¹

The literature that uses open economy DSGE models to analyze the transmission of shocks across countries appears to corroborate this view. Drawing on the two country real business cycle model of Backus, Kehoe, and Kydland (1992), Baxter and Crucini (1995) show that a positive country-specific productivity shock in the foreign sector induces a small *contraction* in domestic output. Thus, accounting for positive comovement in output across countries requires substantial correlation in the underlying shocks. More recent analysis that incorporates nominal price rigidities and a wider set of shocks, including work by Lubik and Schorfheide (2005) and Adolfson, Laséen, Lindé, and Villani (2007), also finds that country-specific shocks abroad tend to have very small effects on home output.²

Although these results support the view that foreign shocks have a small impact on large economies, a key qualification is that they are derived under the assumption that monetary policy has complete latitude to offset shocks by adjusting policy rates. A wide group of economies – including the United States, the euro area, and Japan – have been constrained from reducing policy rates for some time. In our analysis, the effects of foreign shocks on domestic output are greatly amplified by a prolonged liquidity trap, even for relatively closed economies.

We analyze the spillover effects of country-specific foreign shocks in a two country

¹ In support of this perspective, the correlation between U.S. growth and that of its major trading partners is low and has shown little tendency to rise even as trade ties have grown, as documented by Doyle and Faust (2005).

² Alternatively, a large literature has used dynamic factor analysis to decompose output variation into country-specific and global factors, e.g., Kose, Otrok, and Whiteman (2003) and Stock and Watson (2005). However, the global factors reflect both the effects of shocks that are correlated across countries (such as oil shocks), as well as the spillover effects of country-specific shocks.

DSGE model that imposes the zero bound constraint on policy rates. The model incorporates empirically-relevant features such as sticky prices and wages, and habit persistence in consumption.³

Following Eggertsson and Woodford (2003), the closed-economy literature on the zero lower bound has primarily modeled the liquidity trap through an unexpected negative shock to the natural rate of interest that reverts back to its steady state value with a fixed probability in every period.⁴ We break from this approach by assuming that all shocks follow autoregressive processes, as typically used in the empirical validation of DSGE models, including Smets and Wouters (2003) and Christiano, Eichenbaum, and Evans (2005). This approach can trace how the size of shocks and the associated magnitude of the international spillovers interact with the duration of the liquidity trap.⁵

In our analysis, in response to a persistent domestic shock that depresses home economic activity, the short-term nominal interest rate is lowered to zero and is (endogenously) expected to remain at zero for T periods. The international spillover effects of all foreign shocks that occur in addition to the domestic shock are amplified relative to the case in which the home nominal interest rate can be adjusted. However, the size of this amplification depends crucially on the expected duration of the liquidity trap T and the size of the foreign shock. When a foreign shock is too small to change the expected duration of the liquidity trap, the amplification of the spillover depends only on T , and not on the size of the foreign shock or the specifics of the domestic shock responsible for the liquidity trap. Such shocks measure the

³ See Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003).

⁴ The analysis in Eggertsson (2010), Woodford (2010), and Christiano, Eichenbaum, and Rebelo (2009) employs this approach. Notable exceptions are Adam and Billi (2006), Nakov (2008), and Bodenstein, Hebden, and Nunes (2010) who analyze stochastic economies imposing the zero lower bound as an occasionally binding constraint in an otherwise linear model small in scale.

⁵ In the simplest example used in this literature, see for example Christiano, Eichenbaum, and Rebelo (2009), a shock to government spending may either be impotent to affect the expected duration of the liquidity trap or remove the liquidity trap completely. This stark discontinuity stems primarily from modeling the trap as arising from an unexpected negative shock to the natural rate of interest that reverts back to its steady state value with a fixed probability in every period.

marginal spillover effects in our framework.⁶

In contrast, when a foreign shock is large enough to change the duration of the liquidity trap, this change influences the magnification of the spillover effects to the home country. As large negative foreign shocks extend the duration of the liquidity trap beyond T , the measured spillover is an average over increasingly contractionary marginal effects. This averaging is also at play for large positive foreign shocks that prompt an exit from the liquidity trap earlier than T . In that case, the measured spillover is still larger than in normal times, but smaller than for shocks that do not shorten the duration of the liquidity trap. Thus, fixing the length of the liquidity trap exogenously would miss these important non-linearities in the measured spillovers.

Much of the closed economy literature has focused on the marginal effects of changes in government spending by considering shocks that do not affect the duration of the liquidity trap. We show that the amplification of shocks in a liquidity trap applies more broadly than to domestic fiscal shocks and extends to shocks originating abroad. Moreover, we offer a systematic and quantitative exploration of the amplification of a variety of foreign shocks at the zero lower bound, including shocks that affect the duration of the liquidity trap, clearly distinguishing between the marginal and average effects of the shocks.

The two countries in our model are the United States and an aggregate of its trading partners. A foreign demand shock that reduces foreign output by 1 percent induces U.S. GDP to fall only around 0.3 percent in normal circumstances in which U.S. short-term interest rates decline as prescribed by a standard linear Taylor rule. The same foreign shock causes U.S. output to fall 0.7 percent when the expected duration of the U.S. liquidity trap T is equal to 10 quarters.

⁶ Following the literature, our model is linearized with the exception of the zero bound constraint; see for instance Eggertsson and Woodford (2003), Jung, Teranishi, and Watanabe (2005), Christiano, Eichenbaum, and Rebelo (2009), Eggertsson (2010), or Woodford (2010). Even contributions that use global methods, such as that of Adam and Billi (2006), start from a linearized model. We show analytically that a piece-wise linear approach implies that the effects of shocks that do not influence T are linear in the size of the shock.

The foreign shock has a similar contractionary effect on U.S. exports irrespective of whether U.S. monetary policy is constrained: exports fall in response to lower foreign absorption, and because lower foreign policy rates cause the home real exchange rate to appreciate. With policy rates unconstrained, the impact on home output is cushioned by a robust expansion of private domestic demand, as monetary policy responds immediately to lower demand and inflation, and real rates fall at all maturities. By contrast, because U.S. policy rates remain frozen for some time in a liquidity trap, the fall in expected inflation pushes up short-term real interest rates, implying a much smaller expansion in domestic demand than in the unconstrained case. If the liquidity trap is sufficiently prolonged, private demand can even fall.

Sensitivity analysis includes the conduct of domestic and foreign monetary policy, the trade price elasticities, and the nature of the shocks affecting the foreign economy. Our result that the effects of foreign shocks are greatly magnified in a liquidity trap does not hinge on our particular specification of the rule that home monetary policy follows after exiting the liquidity trap. If foreign GDP contracts 1 percent, the spillover effect to U.S. GDP remains in the range of 0.7 even under the assumption that monetary policy reacts very aggressively to inflation and/or the output gap.

When the zero bound is not binding, increasing the trade price elasticity of demand magnifies the decline of home real net exports caused by a foreign demand contraction. However, the spillover effects on home output are partly offset by a more vigorous reaction of domestic monetary policy. By contrast, in a liquidity trap, monetary policy is unable to compensate in such a manner, and the larger effects on real net exports translate into much greater effects on home output.

The magnitude of the spillover effects in our benchmark case depend on the nature of the foreign shocks. Foreign demand shocks exert larger effects on domestic exports and imports than foreign supply shocks, because their impact on the real

exchange rate and foreign activity reinforce each other.⁷ For example, a negative taste shock abroad reduces foreign absorption, and causes the domestic exchange rate to appreciate. By contrast, near unit-root technology shocks, the typical source of fluctuations in open economy models, have comparatively small effects on domestic real net exports because they affect foreign activity and the real exchange rate in an offsetting manner.⁸ Thus, foreign demand shocks have larger effects on domestic output than foreign supply shocks even under normal conditions in which policy can react, but the disparity becomes much greater in a liquidity trap.

It might be expected that the spillover effects of foreign shocks would be further magnified if the foreign sector were also in a liquidity trap. However, our analysis shows that the effects of a given structural shock abroad are similar, irrespective of whether the foreign economy is in a liquidity trap or not. For example, although an adverse foreign demand shock causes foreign absorption to fall more when the foreign economy is in a liquidity trap, it also reduces the appreciation of the home real exchange rate since foreign long-term real interest rates fall by less. Analogously, the transmission of domestic shocks is hardly affected by whether the foreign economy is in a liquidity trap.

In related work, Reifschneider and Williams (2000) argue that there is a significant increase in the volatility of output in a liquidity trap, but their methodology does not allow them to link this higher volatility to structural shocks. McCallum (2000), Orphanides and Wieland (2000), Svensson (2004), and Jeanne and Svensson (2007) show how to use an exchange rate depreciation to facilitate the escape from a liquidity trap. Coenen and Wieland (2003) investigate the quantitative effects of such exchange rate based policies in a model that is partly optimization-based. None of these papers explores the spillover effects of foreign shocks and their dependence

⁷ Stockman and Tesar (1995) extend the model of Backus, Kehoe, and Kydland (1992) to include consumption preference shocks. They argue that such shocks can more closely align the model's predictions on the comovement of prices and quantities with the data for the United States.

⁸ As highlighted by Cole and Obstfeld (1991), exchange rate fluctuations provide insurance against country-specific technology shocks.

on different model parameters.

2 The Model

Apart from the explicit treatment of the zero-lower bound on policy rates, our two-country model is close to Erceg, Guerrieri, and Gust (2006) and Erceg, Guerrieri, and Gust (2008) who themselves build on Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003). We focus on describing the home country as the setup for the foreign country is analogous. The calibration for the home country reflects key features of the United States.

2.1 Firms and Price Setting

Production of Domestic Intermediate Goods. There is a continuum of differentiated intermediate goods (indexed by $i \in [0, 1]$) in the home country, each of which is produced by a single monopolistically competitive firm. Firms charge different prices at home and abroad, i.e., they practice pricing to market. In the home market, firm i faces a demand function that varies inversely with its output price $P_{Dt}(i)$ and directly with aggregate demand at home Y_{Dt} :

$$Y_{Dt}(i) = \left[\frac{P_{Dt}(i)}{P_{Dt}} \right]^{\frac{-(1+\theta_p)}{\theta_p}} Y_{Dt}, \quad (1)$$

where $\theta_p > 0$, and P_{Dt} is an aggregate price index defined below. Similarly, in the foreign market, firm i faces the demand function:

$$X_t(i) = \left[\frac{P_{Mt}^*(i)}{P_{Mt}^*} \right]^{\frac{-(1+\theta_p)}{\theta_p}} M_t^*, \quad (2)$$

where $X_t(i)$ denotes the foreign quantity demanded of home good i , $P_{Mt}^*(i)$ denotes the price, denominated in foreign currency, that firm i sets in the foreign market, P_{Mt}^* is the foreign import price index, and M_t^* is aggregate foreign imports.

Each producer utilizes capital services $K_t(i)$ and a labor index $L_t(i)$ (defined below) to produce its respective output good. The production function has a constant-elasticity of substitution form:

$$Y_t(i) = \left(\omega_K^{\frac{\rho}{1+\rho}} K_t(i)^{\frac{1}{1+\rho}} + \omega_L^{\frac{\rho}{1+\rho}} (z_t L_t(i))^{\frac{1}{1+\rho}} \right)^{1+\rho}, \quad (3)$$

where z_t is a country-specific shock to the level of technology. Firms face perfectly competitive factor markets for hiring capital and labor.

The prices of intermediate goods are determined by Calvo-style staggered contracts, see Calvo (1983). Each period, a firm faces a constant probability, $1 - \xi_p$, to reoptimize its price at home $P_{Dt}(i)$ and probability of $1 - \xi_{px}$ to reoptimize the price that it sets in the foreign country of $P_{Mt}^*(i)$. These probabilities are independent across firms, time, and countries.

Production of the Domestic Output Index. A representative aggregator combines the differentiated intermediate products into a composite home-produced good Y_{Dt} according to

$$Y_{Dt} = \left[\int_0^1 Y_{Dt}(i)^{\frac{1}{1+\theta_p}} di \right]^{1+\theta_p}. \quad (4)$$

The optimal bundle of goods minimizes the cost of producing Y_{Dt} taking the price of each intermediate good as given. A unit of the sectoral output index sells at the price P_{Dt} :

$$P_{Dt} = \left[\int_0^1 P_{Dt}(i)^{\frac{-1}{\theta_p}} di \right]^{-\theta_p}. \quad (5)$$

Similarly, a representative aggregator in the foreign economy combines the differentiated home products $X_t(i)$ into a single index for foreign imports:

$$M_t^* = \left[\int_0^1 X_t(i)^{\frac{1}{1+\theta_p}} di \right]^{1+\theta_p}, \quad (6)$$

and sells M_t^* at price P_{Mt}^* :

$$P_{Mt}^* = \left[\int_0^1 P_{Mt}^*(i)^{\frac{-1}{\theta_p}} di \right]^{-\theta_p}. \quad (7)$$

Production of Consumption and Investment Goods. Assuming equal import content of consumption and investment, there is effectively one final good A_t that is used for consumption or investment, (i.e., $A_t \equiv C_t + I_t$, allowing us to interpret A_t as private absorption). Domestically-produced goods and imported goods are combined to produce final goods A_t according to

$$A_t = \left(\omega_A^{\frac{\rho_A}{1+\rho_A}} A_{Dt}^{\frac{1}{1+\rho_A}} + (1 - \omega_A)^{\frac{\rho_A}{1+\rho_A}} M_t^{\frac{1}{1+\rho_A}} \right)^{1+\rho_A}, \quad (8)$$

where A_{Dt} denotes the distributor's demand for the domestically-produced good and M_t denotes the distributor's demand for imports. The quasi-share parameter ω_A determines the degree of home bias in private absorption, and ρ_A determines the elasticity of substitution between home and foreign goods. Each representative distributor chooses a plan for A_{Dt} and M_t to minimize its costs of producing the final good A_t and sells A_t to households at a price P_t . Accordingly, the prices of consumption and investment are equalized.

