Foreign Exchange Interventions: the Long and the Short of It*

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Abstract

This paper examines the effects of foreign exchange (FX) interventions in a setting where agents exchange both short-term and long-term securities. In a two-region theoretical model, calibrated to match the US and its trade partners (foreign region), we show that FX interventions by the foreign region do not have standard beggar-thy-neighbor consequences. Purchases of short-term FX reserves lead to lower GDP in both regions, whereas purchases of long-term FX reserves lead to higher GDP in both regions. These results are driven by the impact of these interventions on the term premium channel, which dominates the trade balance channel in our calibrated model. Finally, we estimate a structural VAR model that identifies both short-term and long-term FX intervention shocks, and find GDP responses to these shocks that are consistent with our theoretical predictions.

JEL classification codes: F31, F33, F41

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1 Introduction

Foreign exchange (FX) interventions are used as a monetary policy tool in many countries.[1] Under the mercantilist view, the primary effect of an FX intervention is through the trade balance channel: when an FX intervention is applied to depreciate a country's own currency, this leads to improved trade competitiveness, an increase in the trade balance and higher GDP growth. Meanwhile, the country's trade partners experience the opposite effects: a currency appreciation, worsened export competitiveness, a decrease in the trade balance and lower GDP growth. From this perspective, FX interventions are a classic "beggar-thy-neighbor" policy, where countries have an incentive to undertake this policy to their own benefit but at the expense of others.

Although the goals of FX interventions go beyond improving trade competitiveness,[2] the mercantilist perspective has a clear influence in the international political environment. When countries enact policies that appear to deliberately manipulate exchange rates, they are met with considerable reproach from their peers. For example, in the US, amidst a large accumulation in US-dollar denominated securities by foreign central banks over time, concerns of currency manipulation have received noticeable attention from treasury officials in recent years.[3]

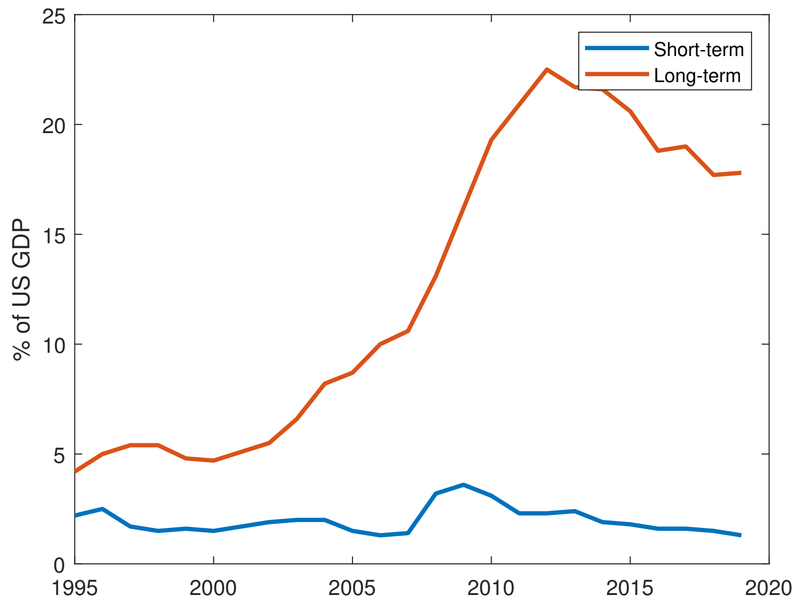
In this paper, we argue that the conventional beggar-thy-neighbor wisdom that underpins the mercantalist view is incomplete. Our argument is based on an important characteristic of FX interventions that has been largely ignored in previous work on this topic; namely, the term structure of FX interventions. Although it is often assumed that FX in-

[1]See Fratzscher et al. (2019) for evidence of active FX interventions across a broad set of countries.

[2]See BIS (2019) for a broader discussion on the motives for FX interventions in recent experience.

[3]For example, in its 2020 report on the macroeconomic and foreign exchange policies of trading partners, the US Treasury under the Trump administration labeled China a "currency manipulator," and voiced concerns over its trade partners' mercantilist efforts. See U.S. Department of the Treasury (2020). As the new Biden Administration prepared to take office in 2021, incoming US Treasury Secretary Janet Yellen communicated similarly against currency manipulators, during a Senate confirmation hearing. See Polity (2021).

Figure 1: FX reserves in US government securities over time



Data source: Bureau of Economic Analysis (BEA)

terventions involve strictly short-term securities such as currency, FX interventions (and FX reserves more generally) also involve the purchase and sale of longer-term securities such as long-term government bonds. This point is illustrated in Figure 1, which reports the evolution of FX reserves held in US government securities over time, distinguishing between reserves held in short-term (ST) and long-term (LT) securities.[4] Nearly all of the reserve accumulation in US government securities that occurred from 2000 to 2012 and much of the variation in FX reserves over time is due to changes in LT as opposed to ST FX reserves.

The composition of FX interventions across these maturity classes matters for understanding the consequences of these interventions. To demonstrate this point, we propose

[4]Figure 1 reports FX reserves for the years 1995 to 2019 inclusive. We define ST government securities as those with maturities of one year or less, which includes treasury bills, central bank reserves, and currency inside and outside of banks. LT government securities are defined as those with maturities of one year or longer. For information on specific definitions and sources of data, see Section 3. According to IMF statistics, roughly 65% of worldwide official FX reserves over this period were claims in US dollars, so our focus on US securities accounts for the majority of global FX reserves.

a two-region open-economy New Keynesian model where governments in both regions issue ST and LT bonds that are imperfect substitutes. This imperfect substitutability provides a basis for effective FX interventions and also gives rise to portfolio balance effects that are consequential for economic growth in both regions.

We then calibrate the model for the US and a foreign region (US trade partners) and simulate the model to investigate how FX interventions made by the foreign region affect the US and foreign economies. We find that the consequences of FX interventions differ greatly depending on whether the intervention is made in ST or LT securities. Purchases of ST FX reserves lead to lower GDP growth in both the US and the foreign region, whereas purchases of LT FX reserves lead to higher GDP growth in both the US and the foreign region. These results arise despite the fact that both interventions have the expected effects on the exchange rate and the trade balance. The key channel that drives GDP growth after these interventions is not the trade balance channel, as is typically emphasized in the mercantalist view, but rather the term premium channel.

The term premium is, by definition, the extra return received from investing in LT bonds above the return from repeatedly investing in ST bonds at the expected future path of ST interest rates. In our model, movements in the term premium arise due to portfolio balance effects from internationally traded ST and LT bonds, combined with differences in the responsiveness of ST and LT rates to economic shocks in the economy.

Purchases of ST FX reserves reduce the relative supply of US ST to LT bonds available to households and therefore lead to a higher term premium in the US economy. Since ST rates are relatively inert (governed by a calibrated Taylor-type rule), the higher term premium corresponds with tighter financial conditions, and lower consumption and GDP growth in the US. Interest rate spillovers lead to similar effects in the foreign economy. In contrast, purchases of LT FX reserves reduce the relative supply of US LT to ST bonds available to households, and this leads to a significant decline in LT rates and the term premium. Again, the ST rate stays relatively inert, so the decline in the term premium corresponds with an easing of financial conditions and higher consumption and GDP growth. These effects again spill over into the foreign economy. Given these results, and the preponderance of US LT bonds in the portfolios of non-US central banks, we conjecture that the FX reserve accumulation these banks undertook from 2000 to 2012 might well have lowered the term premium in the US and supported growth in both the US and the rest of the world over this period.[5]

We also show that FX interventions that are designed to stabilize the exchange rate in response to US monetary policy shocks lead to very different consequences, depending on whether the intervention is made in US ST or LT bonds. When the US monetary authority eases policy, either by lowering the US ST interest rate or through quantitative easing (QE), foreign FX interventions in US LT bonds support the direct effects of US monetary policy on the US economy and lead to higher growth in the foreign economy. In contrast, foreign FX interventions in US ST bonds counteract the direct effects of US monetary policy on the US economy and lead to lower growth in the foreign economy.

Finally, to test the predictions of our calibrated model, we propose a structural VAR model that identifies both ST and LT FX intervention shocks using time and sign restrictions. We estimate the VAR using quarterly data for the US and its trade partners (foreign region) from 2006Q1 to 2022Q1. We then examine impulse responses for GDP and several other variables in both regions. The results are consistent with the main predictions of our calibrated model: positive shocks to ST FX reserves lead to lower GDP in both regions, and positive shocks to LT FX reserves lead to higher GDP in both regions.

Our contribution relates to a recent literature that integrates frictions into the classic

[5] This conjecture could help to reconcile Alan Greenspan's famous 2005 statements on the "conundrum" regarding the disconnect between the US ST policy rate, which was in a tightening cycle at the time, and US LT rates, which were contemporaneously trending lower. Our findings suggest that FX reserve accumulation by non-US central banks could have contributed to driving the US term premium and US LT rates lower during this period.

New Keynesian frameworks, which break down the monetary policy trilemma and facilitate effective FX interventions. Similar to our study, numerous recent articles examine the role of portfolio balance effects in exchange rate determination (Gabaix and Maggiori 2015; Gourinchas et al. 2022) and FX interventions (Benes et al. 2015; Cavallino 2019; Alla et al. 2020; Amador et al. 2020; Boz et al. 2020; Fanelli and Straub 2020). Our study is unique in that it highlights the role of asset maturity structure for understanding the consequences of FX interventions.

Our work also relates to an existing literature that integrates ST and LT bonds and, therefore, term premium effects, into macroeconomic models. These studies primarily focus on examining the effects of QE on the economy (Chen et al. 2012; Alpanda and Kabaca 2020). Our focus is on FX interventions, but the mechanisms that drive our results are not dissimilar from those that drive the real effects of QE in these models. In essence, a foreign FX intervention has similar effects on the US term premium that would arise if the US undertook its own QE campaign; the difference here is that the foreign economy is making this intervention and, therefore, some aspects, such as the exchange rate response, are different.

Finally, we note that a key requirement for our results is that the foreign region is sufficiently large so that its policy actions have an impact on global interest rates, and in our simulations we calibrate the foreign region based on data for the rest of the world (excluding the US). For these reasons, our analysis is distinct from other studies in the literature that examine the impacts of FX interventions from the perspective of small open economies (SOE), and often emerging economies, where factors such as capital flow shocks, balance sheet mismatches, and market imperfections are emphasized (Céspedes et al. 2017; Cavallino 2019; Boz et al. 2020; Céspedes and Chang 2020).

We think of our exercise as most relevant for cases where either a large economy (such as the EU, Japan or China) or a significant set of non-US countries contemplates FX interventions *vis à vis* the US dollar. Given that (i) the majority of global FX reserves are in US dollars, (ii) non-US countries as a whole have engaged in a sustained accumulation of US-dollar FX reserves in recent decades, and (iii) US monetary policy has been found to be a key driver of the global financial cycle (Rey 2013) and, therefore, will have similar impacts on many non-US economies, we argue that non-US countries often face similar trade-offs in terms of FX interventions against the US dollar and therefore modeling the foreign economy as a single block opposite the US is a reasonable approach.[6]

The rest of the paper proceeds as follows. Section 2 describes the main aspects of the model. Section 3 describes the parameters we use in the model-based quantitative analysis. Section 4 provides our model-based quantitative results. Section 5 provides our empirical analysis. Section 6 concludes. An appendix with details from the full model (A) and a sensitivity analysis (B) follows.

2 Model

As a basis for our analysis, we extend the model of Alpanda and Kabaca (2020) to include foreign government reserves of US government bonds, so that the foreign government has the option to purchase and sell these bonds to influence the exchange rate (i.e., FX intervention).[7] Here, we describe only an overview of the model and relegate the rest of the details to Appendix A. The model has two regions each containing agents that buy goods and bonds from both regions. We will describe only the agents in one of the regions, which we take to be the foreign region. The other region, which we take to be the US, is analogous to the foreign region, so we will not describe it in detail. When it is necessary

[6]For example, our approach is very relevant for understanding the implications of FX interventions in the context of currency movements that occurred in 2022, a year when the US undertook an aggressive monetary policy tightening campaign and the US dollar appreciated significantly against most currencies in the world. Facing similar forces, many countries, including China and Japan, intervened in FX markets to support their currencies throughout the year.

[7]Aside from this change, the model is identical to the model in Alpanda and Kabaca (2020).

to include US variables, we will denote these using an asterisk ($*$) in the superscript.

2.1 Households

The economy is populated by a unit measure of infinitely lived households, indexed by i, each with the following utility:

$$U(i) = E_0 \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[\ln \left(c_\tau(i) - \zeta c_{\tau-1}(i) \right) + \xi_a \ln \left(a_\tau(i) \right) - \xi_n \frac{n_\tau(i)^{1+\psi}}{1+\psi} \right], \tag{1}$$

where t denotes a time script, E_0 denotes the expectations operator at period 0, $\beta < 1$ denotes the time discount factor, $c_\tau(i)$ denotes household consumption, $a_\tau(i)$ denotes household holdings of government bonds, $n_\tau(i)$ denotes the household labour input, ζ denotes an external habit parameter, ξ_a and ξ_l are parameters that govern the relative importance of bonds and leisure for utility, and ψ denotes the inverse of the Frisch elasticity of labor supply.

Bonds are included in the utility function to reflect the direct benefits they provide over riskier and/or illiquid assets.[8] The bond portfolio is a constant-elasticity-of-substitution (CES) composite of sub-portfolios consisting of ST and LT government bonds:

$$a_t(i) = \left[\gamma_a^{\frac{1}{\gamma_a}} a_{S,t}(i)^{\frac{\lambda_a - 1}{\lambda_a}} + (1-\gamma_a)^{\frac{1}{\gamma_a}} a_{L,t}(i)^{\frac{\lambda_a - 1}{\lambda_a}} \right]^{\frac{\lambda_a}{\lambda_a - 1}}, \tag{2}$$

[8]The "bonds in utility" approach that we use here can be motivated by the liquidity and safety benefits provided by these securities relative to holding less liquid and riskier assets, as argued by Krishnamurthy and Vissing-Jorgensen (2012), and is a convenient way to capture the portfolio balance channel. Valchev (2020) uses a similar approach to our own, where agents extract direct utility from holding liquid domestic and foreign bonds, which are imperfect substitutes, to help provide an explanation for the UIP puzzle. Other papers that use similar "bonds in utility" approaches to capture the portfolio balance channel include Harrison (2011), Chin et al. (2015), Vitek (2014). As demonstrated in Section D in the Online Appendix of Alpanda and Kabaca (2020), similar results in terms of the real effects of QE can be derived whether using a "bonds in utility" modeling approach or a segmented markets approach. This result is akin to the well-known functional equivalence between the money-in-utility and the transactions cost approaches to modeling money demand (Wang and Yip (1992)).

where $a_{S,t}(i)$ and $a_{L,t}(i)$ denote household holdings of ST and LT bonds, respectively, γ_a is a parameter for the relative importance of ST bonds in utility, and λ_a denotes the elasticity of substitution between ST and LT bonds.[9]

The ST and LT bond sub-portfolios, themselves, each consists of a CES composite of foreign region and US bonds:

$$a_{S,t}(i) = \left[\gamma_S^{\frac{1}{\gamma_S}}\left(\frac{B_{FS,t}(i)}{P_t}\right)^{\frac{\lambda_S-1}{\lambda_S}} + (1-\gamma_S)^{\frac{1}{\gamma_S}}\left(\frac{e_t B_{US,t}(i)}{P_t}\right)^{\frac{\lambda_S-1}{\lambda_S}}\right]^{\frac{\lambda_S}{\lambda_S-1}}, \quad (3)$$

$$a_{L,t} = \left[\gamma_L^{\frac{1}{\gamma_L}}\left(\frac{q_{L,t}B_{FL,t}(i)}{P_t}\right)^{\frac{\lambda_L-1}{\lambda_L}} + (1-\gamma_L)^{\frac{1}{\gamma_L}}\left(\frac{e_t q^*_{L,t} B_{UL,t}(i)}{P_t}\right)^{\frac{\lambda_L-1}{\lambda_L}}\right]^{\frac{\lambda_L}{\lambda_L-1}}, \quad (4)$$

where $B_{Fj,t}(i)$ and $B_{Uj,t}(i)$ denote the household allocation of foreign-originated and US-originated j-term bonds, respectively, with $j = S, L$, γ_j is a parameter that determines the importance of foreign region relative to US j-term bonds in utility, λ_j denotes the elasticity of substitution between foreign region and US j-term bonds, $q_{L,t}$ and $q^*_{L,t}$ denote the relative prices of LT bonds in the foreign economy and in the US, respectively, and e_t denotes the nominal foreign-US exchange rate (i.e., the price of the US currency in terms of the foreign currency).[10]

The household budget constraint is the following:

$$c_t(i)+q_t\left[k_t(i)-(1-\delta)\,k_{t-1}(i)\right]+\frac{B_{FS,t}(i)}{P_t}+\frac{e_t B_{US,t}(i)}{P_t}+\frac{q_{L,t}B_{FL,t}(i)}{P_t}+\frac{e_t q^*_{L,t}B_{UL,t}(i)}{P_t} \leq$$

[9] Imperfect substitution among the various types of government bonds captures the differential "convenience yields" generated by these assets, as well as financial institutions' relative portfolio preferences for different types of government bonds (i.e., their "preferred habitat"). The role of "convenience yields" in explaining imperfectly substitutability between assets and, in turn, exchange rate movements, is studied in Engel and Wu (2018) and Jiang et al. (2021). The role of "preferred habitat" in explaining imperfectly substitutability between assets has been studied in several recent papers, including Vayanos and Vila (2021) and Gourinchas et al. (2022).

[10] Evidence suggests that domestic and foreign assets tend to be less than perfectly substitutable with each other. Hau and Rey (2004), for instance, find evidence in support of the portfolio balance channel affecting exchange rates, as do Valchev (2020), Engel and Wu (2018), and Jiang et al. (2021).

$$\frac{W_t(i)}{P_t}N_t + r_{k,t}K_{t-1} + \frac{R_{t-1}B_{FS,t-1}(i)}{P_t} + \frac{e_t R^*_{t-1}B_{US,t-1}(i)}{P_t} + \frac{R_{L,t}B_{FL,t-1}(i)}{P_t} +$$

$$\frac{e_t R^*_{L,t-1}B_{UL,t-1}(i)}{P_t} + \Pi_{F,t} + \Pi_{U,t} + \frac{TAX_t}{P_t} - \left(\frac{W_t(i)/W_{t-1}(i)}{\pi_{t-1}^{\zeta_w}\bar{\pi}^{1-\zeta_w}} - 1\right)^2 \frac{W_t}{P_t}N_t, \tag{5}$$

where $k_t(i)$ denotes the household capital investment holdings, q_t denotes the relative price of capital, W_t denotes the nominal wage rate, $r_{k,t}$ denotes the rental rate of capital, δ denotes the rate of capital depreciation, R_t and R^*_t denote the ST interest rates in the foreign region and US, respectively (both determined by policy rules), and $q_{L,t}$ and $q^*_{L,t}$ denote the relative prices of LT bonds in the foreign region and US, respectively. LT bonds are modeled as perpetuities that issue a nominal coupon payment of one unit in the first period after issuance, with payments decaying by a factor of κ in subsequent periods. Accordingly, the LT rates, denoted by $R_{L,t}$ and $R^*_{L,t}$, are related to the relative prices of LT bonds, based on the following identities:

$$R_{L,t} = \frac{1}{q_{L,t}} + \kappa, \qquad\qquad R^*_{L,t} = \frac{1}{q^*_{L,t}} + \kappa \tag{6}$$

$\Pi_{H,t}$ and $\Pi_{F,t}$ denote profits earned by monopolistically competitive goods producers (that are transferred to households), and TAX_t denotes lump-sum transfers of government tax revenues. Households supply heterogenous labor services, which are aggregated into a homogenous bundle and rented to domestic producers at the aggregate wage rate. We assume that individual wages are subject to nominal rigidities, modeled in a similar way as in Rotemberg (1982), where wages face a quadratic adjustment cost. This cost is represented by the final term in equation (5), where ζ_w denotes the degree of wage indexation to past inflation, κ_w is a level parameter, $\pi_t = P_t/P_{t-1}$ denotes one-period consumer price inflation, and $\bar{\pi}$ denotes the inflation target.

2.1.1 Short- and long-term investment-savings curves

Households optimize equation (1) subject to (5), which yields the following first-order conditions:

$$\frac{1}{c_t - \zeta c_{t-1}} = \lambda_t, \tag{7}$$

$$q_t \lambda_t = \beta E_t \left[\lambda_{t+1} \left((1-\delta) q_{t+1} + r_{k,t+1} \right) \right], \tag{8}$$

where λ_t denotes the Lagrange multiplier on the budget constraint.

The household first-order conditions for holdings of foreign ST and US ST bonds are the following:

$$\lambda_t = \beta E_t \left[\lambda_{t+1} \frac{R_t}{\pi_{t+1}} \right] + \frac{\xi_a}{A_t} \frac{\partial a_t}{\partial a_{S,t}} \frac{\partial a_{S,t}}{\partial b_{FS,t}} \tag{9}$$

$$rer_t \lambda_t = \beta E_t \left[rer_{t+1} \lambda_{t+1} \frac{R_t^*}{\pi_{t+1}^*} \right] + \frac{\xi_a}{A_t} \frac{\partial a_t}{\partial a_{S,t}} \frac{\partial a_{S,t}}{\partial b_{US,t}}, \tag{10}$$

where $b_{FS,t} = B_{FS,t}/P_t$, $b_{US,t} = B_{US,t}/P_t$ and $rer_t = e_t P_t^*/P_t$ denotes the real exchange rate. Similarly, the first-order conditions for holdings of foreign LT and US LT bonds are the following:

$$q_{L,t} \lambda_t = \beta E_t \left[\lambda_{t+1} \frac{q_{L,t+1} R_{L,t+1}}{\pi_{t+1}} \right] + \frac{\xi_a}{A_t} \frac{\partial a_t}{\partial a_{L,t}} \frac{\partial a_{L,t}}{\partial b_{FL,t}} \tag{11}$$

$$rer_t q_{L,t}^* \lambda_t = \beta E_t \left[rer_{t+1} \lambda_{t+1} \frac{q_{L,t+1}^* R_{L,t+1}^*}{\pi_{t+1}^*} \right] + \frac{\xi_a}{A_t} \frac{\partial a_t}{\partial a_{L,t}} \frac{\partial a_{L,t}}{\partial b_{UL,t}}, \tag{12}$$

where $b_{FL,t} = B_{FL,t}/P_t$ and $b_{UL,t} = B_{UL,t}/P_t$.

After log-linearizing equations (11) and (12), combining them, and iterating forward, we arrive at the following expression for the LT interest rate:

$$\widehat{R}_{L,t} = \left(1 - \frac{\kappa}{\bar{R}_L}\right) E_t \sum_{s=1}^{\infty} \left(\frac{\kappa}{\bar{R}_L}\right)^s \left[\widehat{R}_{t+s} + \left(\frac{\bar{\pi}}{\beta}\bar{R} - 1\right) \widehat{T}_{t+s} \right], \tag{13}$$

where "$\bar{x}$" denotes the steady-state value of variable x, "$\widehat{x}_t$" denotes the log deviation of variable x in period t from its steady-state value. The expression $\bar{R}/\bar{\pi}$ denotes the steady-state real return on ST government bonds, and $1/\beta$ denotes the time discount rate for households. We assume that, for households, the utility value of holding bonds is over and above their pecuniary benefits and, hence, in the steady state, the real return on bonds is lower than their pecuniary benefits and $\bar{\pi}/(\beta\bar{R}) > 1$. The expression $\widehat{T}_{t+s}$ represents the contribution of relative bond holdings in period $t+s$ to the overall term premium.

The term premium is defined as the return on the LT bond that is in excess of the average of the current and future ST interest rates that are expected to prevail over the life of the LT bond. The period t contribution to the overall term premium is defined as the following:

$$\widehat{T}_t = \frac{1}{\lambda_a}\left(\widehat{a}_{L,t} - \widehat{a}_{S,t}\right) - \frac{1}{\lambda_L}\left[\widehat{a}_{L,t} - \left(\widehat{q}_{L,t} + \widehat{b}_{FL,t}\right)\right] + \frac{1}{\lambda_S}\left[\widehat{a}_{S,t} - \widehat{b}_{FS,t}\right] \tag{14}$$

The total term premium can be defined as the term found in the right side of the bracketed expression in equation (13) above:

$$tp_t = \left(1 - \frac{\kappa}{\bar{R}_L}\right)\left(\frac{\bar{\pi}}{\beta}\bar{R} - 1\right) E_t \sum_{s=1}^{\infty} \left(\frac{\kappa}{\bar{R}_L}\right)^s \widehat{T}_{t+s} \tag{15}$$

To see how consumption is related to the term premium, it is useful to log-linearize and combine households' first-order conditions with respect to the four types of bonds to yield an investment-savings (IS) curve equation of the following form:

$$\widehat{\lambda}_t = \beta\frac{\bar{R}}{\bar{\pi}}\left(E_t\widehat{\lambda}_{t+1} + \widehat{R}^a_t - E_t\widehat{\pi}_{t+1}\right) - \left(1 - \beta\frac{\bar{R}}{\bar{\pi}}\right)\widehat{a}_t, \tag{16}$$

where $\widehat{R}_t^a$ is the return on the bond portfolio given by

$$\begin{aligned}\widehat{R}_t^a &\equiv \gamma_a \gamma_S \widehat{R}_t + (1-\gamma_a)\gamma_L \left(\widehat{R}_t + \widehat{T}_t\right) \\ &\quad + \gamma_a(1-\gamma_S)\left(\widehat{R}_t^* + E_t \widehat{d}_{t+1}\right) + (1-\gamma_a)(1-\gamma_L)\left(\widehat{R}_t^* + \widehat{T}_t^* + E_t \widehat{d}_{t+1}\right), \end{aligned} \tag{17}$$

and $\widehat{d}_t = \widehat{e}_t - \widehat{e}_{t-1}$ denotes a nominal depreciation in the foreign currency. Note that, in the absence of imperfect substitutability between the four types of bonds, we would have

$$\widehat{R}_t = \widehat{R}_t + \widehat{T}_t = \widehat{R}_t^* + E_t \widehat{d}_{t+1} = \widehat{R}_t^* + \widehat{T}_t^* + E_t \widehat{d}_{t+1}, \tag{18}$$

and thus, $\widehat{T}_t = \widehat{T}_t^* = 0$ and the IS curve would reduce to

$$\widehat{\lambda}_t = \beta \frac{\bar{R}}{\bar{\pi}} \left(E_t \widehat{\lambda}_{t+1} + \widehat{R}_t - E_t \widehat{\pi}_{t+1}\right) - \left(1 - \beta \frac{\bar{R}}{\bar{\pi}}\right) \widehat{a}_t, \tag{19}$$

where $\widehat{a}_t$ appears in the IS curve as a result of the bonds-in-utility assumption.[11] With imperfect substitutability, however, the relevant interest rate in the IS equation is a function of not only the foreign ST rate but also of the foreign LT rate, as well as the US ST and LT rates. Furthermore, the importance of each interest rate for consumption demand is linked to the portfolio share of the related bonds.

Equation (16) implies that FX interventions can have indirect effects through domestic demand. This is because FX interventions alter the portfolio shares of LT bonds relative to ST bonds and move the foreign term premium, $\widehat{T}_t$. The extent of this domestic-demand effect depends on the maturity structure of the intervention as well as steady-state portfolio shares and the degree of substitution across assets.

[11] In the absence of utility benefits of bonds, the real interest rate at the steady state would be equal to $\bar{R}/\bar{\pi} = 1/\beta$, and the above expression would reduce to the standard IS curve in the New Keynesian literature. Since $\bar{R}/\bar{\pi} < 1/\beta$ in our model, signaling ST interest rate changes in the future by the central bank do not affect current demand as much. Thus, this extra discounting generated by the bonds-in-utility specification can partly help solve the "forward guidance puzzle" (Michaillat and Saez, 2021).

2.1.2 Modified uncovered interest parity condition

After combining equations (9) and (10), and log-linearizing, we can derive a modified ST uncovered interest parity (UIP) condition:

$$E_t\widehat{d}_{t+1} = \widehat{R}_t - \widehat{R}^*_t + \left(\frac{1-\beta\frac{\bar{R}}{\bar{\pi}}}{\beta}\frac{\bar{R}}{\bar{\pi}}\right)\frac{1}{\lambda_S}\left[\left(\widehat{b}^*_{US,t} - \widehat{b}^*_{FS,t}\right) + \widehat{rer}_t\right], \tag{20}$$

The modified UIP condition indicates that the ST interest rates between the two regions can diverge without any movement in the expected nominal exchange rate, provided that the relative holdings of foreign region and US ST bonds by US households adjust. When the US lowers its ST rate, the foreign government can prevent expected depreciation (appreciation today) by purchasing US ST bonds, which induces US households to substitute away from US ST bonds and towards foreign ST bonds. In other words, the foreign government can stabilize the exchange rate and still maintain some degree of ST policy independence from the US.

We also note that the modified UIP condition differs from the classic UIP condition only if the elasticity of substitution between foreign region and US ST bonds (λ_S) is sufficiently small. As λ_S approaches infinity, expression (20) collapses to the classic UIP condition.

The model also yields an analogous UIP condition for LT rates, which is the following:

$$\begin{aligned} E_t\widehat{d}_{t+1} = {} & \frac{\bar{R}_L\widehat{R}_{L,t} - \kappa E_t\widehat{R}_{L,t+1}}{\bar{R}_L - \kappa} - \frac{\bar{R}_L\widehat{R}^*_{L,t} - \kappa E_t\widehat{R}^*_{L,t+1}}{\bar{R}_L - \kappa} + \\ & \left(\frac{1-\beta\frac{\bar{R}}{\bar{\pi}}}{\beta}\frac{\bar{R}}{\bar{\pi}}\right)\frac{1}{\lambda_L}\left[\left(\widehat{q}^*_{L,t} + \widehat{b}^*_{UL,t} - \widehat{q}_{L,t} - \widehat{b}^*_{FL,t}\right) + \widehat{rer}_t\right] \end{aligned} \tag{21}$$

From equation (21), one can see how the analogous dynamics of the LT UIP condition play out. Deviations from LT interest parity can emerge without inducing a change in the expected nominal exchange rate as long there is movement in the cross-region LT bond holdings of US households and provided that the value of λ_L is sufficiently low.

2.2 Monetary policy

Monetary policy has three levers in this environment: interest rate determination, quantitative easing, and FX interventions through bond purchases.

2.2.1 Interest rate determination

The government targets the ST nominal interest rate through the following Taylor-type rule:

$$\ln R_t = \rho \ln R_{t-1} + (1-\rho)\left[\ln R + r_\pi \ln \frac{\pi_t}{\bar{\pi}} + r_y \ln \frac{y_t}{\bar{y}} + r_{\Delta y} \ln \frac{y_t}{y_{t-1}}\right] + e_{r,t}, \tag{22}$$

where $\bar{\pi}$ and $\bar{y}$ denote the steady targets for inflation and output, respectively, r_π and r_y are parameters that govern the sensitivity of interest rate movements to deviations in inflation and output relative to the target, $r_{\Delta y}$ is a parameter that governs the interest rate sensitivity to changes in output, ρ governs the degree of interest rate smoothing, and $e_{b,t}$ denotes an i.i.d shock to monetary policy.

2.2.2 Quantitative easing

In both regions, ST and LT bonds are issued by the government. The government sets the relative supply of these bonds as the following:

$$\frac{q_{L,t} b_{L,t}}{b_{S,t}} = \gamma_{b,t}, \tag{23}$$

where $b_{S,t}$ and $b_{L,t}$ represent the supply of ST and LT government bonds (in real terms), respectively, and $\gamma_{b,t}$ is exogenous and follows an i.i.d. process:

$$\ln\gamma_{b,t} = \ln\bar{\gamma}_b + e_{b,t}, \tag{24}$$

where $\bar{\gamma}_b$ denotes the supply of LT relative to ST bonds issued in the steady state and $e_{b,t}$ denotes an i.i.d. innovation.[12] Decreases in $e_{b,t}$ represent a positive QE shock as the relative supply of LT bonds in the economy is lowered.

2.3 FX interventions through US bond purchases

In addition to purchases made by foreign and US households, the foreign government also purchases US bonds. We assume that these purchases are non-zero in the steady state, and purchases that deviate from the steady state are dictated by an exchange rate stability motive, based on the following rules:

$$\ln b^g_{US,t} = \rho_g \ln b^g_{US,t-1} + (1-\rho_g)\left[\ln\frac{b^{\bar{g}}_{US}}{\bar{y}} + r^g_s \ln\frac{e_t}{e_{t-1}}\right] + e^g_{US,t}, \tag{25}$$

$$\ln b^g_{UL,t} = \rho_g \ln b^g_{UL,t-1} + (1-\rho_g)\left[\ln\frac{b^{\bar{g}}_{UL}}{\bar{y}} + r^g_l \ln\frac{e_t}{e_{t-1}}\right] + e^g_{UL,t}, \tag{26}$$

where $b^g_{Uj,t}$ denotes the foreign government's purchase of US government j-term bonds, with $j = S, L$, ρ_g is a persistence parameter for these purchases, $b^{\bar{g}}_{Uj}$ denotes the steady-state value of j-term bond purchases, r^g_j is a parameter that governs the responsiveness of j-term bond purchases to exchange rate movements, and $e^g_{Uj,t}$ is an i.i.d j-term bond purchase shock.

[12]Since $q_{L,t}$ is equal on 1 in steady state, $\bar{\gamma}_b = \bar{b_L}/\bar{b_S}$.

The foreign government's budget constraint is the following:

$$\frac{P_{F,t}g_t}{P_t} + \frac{R_{t-1}}{\pi_t}b_{S,t-1} + \frac{R_{L,t}}{\pi_t}q_{L,t}b_{L,t-1} + rer_t\left(b^g_{US,t} + q^*_{L,t}b^g_{UL,t}\right) =$$

$$\frac{TAX_t}{P_t} + b_{S,t} + q_{L,t}b_{L,t} + rer_t\left(\frac{R^*_{t-1}b^g_{US,t-1}}{\pi^*_t} + \frac{R^*_{L,t}q^*_{L,t}b^g_{UL,t-1}}{\pi^*_t}\right), \tag{27}$$

where $P_{F,t}g_t$ denotes the nominal value of government spending.

Taxes are imposed according to the following process:

$$TAX_t = \phi_T\left(\frac{y_t}{\bar{y}}\right)^{\tau_y}\left(\frac{b_{S,t-1} + q_{L,t-1}b_{L,t-1}}{b_{S,t} + q_{L,t}b_{L,t}}\right)^{\tau_b}, \tag{28}$$

where ϕ_T is a parameter for the steady-state level of taxes, τ_y and τ_b are parameters that govern the tax response to changes in output relative to the steady state and changes in the supply of government bonds, respectively. Expressions that are analogous to (27) and (28) hold for the US government, but in this case $b^{g*}_{Fj,t}$ is set to zero for $j = S, L$ for all periods.

When the foreign government undertakes an FX intervention, it purchases US government bonds and contemporaneously issues its own government bonds, which balances the government budget constraint in (27). This, in effect, leaves the money supply unchanged and sterilises the intervention, and therefore the intervention does not affect the real economy through a change in the money supply. Moreover, so long as there is no quantitative easing shock, the new issues of foreign bonds are provided in both ST and LT bonds so that their relative supply is consistently equal to the steady state relative supply in accordance with (23). Therefore, there is no sense in which the FX intervention leads to a change in the foreign term premium due to the issuance of new foreign bonds.

To understand how FX interventions do influence economic activity, we consider expressions that are analogous to equations (14), (16) and (17) except for the US economy, which is indicated by superscript $(*)$:

$$\widehat{T}_t^* = \frac{1}{\lambda_a}\left(\widehat{a}_{L,t}^* - \widehat{a}_{S,t}^*\right) - \frac{1}{\lambda_L}\left[\widehat{a}_{L,t}^* - \left(\widehat{q}_{L,t}^* + \widehat{b}_{UL,t}^*\right)\right] + \frac{1}{\lambda_S}\left[\widehat{a}_{S,t}^* - \widehat{b}_{US,t}^*\right] \tag{29}$$

$$\widehat{\lambda}_t^* = \beta\frac{\bar{R}}{\bar{\pi}}\left(E_t\widehat{\lambda}_{t+1}^* + \widehat{R}_t^{a*} - E_t\widehat{\pi}_{t+1}^*\right) - \left(1 - \beta\frac{\bar{R}}{\bar{\pi}}\right)\widehat{a}_t^* \tag{30}$$

$$\begin{aligned}\widehat{R}_t^{a*} &\equiv \gamma_a^*\gamma_S^*\widehat{R}_t^* + (1-\gamma_a^*)\gamma_L^*\left(\widehat{R}_t^* + \widehat{T}_t^*\right) \\ &+ \gamma_a^*(1-\gamma_S^*)\left(\widehat{R}_t - E_t\widehat{d}_{t+1}\right) + (1-\gamma_a^*)(1-\gamma_L^*)\left(\widehat{R}_t + \widehat{T}_t - E_t\widehat{d}_{t+1}\right)\end{aligned} \tag{31}$$

When the foreign government undertakes an FX intervention, the impact on US GDP depends largely on how this intervention impacts the US term premium. A positive shock to foreign government reserves of US ST bonds will reduce the relative supply of US ST bonds in the private bond market, leading to a reduction in US private holdings of US ST bonds and an increase in the US term premium, which can be seen in expression (29). As expressions (31) and (30) indicate, this will raise $\widehat{R}_t^{a*}$ and, in turn, marginal utility (λ_t^*), and correspondingly lower consumption in the US economy. In contrast, a positive shock to foreign government reserves of US LT bonds will reduce the relative supply of US LT bonds in the private bond market. This will lower US private holdings of LT bonds and lower the US term premium, leading to lower marginal utility and, correspondingly, higher consumption in the US economy. Because ST and LT bonds are internationally substitutable, these effects will spill over and have similar effects on the term premium and consumption in the foreign economy.

Key factors that drive these results are that the ST interest rate is relatively inert while the term premium is more responsive to supply and demand. Interventions that lower the supply of ST bonds have little impact on the ST rate but interventions that lower the supply of LT bonds have a larger impact on the LT rate. As a consequence, the average return to savings falls much more with the LT intervention compared to the ST one and, therefore, the former is more successful at inducing households to increase their spending.

The strength of these forces, and the degree to which the impacts on the US economy spill over to the foreign economy, depend to a large degree on the elasticities of substitution presented in the above model (λ_a, λ_S, and λ_L). In the next section we explain how we calibrate these and other parameters.

The remaining details of the model, including the production economy, the labor market, and the price-setting and market-clearing conditions, are provided in Appendix A.