2.2 Households and Wage Setting

A continuum of monopolistically competitive households (indexed on the unit interval) supplies a differentiated labor service to the intermediate goods-producing sector. A representative labor aggregator combines the households' labor hours in the same proportions as firms would choose. This labor index L_t has the Dixit-Stiglitz form:

$$L_t = \left[\int_0^1 N_t(h)^{\frac{1}{1+\theta_w}} dh \right]^{1+\theta_w}, \quad (9)$$

where $\theta_w > 0$ and $N_t(h)$ is hours worked by a typical member of household h . The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking each household's wage rate $W_t(h)$ as given. One unit of the labor index sells at the unit cost W_t :

$$W_t = \left[\int_0^1 W_t(h)^{\frac{-1}{\theta_w}} dh \right]^{-\theta_w}. \quad (10)$$

W_t is referred to as the aggregate wage index. The aggregator's demand for the labor services of household h satisfies

$$N_t(h) = \left[\frac{W_t(h)}{W_t} \right]^{-\frac{1+\theta_w}{\theta_w}} L_t. \quad (11)$$

The utility functional of a representative household h is:

$$\begin{aligned} \tilde{\mathbb{E}}_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1}{1-\sigma} \left(C_{t+j}(h) - \varkappa \frac{C_{t+j-1}}{\zeta} - \nu_{ct} \right)^{1-\sigma} \right. \\ \left. + \frac{\chi_0}{1-\chi} (1 - N_{t+j}(h))^{1-\chi} + V \left(\frac{MB_{t+j+1}(h)}{P_{t+j}} \right) \right\}, \end{aligned} \quad (12)$$

where the discount factor β satisfies $0 < \beta < 1$. As in Smets and Wouters (2003), we allow for the possibility of external habits. At date t household h cares about consumption relative to lagged per capita consumption, C_{t-1} . The preference shock ν_{ct} follows an exogenous first order process with a persistence parameter of ρ_ν . The parameter ζ controls for population size. The household's period utility function depends on current leisure $1 - N_t(h)$, the end-of-period real money balances, $\frac{MB_{t+1}(h)}{P_t}$. The liquidity-service function $V(\cdot)$ is increasing in real money balances at a decreasing rate up to a satiation level. Beyond the satiation level, utility from liquidity services is constant. With this specification of the utility function, the demand for real money balances is always positive regardless of the level of the nominal interest rate.⁹

The budget constraint of each household is given by:

$$\begin{aligned} P_t C_t(h) + P_t I_t(h) + MB_{t+1}(h) - MB_t(h) + \frac{e_t P_{Bt}^* B_{Ft+1}(h)}{\phi_{bt}} - e_t B_{Ft}(h) \\ = W_t(h) N_t(h) + \Gamma_t(h) - T_t(h) + R_{Kt}(1 - \tau_{Kt}) K_t(h) - P_{Dt} \phi_{It}(h). \end{aligned} \quad (13)$$

Final consumption and investment goods are purchased at a price P_t . Investment in physical capital augments the per capita capital stock $K_{t+1}(h)$ according to a linear

⁹ More formally, we follow Jeanne and Svensson (2007) in assuming that $V(MB_{t+1}/P_t) < V_0$, $V'(MB_{t+1}/P_t) > 0$, $V''(MB_{t+1}/P_t) < 0$ for $MB_{t+1} < \bar{m}$, the satiation level of real money. And $V(MB_{t+1}/P_t) = V_0$ for $MB_{t+1} \geq \bar{m}$, and $V'(MB_{t+1}/P_t) \rightarrow \infty$ for $MB_{t+1}/P_t \rightarrow 0$.

transition law of the form:

$$K_{t+1}(h) = (1 - \delta)K_t(h) + I_t(h), \quad (14)$$

where δ is the depreciation rate of capital. The term $R_{Kt}(1 - \tau_{Kt})K_t(h)$ in the budget constraint represents the proceeds to the household from renting capital to firms net of capital taxes.

Financial asset accumulation consists of increases in nominal money holdings $MB_{t+1}(h) - MB_t(h)$ and the net acquisition of international bonds. Trade in international assets is restricted to a non-state contingent nominal bond. $B_{Ft+1}(h)$ represents the quantity of the international bond purchased by household h at time t that pays one unit of foreign currency in the subsequent period. P_{Bt}^* is the foreign currency price of the bond, and e_t is the nominal exchange rate expressed in units of home currency per unit of foreign currency. Following Turnovsky (1985) households pay an intermediation fee ϕ_{bt} .¹⁰ The intermediation fee depends on the ratio of economy-wide holdings of net foreign assets to nominal output according to:

$$\phi_{bt} = \exp\left(-\phi_b \left(\frac{e_t B_{Ft+1}}{P_{Dt} Y_t}\right)\right). \quad (15)$$

If the home economy has an overall net lender position, a household will earn a lower return on any holdings of foreign bonds. By contrast, if the economy has a net debtor position, a household will pay a higher return on any foreign debt.

Households earn labor income, $W_t(h) N_t(h)$, lease capital to firms at the rental rate R_{Kt} , and receive an aliquot share $\Gamma_t(h)$ of the profits of all firms. Furthermore, they pay a lump-sum tax $T_t(h)$. We follow Christiano, Eichenbaum, and Evans (2005) in assuming that households bear a cost of changing the level of gross investment from the previous period, so that the acceleration in the capital stock is

¹⁰ The assumption of an intermediation fee ensures that given our solution technique the evolution of net foreign assets is stationary. See Schmitt-Grohe and Uribe (2003) and Bodenstein (2009) for a discussion. The intermediation cost is asymmetric, as foreign households do not face these costs. Rather, they collect profits on the monopoly rents associated with these intermediation costs.

penalized:

$$\phi_{It}(h) = \frac{1}{2}\phi_I \frac{(I_t(h) - I_{t-1}(h))^2}{I_{t-1}(h)}. \quad (16)$$

Households maximizes the utility functional (12) with respect to consumption, investment, (end-of-period) capital stock, money balances, and holdings of foreign bonds, subject to the labor demand function (11), budget constraint (13), and transition equation for capital (14). They also set nominal wages in staggered contracts that are analogous to the price contracts described above. In particular, each member of a household is allowed to re-optimize its wage contract with probability $1 - \xi_w$.

2.3 Monetary and Fiscal Policy

Monetary policy follows an interest rate reaction function as suggested by Taylor (1993). However, when policy rates reach zero, we assume that no further actions are taken by the central bank. The notional rate that is dictated by the interest rate reaction function is denoted by i_t^{not} , whereas the actual policy rate that is implemented is denoted by i_t . The two differ only if the notional rate turns negative:

$$i_t^{not} = \bar{i} + \gamma_i(i_{t-1}^{not} - \bar{i}) + (1 - \gamma_i)(\pi_t + \gamma_\pi(\pi_t - \bar{\pi}) + \frac{\gamma_y}{4}y_t^{gap}), \quad (17)$$

and the actual (short-term) policy interest rate satisfies

$$i_t = \max(0, i_t^{not}). \quad (18)$$

The terms \bar{i} and $\bar{\pi}$ are the steady-state values for the nominal interest rate and inflation, respectively. The inflation rate π_t is expressed as the logarithmic percentage change of the domestic price level, $\pi_t = \log(P_{Dt}/P_{Dt-1})$. The term y_t^{gap} denotes the output gap, given by the log difference between actual and potential output, where the latter is the level of output that would prevail in the absence of nominal rigidities. Notice that the coefficient γ_y is divided by four as the rule is

expressed in terms of quarterly inflation and interest rates. The parameter γ_i allows for interest rate smoothing.¹¹

Government purchases are a constant fraction of output \bar{g} and they fall exclusively on the domestically-produced good. These purchases make no direct contribution to household utility. To finance its purchases, the government imposes a lump-sum tax on households that is adjusted so that the government's budget is balanced every period.

2.4 Resource Constraints

The home economy's aggregate resource constraint satisfies:

$$Y_{Dt} = C_{Dt} + I_{Dt} + G_t + \phi_{It}. \quad (19)$$

The composite domestically-produced good Y_{Dt} , net of investment adjustment costs ϕ_{It} , is used to produce final consumption and investment goods ($A_{Dt} = C_{Dt} + I_{Dt}$), or directly to satisfy government demand. Moreover, since each individual intermediate goods producer can sell its output either at home or abroad, there are also a continuum of resource constraints that apply at the firm level.

2.5 Calibration of Parameters

The model is calibrated at a quarterly frequency. The values of key parameters are presented in Table 1 and reflect fairly standard calibration choices for the U.S. economy. We choose $\omega_A = 0.15$ to be consistent with an import share of output of 15%. The domestic and foreign population levels, respectively ζ and ζ^* , are set so that the home country constitutes 25 percent of world output. Balanced trade in steady state implies an import (or export) share of output of the foreign country

¹¹ Jung, Teranishi, and Watanabe (2005), Eggertsson and Woodford (2003), Adam and Billi (2006), and Adam and Billi (2007) derive the optimal policy under the zero bound constraint in a closed economy. In the face of contractionary shocks, optimal monetary policy calls for keeping interest rates lower for an extended period in a liquidity trap relative to normal times. This feature is captured by interest rate smoothing in our model.

of 5 percent. Because the foreign country is assumed to be identical to the home country except in its size, $\omega_A^* = 0.05$. We set $\rho_A = 10$, so that the price elasticity of import demand is 1.1.

Nominal rigidities in prices and wages have an average duration of four quarters, determined by the parameters $\xi_p = 0.75$ and $\xi_w = 0.75$. Export price rigidities have a shorter duration of 2 quarters, as implied by the parameter $\xi_{px} = 0.5$. As noted above, monetary policy follows the Taylor rule, aside from allowing for interest rate smoothing and taking account of the zero lower bound constraint. Thus, the parameter γ_π on the inflation gap is 0.5 and the parameter γ_y on the output gap is also 0.5; we set the smoothing parameter γ_i to 0.7. The steady state real interest rate is set to 2% per year ($\beta = 0.995$). Given steady state inflation $\bar{\pi}$ equal to zero, the implied steady state nominal interest rate is two percent. The values of remaining parameters are also fairly standard in the literature, and are summarized in Table 1.

3 Solution Method

Following Jung, Teranishi, and Watanabe (2005), Eggertsson and Woodford (2003), and Adam and Billi (2006), all equilibrium conditions except the non-linear policy rule are linearized around the model's non-stochastic steady state. We solve the model using a shooting algorithm described in Juillard (1996).¹² Following Anderson (1999), instead of using the steady state values as end point for the shooting algorithm, we use a mid-way point from the linear solution computed from standard algorithms. As shown by Anderson (1999), this alternative procedure leads to a shorter length of the simulation horizon needed to achieve any desired level of accuracy for those values that are at the beginning of the simulation. The end point implies that the economy will eventually exit from the liquidity trap.

¹² The algorithm we employ builds on Fair and Taylor (1983) by stacking all equations through time, which is equivalent to collapsing the Type I and II iterations in the Fair-Taylor algorithm into one step.

The solution from our algorithm is numerically equivalent to that obtained following the method described by Eggertsson and Woodford (2003) and Jung, Teranishi, and Watanabe (2005) adapted to our model environment with autoregressive shock processes. The solution proposed by these authors recognizes that the model is piecewise-linear. All model equations are linear when the zero bound constraint binds, and they are also linear, albeit modified, when the zero bound constraint does not bind. However, the time period for which the economy is at the zero bound is a non-linear function of the exogenous disturbances.

Relative to Eggertsson and Woodford (2003) and Jung, Teranishi, and Watanabe (2005), our method deals easily with shocks whose effects build up over time and only eventually lead to zero short-term interest rates. Moreover, our algorithm extends naturally to deal with the case when multiple countries are constrained by the zero lower bound on nominal interest rates.

4 Initial Baseline Path

Our principal goal is to compare the impact of foreign shocks on the home country when it faces a liquidity trap with the effects that occur when policy rates can be freely adjusted. In the former case, the impact of a foreign shock depends on the economic conditions that precipitated the liquidity trap. Intuitively, the effects of an adverse foreign shock against the backdrop of a recession-induced liquidity trap in the home country should depend on the expected severity of the recession, and the perceived duration of the liquidity trap. In a shallow recession in which interest rates are only constrained for a short period, the effects of the foreign shock would not differ substantially from the usual case in which rates could be cut immediately.¹³ By contrast, the effects of the foreign shock on the home country might be amplified substantially if it occurred against the backdrop of a steep recession in which policy

¹³ In the case of a linear model, the effects of a shock are unrelated to the initial conditions.

rates were expected to be constrained from falling for a protracted period.

We use the term “initial baseline path” to describe the evolution of the economy that would prevail in the absence of the foreign shock. Given agents’ full knowledge of the model, the initial baseline path depends on the underlying shocks that push the economy into a liquidity trap, including their magnitude and persistence, as these features play an important role in determining agents’ perceptions about the duration of the liquidity trap.

Our analysis focuses on the effects of foreign shocks against the backdrop of an initial baseline path that is intended to capture a severe recession in the home country. This “severe recession” baseline is depicted in Figure 1 by the solid lines. It is generated by a preference shock ν_{ct} that follows an autoregressive process with persistence parameter equal to 0.75. The shock reduces the home country’s marginal utility of consumption. As the shock occurs exclusively in the home country, the foreign economy has latitude to offset much of the contractionary impact of the shock by reducing its policy rate.¹⁴

As shown in Figure 1 policy rates immediately fall to 0 (2 percentage points below their steady state value at annualized rates) and remain frozen at this level for ten quarters.¹⁵ Given that the shock drives inflation persistently below its steady state value and that nominal interest rates are constrained from falling by the zero bound, real rates increase substantially in the near term. This increase in real interest rates accounts in part for the substantial output decline, which peaks in magnitude at about 9 percent below its steady state value. Real interest rates decline in the longer term, helping the economy recover. This longer term decline also causes the home currency to depreciate in real terms, and the ensuing expansion of real net exports mitigates the effects of the shock on domestic output. However, the improvement in real net exports is delayed due to the zero bound constraint, since

¹⁴ We investigate the sensitivity of our results to the initial baseline path in Section 5.1.

¹⁵ In Figure 1, real variables are plotted in deviation from their steady-state values, while nominal variables are in *levels* to highlight the zero bound constraint. The policy rate, real interest rate, and inflation are annualized.

higher real interest rates limit the size of the depreciation of the home currency in the near-term.

For purposes of comparison, the Figure 1 also shows the effects of the same shocks in the case in which the home country's policy rates can be adjusted, i.e., ignoring the zero bound constraint. In this linear simulation, the home nominal interest rate falls more sharply, turns negative, and induces a decline in real interest rates in the short term. Hence, the fall in home output is smaller than in the benchmark framework in which the zero bound constraint is binding. The home output contraction is also mitigated by a more substantial improvement in real net exports. Given that real interest rates fall very quickly, the real depreciation is considerably larger and more front-loaded, contributing to a more rapid improvement in real net exports.

To simplify an already complex model, the baseline calibration abstracts from lagged inflation indexation in price and wage setting, as well as from additional real rigidities as modeled for instance in Guerrieri, Gust, and Lòpez-Salido (2010). Consequently, inflation shows little persistence in our baseline simulation and leads to an outside drop in the output gap. As shown in Appendix B the addition of features that increases the persistence of inflation reduces the initial response of inflation and narrows the output gap response. However, as the inflation response becomes more persistent, the real interest rate responds less on impact but remains elevated relative to the case shown in Figure 1 as time progresses, implying little change in the substance of the results from the more realistic model.

5 International Transmission at the Zero Bound

We turn to assessing the impact of a negative foreign consumption preference shock ν_{ct}^* when the home country faces a liquidity trap. The foreign shock is scaled to induce a 1 percent reduction in foreign output relative to the initial baseline when it occurs against the backdrop of the severe recession scenario in Figure 1. The size

of the foreign shock is small enough that the duration of the liquidity trap in the home country remains at ten quarters.

Figure 2 shows the effects of the foreign shock abroad, while Figure 3 reports the effects on the home country. The solid lines show the responses when the zero bound constraint is imposed on home policy rates, while the dashed lines report the responses to the same shock when the zero lower bound is ignored. To be specific, the responses in Figures 2 and 3 are derived from a simulation that adds both the adverse domestic taste shock from Figure 1 and the foreign taste shock, and then subtracts the impulse response functions associated with the domestic taste shock alone.¹⁶ Thus, all variables are measured as deviations from the baseline path shown in Figure 1.

As shown in Figure 2 the preference shock leads to a contraction in foreign output. Foreign policy rates are cut. As real rates also drop, investment is stimulated. Lower real rates contribute to a real exchange rate depreciation that boosts foreign exports. Perhaps surprisingly, whether the home country is at the zero lower bound or not has minimal implications for the foreign responses. This reflects that there are offsetting effects on the exports of the foreign country that arise from the responses of home activity and relative prices, as more fully discussed below.