3 Data and calibration

The model presented in Section 2 is similar to the model provided in Alpanda and Kabaca (2020) and, where possible, we set the parameters to values that were either calibrated or estimated in that paper.[13] Table 1 reports the calibrated parameter values and Table 2 reports the calibrated steady-state values that we apply in our simulations.

One important way the model in this paper differs from the model provided in Alpanda and Kabaca (2020) is that it separates the steady-state foreign region holdings of US bonds (ST and LT) into those held by foreign households and those held by the foreign government. We calculate the total supply of US ST bonds, based on data from the Federal Reserve's Financial Accounts of the United States (FRFAUS). Our definition of US ST bonds includes government-issued cash, reserves and bonds with maturities of one year or less. Formally, our definition includes total marketable treasury bills, vault cash held by depository institutions, reserves of depository institutions held at the Federal Reserve, and currency held outside of banks. We calculate foreign-held US ST bonds to include rest-of-

[13]More specifically, we set parameters equal to the estimates from Alpanda and Kabaca (2020), from a version of their model where λ_a, λ_S, and λ_L are each restricted to being equal across regions.

the-world-owned treasury bills and rest-of-the-world-owned currency, both derived from the FRFAUS data. For the foreign government-held share of these assets, we look to US net international investment position data provided by the US Bureau of Economic Analysis (BEA). From this source, we include official foreign assets that fall under US treasury bills and certificates, and currency and deposits.[14]

We calculate the total supply of US LT bonds based on the FRFAUS data to include all US government-issued bonds with maturities greater than one year. Formally, our definition includes other marketable treasuries excluding those held by the Federal Reserve. We calculate foreign-held US LT bonds to include rest-of-the-world-owned other treasury securities. For the foreign government-held share of these assets, we again look to the US net international investment position data provided by the BEA. From this source, we include official foreign assets that fall under US treasury bonds and notes.

Figure 2 reports the breakdown of US government-issued ST and LT securities across the types of holders of these assets for the 2000 to 2007 period, based on our calculations.[15] The figure shows that US private residents account for a high share of US ST bond holdings and that US private residents and foreign government entities, together, account for the lion's share of US LT bond holdings. For all three types of holders, holdings of LT bonds are higher than holdings of ST bonds and this is particularly true for foreign government holdings (FX reserves).[16]

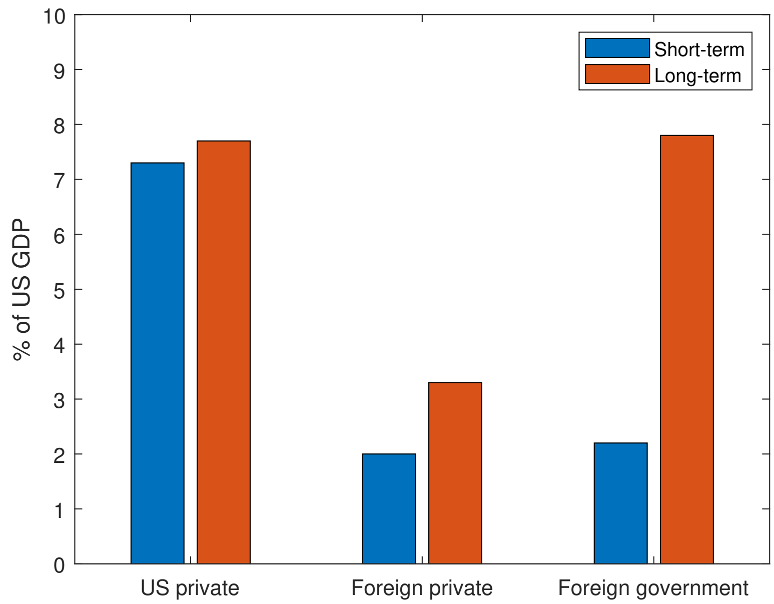
In the baseline version of the model, we set r_s^g and r_l^g to zero so that FX interventions by the foreign government do not respond directly to exchange rate movements. In section

[14]We assume that all US holdings of foreign region bonds are held by the private sector. This is roughly consistent with our estimates from the data, where the US government share of total US resident holdings of foreign bonds is very low (less than 5%) and, in value terms, are only a small fraction of the value of foreign government holdings of US bonds.

[15]We focus on the 2000 to 2007 period to match the calibration window used in Alpanda and Kabaca (2020), which was chosen in that paper due to a combination of data constraints and a desire to avoid the zero lower bound (ZLB) period.

[16]In more-recent years, the total supply of US ST and LT bonds has increased substantially (as a percentage of GDP). This greater supply has led to higher holdings for all three types of holders, and foreign government entities have increased their relative holdings of LT to ST bonds.

Figure 2: Distribution of US government liabilities across holders, 2000 to 2007



Data source: BEA and FRFAUS data

4.3, we consider simulations where r_s^g and r_l^g are set sufficiently high so that the exchange rate is partially stabilized for a period of time. We also set the parameter $\rho_g = 0.97$ so that the FX interventions are quite persistent.

In terms of country size, the foreign region is 2.5 times the size of the US, and both regions rely on domestic and imported goods and bonds, according to the calibration. For the between-region bond-substitution elasticity parameters, we set the values $\lambda_S = 10.98$ and $\lambda_L = 3.61$. Both are significantly higher than one but sufficiently low so that the FX interventions will have an effect on the nominal exchange rate (see equations (20) and (21)). In terms of the the ST-LT bond-substitution elasticity, we set $\lambda_a = 0.78$. As we show in our sensitivity analysis, a low value of λ_a leads to much larger GDP impacts from FX interventions and also aids in generating the qualitative patterns we find in our results.

For a discussion on the remainder of the model parameters shown in Tables 1 and 2 and for details regarding the sources of the calibration and the techniques for the estimation,

Table 1: Calibrated parameters

	Symbol	Foreign	US
Preferences and bonds			
ST-LT subs	λ_a	0.7787	
ST foreign-US subs	λ_S	10.9760	
LT foreign-US subs	λ_L	3.6104	
ST-LT portfolio shares	γ_a	0.2698	0.4209
ST foreign-US portfolio shares	γ_S	0.8839	0.9784
LT foreign-US portfolio shares	γ_L	0.8863	0.7505
Discount factor	β	0.9857	
Portfolio in utility	ξ_a	0.0710	0.0539
Labor in utility	ξ_n	34.97	67.41
Domestic consumption share	γ_c	0.9438	0.857
Domestic investment share	γ_i	0.9438	0.857
Habit in consumption	ζ	0.6086	0.8111
Inverse Frisch elasticity	ϑ	1.4685	1.2814
Foreign-US consumption elasticity	λ_c	0.5610	0.5072
Foreign-US consumption elasticity	λ_i	0.7762	0.7340
LT bond coupon rate	κ	0.9773	
Real economy			
Capital share in production	α	0.34	
Capital depreciation rate	δ	0.0195	
Domestic price adj. cost	κ_F, κ_U^*	1424.46	751.60
Imported price adj. cost	κ_U, κ_F^*	705.27	211.13
Wage adj. cost	κ_w	276.67	1435.86
Domestic price indexation	ζ_F, ζ_U^*	0.1459	0.3791
Domestic price indexation	ζ_U, ζ_F^*	0.3315	0.4730
Wage indexation	ζ_w, ζ_U^*	0.0734	0.1205
Capital adj. cost	φ	5.6428	
Utilization cost elasticity	ϖ	0.3203	0.3332
Policy rules			
FX: ST exchange rate	r_s^g	0	-
FX: LT exchange rate	r_l^g	0	-
FX: persistence	ρ_g	0.97	-
Taylor: inflation	r_π	1.4502	1.5844
Taylor: output	r_y	0.2418	0.1539
Taylor: output change	$r_{\delta y}$	0.1357	0.1417
Taylor: persistence	ρ	0.9107	0.9139
Tax: output	τ_y	0.9828	1.0112
Tax: debt	τ_b	0.8570	0.7917

Table 2: Calibrated steady-state ratio parameters

	Symbol	Foreign	US
Real economy			
Output	$\bar{y}$	2.5	1
Gross qtr. inflation	$\bar{\pi}$	1.005	
Gross markup domestic goods	$\bar{\theta_F}, \bar{\theta_U^*}$	1.25	
Gross markup imported goods	$\bar{\theta_U}, \bar{\theta_F^*}$	1.25	
Gross markup wages	$\bar{\theta_w}$	1.25	
Utilization cost level	κ_k	0.034	
Tax level	ϕ_T	0.2115	0.2073
Consumption/GDP	$\bar{c}/\bar{y}$	0.6062	0.6020
Investment/GDP	$\bar{i}/\bar{y}$	0.195	
Government/GDP	$\bar{g}/\bar{y}$	0.2	
Exports/GDP	$\bar{y_F^*}/\bar{y}, \bar{y_U}/\bar{y^*}$	0.0438	0.1171
Imports/GDP	$\bar{y_U}/\bar{y}, \bar{y_F^*}/\bar{y^*}$	0.0450	0.1140
Capital/GDP (ann.)	$\bar{y_U}/\bar{y}, \bar{y_F^*}/\bar{y^*}$	2.5	
Bond supply			
ST/GDP	$\bar{b_s}/\bar{y}$	0.1270	0.1139
LT/GDP	$\bar{b_l}/\bar{y}$	0.3530	0.1864
Privately held bonds			
Domestic ST / GDP	$\bar{b_{FS}}/\bar{y}$, $\bar{b_{US}^*}/\bar{y^*}$	0.1264	0.0724
Domestic LT / GDP	$\bar{b_{FL}}/\bar{y}$, $\bar{b_{UL}^*}/\bar{y^*}$	0.3428	0.0764
Imported ST / GDP	$\bar{b_{US}}/\bar{y}$, $\bar{b_{FS}^*}/\bar{y^*}$	0.0080	0.0016
Imported LT / GDP	$\bar{b_{UL}}/\bar{y}$, $\bar{b_{FL}^*}/\bar{y^*}$	0.0133	0.0254
Government-held bonds			
Imported ST / GDP	$\bar{b_{US}^g}/\bar{y}$	0.0086	-
Imported LT / GDP	$\bar{b_{UL}^g}/\bar{y}$	0.0307	-

we refer readers to descriptions provided in Alpanda and Kabaca (2020).

4 Model-based quantitative analysis

In this section, we use our calibrated model to simulate an FX intervention by the foreign government through US ST and LT bonds purchases. This exercise illustrates the impact of this type of policy on the US and foreign economies. We then evaluate the efficacy of a policy rule in the foreign economy that stabilizes the nominal exchange rate through FX interventions in response to US ST interest rate and QE shocks.

4.1 Impact of a foreign FX intervention in US ST bonds

Figures 3 and 4 show the impulse responses from an FX intervention made by the foreign government through US ST bonds purchases. Figure 3 shows the impact on the US economy and Figure 4 shows the impact on the foreign economy.

The intervention is scaled to be equivalent to a one percentage point increase in the foreign government's US ST bond reserves relative to its steady-state annual GDP. The foreign government holds roughly 19% of total US ST bonds outstanding in the steady state, and this shock moves this share to almost 26%. This intervention leads to a 1.5% appreciation in the US currency and a small deterioration in the US trade balance. US GDP and inflation fall by around 0.2% and 0.1%, respectively. For the foreign economy, GDP declines by about 0.2% despite the improvement in the trade balance. The foreign inflation rate increases slightly due to pass-through of the weaker foreign currency to consumer prices.

The key channel that drives the decline in GDP for both regions is the impact of the intervention on the term premium. The foreign government's intervention lowers the relative supply of US ST to LT bonds in the private bond market, which raises the relative price and lowers the relative yield of ST bonds and raises the term premium in the US. In equilibrium, US households lower their holdings of US ST bonds and raise their holdings of US LT bonds and both types of foreign region bonds. These changes lead to higher savings and lower consumption in the US, in accordance with the ST IS equation described in equation (16).

Since bonds are internationally substitutable, these effects spill over to foreign bonds so that the term premium rises in that region as well. Similar to US households, foreign households reallocate their holdings away from ST and towards LT bonds, but in the foreign case, the US currency appreciation also raises the price of US ST and LT bond holdings. Overall, the shock leads to similar effects in the foreign economy as in the US, where total savings increase and consumption and GDP decrease. The downward pressure from the term premium channel is complemented by the US demand channel, where the weaker GDP growth in the US lowers the foreign economy's exports growth and weighs on its GDP.

The trade balance channel, which is expansionary for the foreign economy after the intervention, is not sufficiently large to overcome the negative impact on foreign GDP through the higher term premium and weaker US demand. Therefore, the foreign GDP impact is, on balance, negative. This result supports the notion that the consequences of FX interventions can go well beyond the trade balance channel and, according to our results, can actually overturn the conventional wisdom.

4.2 Impact of a foreign FX intervention in US LT bonds

Next we turn to the case where the foreign government undertakes an FX intervention by purchasing US LT bonds. We calibrate the shock to equal a one percentage point increase in the foreign government's US LT bond reserves relative to its steady-state annual GDP. The foreign government's reserves of US LT bonds account for roughly 41% of the

Figure 3: US responses to foreign FX intervention in US ST bonds

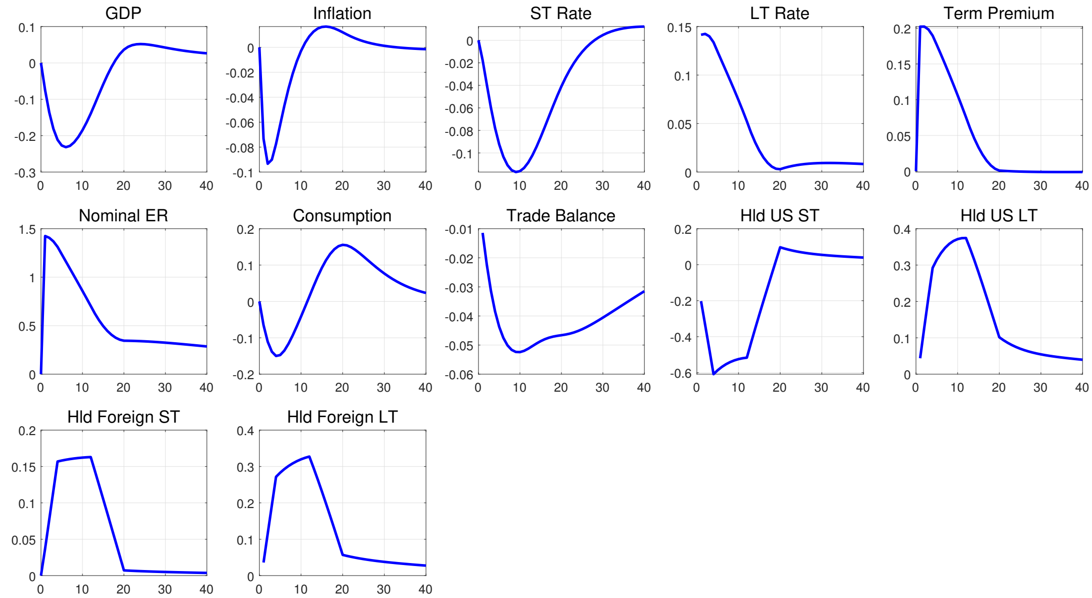


Figure 4: Foreign responses to foreign FX intervention in US ST bonds

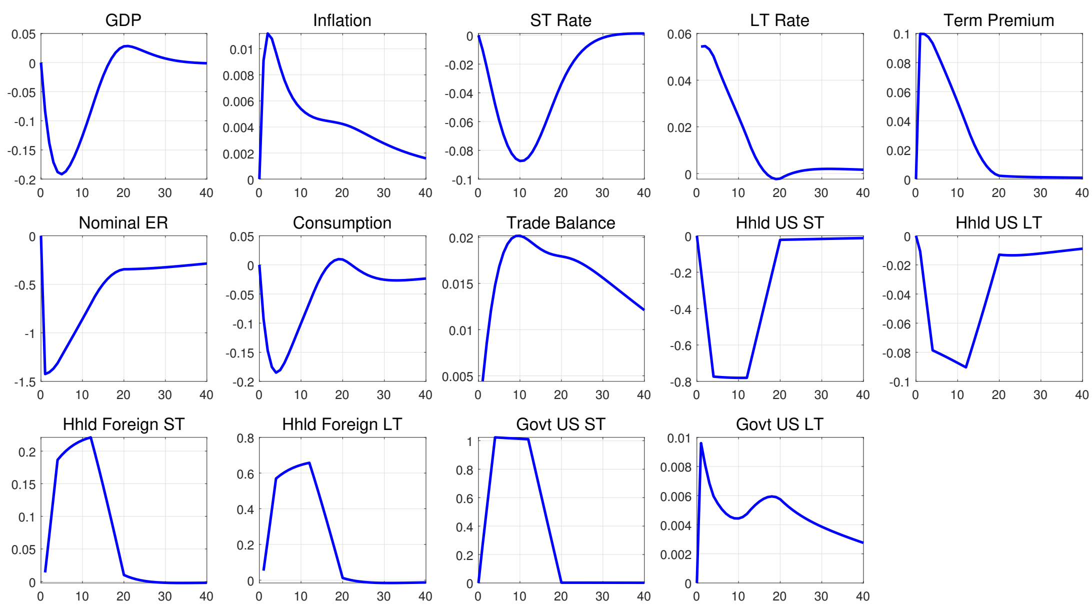


Figure 5: US responses to foreign FX intervention in US LT bonds

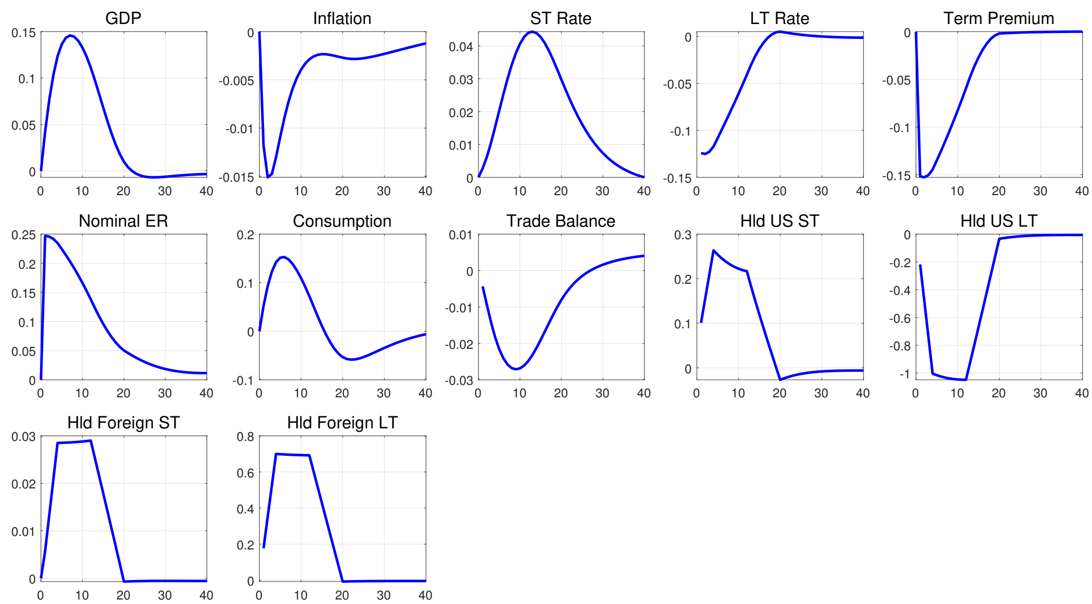
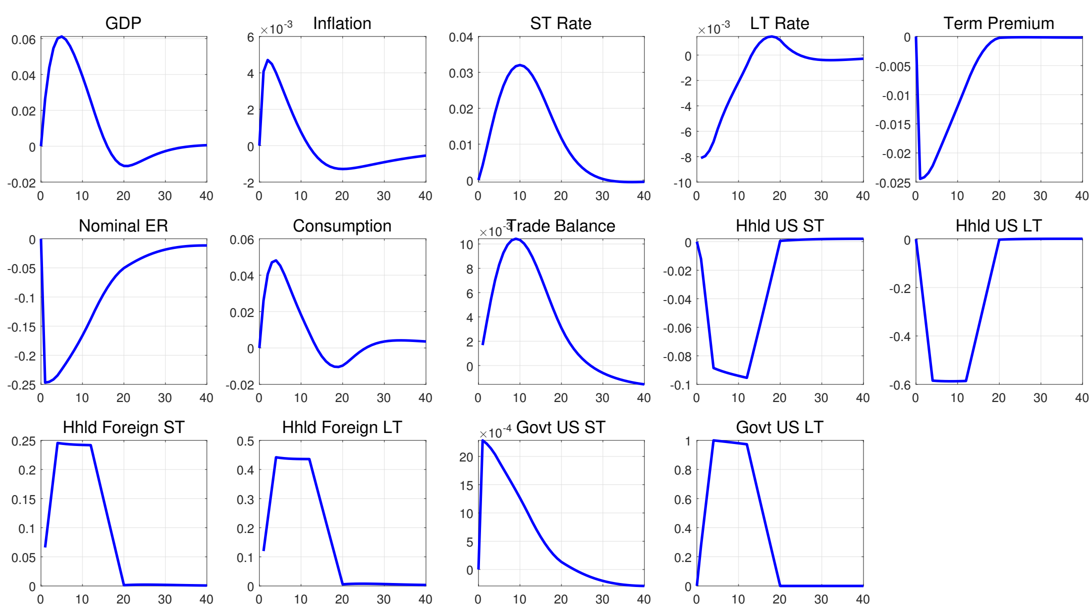


Figure 6: Foreign responses to foreign FX intervention in US LT bonds



total outstanding US LT bonds in the steady state and this shock moves this share to about 45%.