By contrast, the effects of the foreign demand shock on the home country, shown in Figure 3, are strikingly different whether the zero lower bound is imposed or not. Although the foreign shock has nearly the same effect on foreign output across the two cases, the effects on home output are more than twice as large when the zero bound constraint is imposed. In either case home real net exports contract because foreign absorption falls and the home real exchange rate appreciates. However, in a liquidity trap, the decline in home export demand causes a fall in the marginal cost of production and inflation that is not accompanied by lower policy rates.

¹⁶ Because the model we solve is linear when the zero lower bound does not bind, the dashed lines in Figures 2 and 3 can also be interpreted as the responses starting from the model's steady state, rather than the severe recession.

The zero bound constraint keeps nominal rates from declining for ten quarters. Real rates rise sharply in the short run, even though they fall at longer horizons. Consequently, domestic absorption does not expand as much as when policy rates can be cut immediately. If the initial recession were more pronounced, private absorption could even fall, as shown below. With net exports falling and with domestic absorption not filling the gap, output falls by nearly as much in the home country as abroad. Appendix B shows that the magnification of the spillover effects of foreign shocks when the home economy is at the zero lower bound is not particular to the consumption shock but also to shocks to the discount factor, capital tax rates (investment), and government spending. The case of technology shocks is discussed later in this section.

5.1 Alternative Initial Conditions and Monetary Policy

The analysis so far has been based on one particular choice of the size of the underlying baseline shock and the size of the additional foreign shock. Sensitivity to these values and to alternative monetary policy rules is examined below.

Alternative Initial Baseline Paths

In Figure 4, we change the assumptions concerning the initial domestic recession by increasing its persistence. The underlying initial domestic preference shock ν_{ct} is now assumed to follow an autoregressive process of order one with persistence parameter equal to 0.9 instead of 0.75. With this prolonged recession, the liquidity trap is initially expected to last 16 quarters, instead of the 10 quarters considered previously. The figure compares the effects of the same additional foreign consumption shock with the liquidity trap lasting 10 quarters and with the trap lasting 16 quarters. When the duration of the liquidity trap is extended, the rise in short-term real interest rate at home is so large as to generate a initial drop in absorption, thus widening the fall in home output. The analysis that follows traces more systematically how the duration of the liquidity trap affects the spillover of foreign

shocks.

In Figure 5, we consider the impact of the same foreign consumption shock ν_{ct}^* under different initial baseline paths and policy rules. For each baseline path, we choose the size of the domestic shock to ensure that the zero lower bound will bind for the number of quarters in the figure’s abscissae. We calculate the spillover effects of the foreign shock ν_{ct}^* as the ratio of the shock’s effects on home GDP (expressed in deviation from the baseline path) to the effects on foreign GDP (also expressed in deviation from the baseline path). The figure’s ordinates show an average of these spillover effects for the first four quarters.

Focusing first on the results for the benchmark Taylor rule, the same rule used for Figures 1 to 3, the spillover effects become larger as the number of periods spent at the zero lower bound increases. Intuitively, the longer the policy rates are constrained from adjusting, the higher is the increase in the home real interest rates stemming from the contractionary foreign demand shock. As real interest rates rise more, they progressively hinder domestic absorption from cushioning the contraction in home GDP that is caused by the fall in net exports. When policy rates in the home economy are expected to be constrained for longer than two years, the spillover effects from a small foreign consumption shock more than double relative to the unconstrained case.

The figure also shows the same measure of spillover effects under alternative interest rate rules. Both rules leave the basic form of reaction function described in Equation (17) unchanged. However, the rule that is labeled “more aggressive on inflation” doubles the elasticity with respect to inflation γ_π from 1.5 to 3, while the rule that is labeled “more aggressive on output gap” uses an elasticity with respect to the output gap γ_y equal to 4 instead of 0.5. When the baseline conditions lead to a higher number of periods spent at the zero lower bound, both alternative rules imply a substantial increase in the spillover effects of the foreign consumption shock, confirming that our results do not hinge on the specific weights in the policy rule.

Alternative Foreign Consumption Shocks

The spillover effects shown in Figure 5 abstract from non-linear dynamics that are associated with changes in the number of periods for which the zero lower bound is expected to bind. As long as the foreign consumption shock does not affect the duration of the liquidity trap, the effects of the shock are linear in the size of its innovation. However, there is a size of the innovation above which the duration of the liquidity trap is extended, thus decoupling the marginal and average effects of shocks. Furthermore, the duration of the liquidity trap is a nonlinear function of the size of the innovations. Appendix A offers an analytical proof of the results summarized above.

These properties are illustrated in Figure 6 using the same baseline path as in Figure 1. Figure 6 shows the effects of progressively larger foreign shocks on the duration of the liquidity trap (upper panel), as well as the spillover effect to the home country. The magnitude of the foreign shock is measured by the change in foreign GDP relative to the baseline path (on average over the first four quarters).

We first consider the case of the benchmark Taylor rule (the solid lines). If the foreign shock is sufficiently small, the number of periods at the zero lower bound does not change relative to the initial baseline and remains at 10 quarters, as reported in the upper panel. Then, the spillover effect shown in the lower panel of Figure 6 is roughly $3/4$, the same magnitude as in Figure 5 when the trap lasts 10 quarters. The spillover effects are linear in the size of the shock and remain $3/4$ as long as the additional shock does not vary the duration of the liquidity trap. Hence, within the range over which the line depicting the domestic spillover is flat, the marginal and average effects of the foreign shock coincide.

Once the magnitude of the foreign shocks is sufficiently large, the shocks can affect the duration of the liquidity trap, as shown in the top panel. As negative foreign shocks prolong the time spent at the zero lower bound, the spillover effects become larger. Conversely, larger and larger expansionary shocks abroad can

shorten the time for which the zero lower bound constraint binds at home, and thus reduce the spillover effects. However, even shocks that are sufficiently large to push the economy out of the liquidity trap cause spillovers that are elevated relative to the case when the zero bound does not bind initially (the latter case is shown in the bottom right panel).¹⁷ The reason is that the average effect of the shock differs from the shock's marginal effect. The latter falls below the former and the two will only coincide again asymptotically. One way of capturing the importance of an endogenous duration for the liquidity trap is that an exogenously fixed duration would imply no decoupling between the average and marginal effects of a shock regardless of its size. Equivalently, the lines depicting the domestic spillover effects of a foreign shock would remain flat through the domain shown in the bottom left panel of Figure 6.

We now turn to comparing the effects of the foreign shocks under alternative monetary policy rules. For the given initial baseline shock, the rules that are more aggressive on inflation or the output gap tend to increase the duration of the liquidity trap although they dampen the contraction of the economy. Intuitively, more aggressive rules call for a more sustained fall in the interest rate in reaction to a deflationary shock, and may extend the number of periods spent at the zero lower bound. For the specific rules chosen, the benchmark Taylor rule delivers larger marginal spillover effects when the foreign shock is too small to affect the number of periods spent at the zero lower bound, as shown in the bottom panel.

The top panel of Figure 6 also shows that different rules imply different threshold sizes for shocks to influence the duration of the liquidity trap. The rule that is more aggressive on inflation requires larger foreign expansionary shocks to reduce the home economy's time spent at the zero lower bound.

¹⁷ It bears emphasizing that the spillover effects are constant at the level shown in the bottom right panel of Figure 6 if the zero lower bound constraint does not bind.

5.2 Alternative Trade Elasticities

The value of the import price elasticity of demand is an important determinant of the duration of a liquidity trap and the spillover effects of country-specific shocks. When the zero bound is not binding, increasing the trade price elasticity of demand magnifies the decline of home real net exports caused by a foreign demand contraction. The spillover effects on home output are partly offset by a more vigorous reaction of domestic monetary policy. However, in a liquidity trap, monetary policy is unable to compensate in such a manner, and the larger effects on real net exports translate into greater effects on home output.

Figure 7 shows how the spillover effects of a foreign consumption shock are affected by a higher elasticity, equal to 1.5 versus 1.1 in our original calibration, or a lower elasticity, equal to 0.75. Away from the zero lower bound, the linearization of the model ensures that spillover effects are unrelated to the size of shocks. The figure's bottom right panel, shows that when the policy rule is unconstrained, a higher elasticity increases the spillover effects. The higher elasticity reduces the responsiveness of exchange rates to country-specific shocks. However, the increased sensitivity to movements in relative import prices more than offsets the decreased volatility of exchange rates. Accordingly, with the higher elasticity, home country net exports drop by more in response to a contractionary foreign consumption shock, leading to a larger fall in home GDP.

The figure's bottom left and top panels consider instead how the spillover effects are influenced by the size of the foreign shock against the backdrop of the same domestic recession considered above. The top panel of Figure 7 shows that the higher the trade elasticity the smaller is the size of foreign shocks that can lift the home economy out of the liquidity trap. The lower panel confirms that the zero lower bound constraint magnifies the spillover effects regardless of the elasticity chosen. However, the higher the trade price elasticity of demand, the more pronounced is the magnification.

5.3 A Foreign Technology Shock

Near unit-root technology shocks are the typical source of fluctuations in open economy models. However, the spillover effects of country-specific technology shocks are quite small and remain so even in a liquidity trap. The basic reason is that lower foreign activity retards the demand for home exports, but this effect is counterbalanced by a depreciation of the home real exchange rate, which boosts home exports. Under our benchmark calibration, the exchange rate channel initially dominates, implying a rise in home real net exports, and a small and short-lived *expansion* in home GDP; the effects when the home country is constrained by the zero lower bound are not noticeably different.

It is possible for a negative foreign technology shock to induce a contraction of home GDP if domestic and foreign absorption respond more quickly to the foreign shock. This is illustrated in Figure 8, which shows the effects of a foreign technology shock z_t^* under a model calibration which eliminates consumption habits and investment adjustment costs.¹⁸ In the absence of these real rigidities, foreign absorption falls more quickly, inducing home real exports to contract rapidly. If interest rates cannot fall immediately to counteract the export contraction – as in the liquidity trap case – then home output declines; nevertheless, the fall in home GDP is only a tiny fraction of that abroad.

5.4 Both Countries in a Liquidity Trap

We showed that when one country is in a liquidity trap, the spillover effects of foreign shocks are greatly amplified. We next consider whether or not these spillover effects reverberate back and forth when both countries are mired a liquidity trap, further exacerbating the domestic spillovers of a foreign shock.

Figure 9 illustrates the effects of a foreign consumption preference shock under three distinct initial baseline paths: both countries are at the zero bound for 10

¹⁸ The shock is assumed to follow an AR(1) process with persistence parameter equal to 0.95.

quarters (the dotted line), only the home country is at the zero bound for 10 quarters (the solid line), and no country is at the zero bound (the dashed line). In each case, the baseline paths were constructed using different domestic consumption shocks.

The size of the foreign consumption shock is unchanged across the three scenarios and is set to induce a 1% decline of foreign GDP if neither country is at the zero bound. Unsurprisingly, the effects of the foreign consumption shock on foreign GDP are greatly amplified if the foreign country is constrained by the zero bound. The maximum decline of foreign GDP is about 3.5% relative to baseline if the zero bound binds (dotted line) but only 1% if the policy rate is unconstrained.

However, the spillover effects on the home country of the foreign shock are little changed irrespective of whether the foreign economy is in a liquidity trap, so the dotted and solid lines almost overlap. Although an adverse foreign demand shock causes foreign absorption to fall more when the foreign economy is in a liquidity trap, it also reduces the appreciation of the home real exchange rate since foreign long-term real interest rates fall by less. As the relative price movement offsets the movement in foreign activity, home exports and GDP are little varied.

The apparent irrelevance of the foreign zero lower bound for the spillover effects on the home country is predicated on the particular calibration of the trade price elasticity. With a lower trade elasticity, the activity channel dominates the relative price channel. With real net exports responding more vigorously, spillover effects on home GDP are larger when the foreign economy is at the zero lower bound, as illustrated in Figure 10. Each line in the figure is constructed by subtracting the impulse responses to a foreign consumption shock in the case when both countries are at the zero bound from those which obtain when only the home country is at the zero bound. This difference captures the reverberation effects on the home country that are associated with the liquidity trap in the foreign country.¹⁹

Figure 10 considers two cases: the benchmark elasticity equal to 1.1 (the solid

¹⁹ More specifically, the solid line in Figure 10 shows the difference between the dotted and solid lines of Figure 9.

lines), and a case in which the elasticity is equal to 0.5. When the foreign economy is also at the zero lower bound, lower foreign activity causes a bigger contraction in home exports, which exacerbates the contraction in home GDP relative to the case when only the home economy is at the zero lower bound.²⁰

6 Conclusions

When monetary policy is unconstrained, it can cushion the impact of foreign disturbances. By contrast, in a liquidity trap, monetary policy cannot crowd in domestic demand as effectively, and the spillover effects of foreign shocks can be magnified greatly. The amplification of idiosyncratic foreign shocks depends both on the duration of the liquidity trap and as well as on key structural features such as the trade price elasticity. The size of the foreign shock is of particular importance as it can effect the length of the liquidity trap and thereby decouple the marginal and average spillover effects of the shock. With our autoregressive shock processes, as typically postulated in the empirical validation of DSGE models, the model can generate substantial differences between the marginal and the average effect of a shock. A simplification of the treatment of the zero lower bound that fixed the duration of the liquidity trap exogenously would miss this feature completely.

Our model results allay fears that a global liquidity trap is likely to worsen the spillover effects of a given-size country-specific shock, relative to the case in which the trap is limited to one region. Although demand shocks abroad cause foreign activity to fall more sharply when the foreign economy is also in a liquidity trap, the home real exchange rate appreciates less, so that home exports are roughly unaffected. Hence, the spillover effects on the home GDP are very similar to those when only the home country is in a liquidity trap.

²⁰ A high value for the trade elasticity skews the determination of trade flows towards the price channel. In that case, the contraction of home GDP is reduced if the foreign country is also mired in a liquidity trap.

References

- Adam, K. and R. M. Billi (2006). Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates. *Journal of Money, Credit, and Banking* 7, 1877–1905.
- Adam, K. and R. M. Billi (2007). Discretionary Monetary Policy and the Zero Lower Bound on Nominal Interest Rates. *Journal of Monetary Economics* 3, 728–752.
- Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2007). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics* 72, 482–511.
- Anderson, G. (1999). *Analyses in Macroeconomic Modelling*, Chapter 9: Accelerating Non Linear Perfect Foresight Model Solution by Exploiting the Steady State Linearization, pp. 57–85. Springer.
- Backus, D. K., P. J. Kehoe, and F. E. Kydland (1992). International Real Business Cycles. *Journal of Political Economy* 100, 745–775.
- Baxter, M. and M. Crucini (1995). Business Cycles and the Asset Structure of Foreign Trade. *International Economic Review* 36(4), 821–854.
- Bodenstein, M. (2009). Closing Large Open Economy Models. International Finance Discussion Paper 867.
- Bodenstein, M., J. Hebden, and R. Nunes (2010). Imperfect Credibility and the Zero Lower Bound on the Nominal Interest Rate. *International Finance Discussion Papers* 1001.
- Calvo, G. A. (1983). Staggered Prices in a Utility-Maximizing Framework. *Journal of Monetary Economics* 12, 383–398.
- Christiano, L., M. Eichenbaum, and S. Rebelo (2009). When is the Government Spending Multiplier Large? Mimeo, Northwestern University.
- Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy* 113(1), 1–45.
- Coenen, G. and V. Wieland (2003). The zero-interest-rate bound and the role of the exchange rate for monetary policy in Japan. *Journal of Monetary Economics* 50(5), 1071–1101.
- Cole, H. and M. Obstfeld (1991). Commodity Trade and International Risk Sharing: How Much Do Financial Markets Matter? *Journal of Monetary Economics* 28, 3–24.
- Doyle, B. and J. Faust (2005, November). Breaks in the Variability and Co-Movement of G-7 Economic Growth. *Review of Economics and Statistics* 87(4), 721–740.
- Eggertsson, G. B. (2010). What Fiscal Policy is Effective at Zero Interest Rates?

- In *NBER Macroeconomics Annual 2010, Volume 25*, NBER Chapters. National Bureau of Economic Research, Inc.
- Eggertsson, G. B. and M. Woodford (2003). The Zero Bound on Interest Rates and Optimal Monetary Policy. *Brookings Papers on Economic Activity* (1), 139–233.
- Erceg, C. J., L. Guerrieri, and C. Gust (2006). SIGMA: A New Open Economy Model for Policy Analysis. *International Journal of Central Banking*, 1–50.
- Erceg, C. J., L. Guerrieri, and C. Gust (2008). Trade Adjustment and the Composition of Trade. *Journal of Economic Dynamics and Control*, 2622–2650.
- Fair, R. and J. B. Taylor (1983). Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models. *Econometrica* 51, 1169–1185.
- Guerrieri, L., C. Gust, and D. López-Salido (2010). International Competition and Inflation. Forthcoming in *American Economic Journal: Macroeconomics*.
- Jeanne, O. and L. E. Svensson (2007). Credible Commitment to Optimal Escape from a Liquidity Trap: The Role of the Balance Sheet of an Independent Central Bank. *American Economic Review* 97, 474–490.
- Juillard, M. (1996). DYNARE: A Program for the Resolution and Simulation of Dynamic Models with Forward Variables Through the Use of a Relaxation Algorithm. CEPREMAP Working Paper No. 9602.
- Jung, T., Y. Teranishi, and T. Watanabe (2005). Zero Bound on Nominal Interest Rates and Optimal Monetary Policy. *Journal of Money, Credit, and Banking* 37, 813–836.
- Kose, M., C. Otrok, and C. Whiteman (2003). International Business Cycles: World, Region, and Country-Specific Factors. *American Economic Review* 93, 1216–1239.
- Lubik, T. A. and F. Schorfheide (2005). A Bayesian Look at New Open Economy Macroeconomics. In M. Gertler (Ed.), *NBER Macroeconomics Annual*. NBER.
- McCallum, B. (2000). Theoretical Analysis Regarding a Zero Lower Bound on Nominal Interest Rates. *Journal of Money, Credit, and Banking* 32, 870–904.
- Nakov, A. (2008). Optimal and Simple Monetary Policy Rules with Zero Floor on the Nominal Interest Rate. *International Journal of Central Banking* 4(2), 73–127.
- Orphanides, A. and V. Wieland (2000). Efficient monetary policy design near price stability. *Journal of the Japanese and International Economies* 14, 327–365.
- Reifschneider, D. and J. C. Williams (2000). Three Lessons for Monetary Policy in Low Inflation Era. *Journal of Money, Credit, and Banking* 32(4), 936–966.
- Schmitt-Grohe, S. and M. Uribe (2003). Closing Small Open Economy Models. *Journal of International Economics* 61(3), 163–185.

- Smets, F. and R. Wouters (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association* 1, 1124–1175.
- Stock, J. and M. Watson (2005). Understanding Changes in International Business Cycle Dynamics. *Journal of the European Economic Association* 3, 968–1006.
- Stockman, A. C. and L. L. Tesar (1995). Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements. *American Economic Review* 85(1), 168–185.
- Svensson, L. E. (2004). The Magic of the Exchange Rate: Optimal Escape from a Liquidity Trap in Small and Large Open Economies.
- Taylor, J. B. (1993). Discretion versus Policy Rules in Practice. *Carnegie-Rochester Conference Series on Public Policy* 39, 195–214.
- Turnovsky, S. J. (1985). Domestic and Foreign Disturbances in an Optimizing Model of Exchange-Rate Determination. *Journal of International Money and Finance* 4(1), 151–71.
- Weidner, J. and J. C. Williams (2010). Update of “How Big is the Output Gap” as of May 11, 2010. *FRBSF Economic Letter*.
- Woodford, M. (2010). Simple Analytics of the Government Expenditure Multiplier. NBER Working Paper No. 15714.

Table 1: Calibration*

Parameter	Determines:	Parameter	Determines:
$\beta = 0.995$	s.s. real interest rate = 2% per year	$\delta = 0.025$	depreciation rate = 10% per year
χ_0	leisure's share of time = 1/2	$\chi = 10$	labor supply elasticity = 1/5
$\sigma = 2$	intertemporal substitution elast. 1/2	$\phi_b = 0.001$	interest elasticity of foreign assets
$\rho = -2$	capital-labor substitution elast. = 1/2	$\rho_A = 10$	long-run import price elasticity = 1.1
$\omega_A = 0.15$	import share of output = 15%	$\omega_A^* = 0.05$	foreign import share of output = 5%
$\zeta = 1$	population size	$\zeta^* = 3$	foreign population size
$\kappa = 0.8$	consumption habits	$\phi_I = 3$	investment adjustment costs
$\theta_w = 0.1$	wage markup = 10%	$\theta_p = 0.1$	domestic/export price markup = 10%
$\xi_p = 0.75$	price contract expected duration = 4 quarters	$\xi_w = 0.75$	wage contract expected duration = 4 quarters
$\xi_{px} = 0.5$	export price contract expected duration = 2 quarters	$\tau_k = 0$	capital tax rate
$\gamma_i = 0.7$	monetary policy's weight on lagged interest rate	$\gamma_\pi = 0.5$	monetary policy's weight on inflation
$\gamma_y = 0.5$	monetary policy's weight on output gap		

* Parameter values for the foreign country are chosen identical to their home country counterparts except for the population size ζ^* and the import share ω_A^* .

Figure 1: Severe Domestic Recession Scenario (Initial Baseline Path)

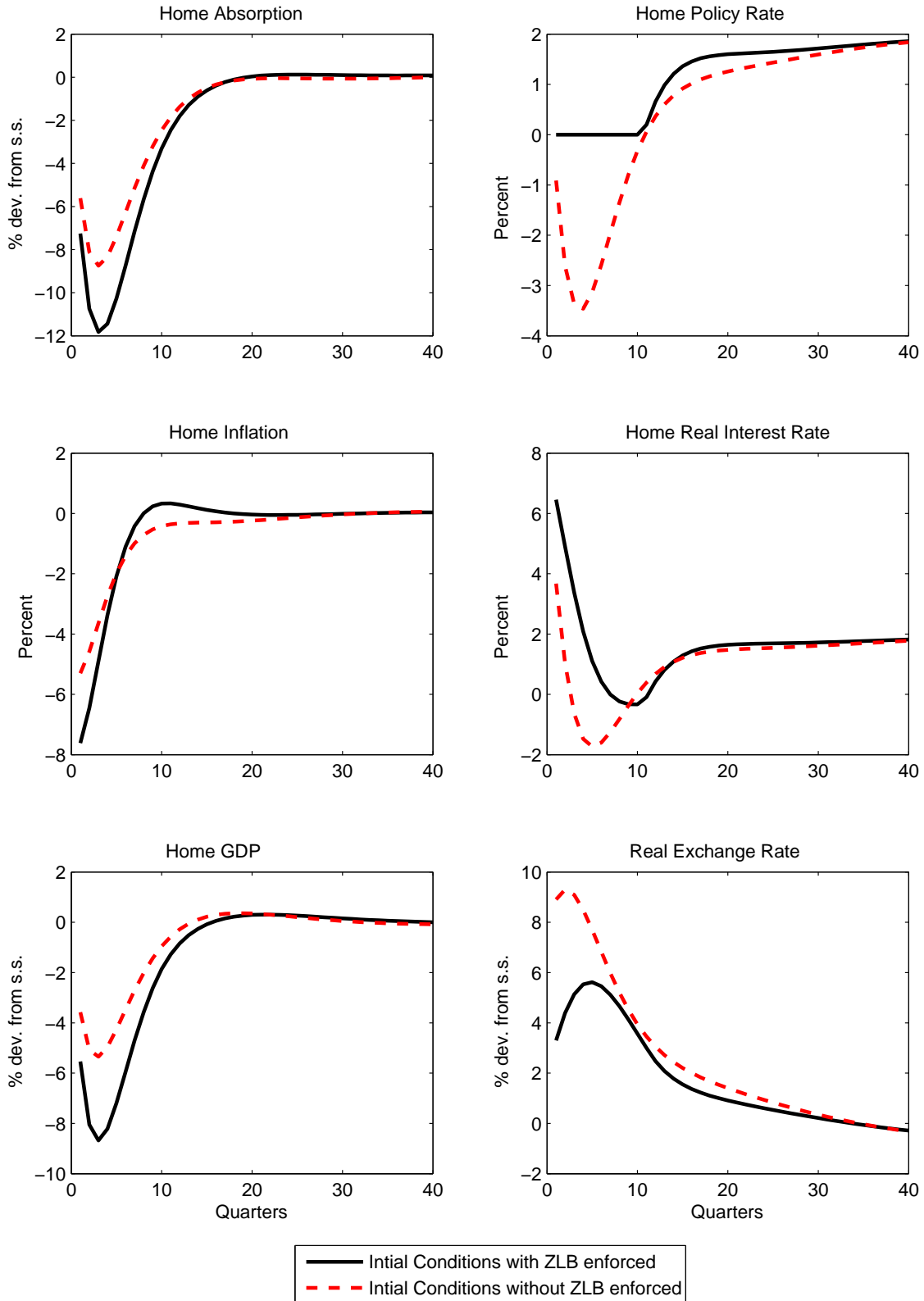


Figure 2: Effects of Foreign Consumption Shock against Backdrop of Domestic Recession

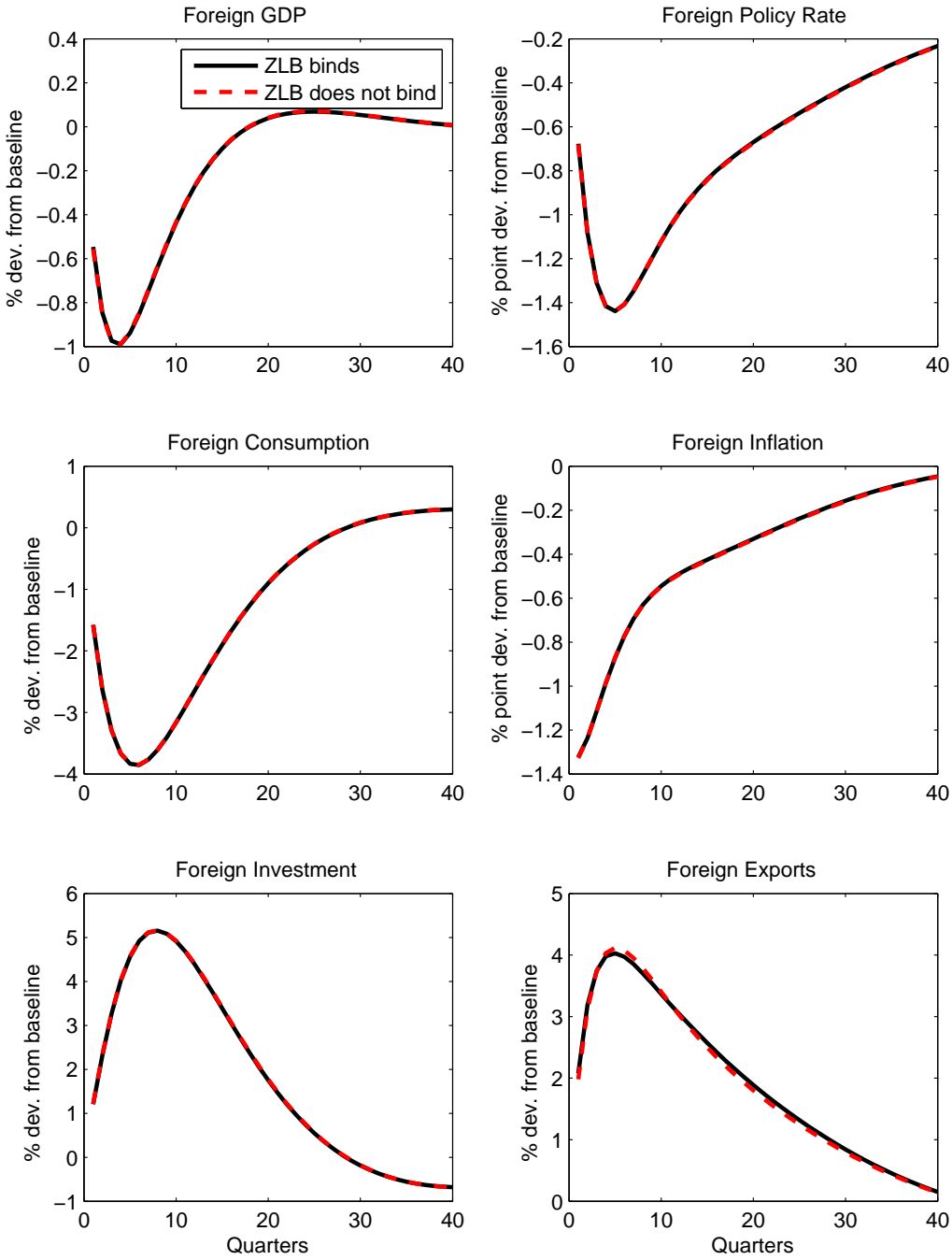


Figure 3: Effects of Foreign Consumption Shock against Backdrop of Domestic Recession