Figures 5 and 6 show the impacts of this intervention on the US and foreign economies. In the US, the intervention leads to a 0.25% appreciation in the currency and small declines in the trade balance and inflation. These impacts are qualitatively similar to the impacts from the ST bond intervention. By contrast, the LT intervention has a positive impact of about 0.15% on US GDP , which is qualitatively different from the negative impact on US GDP from the ST intervention.

Similar to the case of the ST intervention, the key driver of the US GDP response to the LT intervention is the term premium. This time, however, the term premium declines due to the shock. This is because the foreign government's purchase of US LT bonds has the effect of lowering the relative supply of US LT to ST bonds in the private market, leading to higher prices and lower yields for LT bonds. Since the relative supply of US ST bonds (and the ST interest rate) increases due to the intervention, agents hold more of these bonds, and also increase their holdings of foreign ST and LT bonds. However, these higher holdings do not compensate for the decrease in holdings of US LT bonds; consequently, savings fall and consumption rises as the marginal propensity to consume drops in accordance with equation (16).

For the foreign region, the lower term premium in the US spills over into a lower term premium in the foreign economy. The exchange rate depreciation leads to mildly higher inflation in the foreign economy and an improvement in the foreign economy's trade balance, and foreign GDP grows by about 0.06% after the shock. However, the LT intervention again illustrates how the trade balance channel does not dominate in our model. For the foreign economy, the trade balance channel, the foreign demand channel, and the term premium channel all contribute to positive GDP growth. In contrast, for the US economy, the trade balance channel negatively impacts GDP, and yet the term premium channel is sufficiently strong to generate a positive net effect on US GDP. Moreover, this net effect is actually larger than the total effect on foreign GDP, since the US term premium effect only partially spills over to the foreign term premium. Altogether, these results show that the term premium channel is the key channel in determining the GDP impacts of FX interventions in this model.

An important result here is that, for both economies, the consequences of FX interventions differ greatly depending on whether the intervention is made through US ST or LT bonds bond purchases. From the foreign perspective, which is the region making the intervention, the benefits of an LT intervention are clear as this leads to higher GDP and higher inflation, a combination that can be moderated with conventional monetary policy if required. By contrast, for the ST intervention, the impact is stagflationary for the foreign economy, as GDP falls and inflation rises. Hence, the policy is not only poor from the perspective of supporting GDP growth, conventionally a key goal of FX intervention, but it also leads to a monetary policy trade-off between curbing inflation and accelerating GDP growth. From the US perspective, the ST intervention lowers GDP growth and inflation. These impacts provide reasonable grounds for complaint and possible retaliation in normal times; they are especially bad when the US is close to the ZLB since it cannot effectively respond with conventional monetary policy easing (we show this in Appendix B). In contrast, the LT intervention leads to positive GDP growth and lower inflation and, hence, is consistent with more-favorable outcomes from the US perspective.

To summarize, these results show that the effects of FX interventions are very different, depending on the type of security that is purchased in the intervention. When ST bonds are purchased, the intervention leads to lower GDP growth for both regions, whereas when LT bonds are purchased, the intervention leads to higher GDP growth for both regions. These results appear surprising, and go against the classic beggar-thy-neighbor narrative that is typically applied to this issue. Our findings result from the fact that, in our model, the trade balance channel does not dominate but rather the term premium channel does and, as such, the portfolio balance effects of these interventions are key to understanding the implications for growth.

4.3 Exchange rate stabilization through FX interventions

In this section, we examine the consequences of a US ST interest rate shock and a US QE shock for the US and foreign economies. Under the benchmark scenario, both the US and the foreign economy set their respective ST interest rates according to the Taylor rule described in equation (22), with the calibrated parameters reported in Tables 1 and 2, where $\tau_e = \tau_{\delta e} = 0$ so that the exchange rate is allowed to float. We then compare this benchmark scenario to scenarios where the foreign government employs FX interventions to stabilize the exchange rate through purchases of i) US ST bonds and ii) US LT bonds. In both cases, we calibrate the size of these interventions so that they reduce the peak change in the nominal exchange rate by 50% relative to the benchmark no-intervention cases.

4.3.1 US ST interest rate shock

Figure 7 shows the US impulse responses from an exogenous change of -100 bps in the US ST interest rate. This leads to growth of 0.4% in US GDP, 0.15% in US inflation, and a 2.5% depreciation of the US currency in the benchmark case, indicated by the black lines. The US trade balance declines initially but then improves over the longer run, reflecting the classic "J-curve" response. Figure 8 shows the impulse responses from this shock for the foreign economy, where inflation declines slightly due to the pass-through of the appreciated exchange rate to consumer prices. In response to this weaker inflation, the foreign ST rate falls slightly and foreign GDP increases slightly due to the combination of this monetary easing and stronger US demand. Overall, the responses in the US are in line with conventional findings and, in the foreign economy, the exchange rate is the key factor that drives the inflation response and, in turn, the monetary policy response that contributes to positive GDP growth.

When the foreign government stabilizes the exchange rate through US ST bond purchases, this reduces the relative supply of private US ST to LT bonds and leads to a rise in the term premium, as indicated by the blue lines in Figure 7. The higher term premium induces US households to increase their holdings of US LT bonds and reduce their holdings of US ST bonds, relative to the benchmark case, and to increase their holdings of foreign region LT and ST bonds as well. The greater overall demand for bonds leads to lower US consumption and, as a consequence, lower GDP and inflation in the US. As indicated in Figure 8, the intervention supports the trade balance in the foreign economy (blue lines), which is often a stated goal of FX interventions. However, it does little to stabilize inflation, and foreign GDP declines by nearly 0.1% instead of rising as it does in the baseline case, a consequence of spillovers from the US economy that lead to an increase in the foreign term premium and lower consumption growth.

In sum, when the foreign economy intervenes through US ST bond purchases, US GDP increases by less than it does in the benchmark case and inflation rises initially but then declines after a few periods, as opposed to remaining positive over a longer period as it does in the benchmark case. Since US monetary policy is applied to stimulate US GDP and inflation, the fact that the foreign region's intervention suppresses these stimulative effects suggests that authorities in the US have good reason to criticize such a policy. From the foreign perspective, the intervention succeeds in supporting the region's trade balance, but this success comes at the cost of weaker GDP growth and little change in inflation.

When the foreign government stabilizes the exchange rate through US LT bond purchases, this reduces the relative supply of privately available US LT to ST bonds and leads to a decline in the term premium, indicated by the red lines in Figure 7. These changes

Figure 7: US ST interest rate shock: US impacts under different FX interventions

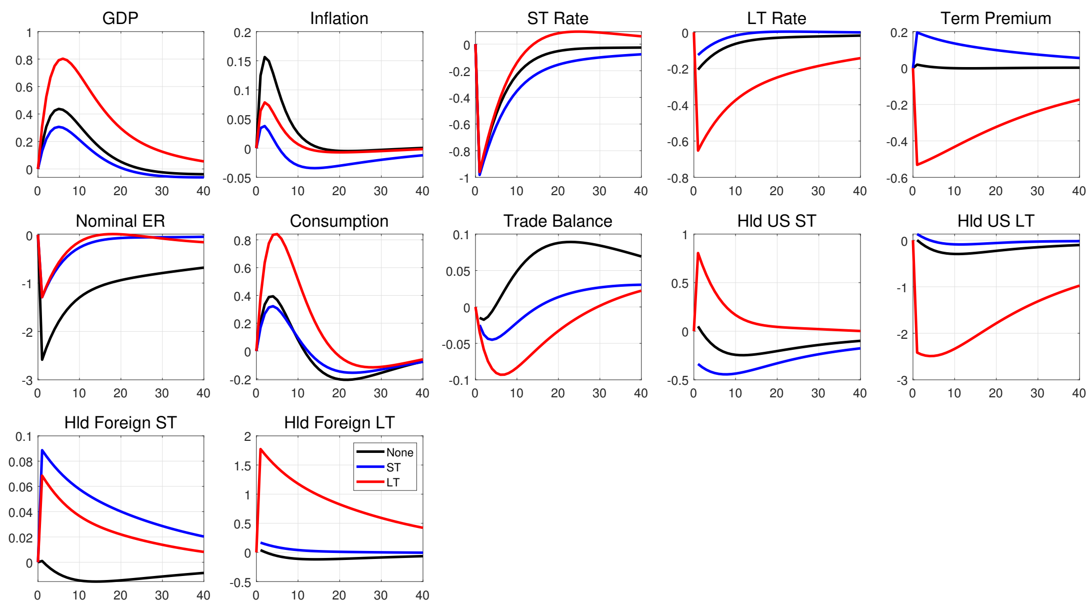
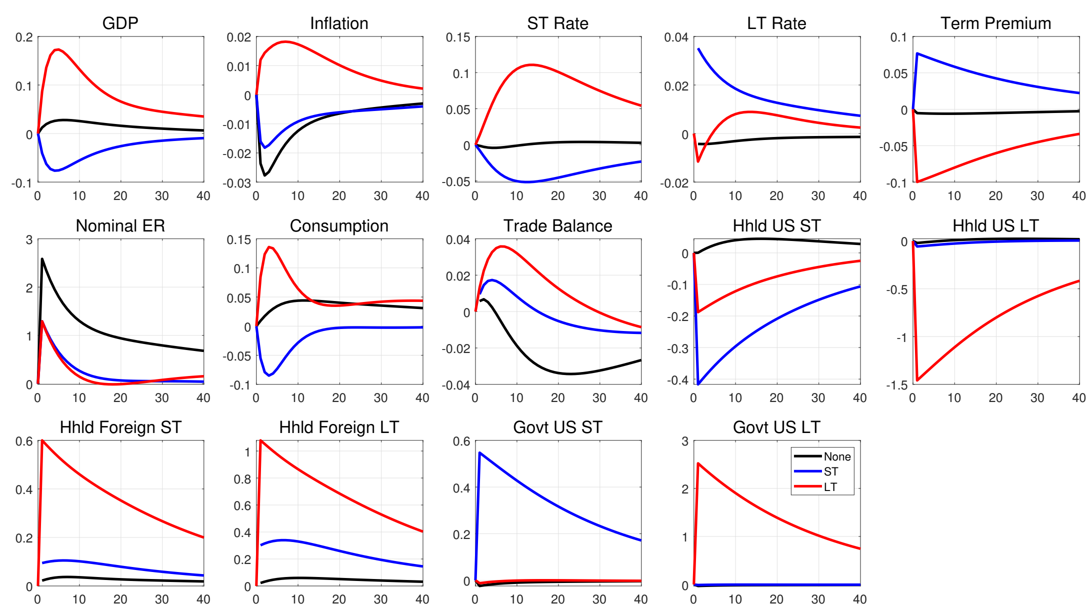


Figure 8: US ST interest rate shock: Foreign impacts under different FX interventions



lead to lower private holdings of US LT bonds and greater holdings of US ST bonds, relative to the benchmark and, as a consequence, US GDP rises. The intervention restrains the US currency depreciation that occurs due to the US ST interest rate shock, and this limits the US inflation that arises from exchange rate pass-through in the benchmark case. In the foreign economy, the intervention succeeds in supporting the trade balance, as was the case for the ST bond intervention, but in this case foreign GDP and inflation are also both stronger relative to the benchmark case. These effects arise due to spillovers of portfolio balance effects from the US, which lead to a decrease in the foreign term premium.

In sum, there are numerous reasons to support LT interventions over ST ones, and perhaps even over a no-intervention policy, as responses to conventional US monetary policy. From the US perspective, the LT intervention leads to higher growth and, hence, if the motivation for US monetary policy easing is to stimulate US GDP growth, then the LT intervention actually supports this effort. If the associated inflation that comes with the monetary policy shock is desirable, then the LT (and ST) FX intervention is problematic since it prevents the inflation that is brought on by exchange rate pass-through. But if this inflation were an undesirable consequence of stimulating the economy, then the LT FX intervention would actually help to limit the inflationary impact of monetary policy while supporting GDP growth. From the foreign perspective, the LT intervention would be successful both in preventing the deflation that arises from US monetary policy and in preventing a fall in the trade balance while also supporting domestic demand and overall output.

4.3.2 US quantitative easing shock

Figures 9 and 10 show the impulse responses for the US and foreign economies, respectively, to a US QE shock. The shock is modeled as a 2% decrease in the relative supply of the US LT to ST bonds issued, where the US ST interest rate is fixed for four periods to approximate either the ZLB on ST interest rates or a period of forward guidance. For the US economy, the benchmark no-intervention scenario sees an increase of 0.3% for GDP and 0.04% for inflation and a depreciation in the US currency, as indicated by the black lines in the figure. These effects are qualitatively similar to conventional monetary policy impacts, as described in the previous sub-section, and are in line with existing literature on the effects of QE (Alpanda and Kabaca 2020). For the foreign economy, the QE shock leads to lower inflation and a longer-run deterioration in the trade balance, both of which are a consequence of the exchange rate appreciation, as was the case for the US ST interest rate shock. We also see that foreign GDP rises in response to the US QE shock; in fact, it rises more so than it did due to the US ST interest rate shock discussed in the previous sub-section. This result is driven by a spillover of the lower US term premium to the foreign economy.

When the foreign government intervenes in the US ST bond market to stabilise the exchange rate, US GDP increases by less than it does under the benchmark scenario and US inflation is comparatively more stable in the short run, as indicated by the blue lines in Figure 9. These effects are due to the impact of the intervention on the term premium, which rises due to the intervention, leading to lower US consumption compared to the no-intervention case.[17] In a sense, the term premium effects from the FX intervention partly undo the term premium effects from the QE policy for the US economy. In the foreign economy, the intervention supports the trade balance and mildly supports inflation, both of which are likely desirable from the foreign perspective. But, as was the case in the previous sub-section, these effects come at the expense of weaker foreign GDP growth, as the lower term premium in the foreign economy that results from the US QE spillover is countered by the term premium increase that is due to the FX intervention.

When the foreign government intervenes in the US LT bond market to stabilise the

[17] In the case of US inflation, the weaker response is also due to a more-stable exchange rate.

Figure 9: US QE shock: US impacts under different FX interventions

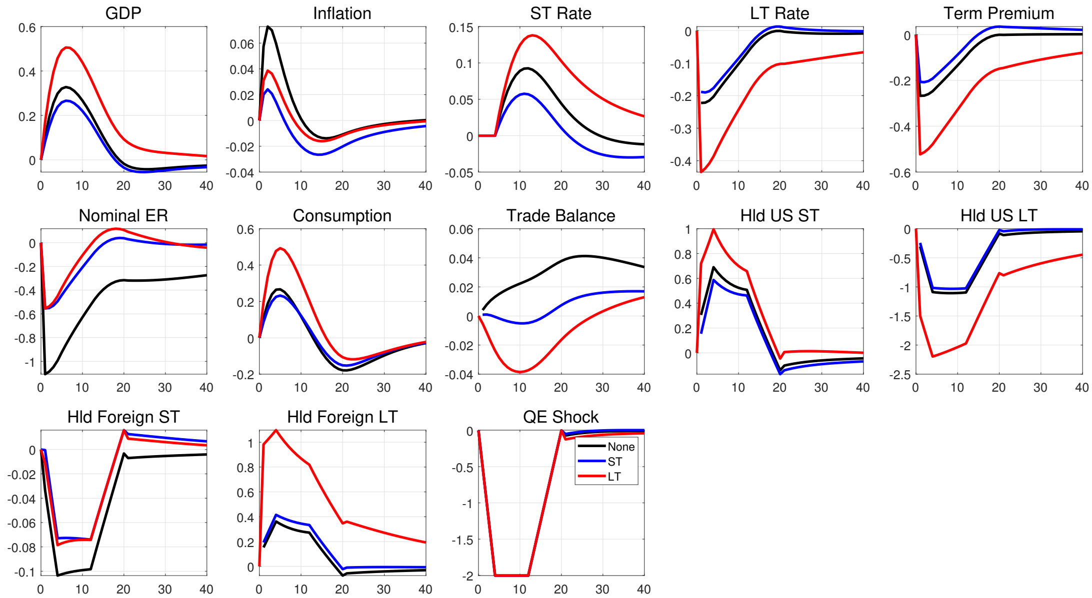
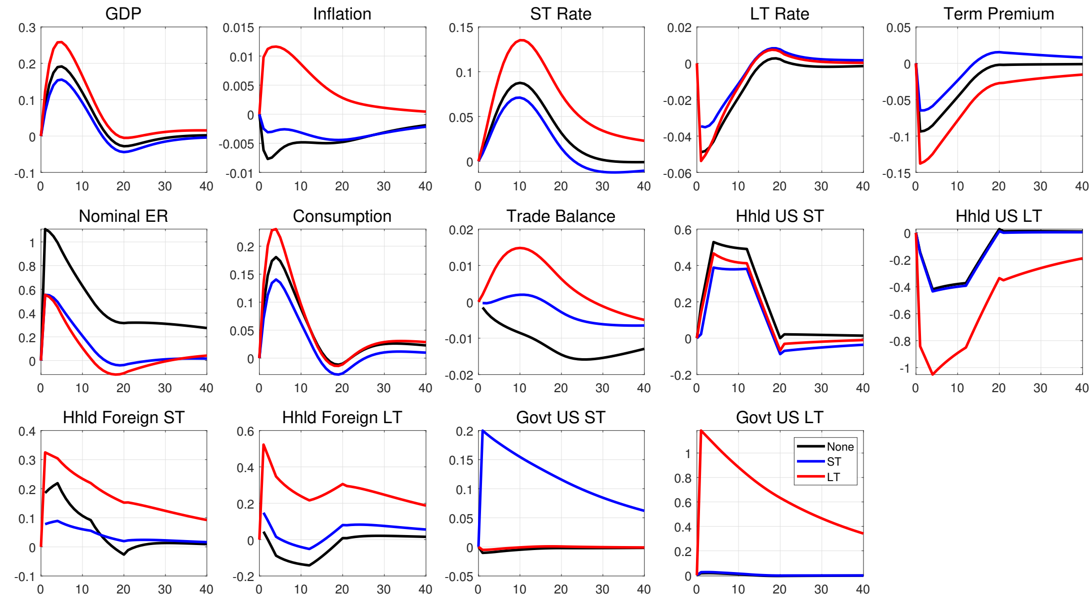


Figure 10: US QE shock: Foreign impacts under different FX interventions



exchange rate, US inflation is more stable and GDP increases by more than it does under the no-intervention case, as indicated by the red lines in Figure 9. These effects are driven by the lower term premium that results from the intervention, which in this case supports the lower term premium that arises from the QE policy. In the foreign economy, the intervention leads to stronger GDP growth and higher inflation, relative to the no-intervention case, and these are consequences of both a lower term premium and a more-stable exchange rate.