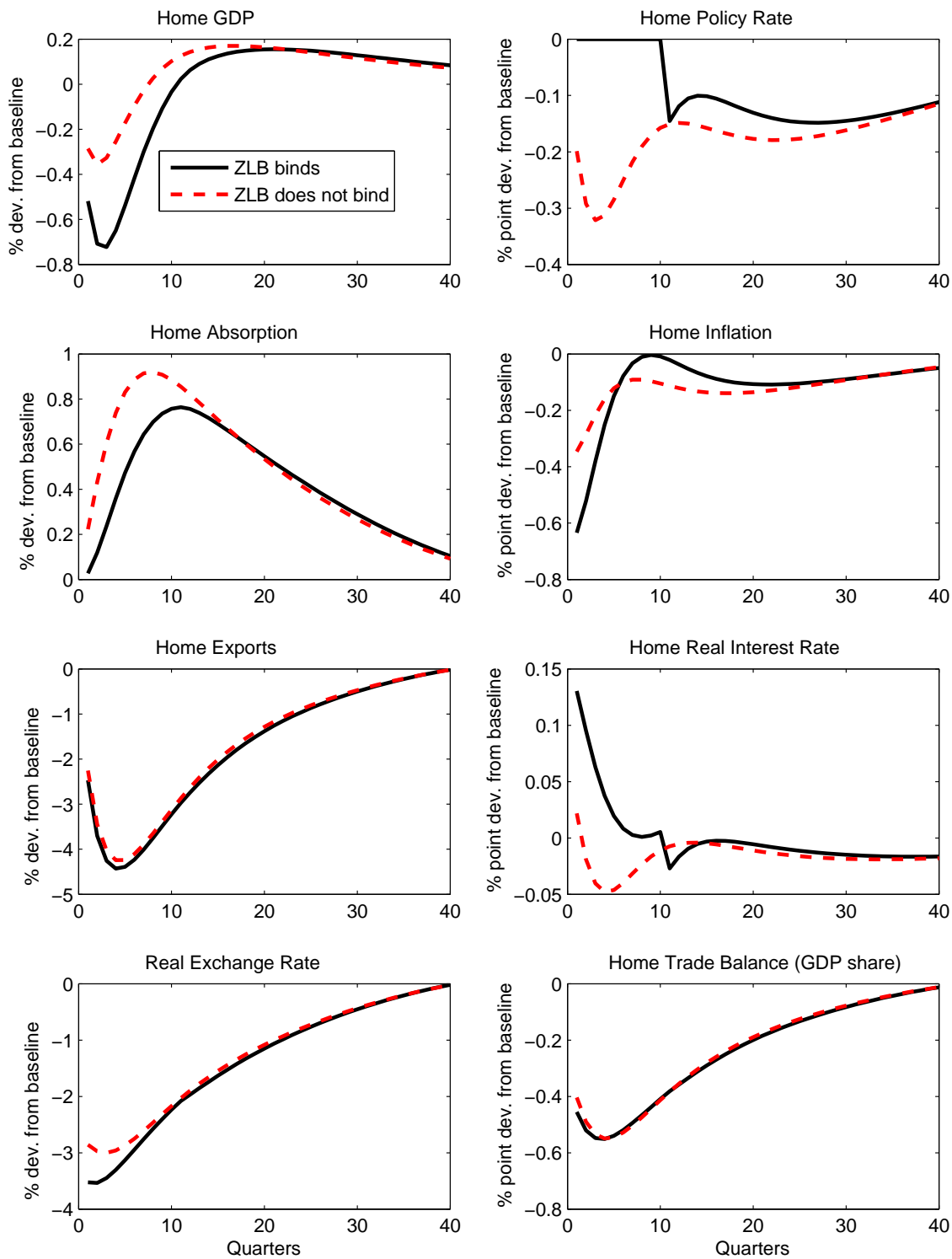


Figure 4: Effects of Foreign Consumption Shock against Backdrop of Deeper Domestic Recession

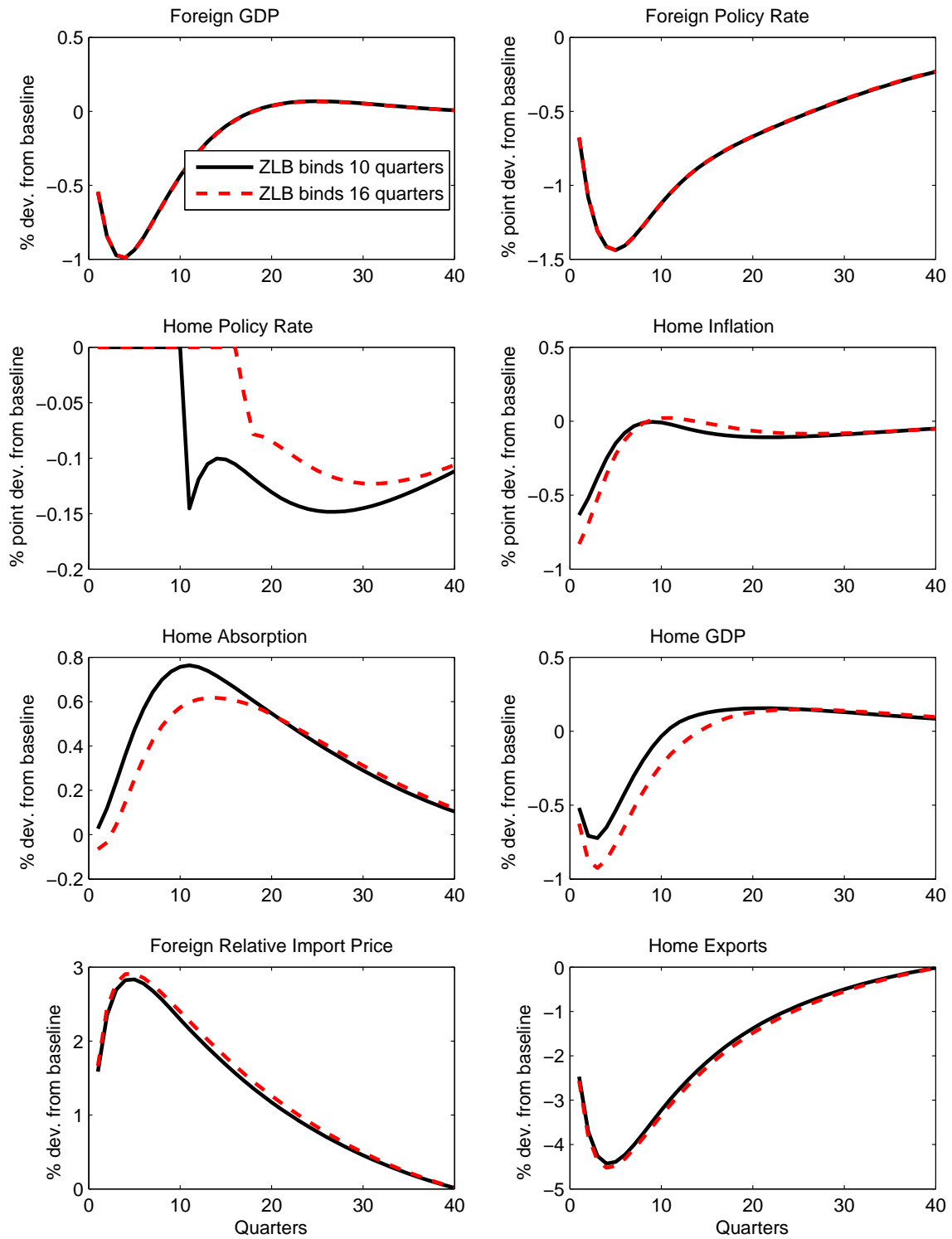
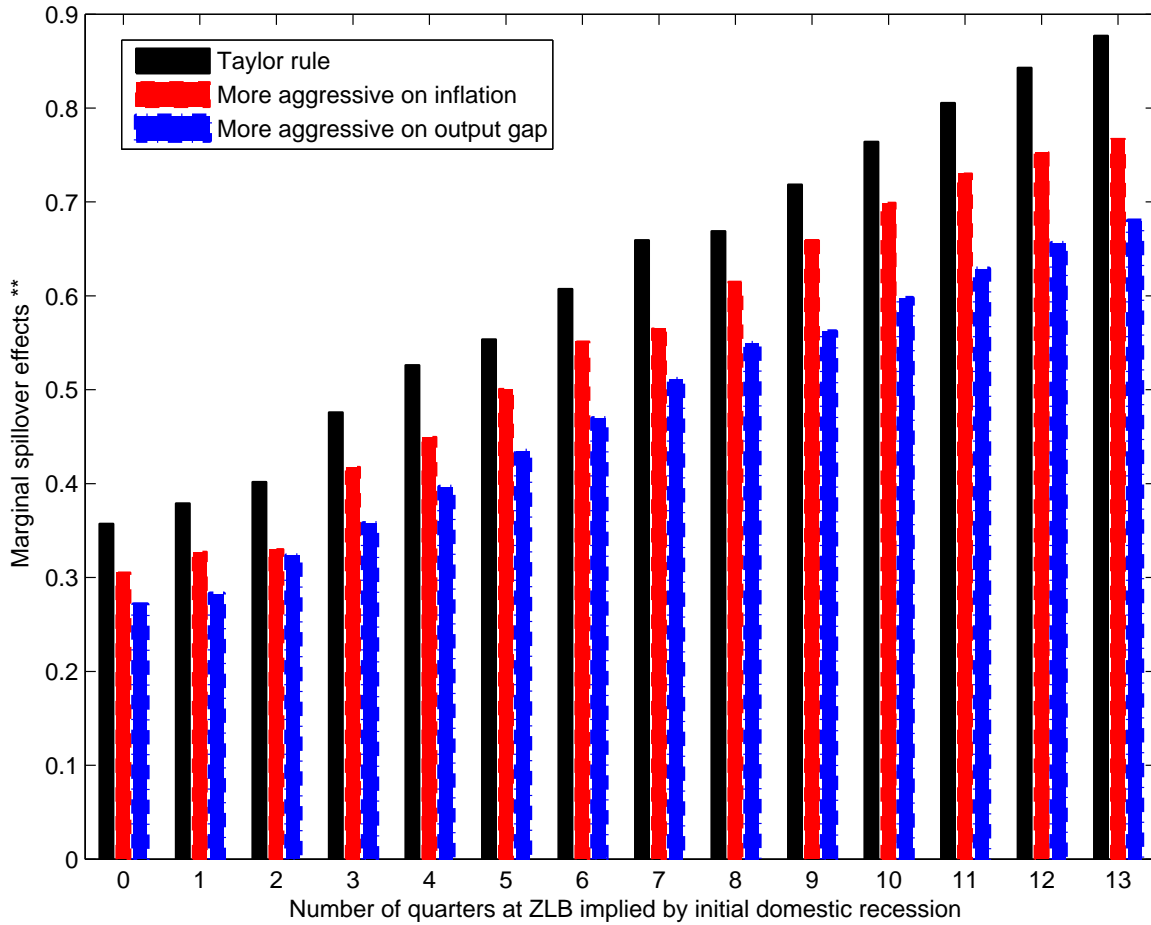


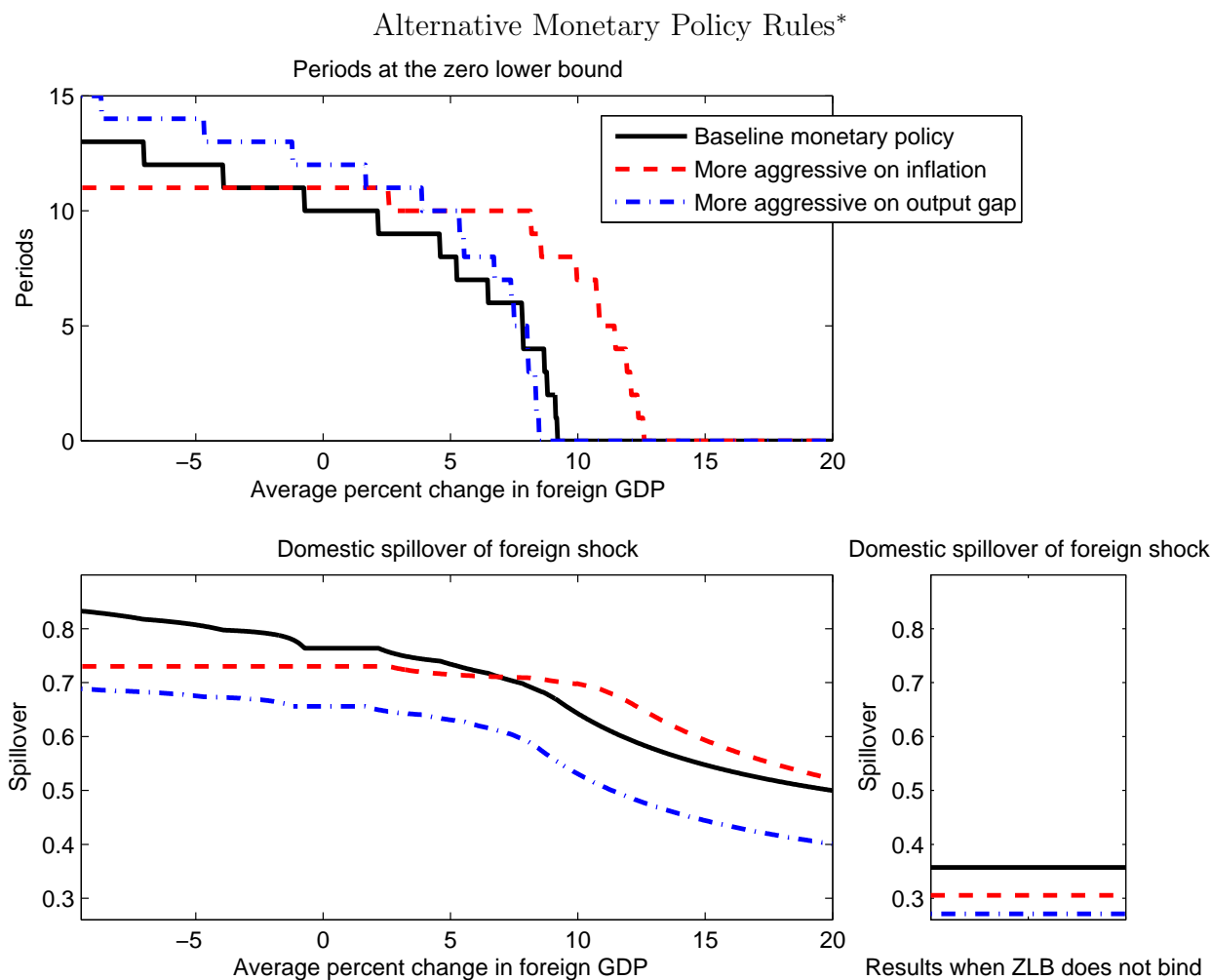
Figure 5: Effects of Foreign Consumption Shock against the Backdrop of Domestic Recession
Alternative Monetary Policy Rules*



* The parameters for the policy rule described in equation (17) are chosen as: $\gamma_i = 0.7, \gamma_\pi = 1.5, \gamma_y = 0.5$ for the benchmark Taylor rule; the rule more aggressive on inflation takes $\gamma_\pi = 3$ while leaving the other parameters unchanged; and the rule more aggressive on the output gap takes $\gamma_y = 4$ while leaving the other parameters unchanged.

** The spillover effects are defined as the ratio of the response of home GDP (in log deviation from the path implied by the initial baseline recession) to the response of foreign GDP (also in deviation from its initial path). The measure shown is an average of the spillover effects over the first four quarters. The size of the foreign consumption shock is small enough not to influence the number of periods for which the zero lower bound on policy rates is binding.

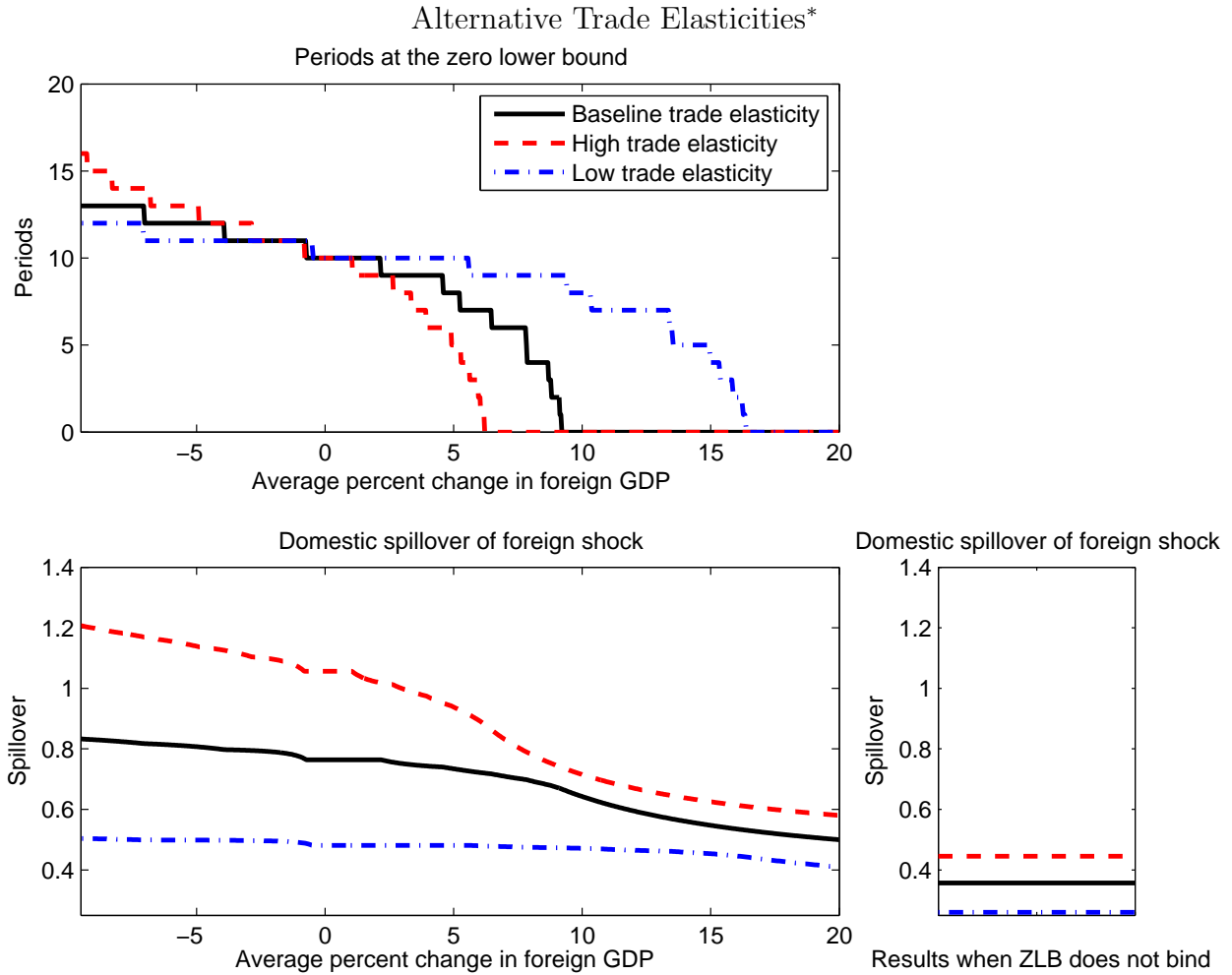
Figure 6: Effects of Foreign Consumption Shock against Backdrop of Domestic Recession



* The parameters for the policy rule described in equation (17) are chosen as: $\gamma_i = 0.7$, $\gamma_\pi = 1.5$, $\gamma_y = 0.5$ for the benchmark Taylor rule; the rule more aggressive on inflation takes $\gamma_\pi = 3$ while leaving the other parameters unchanged; and the rule more aggressive on the output gap takes $\gamma_y = 4$ while leaving the other parameters unchanged.

** The spillover effects are defined as the ratio of the response of home GDP (in deviation from the path implied by the initial baseline recession) to the response of foreign GDP (also in deviation from its initial path). The measure shown is an average of the spillover effects over the first four quarters.

Figure 7: Effects of Foreign Consumption Shock against Backdrop of Domestic Recession



* The baseline trade elasticity is 1.1; the high trade elasticity is 1.5; the low trade elasticity is 0.75.

** The spillover effects are defined as the ratio of the response of home GDP (in deviation from the path implied by the initial baseline recession) to the response of foreign GDP (also in deviation from its initial path). The measure shown is an average of the spillover effects over the first four quarters.

Figure 8: Foreign Technology Shock when Home Country is at Zero Lower Bound

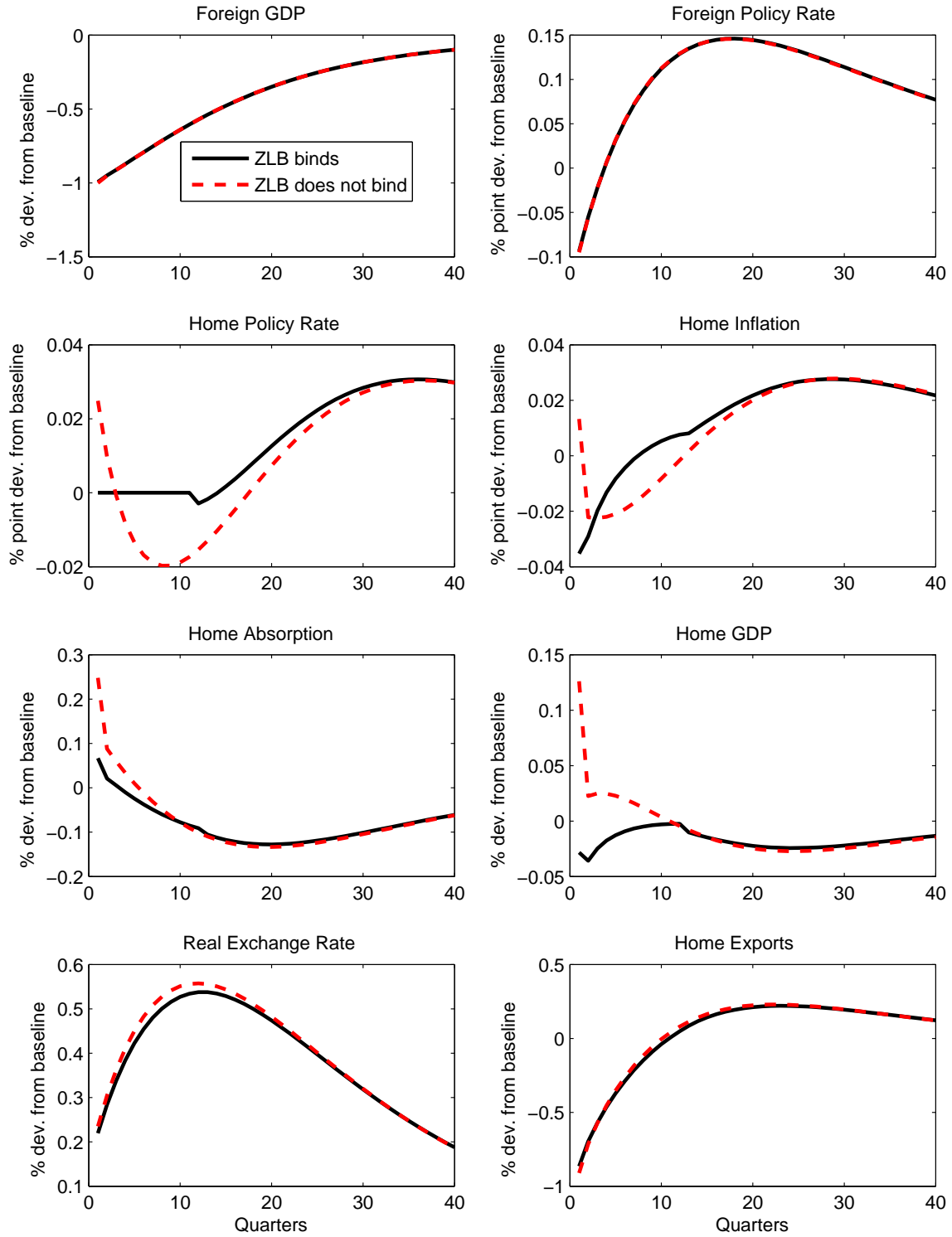


Figure 9: Zero Lower Bound Binds at Home and Abroad

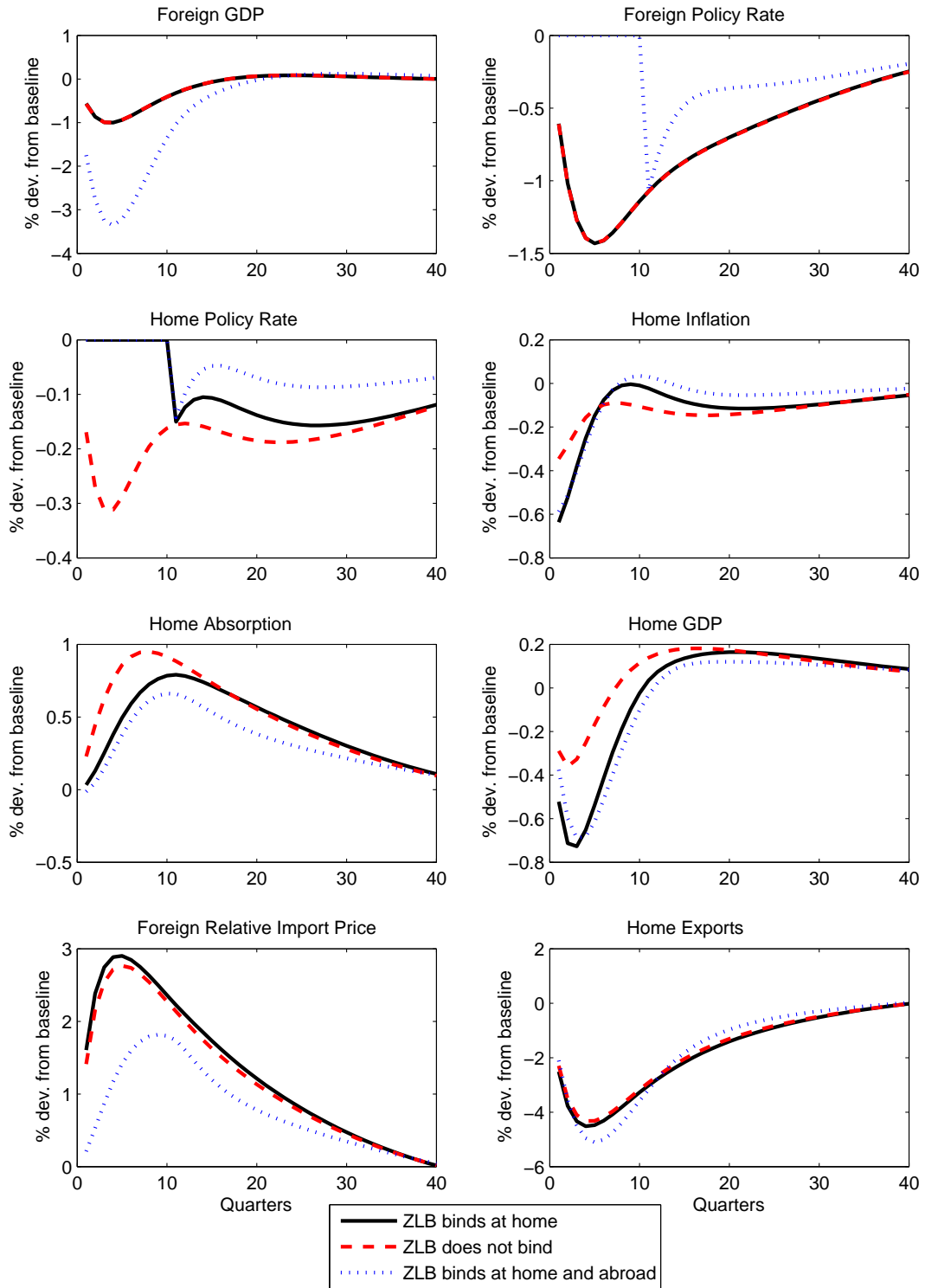
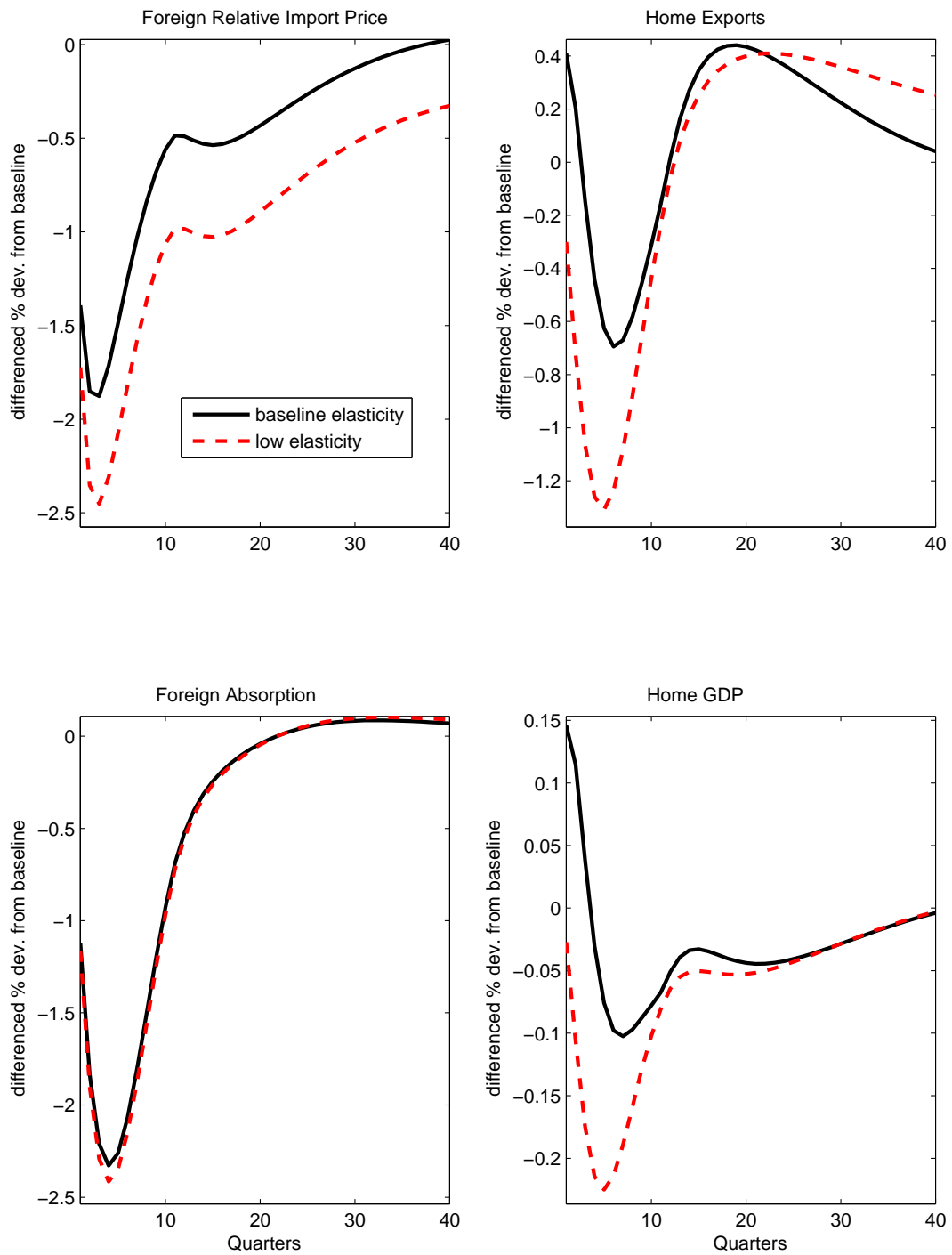


Figure 10: Reverberation Effects when Both Countries are in a Liquidity Trap*



* Each line is constructed by subtracting the impulse responses to a foreign consumption shock in the case when both countries are at the zero bound from those which obtain when only the home country is at the zero bound.