To summarize, the results from the US QE scenarios are similar, in terms of consequence, to the results from the US ST interest rate shock scenarios. When the foreign economy intervenes in the ST bond market to prevent an exchange rate appreciation, this leads to lower growth in the US compared to the benchmark case and also to lower inflation. For the foreign economy, the intervention leads to lower GDP growth and has modest impacts on inflation. When the foreign economy intervenes in the LT bond market, this increases the positive GDP effects of the QE shock for both the US and the foreign economies, while moderating the inflationary effects in the US and the deflationary effects in the foreign economy.

Compared to the conventional monetary policy results, these QE results are arguably more interesting since the channels through which the FX interventions operate are largely the same as those the QE policy operates through. QE is effective in this model because it lowers the term premium in the US and this spills over to the foreign economy due to the international substitutability of ST and LT bonds. The ST FX intervention counteracts the QE policy in the US and prevents the positive GDP impacts of QE from taking hold in both economies. The LT FX intervention does the opposite: it supports the QE policy and leads to larger term premium effects in both regions and, therefore, stronger growth. Meanwhile, for inflation, both FX interventions lead to an appreciation in the US dollar relative to the benchmark case and, therefore, due to exchange rate pass-through, the impacts on inflation from the FX interventions are different from the standard effects that arise from QE. In the end, the LT intervention is attractive in that it leads to higher GDP growth in both regions with no clear cost in terms of higher or more-volatile inflation. The ST intervention leads to lower GDP growth in the US, counteracting the QE policy, and hence might well be viewed as undesirable from that country's perspective. For the foreign economy, the ST invention leads to lower GDP growth, with little benefit in terms of inflation stability.

4.4 Robustness

In Appendix B, we examine the sensitivity of our main results from Sections 4.1 and 4.2 to several changes in the model's parameters. We find that our qualitative findings are robust to holding the ST rate in both regions fixed (e.g., due to the zero lower bound or forward guidance). We also examine how changing the bonds-in-utility elasticity parameters (λ_a, λ_S and λ_L) to more-extreme values affects our results. In several cases, these changes lead to qualitatively different results in terms of the impact of FX interventions on each economy. This result is not surprising, since changing these parameters to extreme values can severely alter the impact of the FX intervention on both the exchange rate and the term premium, and these are the channels that drive the GDP and inflation growth in our model.

5 Empirical analysis

The calibrated model described in Section 4 emphasizes the distinct implications of foreign FX interventions that involve the purchase of US ST versus LT bonds. Whereas purchases of ST FX reserves reduce GDP in both the US and foreign economies, purchases of LT FX reserves stimulate GDP in both regions. We now describe the methodology and data used to test whether these predictions are consistent with data. We then discuss the main results from our estimation.

5.1 Econometric methodology and data

We estimate the following reduced form VAR Model, for $t = 1, \ldots, T$.

$$\mathbf{Y}_t = \boldsymbol{\alpha} + \mathbf{A}_1 \mathbf{Y}_{t-1} + \cdot + \mathbf{A}_p \mathbf{Y}_{t-p} + \mathbf{u}_t,$$

where $\mathbf{Y}_t$ is a 8×1 vector of endogenous variables, $\mathbf{A}_j$'s are coefficient matrices for $j = 1, \ldots, p$, and $\mathbf{u}_t$ is a vector of reduced-form errors. We estimate the model with Bayesian methods using commonly-known Minnesota priors. We set the lag length to be three based on standard SIC and HQ criteria.[18]

Our dataset consists of eight variables at a quarterly frequency spanning the time period between 2006Q1 and 2022Q1 inclusive.[19] The variables include US GDP (in logs), US consumer price index (in logs), the effective federal funds rate, foreign GDP (in logs), foreign consumer price index (in logs), the foreign policy rate, foreign FX reserves in US ST and LT government securities, and the nominal effective exchange rate for the US. The foreign region series are constructed using the weighted average of data for Australia, Canada, China, the Euro Area, Japan, Norway, Sweden, Switzerland, and the United Kingdom. Since we have several observations during ZLB periods, we replace policy rates with shadow rates when policy rates are at zero.[20]

We assume that the structural economic shocks $\boldsymbol{\varepsilon}_t$ are related to the reduced-form errors $\mathbf{u}_t$ according to $\mathbf{u}_t = \mathbf{B}\boldsymbol{\varepsilon}_t$, where $\mathbf{B}$ is the contemporaneous impact matrix. To iden-

[18]The results are robust to using different priors as well as different lag lengths such as one (as suggested by AIC criterion).

[19]Our starting point reflects the time when the quarterly data start for official foreign reserves of US government securities.

[20]Shadow rates for US and foreign economies come from LJK Macro Finance Analysis (see https://www.ljkmfa.com). The foreign region's shadow rate is a weighted average of shadow rates from the foreign economies listed above.

tify FX intervention shocks, we use time restrictions following Christiano et al. (2005) combined with sign restrictions on the US effective exchange rate and foreign FX reserves (see Table 3). Specifically, we assume macroeconomic variables slowly adjust in response to FX intervention shocks, whether interventions increase foreign FX reserves of US ST or LT securities. On the other hand, the exchange rate (i.e., the financial variable) is assumed to adjust immediately to the FX intervention shocks. We restrict the foreign region's currency to depreciate (US dollar to appreciate) following an FX intervention shock, consistent with standard models with FX interventions, and test whether macroeconomic variables respond differently to FX intervention shocks depending on whether the interventions involve purchases of US ST or LT government bonds. For this reason, we do not impose any sign restrictions on macroeconomic variables such as GDP or CPI.

Let us now discuss the identification scheme further. First, we define an ST FX intervention shock to increase official reserves of US ST bonds. An LT FX intervention shock is defined to increase official reserves of US LT bonds. By definition, these two shocks are separate from each other. Second, they are also distinguished from real shocks such as demand or supply shocks, since such shocks would be expected to move output and/or inflation on impact. Third, our shocks are also distinguished from other monetary policy shocks in US or foreign region such as interest rate policy shocks, which would move policy rates on impact. Morevoer, in the case where FX interventions respond endogenously to a US or foreign region monetary policy shock, we would expect purchases of FX reserves to move in the opposite direction of the US dollar exchange rate, rather than the same direction. Hence, our identifying restrictions are well-suited to distinguish FX intervention shocks.

Table 3: Identifying restrictions

	ST intervention shock	LT intervention shock
US GDP	0	0
US inflation rate	0	0
US policy rate	0	0
Foreign GDP	0	0
Foreign inflation rate	0	0
Foreign policy rate	0	0
ST FX reserves	+	0
LT FX reserves	0	+
US nominal ER	+	+

Notes: Sign restrictions are imposed contemporaneously for one quarter.

5.2 Results

Figure 11 shows the impulse responses of US and foreign variables to ST and LT FX intervention shocks made by the foreign region. Shaded areas represent 68% Bayesian credible sets. Both columns represent a one-standard shock to foreign region official reserves of US ST or LT bonds, respectively. The ST intervention shock is recessionary for both US and foreign region, whereas the LT intervention shock is expansionary in both economies. Particularly, a one-standard ST intervention shock decreases US and foreign output by about 0.30% and 0.15%, respectively. On the other hand, a one-standard LT intervention shock increases US and foreign output by about 0.15% and 0.20%, respectively. These results are consistent with the predictions of our calibrated model.

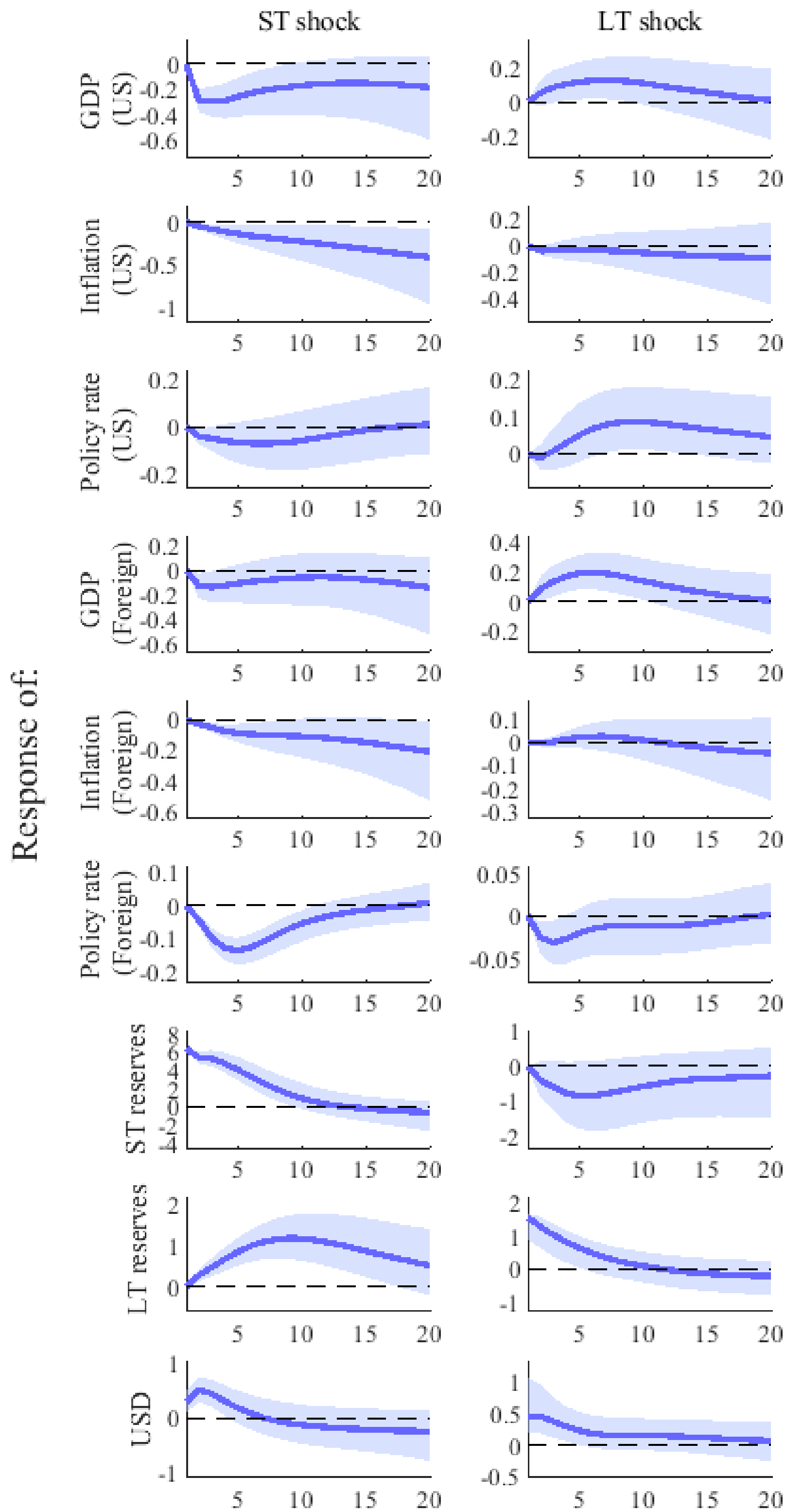
Turning to inflation, the ST intervention shock lowers prices in both economies. Our model predicts that an ST intervention leads to a fall in inflation in the US and a very small increase in the foreign region's inflation as exchange rate pass-through dominates the deflationary effects from the recessionary term premium channel. Thus, the data suggest that exchange rate pass-through might be somewhat smaller than what we assume in our model. Nevertheless, inflation falls much less in the foreign region compared to the US, likely due to the depreciation of the foreign currency *vis à vis* the US dollar. The

LT intervention shock has differential effects on inflation in the two economies, consistent with our model. While it lowers inflation in the US at the median response, it increases inflation in the foreign region up to 10 periods after the shock. In our model, these differential effects arise due to the exchange rate channel, which lowers inflation in the US but raises inflation in the foreign region after the shock.

The policy rate responses to FX intervention shocks are also generally consistent with the model and evolve to stabilize the economy depending on whether the shock is recessionary or expansionary. Policy rates in each region increase when the economy is expanding and vice versa. The only exception is the response of the foreign region's policy rate to the LT FX intervention shock. Although the shock is expansionary for the foreign region, the policy rate falls slightly, perhaps reflecting uncertainty around the inflation response in the foreign region. However, note that the policy rate is reversed quickly after the second period and the credible bands around the median policy rate are wide enough so that the cumulative reaction of the rate after a few periods is inconclusive.

Overall, these results are broadly in line with the predictions of our calibrated model, suggesting that the mechanisms that we stress in our theoretical analysis are consistent with the data. The empirical results also suggest that there could be an interaction between ST and LT FX interventions. Particularly, foreign LT FX reserves gradually increase following an ST FX intervention shock, and foreign ST FX reserves gradually decrease following an LT FX intervention shock. Although we do not explore this interaction in our model, this could reflect behaviour where official portfolio managers are more long-term focused and try to lock in higher returns by investing in long-term bonds.

Figure 11: Impulse responses to ST and LT FX intervention shocks



Notes: Solid lines denote the median impulse responses while the shaded regions denote the 68% equal-tailed confidence bands.

6 Conclusion

In this paper, we study the economic effects of FX interventions. The key innovation we bring to this topic is to emphasize the differences between FX interventions in ST versus LT securities. We document that, empirically, FX interventions (and FX reserves more generally) involve not only the exchange of US ST government securities, but also the exchange of US LT securities, a fact that is largely ignored in the FX intervention literature. To examine the implications of this, we consider a model that includes both ST and LT internationally tradable government bonds as well as imperfect substitutability between these bonds. This imperfect substitutability gives rise to portfolio balance effects and, in turn, a basis for effective exchange rate interventions.

We calibrate the model using data for the US and a foreign region (US trade partners), and then simulate FX interventions made by the foreign region. Our results go significantly against the standard wisdom regarding the beggar-thy-neighbor implications of FX interventions. Specifically, we find that purchases of ST FX reserves lead to lower GDP growth in both regions, and that purchases of LT FX reserves lead to higher GDP growth in both regions. These findings are driven by the term premium effect of these interventions, which is more important than the trade balance effect in terms of GDP impact.

To examine these predictions empirically, we estimate a structural VAR model that identifies both ST and LT FX intervention shocks, using data for the US and its trade partners (foreign region). We find responses to FX intervention shocks are generally consistent with our theoretical predictions. In particular, purchases of ST FX reserves lead to lower GDP in both the US and foreign region, and purchases of LT FX reserves lead to higher GDP in both the US and foreign region. These results highlight the importance of distinguishing between ST and LT FX interventions, and show that the channels highlighted in our model deliver theoretical predictions that are consistent with the data.

Our findings come with some caveats. We model our simulations using two large regions, and scenarios where a small open economy undertakes these interventions could require different estimates for several key elasticity parameters that we use in our simulations and, therefore, yield different results. That said, the evidence suggests that FX interventions made by large economies (such as Japan and China) account for the lion's share of FX interventions involving US securities; hence, for these cases, or for cases where a large set of non-US economies considers similar interventions, we view our results as highly relevant for interpreting the consequences. While our results do suggest that the conventional wisdom on FX interventions is incomplete, we do not conclude that FX interventions, whether in ST or LT securities, are necessarily desirable from a policy perspective. Drawing conclusions on the desirability of these policies would require integrating some of the elements from our model into a setting where considerations regarding welfare and optimal policy are front and center. We leave this to future work.

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Appendix

A Details on the model

In what follows, we describe the details that were omitted from the model presented in Section 2 of the main text. Here we describe production and price setting for domestic and importing firms and how their goods are aggregated for final use and for use in capital goods production. We also describe the labor production and wage setting processes. These details are described from the foreign region perspective, and analogous expressions hold for the US perspective.

A.1 Domestic firms

There is a unit measure of monopolistically competitive domestic firms indexed by o. They have the following technology:

$$y_{F,t}(o) = z_t \left[u_t(o)k_{t-1}(o)\right]^{\alpha} \left[n_t(o)\right]^{1-\alpha} - f, \tag{32}$$

where z_t denotes the level of productivity, $u_t(o)$ denotes the capital utilization rate, $k_t(o)$ denotes the level of capital, $n_t(o)$ denotes the level of labor input, α denotes the capital share of production, and f represents a fixed cost.

These goods are assembled according to a standard CES aggregator, which yields the following demand function for individual goods:

$$y_{F,t}(o) = \left(\frac{P_{F,t}(o)}{P_{F,t}}\right)^{-\Theta_{F,t}} y_{F,t}, \tag{33}$$

where $y_{F,t}$ denotes domestic output, $\Theta_{F,t}$ denotes the elasticity of substitution between individual goods, $P_{F,t}(o)$ denotes the price of the good produced by domestic firm o, and

$P_{F,t}$ denotes the aggregate price of the foreign good. Firm profits in period t are given by:

$$\frac{\Pi_{F,t}(o)}{P_t} = \frac{P_{F,t}(o)}{P_t} y_t(o) - \frac{W_t}{P_t} n_t(o) - r_{k,t} k_{t-1}(o) - \frac{\kappa_k}{1+\varpi} \left[u_t(o)^{1+\varpi} - 1 \right] k_{t-1}(o) - \frac{\kappa_F}{2} \left(\frac{P_{F,t}(o)/P_{F,t-1}(o)}{\pi_{F,t-1}^{\zeta_F} \bar{\pi}^{1-\zeta_F}} - 1 \right)^2 \frac{P_{F,t}}{P_t} y_{F,t}(o), \tag{34}$$

where κ_k and ϖ are parameters that govern the level and elasticity of the capital utilization cost. The final term in this expression captures a quadratic cost of price adjustment similar to the rigidities postulated in Rotemberg (1982), where κ_F is a level parameter and ζ_F captures the extent to which adjustments are indexed to past inflation.