A Appendix: Formalizing the Role of the Initial Baseline Forecast

This Appendix provides background notes for implementing the piecewise-linear approach. This approach is very helpful in conducting sensitivity analysis. Moreover, we highlight limited relevance of the initial baseline path with regard to the international spillover effects; we also show that the effects of additional shocks are linear provided that the shock does not affect the duration of the liquidity trap.

For simplicity, assume that a shock immediately depresses the policy rate so that the zero lower bound binds from periods 1 to T .²¹ If the shock does not also bring down policy rates in the foreign country to the zero lower bound, there are two linear systems that summarize the equilibrium conditions.²²

Let the linear system that summarizes the equilibrium conditions for $t \geq T + 1$ be written as

$$\bar{A}E_t s_{t+1} + \bar{B}s_t + \bar{C}s_{t-1} + \bar{D}\varepsilon_t = 0, \quad (20)$$

where s is a $N \times 1$ vector stacking all the N variables in the model; ε is a $M \times 1$ vector stacking the innovations to the shock processes; and \bar{A} , \bar{B} , \bar{C} , are $N \times N$ matrices and \bar{D} is a $N \times M$ matrix of coefficients. For $1 \leq t \leq T$, the linear equilibrium conditions are denoted by

$$\bar{A}E_t s_{t+1} + \bar{B}^* s_t + \bar{C}s_{t-1} + \bar{D}\varepsilon_t + \bar{d} = 0, \quad (21)$$

where \bar{B}^* is an $N \times N$ matrix and \bar{d} is a $N \times 1$ vector. Furthermore, $\varepsilon_t = 0$ for all $t > 1$.

The matrices \bar{B} and \bar{B}^* differ in one entry only. Without loss in generality, let the N th row in these two matrices record the relationship between the nominal interest rate r_t and the notional interest rate r_t^{not} , where in the original nonlinear system $r_t = \max(-\bar{r}, r_t^{not})$. Let r_t^{not} be the $n_{r^{not}}$ th entry into s_t , and $\bar{B}(N, n_{r^{not}})$, $\bar{B}^*(N, n_{r^{not}})$ be the entry in row N , column $n_{r^{not}}$ into \bar{B} and \bar{B}^* , respectively. Then $\bar{B}(N, n_{r^{not}}) = -1$ and $\bar{B}^*(N, n_{r^{not}}) = 0$.²³ The vector \bar{d} contains zeros everywhere except in the N th row, which equals \bar{r} .²⁴

²¹ The extension to the case in which the interest rate does not reach zero on impact is straightforward, but is omitted for brevity.

²² There is a proliferation of the number of linear systems for more complex cases in which the ZLB binds in both countries

²³ Notice that r_t is expressed in deviation from its steady state level. Thus, using the notation of equation 17, $r_t = i_t - \bar{i}$ and $r_t^{not} = i_t^{not} - \bar{i}$.

²⁴ An alternative way to think about the dynamics under the zero lower bound is in terms of monetary policy shocks. Instead of replacing \bar{B} by \bar{B}^* and introducing \bar{d} , one can simply add a monetary policy shock in the policy rule of size $\varepsilon_{m,t} = \max(-\bar{r} - r_t^{not}, 0)$ and $r_t = r_t^{not} + \varepsilon_{m,t}$.

Dynamics for $t \geq T + 1$ The solution of the system (20) is given by

$$s_t = P s_{t-1} + Q \varepsilon_t, \quad (22)$$

where P is the matrix that solves the linear rational expectations model in which the zero bound constraint on i_t is ignored.

Dynamics for $t \leq T$ As Eggertsson and Woodford (2003) and Jung, Teranishi, and Watanabe (2005) we derive the solution using backward induction. In the last period in which the economy is at the zero bound, the values of the endogenous variables is computed from (21) and the fact that $s_{T+1} = P s_T$:

$$\begin{aligned} s_T &= -(\bar{A}P + \bar{B}^*)^{-1} \bar{C} s_{T-1} - (\bar{A}P + \bar{B}^*)^{-1} \bar{d} \\ &= G^{(1)} s_{T-1} + h^{(1)}. \end{aligned} \quad (23)$$

In all other periods

$$\begin{aligned} s_t &= A s_{t+1} + C s_{t-1} + d, \\ s_1 &= A s_2 + C s_0 + d + D \varepsilon_1, \end{aligned} \quad (24)$$

where $X = -(\bar{B}^*)^{-1} \bar{X}$.

Combining (23) and (24) we obtain

$$\begin{aligned} s_t &= G^{(T-t+1)} s_{t-1} + h^{(T-t+1)}, \quad 2 \leq t \leq T \\ s_1 &= G^{(T)} s_0 + h^{(T)} + (I - A G^{(T-1)})^{-1} D \varepsilon_1. \end{aligned} \quad (25)$$

G^{T-t} and h^{T-t} are generated recursively with

$$\begin{aligned} G^{(T-t+1)} &= (I - A G^{(T-t)})^{-1} C, \\ h^{(T-t+1)} &= (I - A G^{(T-t)})^{-1} (A h^{(T-t)} + d). \end{aligned} \quad (26)$$

with

$$\begin{aligned} G^{(1)} &= -(\bar{A}P + \bar{B}^*)^{-1} \bar{C}, \\ h^{(1)} &= -(\bar{A}P + \bar{B}^*)^{-1} \bar{d}. \end{aligned} \quad (27)$$

We can also express the values of the endogenous variables as a function of the time 1 innovations. If

$$\begin{aligned} s_0 &= \vec{0}, \\ s_1 &= (I - A G^{(T-1)})^{-1} D \varepsilon_1 + h^{(T)}, \end{aligned}$$

then for $2 \leq t \leq T$

$$\begin{aligned} s_t &= \left(\prod_{i=1}^{t-1} G^{(T-i)} \right) s_1 + \sum_{j=1}^{t-1} \left(\prod_{i=j+1}^{t-1} G^{(T-i)} \right) h^{(T-j)} \\ &= \left(\prod_{i=1}^{t-1} G^{(T-i)} \right) (I - A G^{(T-1)})^{-1} D \varepsilon_1 + \sum_{j=0}^{t-1} \left(\prod_{i=j+1}^{t-1} G^{(T-i)} \right) h^{(T-j)}, \end{aligned} \quad (28)$$

where $\prod_{i=j+1}^{t-1} G^{(T-i)} = I$ if $j+1 > t-1$.

Finding T Given the guess for T , compute r_T^{not} and r_{T+1}^{not} . The current guess for T is associated with the model's solution path if $r_T^{not} < -\bar{r}$ and $r_{T+1}^{not} \geq -\bar{r}$. We denote the number of periods for which policy rates are expected to remain at the zero lower bound following a set of innovations ε_1 by $T(\varepsilon_1)$.

The following statements are implied by these observations.

Proposition 1 *Linearity at the zero bound: Consider the two shock vectors ε_1 and $\varepsilon_1 + \mu_1$, $\mu_1 \neq 0$. If $T(\varepsilon_1) = T(\varepsilon_1 + \mu_1) = T^*$, then $\left\{s_t^{(\varepsilon_1, T^*)}\right\}_{t=1}^{\infty} - \left\{s_t^{(\varepsilon_1 + \mu_1, T^*)}\right\}_{t=1}^{\infty} = \left\{s_t^{(\mu_1, T^*)}\right\}_{t=1}^{\infty}$.*

Corollary 2 *Consider the four different shock realizations: ε_1 , $\varepsilon_1 + \mu_1$, ε_1^* , $\varepsilon_1^* + \mu_1$. Let $T^* = T(\varepsilon_1) = T(\varepsilon_1 + \mu_1) = T^*(\varepsilon_1^*) = T^*(\varepsilon_1^* + \mu_1)$. Then $\left\{s_t^{(\varepsilon_1, T^*)}\right\}_{t=1}^{\infty} - \left\{s_t^{(\varepsilon_1 + \mu_1, T^*)}\right\}_{t=1}^{\infty} = \left\{s_t^{(\varepsilon_1^*, T^*)}\right\}_{t=1}^{\infty} - \left\{s_t^{(\varepsilon_1^* + \mu_1, T^*)}\right\}_{t=1}^{\infty}$, i.e. the effect of the μ_1 does not depend on the initial conditions ε_1 or ε_1^* , provided that the duration of the liquidity trap is unchanged.*

The effect of a positive and a negative shocks are symmetric if the duration of the liquidity trap is not affected by the additional shock μ_1 .

Corollary 3 *Consider the shocks $\varepsilon_1 + \mu_1$ and $\varepsilon_1 - \mu_1$ with $T(\varepsilon_1 + \mu_1) = T(\varepsilon_1 - \mu_1)$. Then $\left\{s_t^{(\varepsilon_1 + \mu_1, T^*)}\right\}_{t=1}^{\infty} = -\left\{s_t^{(\varepsilon_1 - \mu_1, T^*)}\right\}_{t=1}^{\infty}$.*

Closely related to the question of how to find $T(\varepsilon_1)$, note that one can define combinations of the innovations such that agents expect the zero lower bound to be binding for any number of periods.

Corollary 4 *Any shock vector $\bar{\varepsilon}_1$ that is compatible with policy rates at the zero bound for T periods needs to satisfy:*

$$e'_{n_r, not} P \left[\left(\prod_{i=1}^{t-1} G^{(T-i)} \right) (I - AG^{(T-1)})^{-1} D\bar{\varepsilon}_1 + \sum_{j=0}^{T-1} \left(\prod_{i=j+1}^{T-1} G^{(T-i)} \right) h^{(T-j)} \right] = -\bar{r}$$

where $e_{n_r,not}$ is a $N \times 1$ vector with zeros everywhere except for the n_r,not th position, which has an entry of 1. If $\bar{\varepsilon}_1$ contains only a non-zero element in its k th position, then

$$\bar{\varepsilon}_{k,1} = \frac{-\bar{r} - e'_{n_r,not} P \sum_{j=0}^{T-1} \left(\prod_{i=j+1}^{T-1} G^{(T-i)} \right) h^{(T-j)}}{e'_{n_r,not} P \left(\prod_{i=1}^{t-1} G^{(T-i)} \right) (I - AG^{(T-1)})^{-1} D e_k}.$$

B Appendix: Additional Sensitivity Analysis

The magnification of foreign spillover effects is not peculiar to foreign preference shocks. We show in this appendix how shocks to government spending and capital tax rates in the foreign country affect the home economy. We also consider an alternative preference shock that influences intertemporal consumption allocation directly through the discount factor. Furthermore, we provide sensitivity analysis relative to the economy's inflation persistence.

Government Spending Shock

Figure 11 shows the impulse responses for the case of a contraction in foreign government spending. The shock follows an AR(1) process with persistence parameter equal to 0.995. The channels for the transmission of the decline in foreign demand are very similar to the ones described for a consumption preference shock. The spillover effects are smaller, because the effects of the government spending shock are less persistent, as consumption habits increase the endogenous persistence of the preference shock. Choosing an AR(2) process for government spending shocks could increase the persistence of the effects of government spending shocks and bring the quantitative responses to this shock closer to those of the preference shock considered in the paper.

Capital Tax Rate Shock

Figure 12 shows the impulse responses for the case of an increase in the foreign capital tax rate. This shock could be interpreted as boosting investment demand and similar effects would obtain in response to a shock increasing the productivity of investment in the capital accumulation equation. The AR(1) persistence parameter for the shock is set to 0.95. In a liquidity trap, the cross-country spillover effects are magnified at least twofold as measured by the reaction of home GDP relative to the movement in foreign GDP. Increases in the shock persistence would again act to increase the spillover effects.

Alternative Consumption Preference Shock

Figure 13 considers an alternative consumption preference shock. We modified households preferences, described in equation 12, to encompass a time-varying discount factor β_t as follows:

$$\begin{aligned} \tilde{\mathbb{E}}_t \sum_{j=0}^{\infty} \beta_{t+j}^j \left\{ \frac{1}{1-\sigma} \left(C_{t+j}(h) - \varkappa \frac{C_{t+j-1}}{\zeta} - \nu_{ct} \right)^{1-\sigma} \right. \\ \left. + \frac{\chi_0}{1-\chi} (1 - N_{t+j}(h))^{1-\chi} + V \left(\frac{MB_{t+j+1}(h)}{P_{t+j}} \right) \right\}. \end{aligned}$$

We let β_t be governed by the following process:

$$\beta_t - \beta = 0.75(\beta_{t-1} - \beta) + \epsilon_{\beta t}, \quad (29)$$

where $\epsilon_{\beta t}$ is an exogenous innovation. The responses shown in Figure 13 were constructed using an initial shock to β_t that delivered a liquidity trap lasting ten quarters in the home country. The additional contraction in foreign consumption was engineered through a shock to β_t^* .

An increase in β_t^* makes postponing consumption relatively more attractive to the foreign households, just like a decrease in ν_{ct}^* considered previously does. However, an increase in β_t^* is associated with a direct fall in foreign real rates and a robust increase in investment. These forces underlie the quick and dramatic rebound in foreign output. After about 10 quarters, foreign output increases 0.5 percent relative to the initial baseline path.

The figure still shows a magnification of the spillover effects of the foreign shock on home GDP when the zero lower bound is imposed. The early rebound in foreign activity, leads to a quicker recovery in the level of home exports. As demand for the home production inputs is expected to recover quickly, home inflation does not drop as much. Accordingly, the Taylor rule for monetary policy, when policy rates are unconstrained, does not call for quite as much easing as after the shock to ν_{ct}^* . Accordingly, the magnification of the spillover effects is not as large as for the benchmark preference shock.

Sensitivity to Inflation Persistence

Finally, figures 14 and 15 offers sensitivity analysis with respect to the model's inflation persistence. Relative to the benchmark model, we introduced full indexation to lagged inflation in the setting of domestic prices and wages following Christiano, Eichenbaum, and Evans (2005). Furthermore we flattened the price and wage inflation Phillips curve as would be consistent with the introduction of firms specific capital and of an increase in the elasticity of substitution between labor varieties.²⁵ As a result, the baseline shock that achieves the same expected duration for the liquidity trap of 10 quarters now leads to a decline in inflation and widening of

²⁵ Equivalently, we set the parameters ξ_p and ξ_w governing the Calvo probabilities for price and wage setting to 0.95.

the output gap that are in line with recent experience. In fact, according to U.S. NIPA data, the rate of change of the deflator for personal consumption expenditures declined about 1 percentage point from the average for the 1990-2009 period during the recent brush with the zero lower bound. Moreover, Weidner and Williams (2010) places different measures of the output gap in a range between -1.5 to -8 for the period between 2008q4 till 2010q1. Figure 15 shows little change for the spillover effects of a foreign consumption shock onto the United States relative to the effects reported in Figures 2 and 3. While the initial response of U.S. inflation following the foreign demand shocks is not as pronounced, the additional rigidities add persistence to the change in inflation. As a result, longer term measures of the real interest rate are little changed and the spillover effects of the foreign consumption shock undergo the same kind of magnification at the zero lower bound as in our benchmark experiments.

Figure 11: Foreign Government Spending when Home Country is at Zero Lower Bound

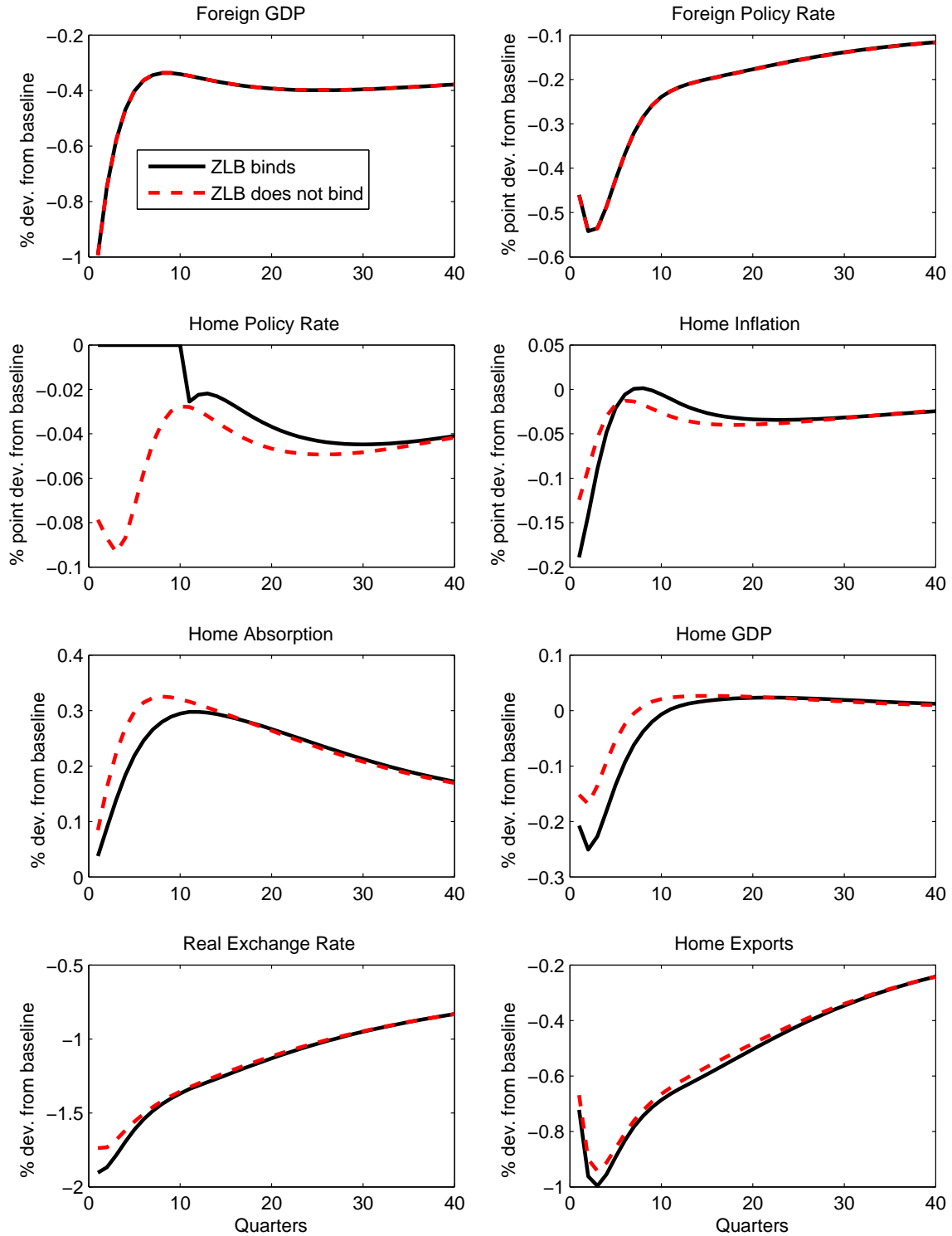


Figure 12: An Increase in the Capital Tax Rate Abroad when Home Country is at Zero Lower Bound

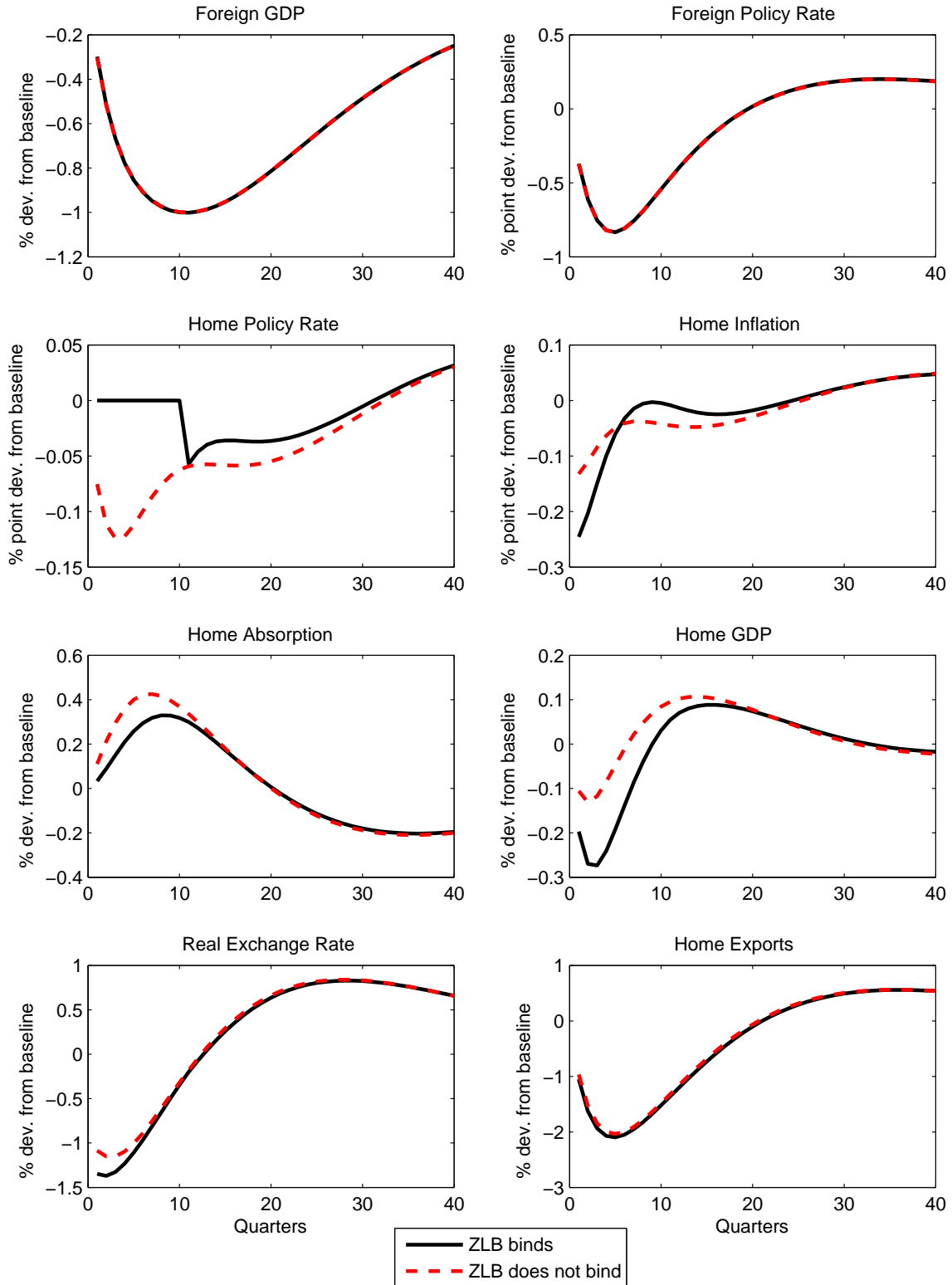


Figure 13: Alternative Preference Shock to Discount Factor

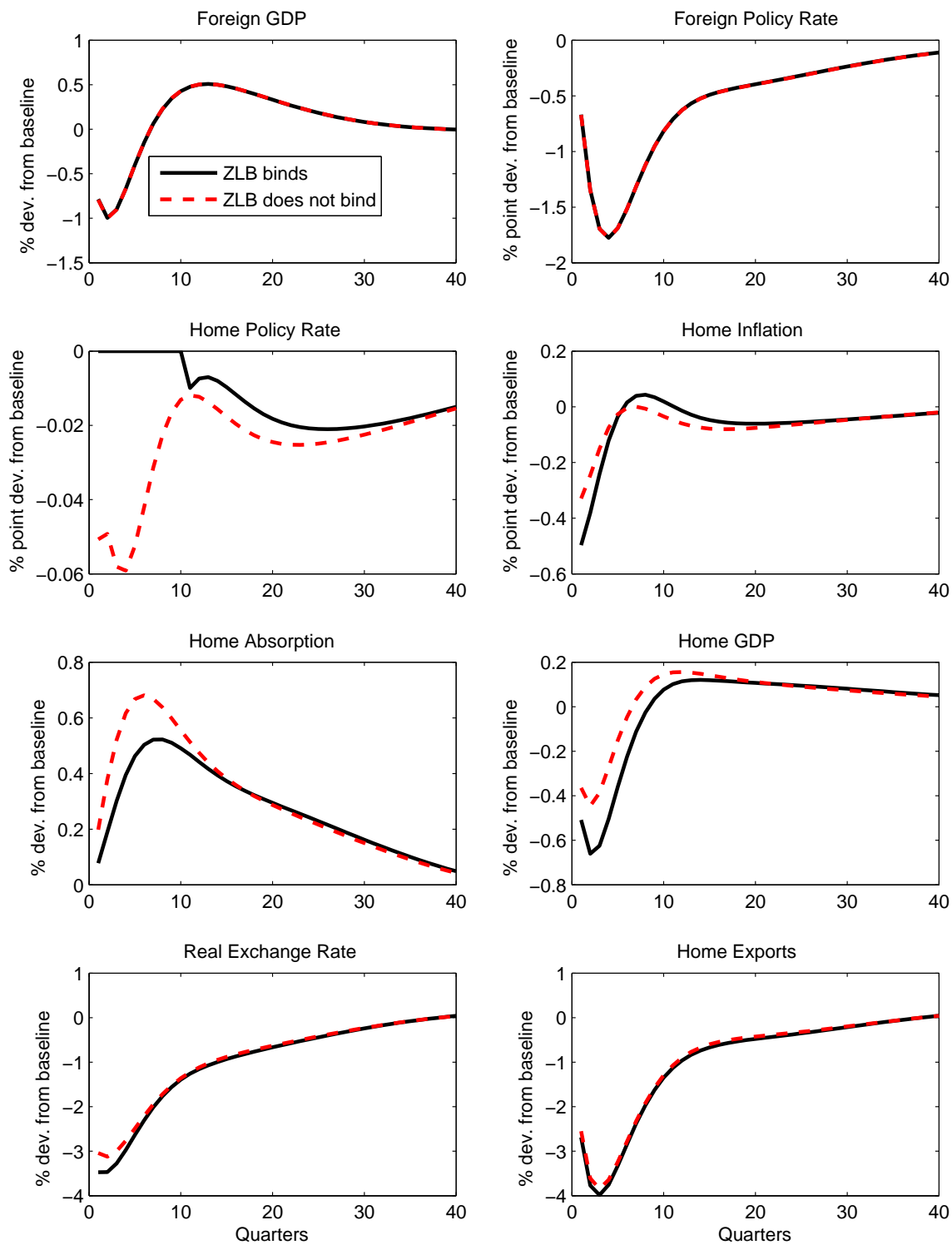


Figure 14: Severe Domestic Recession Scenario (Initial Baseline Path) in a Model with Greater Inflation Persistence

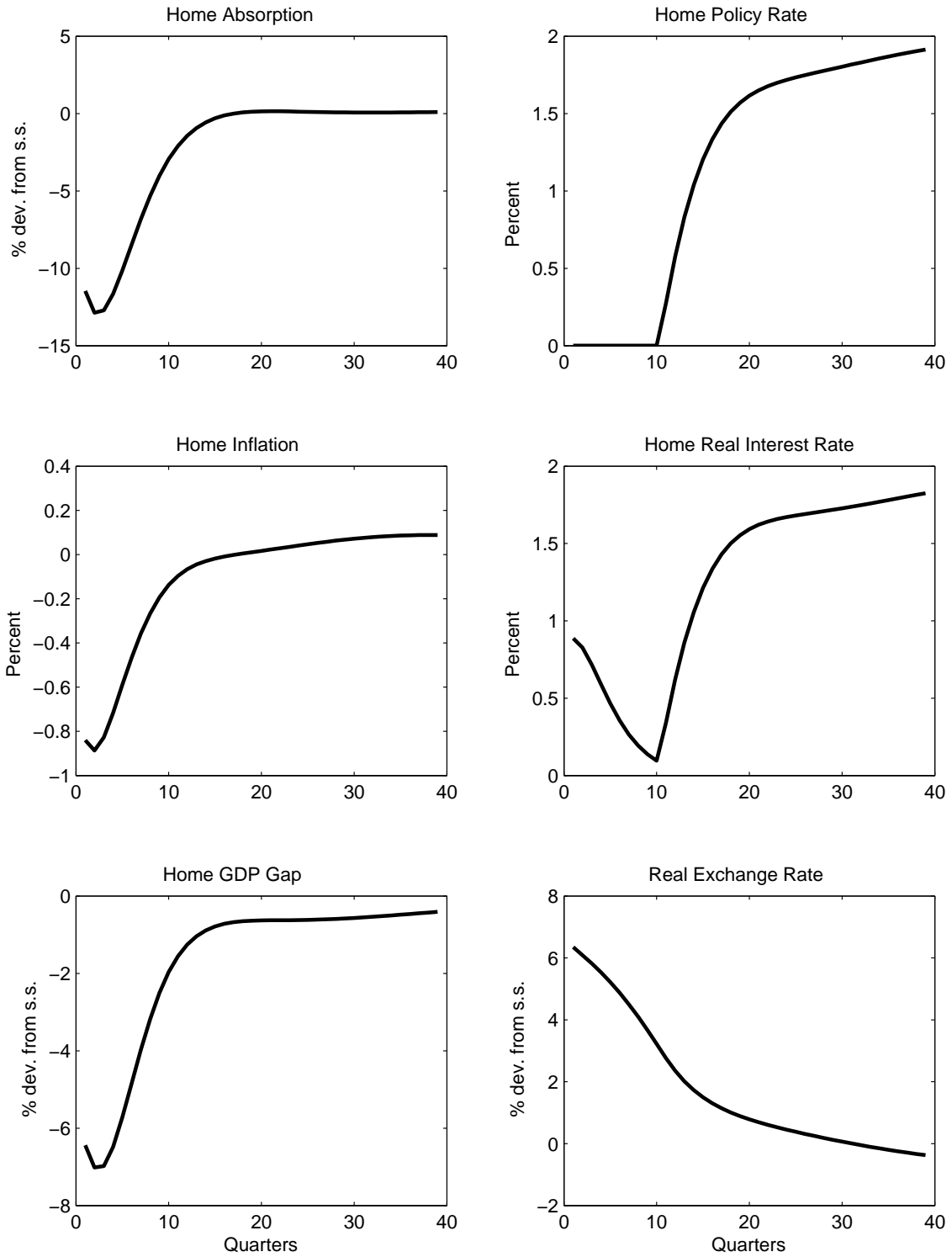


Figure 15: Severe Domestic Recession Scenario (Initial Baseline Path) in a Model with Greater Inflation Persistence