Firms choose labor, capital inputs, and prices to maximize (34) subject to goods demand in equation (33). The first-order conditions for capital and labor yield the following equation that related inputs to relative prices:

$$\widehat{w}_t - \widehat{r}_{k,t} = \widehat{w}_t + \widehat{k}_{t+1} - \widehat{n}_t \tag{35}$$

Similarly, the first-order equations for capital and utilization, combined, yield the following:

$$\widehat{u}_t = \frac{1}{\varpi} \widehat{r}_{k,t}. \tag{36}$$

The first-order condition for prices yields the following version of a New Keynesian Phillips curve (log-linearized):

$$\widehat{\pi}_{F,t} - \zeta_F \widehat{\pi}_{F,t-1} = \beta E_t \left[\widehat{\pi}_{F,t+1} - \zeta_F \widehat{\pi}_{F,t} \right] - \frac{\bar{\Theta}_f - 1}{\kappa_F} \left(\widehat{p}_{F,t} + \widehat{z}_t + \alpha \left(\widehat{u}_t + \widehat{k}_{t-1} - \widehat{n}_t \right) - \widehat{w}_t - \widehat{\theta}_{F,t} \right), \tag{37}$$

where $\theta_{F,t} = \Theta_{F,t} / \left(\Theta_{F,t} - 1 \right)$ is a time-varying gross markup with steady-state value $\bar{\theta_F} = \bar{\Theta_F} / \left(\bar{\Theta_F} - 1 \right)$, and $p_{F,t} = P_{F,t}/P_t$.

A.2 Importing firms

Importing firms are similar to domestic firms, except that rather than producing goods themselves, importers act as intermediaries that import individual goods that are produced in the US, differentiate them, and then choose prices to maximized their profits from domestic sales. The demand for imports is the following:

$$y_{U,t}(o) = \left(\frac{P_{U,t}(o)}{P_{U,t}}\right)^{-\Theta_{U,t}} y_{U,t}, \tag{38}$$

where $y_{U,t}$ denotes aggregate imports, $\Theta_{U,t}$ denotes the elasticity of substitution between individual imported goods, $P_{U,t}(o)$ denotes the price of the good produced by importing firm o, and $P_{U,t}$ denotes the aggregate price of the US good. Importing firm profits in period t are given by

$$\frac{\Pi_{U,t}(o)}{P_t} = \frac{P_{U,t}(o)}{P_t} y_{U,t}(o) - \frac{e_t P^*_{U,t}(o)}{P_t} y_{U,t}(o) - \frac{\kappa_U}{2}\left(\frac{P_{U,t}(o)/P_{U,t-1}(o)}{\pi^{\zeta_u}_{U,t-1}\bar{\pi}^{1-\zeta_U}} - 1\right)^2 \frac{P_{U,t}}{P_t} y_t(o), \tag{39}$$

where κ_U is a level parameter for the price adjustment cost and ζ_U captures the extent to which the adjustments are indexed to past imported goods inflation, and $\pi_{U,t} = P_{U,t}/P_{U,t-1}$ denotes imported goods inflation.

The first-order condition for importers with respect to prices yields the following version of a New Keynesian Phillips curve for import prices (log-linearized):

$$\widehat{\pi}_{U,t} - \zeta_U \widehat{\pi}_{U,t-1} = \beta E_t\left[\widehat{\pi}_{U,t+1} - \zeta_U \widehat{\pi}_{U,t}\right] - \frac{\bar{\Theta}_u - 1}{\kappa_F}\left(\widehat{p}_{U,t} - \widehat{rer}_t - \widehat{p}^*_{U,t} - \widehat{\theta}_{U,t}\right), \tag{40}$$

where $\theta_{U,t} = \Theta_{U,t}/\left(\Theta_{U,t} - 1\right)$ is a time-varying gross markup with steady-state value $\bar{\theta_U} = \bar{\Theta_U}/\left(\bar{\Theta_U} - 1\right)$, and $p_{U,t} = P_{U,t}/P_t$.

A.3 Goods market

The aggregate consumption good, C_t, is produced by a perfectly competitive sector that uses the following CES technology:

$$c_t = \left[\gamma_c^{\frac{1}{\lambda_c}} c_{F,t}^{\frac{\lambda_c - 1}{\lambda_c}} + (1-\gamma_c)^{\frac{1}{\lambda_c}} c_{U,t}^{\frac{\lambda_c - 1}{\lambda_c}}\right]^{\frac{\lambda_c}{\lambda_c - 1}}, \tag{41}$$

where γ_c denotes the share of foreign goods in consumption and λ_c denotes the elasticity of substitution between foreign and US goods. Given this technology, we have the following demand functions for foreign and US goods:

$$c_{F,t} = \left(\frac{P_{F,t}}{P_t}\right)^{-\lambda_c} \gamma_c c_t, \qquad c_{U,t} = \left(\frac{P_{U,t}}{P_t}\right)^{-\lambda_c} (1-\gamma_c)\, c_t \tag{42}$$

The aggregate price of the consumption good is given by

$$P_t = \left[\gamma_c P_{F,t}^{1-\lambda_c} + (1-\gamma_c)\, P_{U,t}^{1-\lambda_c}\right]^{\frac{1}{1-\lambda_c}}, \tag{43}$$

Investment is based on the same technology as consumption and, as such, we have the following equations for investment that are analogous to equations (41), (42) and (43):

$$i_t = \left[\gamma_i^{\frac{1}{\lambda_i}} i_{F,t}^{\frac{\lambda_i - 1}{\lambda_i}} + (1-\gamma_i)^{\frac{1}{\lambda_i}} i_{U,t}^{\frac{\lambda_i - 1}{\lambda_i}}\right]^{\frac{\lambda_i}{\lambda_i - 1}}, \tag{44}$$

$$i_{F,t} = \left(\frac{P_{F,t}}{P_t}\right)^{-\lambda_i} \gamma_i i_t, \qquad i_{U,t} = \left(\frac{P_{U,t}}{P_t}\right)^{-\lambda_i} (1-\gamma_i)\, i_t, \tag{45}$$

$$P_{i,t} = \left[\gamma_i P_{F,t}^{1-\lambda_i} + (1-\gamma_i)\, P_{U,t}^{1-\lambda_i}\right]^{\frac{1}{1-\lambda_i}}, \tag{46}$$

A.4 Capital producers

A sector of perfectly competitive capital goods producers purchases previously used (undepreciated) capital from entrepreneurs at a relative price of q_t, and new investment goods, i_t, from domestic goods producers at a price of $P_{i,t}$, to produce new capital goods that are to be used for production in the next period. The capital law of motion is the following:

$$k_t = (1-\delta)\,k_{t-1} + \left[1 - \frac{\varphi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right] i_t, \tag{47}$$

where φ denotes a capital adjustment cost. Once produced, capital is sold to entrepreneurs at price q_t. Given this, capital producers maximize the following profit function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0}\left[q_t k_t - q_t\,(1-\delta)\,k_{t-1} - \frac{P_{i,t}}{P_t} i_t\right], \tag{48}$$

subject to equation (47). The first-order condition for capital producers with respect to investment yields the following log-linearized investment demand equation:

$$\widehat{i}_t - \widehat{i}_{t-1} = \beta E_t\left[\widehat{i}_{t+1} - \widehat{i}_t\right] + \frac{1}{\varphi}\left(\widehat{q}_t - \widehat{p}_{i,t}\right), \tag{49}$$

where $p_{i,t} = P_{i,t}/P_t$.

A.5 Labor market

Labor inputs are heterogeneous across households and are aggregated by a labor intermediary according to a Dixit-Stiglitz technology. This gives rise to the following labor demand schedule of input from household i:

$$n_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{\Theta_{n,t}} n, \tag{50}$$

where $W_t(i)$ denotes the individual wage rate and $\Theta_{n,t}$ denotes the elasticity of substitution between the differentiated labor inputs. Wage adjustments are subject to rigidities that are similar to those applied to domestic and imported goods prices and are of the following form:

$$\frac{\kappa_w}{2}\left(\frac{W_t(i)/W_{t-1}}{\pi_{t-1}^{\zeta_w}\bar{\pi}^{1-\zeta_w}}-1\right)^2\frac{W_t}{P_t}y_t, \tag{51}$$

where κ_w is a scale parameter and ζ_w determines the indexation of wage adjustments to past in inflation.

Household optimization of labor inputs gives rise to the following log-linearized version of a New Keynesisan Phillips curve for wages:

$$\widehat{\pi}_{w,t}-\zeta_w\widehat{\pi}_{t-1}=\beta E_t\left[\widehat{\pi}_{w,t+1}-\zeta_w\widehat{\pi}_t\right]-\frac{\eta_n-1}{\kappa_w}\left(\widehat{w}_t-\vartheta\widehat{n}_t-\frac{1}{1-\zeta}\left(\widehat{c}_t-\zeta\widehat{c}_{t-1}\right)-\widehat{\theta}_{w,t}\right), \tag{52}$$

where $\theta_{w,t}=\Theta_{n,t}/\left(\Theta_{n,t}-1\right)$ is a time-varying gross markup with steady-state value $\bar{\theta_w}=\bar{\Theta_n}/\left(\bar{\Theta_n}-1\right)$, and $\widehat{\pi}_{w,t}-\widehat{\pi}_t=\widehat{w}_t-\widehat{w}_{t-1}$.

A.6 Market-clearing conditions

Domestically produced goods, y_t, are used for consumption, investment, and government consumption in the foreign economy and for imported consumption and investment in the US economy, therefore, satisfying the following market-clearing condition:

$$y_t=c_{F,t}+i_{F,t}+g_t+c^*_{F,t}+i^*_{F,t} \tag{53}$$

The market-clearing conditions for ST and LT bonds, respectively, are

$$\frac{B_{S,t}}{P_t}=\frac{B_{FS,t}}{P_t}+\frac{B^*_{FS,t}}{P_t},\qquad \frac{q_{L,t}B_{L,t}}{P_t}=\frac{q_{L,t}B_{FL,t}}{P_t}+\frac{q_{L,t}B^*_{FL,t}}{P_t} \tag{54}$$

In the case of US-issued bonds, the market-clearing conditions for ST and LT bonds, respectively, are

$$\frac{B^*_{S,t}}{P^*_t} = \frac{B^*_{US,t}}{P^*_t} + \frac{B_{US,t}}{P^*_t} + \frac{B^g_{US,t}}{P^*_t}, \qquad \frac{q^*_{L,t}B^*_{L,t}}{P^*_t} = \frac{q^*_{L,t}B^*_{UL,t}}{P^*_t} + \frac{q^*_{L,t}B_{UL,t}}{P^*_t} + \frac{q^*_{L,t}B^g_{UL,t}}{P^*_t} \tag{55}$$

Finally, the balance of payments must satisfy the following identity:

$$\begin{aligned}
&\frac{e_t\left(B_{US,t}+B^g_{US,t}\right)}{P_t} - \frac{e_tR^*_{t-1}\left(B_{US,t-1}+B^g_{US,t-1}\right)}{P_t} + \frac{e_tq^*_{L,t}\left(B_{UL,t}+B^g_{UL,t}\right)}{P_t} - \\
&\frac{e_tq^*_{L,t}R^*_{L,t}\left(B_{UL,t-1}+B^g_{UL,t-1}\right)}{P_t} - \left(\frac{B^*_{US,t}}{P_t} - \frac{R_{t-1}B^*_{US,t-1}}{P_t}\right) + \\
&\left(\frac{q_{L,t}B^*_{UL,t}}{P_t} - \frac{q_{L,t}R_{L,t}B^*_{UL,t-1}}{P_t}\right) = \frac{P_{F,t}}{P_t}y^*_{F,t} - \frac{e_tP^*_{U,t}}{P_t}y_{U,t}.
\end{aligned} \tag{56}$$

The model equilibrium is defined as the set of prices and allocations that satisfy household utility maximization and firm profit maximization, subject to constraints, where all markets clear.

B Sensitivity analysis

In this section, we explore how the quantitative results from FX intervention shocks, where the baseline cases are described in 4.1 and 4.2, change under different parameterizations.

B.1 Zero lower bound

Many countries in recent years have found themselves close to the ZLB on ST interest rates. In this sub-section, we consider the effects of FX interventions when both the US and foreign region are constrained by the ZLB on ST interest rates, where the ST rate is set to its steady-state value for 30 periods after the shock in both regions.

Figure 12: US responses to FX intervention in US ST bonds (ZLB sensitivity)

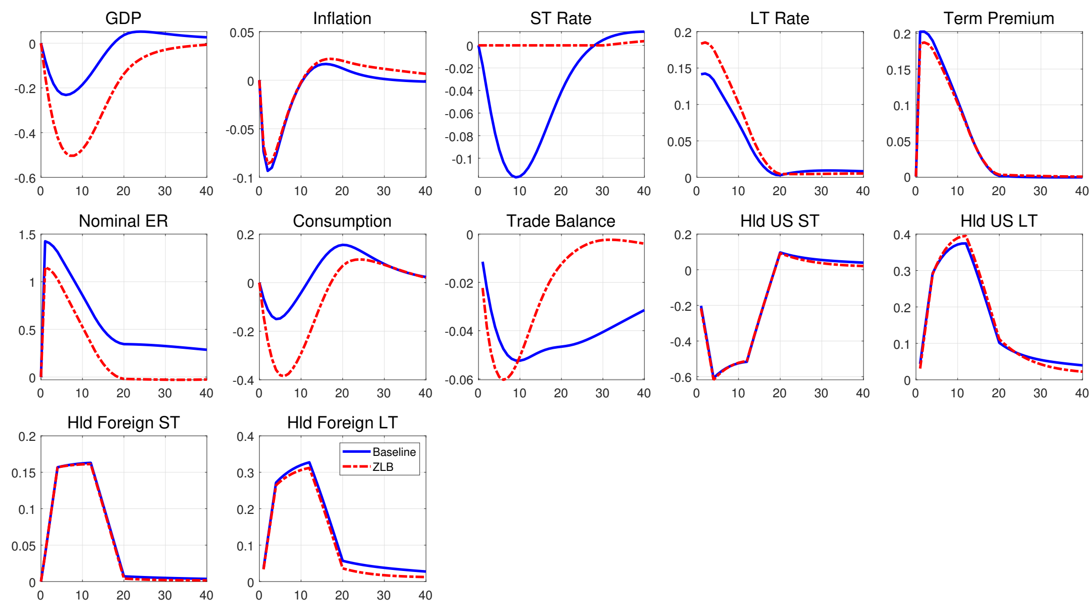


Figure 13: Foreign responses to FX intervention in US ST bonds (ZLB sensitivity)

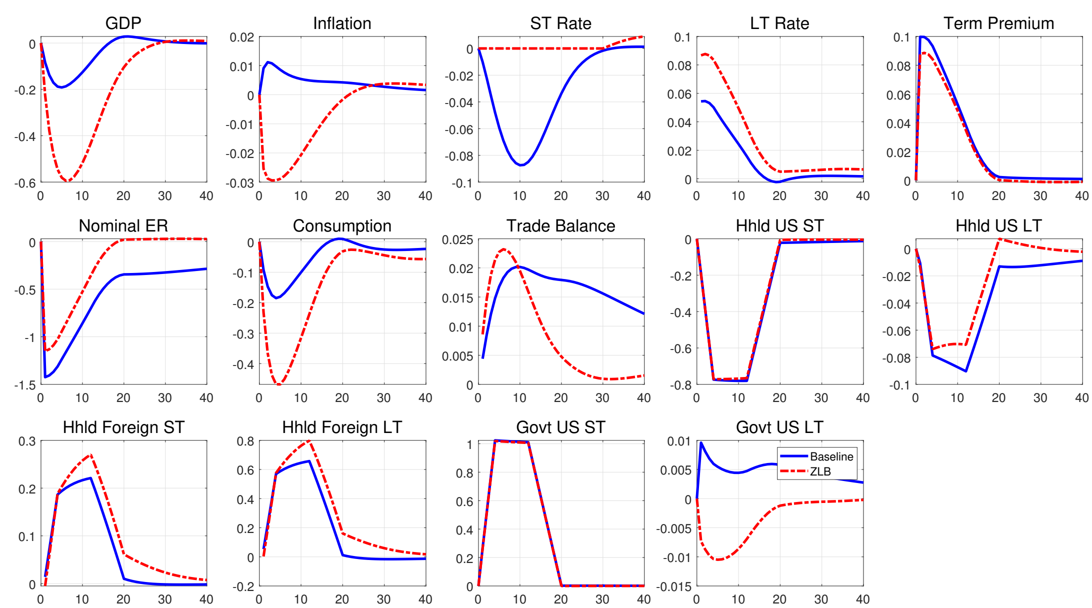


Figure 14: US responses to FX intervention in US LT bonds (ZLB sensitivity)

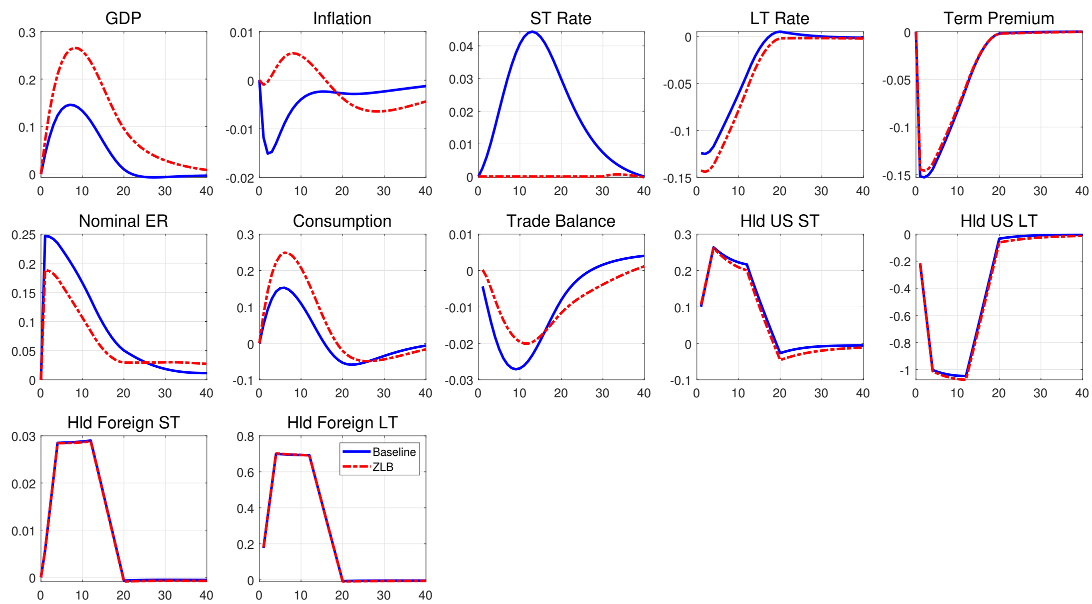
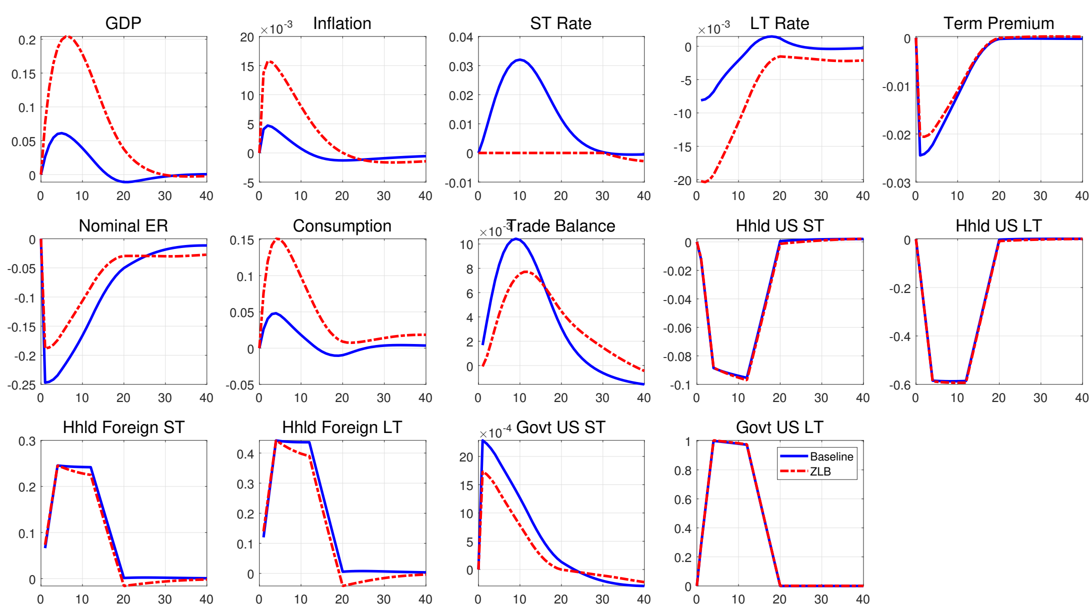


Figure 15: Foreign responses to FX intervention in US LT bonds (ZLB sensitivity)



The results from the FX intervention by the foreign economy in the US ST bond market are reported in Figures 12 and 13. In the US case, the monetary authority responds to the contractions in GDP and inflation by lowering the ST interest rate in the baseline case, but when the ZLB binds, it does not do this and so the impact of the intervention is more significant. For example, the peak negative impact on US GDP growth is about -0.5% under the ZLB compared to -0.2% under the baseline model. Aside from this, the US LT rate increases more compared to the baseline model, and the term premium impact is roughly the same compared to the baseline model.

For the foreign economy, a similar story holds, where the foreign monetary authority responds to the negative GDP impact of the intervention by lowering the ST rate under the baseline case but no longer does this under the ZLB; hence, the negative impact on GDP growth is more severe, in fact roughly three times more severe, than under the baseline case. The intervention continues to effectively depreciate the foreign currency and improve the foreign trade balance, but inflation actually declines now rather than increasing, as was the case in the baseline model. This is because the negative effects of lower economic activity now dominate the positive effects of the exchange rate pass-through for inflation. Overall, it is clear that being at the ZLB constraint worsens the negative impacts of the ST FX intervention on both regions.

When the FX intervention by the foreign government is made in the US LT bond market, the positive impact on US GDP growth causes the US monetary authority to raise the ST interest rate in the baseline scenario. If we assume that the ST rate is fixed for an extended period, as we do in the ZLB case, then the positive impact of the intervention on US GDP is even more significant (Figure 14). Interestingly, the lack of an interest rate response under the ZLB scenario implies that the exchange rate appreciation from the shock is less significant and, hence, the negative impacts on the US trade balance and inflation are smaller (for inflation, the effect is actually positive under the ZLB compared to the negative effect under the baseline model).

For the foreign economy, the implications are generally similar to those for the US economy. Since the foreign monetary authority responds to stronger GDP growth from the FX intervention by raising the ST interest rate in the baseline model, the fixed ST rate under the ZLB model leads to stronger GDP growth after the intervention. The impact on inflation is also stronger under the ZLB case due to stronger GDP growth. The term premium effect is roughly in line with its effect in the original model. Overall, the ZLB constraint strengthens the positive impacts of the FX intervention in the US LT bond market for both the foreign and US economies.

B.2 Different λ_a parameters

In this sub-section, we consider the results under different values for the elasticity of substitution between ST and LT bonds, represented by the parameter λ_a. This parameter is instrumental in generating movements in the term premium after the FX interventions, where movements in private bond holdings have a larger impact on the term premium for lower values of λ_a. In the baseline calibration, we use a value of $\lambda_a = 1.86$.

Figures 16 and 17 show the results for the FX intervention in the US ST bond market for the baseline parameters (black lines), the case where $\lambda_a = 0.5$ (blue lines), and the case where $\lambda_a = 50$ (red lines), with the rest of the parameters set identically to those in the baseline simulations. The results indicate that higher values of λ_a weaken the effect of the intervention on the exchange rate. For higher values of λ_a, households are more responsive to changes in relative prices across bond maturities and, therefore, reduce their holdings of ST bonds and increase their holdings of LT bonds to a greater degree in response to the intervention. This implies that households do not demand a large term premium in order to hold LT bonds and, therefore, in equilibrium, the term premium effect of the intervention is greatly reduced. As a consequence of this, the intervention also has a smaller negative impact on US GDP and US inflation when λ_a is higher. In fact, when $\lambda_a = 50$, the ST intervention actually leads to a slight decline in the term premium and an increase in GDP, as households' substitution out of ST bonds and into LT bonds is high enough to lower R_L and the term premium.

The results for the foreign economy are depicted in Figure 17. These indicate that the negative impacts of the intervention on foreign GDP and the foreign term premium are smaller with higher values of λ_a. This result reflects the lower spillovers under higher values of this parameter, as high substitutability between ST and LT bonds in the US induces bond holders to substitute less towards foreign region bonds. Again, as is the case for the US, when $\lambda_a = 50$, the ST intervention actually leads to a slight decline in the term premium in the foreign economy and an increase in foreign GDP, as the substitution out of ST bonds and into LT bonds by households is high enough to lower R_L and the term premium.

The results from the FX intervention in US LT bonds are reported in Figures 18 and 19. Interestingly, and in contrast to the results from the ST intervention where the impact on the exchange rate is smaller for higher values of λ_a, in this case the opposite is true, and the intervention has a larger impact on the exchange rate when λ_a is higher. When λ_a is low, US households respond to the LT intervention by substituting away from US LT bonds and towards foreign region LT bonds, whereas when λ_a is high, US households respond by substituting away from US LT bonds and towards US ST bonds. In the former case, the response leads to greater demand for foreign bonds and, as a result, some reversal of the FX movement, while in the latter case this does not happen. Meanwhile, higher values of λ_a lead to a weaker impact on the term premium, as was the case with the ST interventions. In the LT intervention case, this means there is a smaller negative impact on the term premium and a smaller positive impact on US GDP.

In the case of the foreign economy, the situation is slightly more complicated. Higher

Figure 16: US responses to FX intervention in US ST bonds (λ_a sensitivity)

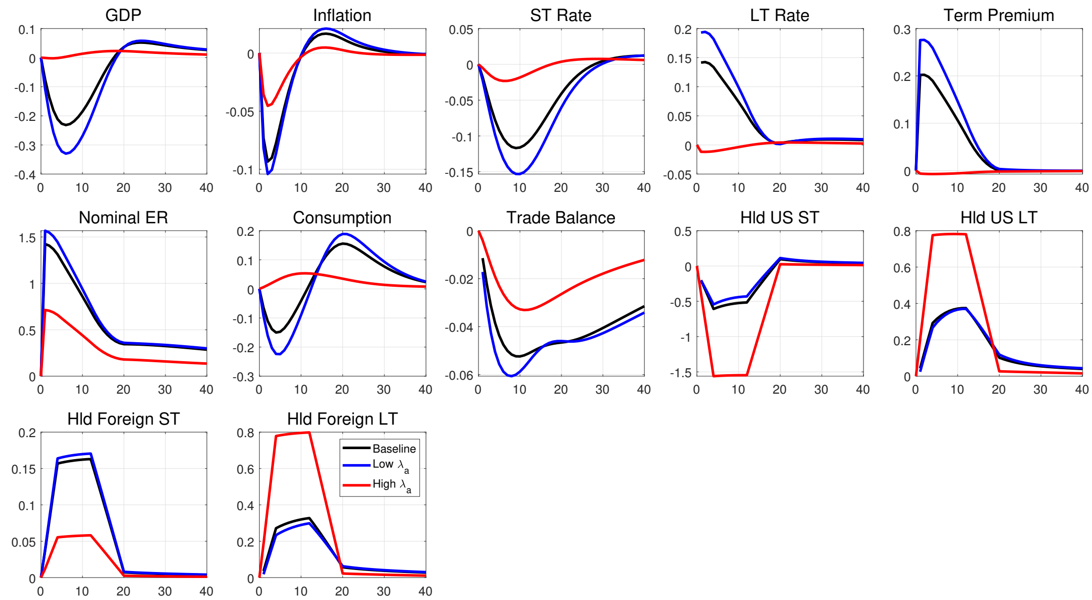


Figure 17: Foreign responses to FX intervention in US ST bonds (λ_a sensitivity)

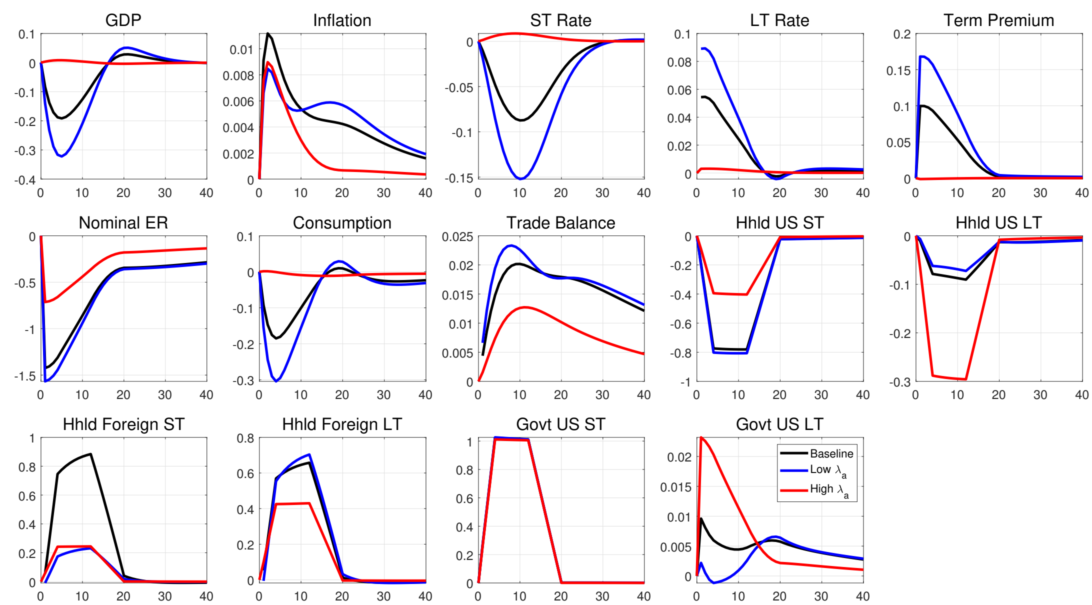


Figure 18: US responses to FX intervention in US LT bonds (λ_a sensitivity)

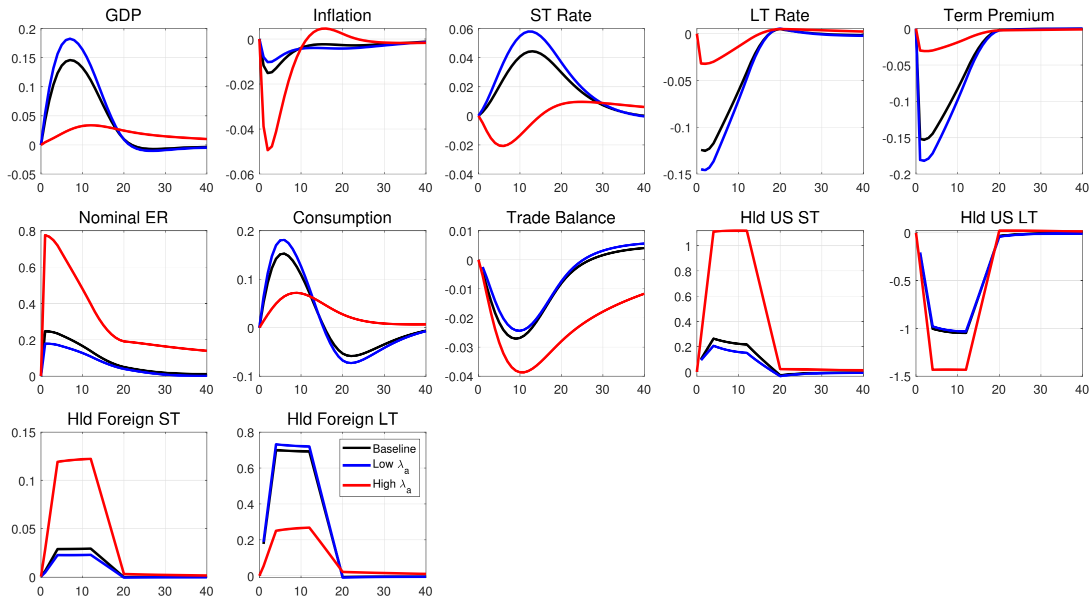
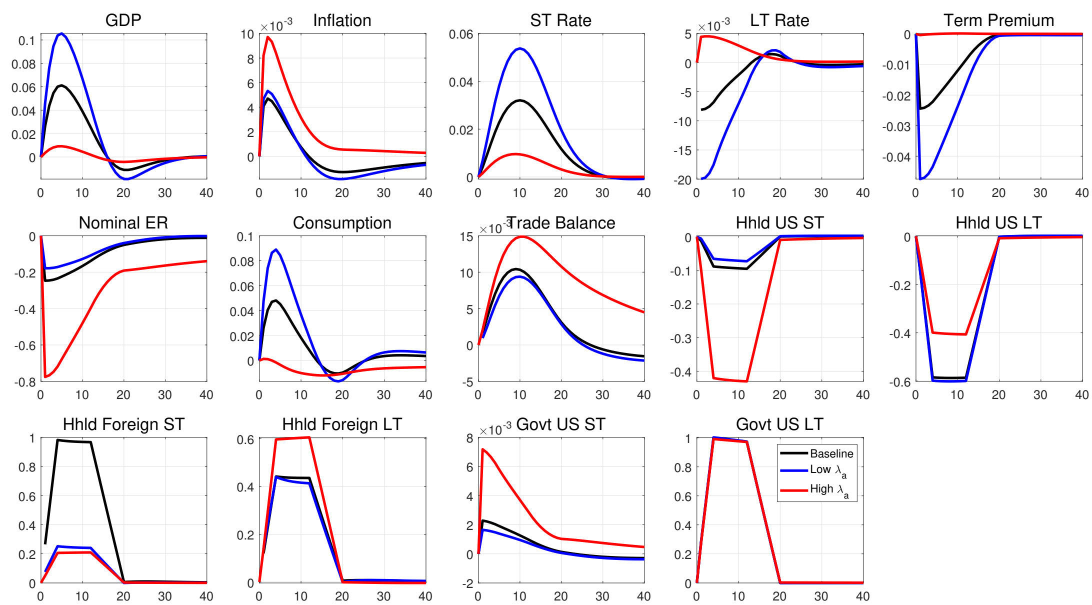


Figure 19: Foreign responses to FX intervention in US LT bonds (λ_a sensitivity)



values of λ_a are associated with a larger exchange rate impact and a stronger improvement in the trade balance, which contribute to stronger GDP growth. On the other hand, for high values of λ_a, the impact on the term premium is more positive in both regions and this dampens GDP growth due to both the direct term premium effects in the foreign economy and weaker US demand. On balance, the term premium and US demand effects dominate, so that higher a value of λ_a leads to smaller positive effects of the intervention on foreign GDP growth, as was the case for US GDP growth.

B.3 Different λ_S parameters

In this sub-section, we consider the results under different values for the elasticity of substitution between US and foreign ST bonds, represented by the parameter λ_S. In the baseline calibration, we use a value of $\lambda_S = 9$. The λ_S parameter is important in several ways that become more clear in looking at these different results.

For the US economy, the results from the ST FX intervention under different values of λ_S are reported in Figure 20, which includes results for the baseline case (black lines), the case where $\lambda_S = 0.5$ (blue lines), and the case where $\lambda_S = 50$ (red lines), with the rest of the parameters set identically to those in the baseline simulations. The figure reveals that higher values of λ_S are associated with a much smaller exchange rate impact and smaller impacts on the term premium, GDP and inflation for the US. Higher values of λ_S imply greater substitution from US ST bonds to foreign ST bonds, and so households respond to the term premium effect of the intervention by substituting more towards foreign bonds rather than towards US LT bonds. From equation (14), it is clear that higher values of λ_S dampen the positive effect of a reduction in private holdings on the term premium and, consistent with this, the impact of the reduction of US ST bonds on the US term premium is weaker for higher values of λ_S. This weaker term premium effect implies weaker impacts on US GDP and US inflation, as we observe in the figure.

Figure 20: US responses to FX intervention in US ST bonds (λ_S sensitivity)

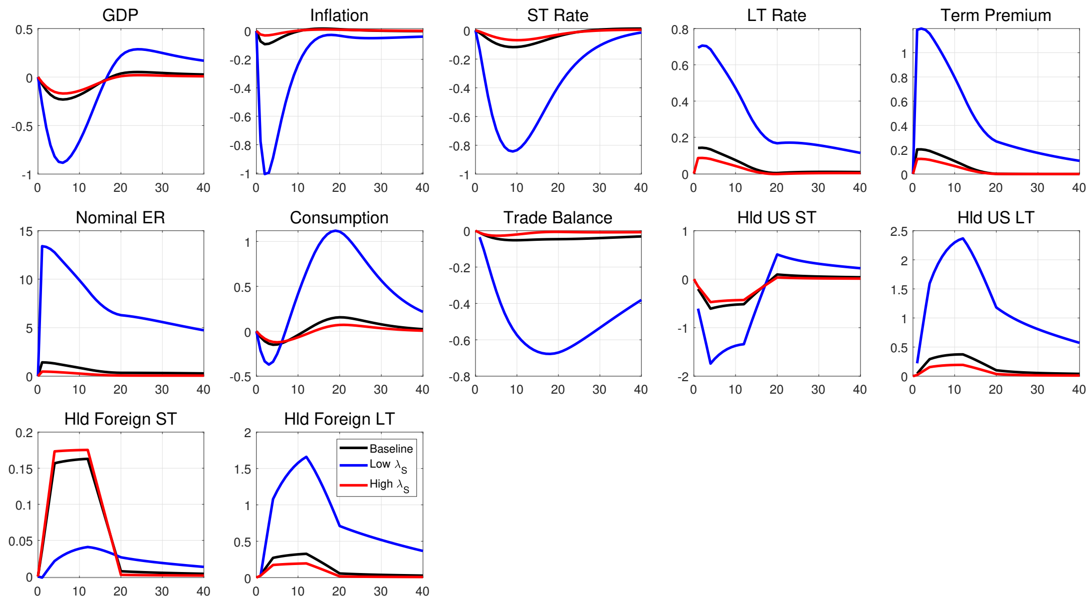
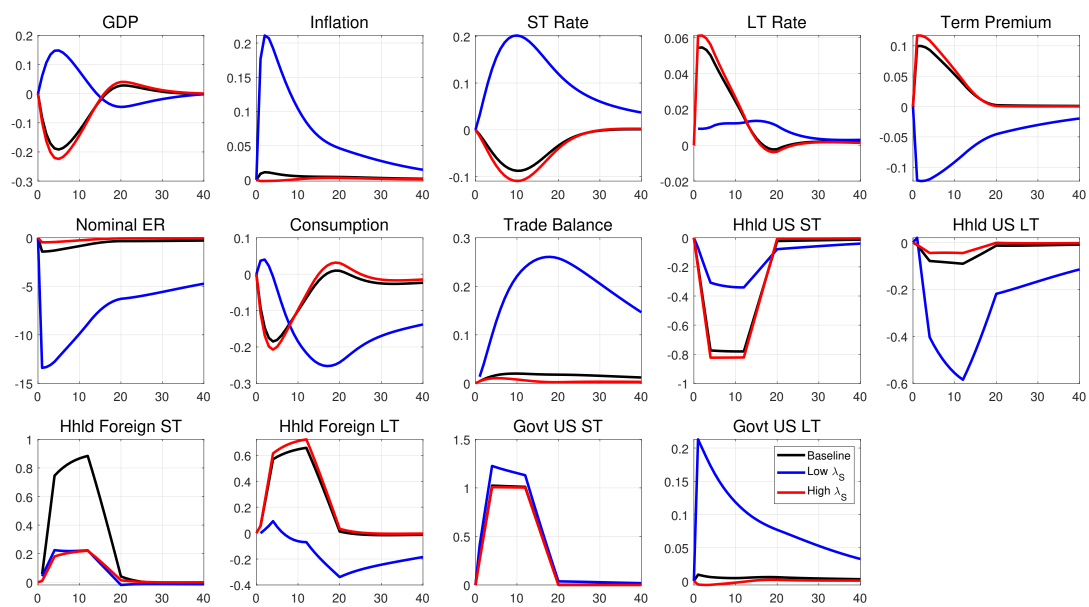


Figure 21: Foreign responses to FX intervention in US ST bonds (λ_S sensitivity)



In contrast, for the foreign economy, the positive impact on the term premium and the negative impact on GDP from the intervention are actually larger for higher values of λ_S, and inflation is significantly less positive, as indicated in Figure 21. These results occur because higher values of λ_S imply higher spillovers from the US term premium to the foreign term premium. In response to term premium increase in the US, households withdraw their holdings of US ST bonds and invest more in foreign ST bonds and, as a consequence of this, the foreign term premium rises more than it does in the baseline case, and GDP and inflation both decline more as well.

For the LT FX intervention, the impact on the exchange rate is again smaller when λ_S is higher. US inflation is smaller as well, partly due to lower exchange rate pass-through, as reported in Figure 22. But in this case, the impact on the US term premium, which falls after the LT intervention, is stronger when λ_S is high, and therefore the increase in GDP is larger. This is because when λ_S is higher, a lower term premium is required to clear the bond market in the US after the intervention.

For the foreign economy, when λ_S is higher, the LT intervention leads to smaller decrease in the term premium, and a weaker GDP and inflation response, as reported in Figure 23. This is because, when λ_S is higher, a higher term premium is required to clear the bond market in the foreign economy after the intervention.

B.4 Different λ_L parameters

In this section, we consider the results under different values for the elasticity of substitution between US and foreign LT bonds, represented by the parameters λ_L. In the baseline estimation, we use a value of $\lambda_L = 3$. The λ_L parameter is important in several ways that become more clear when looking at these different results.

Figure 24 reports the impacts of the ST FX intervention on the US economy, including the results for the baseline case (black lines), the case where $\lambda_L = 0.5$ (blue lines), and

Figure 22: US responses to FX intervention in US LT bonds (λ_S sensitivity)

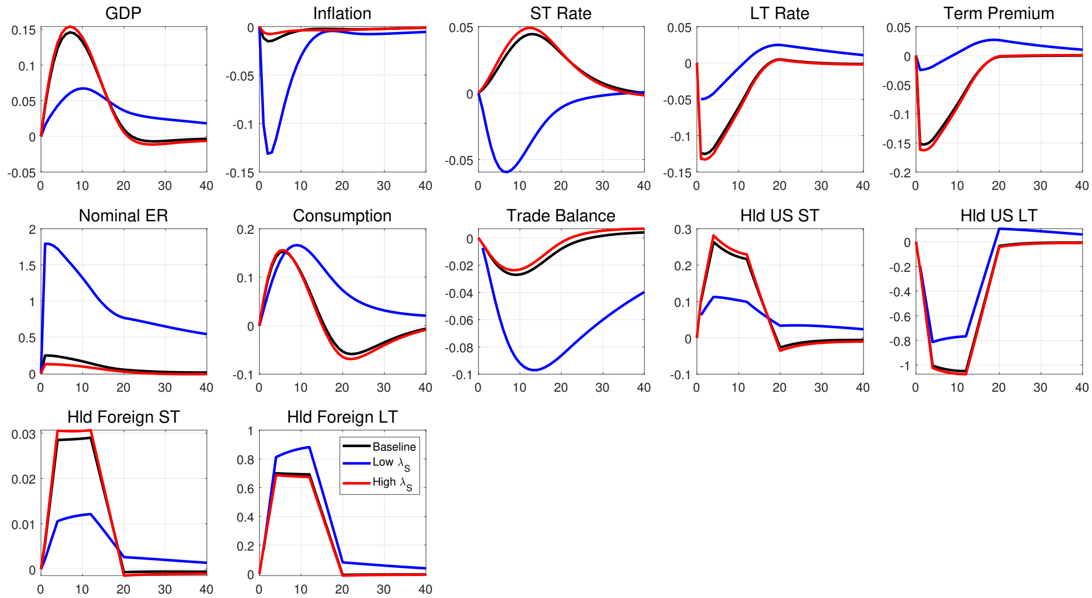
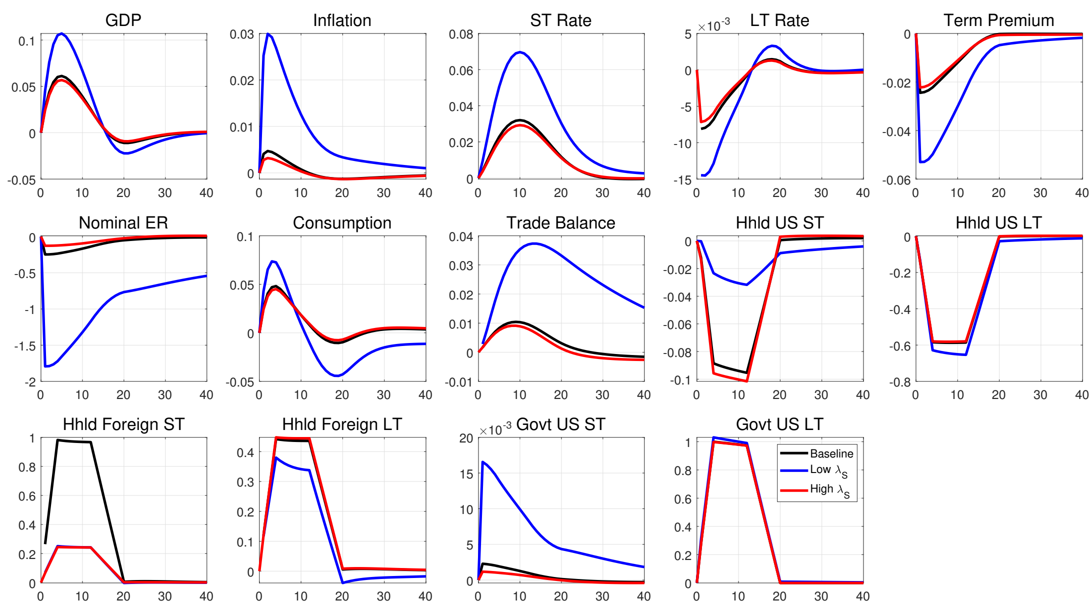


Figure 23: Foreign responses to FX intervention in US LT bonds (λ_S sensitivity)



the case where $\lambda_L = 50$ (red lines), with the rest of the parameters set identically to those in the baseline simulations. As seen in the figure, higher values of λ_L lead to weaker impacts of the intervention on the exchange rate and US inflation but to a larger increase on the US term premium and, therefore, a larger contraction in US GDP. In response to the intervention, US households lower their holdings of ST bonds and increase their holdings of LT bonds more under higher values of λ_L. In equilibrium, a higher term premium is required to clear the market.

The impact of the intervention on the foreign economy, reported in Figure 25, shows that higher values of λ_L lead to a mildly weaker impact of the intervention on the term premium and GDP, which is the opposite pattern observed in the US case. When λ_L ia higher, foreign households respond to the intervention by considerably lowering their holdings of US LT bonds and using more resources for consumption, but they do not substantially increase their holdings of foreign LT or ST bonds.

Figure 26 reports the impacts of the LT FX intervention on the US economy under different values of λ_L. The figure reveals that higher values of λ_L lead to a weaker impact of the intervention on the exchange rate and US inflation and, in this case, also a weaker impact on the US term premium, which falls after the intervention and, therefore, a weaker positive impact on US GDP. When λ_L is higher, US households respond to the intervention by substituting away from US LT bonds and towards foreign LT bonds, rather than towards US ST bonds. From equation (14), it is clear that higher values of λ_L dampen the negative effect of bond substitution on the term premium and, consistent with this, the impact of the reduction in US LT bonds holdings on the US term premium is weaker for higher values of λ_L.

The results for the foreign economy, reported in Figure 27, show that larger values of λ_L lead to stronger negative responses for the foreign term premium after the intervention and, as a consequence, foreign GDP increases more after the shock. This result reflects

Figure 24: US responses to FX intervention in US ST bonds (λ_L sensitivity)

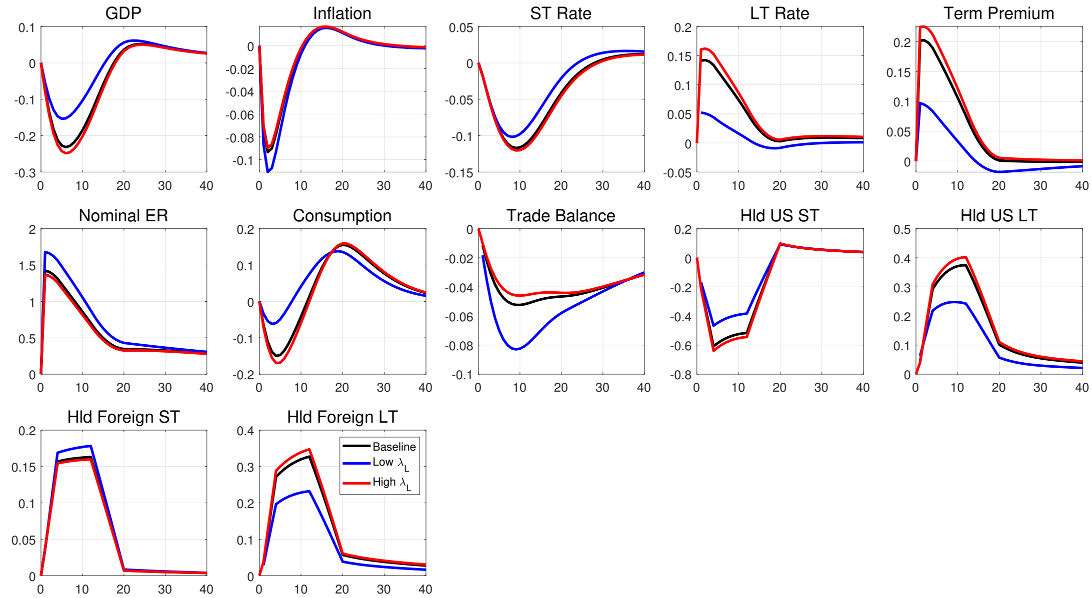


Figure 25: Foreign responses to FX intervention in US ST bonds (λ_L sensitivity)

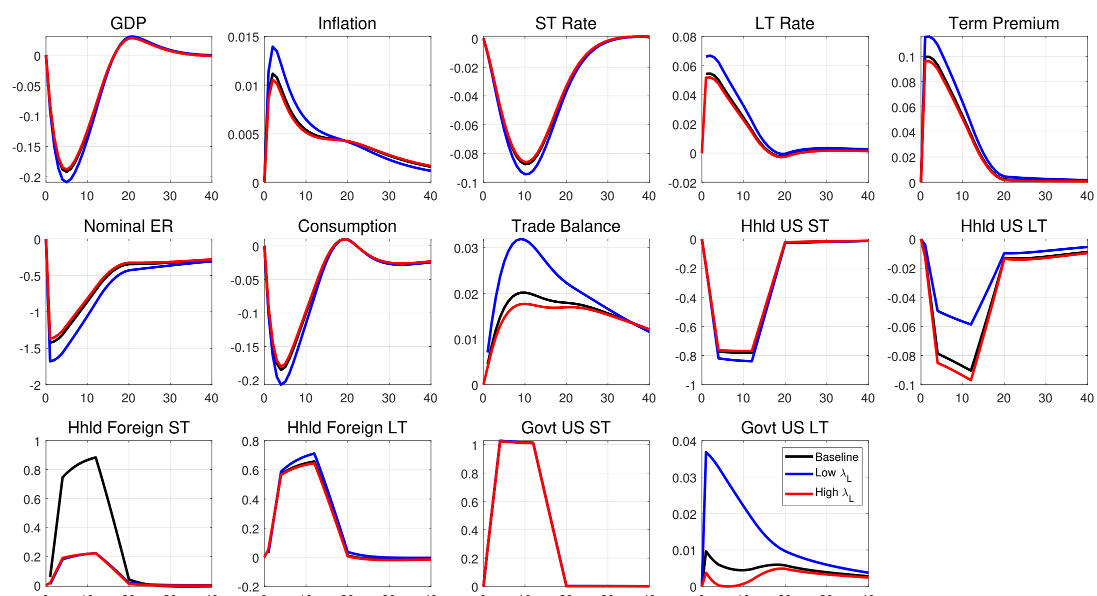


Figure 26: US responses to FX intervention in US LT bonds (λ_L sensitivity)

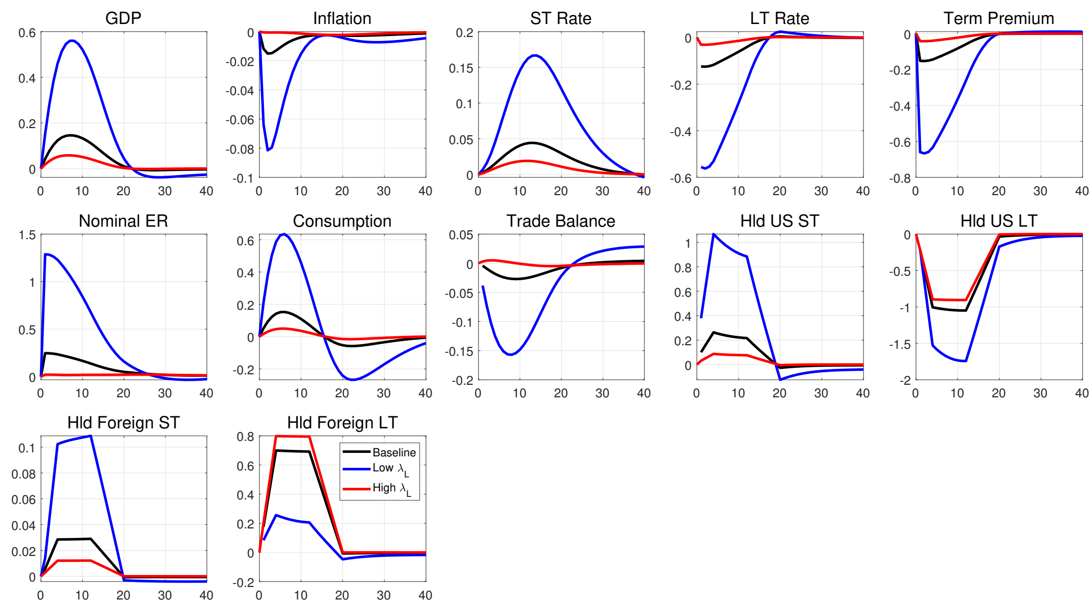
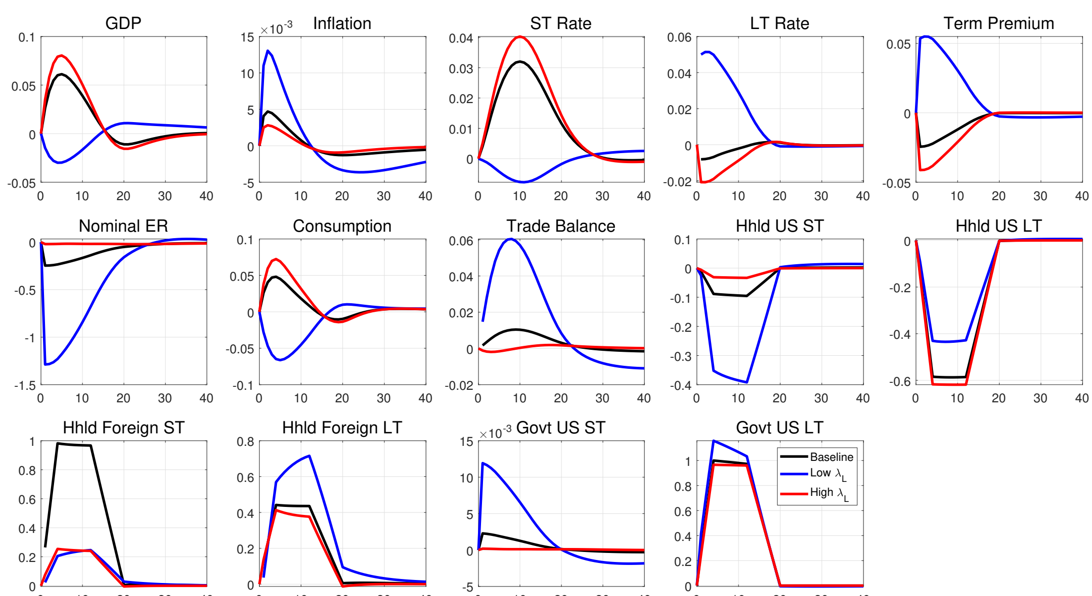


Figure 27: Foreign responses to FX intervention in US LT bonds (λ_L sensitivity)



how the US term premium effect spills over to the foreign economy when λ_L is higher as foreign households move out of US LT bonds and, compared to the baseline model, move more resources into consumption, which spurs foreign GDP growth.

Overall, it is quite clear from this sensitivity analysis that changes in the λ parameters can lead to very large differences in the effects of FX interventions. For the λ_a parameter, larger values weaken the portfolio balance effects that our main results rely heavily on. As a result, when λ_a is higher, we observe weaker negative GDP effects in the US and the foreign economy after an ST FX intervention, weaker positive GDP effects in the US and the foreign economy after an LT FX intervention, and our main results rely on a sufficiently low value for this parameter.

For the λ_S parameter, a clear pattern from our sensitivity analysis is that higher values of this parameter weaken the effects of the ST FX interventions on the US economy that we find in our baseline results. This is because the greater between-region substitutability in ST bonds has the effect of both weakening the strength of the exchange rate impact, and also diluting the portfolio balance effects of the intervention, as bond holders that want to substitute away from US ST bonds choose to hold more foreign ST bonds rather than holding more US LT bonds. For the foreign economy, higher values of λ_S lead to larger spillovers of US term premium effects to the foreign term premium and, consequently, we see larger negative effects of the ST FX intervention on foreign GDP when λ_S is higher.

For the λ_L parameter, we see analogous patterns when looking at the implications from an LT FX intervention. Higher values of this parameter weaken the effects of the LT FX interventions on the US economy we find in our baseline results. This is because greater between-region substitutability in LT bonds weakens the exchange rate impact, and dilutes the portfolio balance effects of the intervention, as bond holders that want to substitute away from US LT bonds opt to hold more foreign LT bonds rather than holding more US ST bonds. For the foreign economy, higher values of λ_L again lead to larger spillovers of

US term premium effects to the foreign term premium and we therefore see larger positive effects of the LT FX intervention on foreign GDP when λ_L is higher.