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Central Bank Exit Strategies: Domestic Transmission and International Spillovers

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ABSTRACT: We study alternative approaches to the withdrawal of prolonged unconventional monetary stimulus (“exit strategies”) by central banks in large, advanced economies. We first show empirically that large-scale asset purchases affect the exchange rate and domestic and foreign term premiums more strongly than conventional short-term policy rate changes when normalizing by the effects on domestic GDP. We then build a two-country New Keynesian model that features segmented bond markets, cognitive discounting and strategic complementarities in price setting that is consistent with these findings. The model implies that quantitative easing (QE) is the only effective way to provide monetary stimulus when policy rates are persistently constrained by the effective lower bound, and that QE is likely to have larger domestic output effects than quantitative tightening (QT). We demonstrate that “exit strategies” by large advanced economies that rely heavily on QT can trigger sizeable inflation-output tradeoffs in foreign recipient economies through the exchange rate and term premium channels. We also show that these tradeoffs are likely to be stronger in emerging market economies, especially those with fixed exchange rates.

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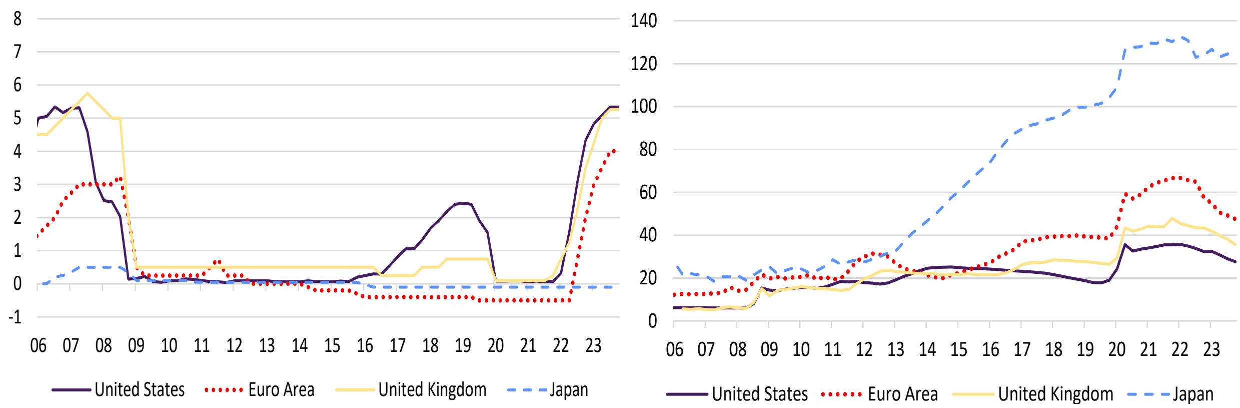
1. Introduction

Since the global financial crisis, central banks in major economies – the US Federal Reserve, European Central Bank (ECB), Bank of Japan and the Bank of England – have undertaken sizeable purchases of long-term bonds to provide economic stimulus and anchor inflation expectations, as shown in Figure 1. During this episode, expected short-term policy rates were expected to be constrained by the effective lower bound (ELB) for an extended period.[1] Recent inflationary outcomes have led to tighter monetary policy, implemented by raising short-term interest rates, and by selling-off long-term bonds via "quantitative tightening" (QT). The goals of this paper are to compare these alternative ways of withdrawing monetary stimulus in large advanced economies and to analyze their domestic propagation and international spillovers.

Figure 1. Advanced Economy Central Bank Monetary Operations



(a) Central Bank Policy Rates **(b)** Central Bank Asset Holdings (as % of GDP)

To that end, we first generate novel empirical evidence on the transmission of large scale asset purchases (LSAP) and conventional interest rate measures. We then build a structural open economy model consistent with the empirical findings and use it to contrast tightening undertaken via conventional interest rate hikes – in which the long-term asset portfolio is subject to gradual runoff – to an alternative, in which a quicker portfolio unwind is accompanied by slower short-term policy rate increases.

To obtain evidence for our structural model, we first use US data to empirically assess domestic and international aspects of interest rate and LSAP transmission. Specifically, we use proxies for the associated shocks constructed using high frequency yield curve data by Lewis (2023), who

[1] See also Adrian et al. (2021a) for an overview of the international evidence on the size of associated interventions.

builds on the analysis in Swanson (2021) and Gurkaynak et al. (2005). In line with Lewis (2023), we relax the assumption that the relationship between policy shocks and high frequency yields is constant over time and we exploit heteroscedasticity in the intraday yield curve on monetary policy announcement days to eliminate the need for imposing identifying restrictions á la Swanson (2021).

Using local projections á la Jorda (2005), we show that one standard deviation contractionary shocks of both types (conventional policy rate and LSAPs) trigger similar, negative effects on PCE inflation and on industrial production. However, only conventional policy significantly elevates short and medium term interest rates, while LSAPs propagate by significantly increasing ten year term premiums and depreciating the dollar nominal effective exchange rate. Finally, while there is considerable heterogeneity in international 10-year term premium responses, we show that US quantitative tightening tends to increase term premiums abroad, both in advanced and emerging market economies (EMEs), while conventional policy rate shocks have either insignificant or negative effects.

Our two-country open economy New Keynesian (NK) model matches the key empirical patterns discussed above. One of its distinguishing features is asset market segmentation, implemented in line with Chen et al. (2012), wherein short- and long-term bonds are imperfect substitutes because of the presence of portfolio transaction costs. These costs depend on positions taken by agents and are influenced by central bank asset purchases, as those affect the outstanding supply of bonds. In addition, segmentation prevents some agents from trading in short-term bonds, limiting the extent to which changes in term premiums can be arbitraged away. Accordingly, since a share of agents' consumption decisions are tied to the long-rate, policy-induced changes in the term-premium end up mattering for real allocations. While specifying financial linkages and international asset market segmentation, we assume that only long-term bonds are internationally tradable. As shown by Kolasa and Wesołowski (2020), this ensures realistic exchange rate dynamics as well as international term premium comovement. Both of these features are crucial to our main result.

Motivated by recent studies on the efficacy of monetary policy tools as well as the dynamics of inflation over the last 15-year period, we introduce two additional model features. First, we tackle the so-called forward guidance puzzle (Del Negro et al., 2012), i.e., the extreme and counterfactual potency of forward guidance in the canonical NK model. To mitigate the puzzle, we allow for a moderate degree of cognitive discounting, in the spirit of Gabaix (2020), which makes household consumption in the model considerably less sensitive to the future path of policy rates.

Our second key modification is predicated on the results of Harding et al. (2021, 2023), who argue that strategic complementarities in price setting are crucial in accounting for the "missing deflation puzzle" during the global financial crisis as well as the recent surge in inflation. Hence, we replace the standard log-linear Dixit and Stiglitz (1977) demand aggregators with quasi-kinked alternatives (Kimball, 1995). This tends to flatten pricing curves in an economic slump, when inflation is below the central bank's target, but raises its sensitivity to economic shocks whenever inflation is elevated.[2] The mechanism additionally attenuates the FGP in a long-lived ELB episode by making inflation and inflation expectations more sticky when inflationary pressures are subdued.

These two modifications jointly imply that QE becomes the only effective monetary policy instrument whenever the ELB is expected to constrain short-term interest rates for a prolonged period (e.g., for about three years and longer, as we shall demonstrate). To the best of our knowledge, this paper is thus the first to consider merits of alternative exit strategies in a framework capable of rationalizing why LSAPs were at all undertaken by central banks. An important additional implication of these mechanisms is that the effects of large scale asset sales do not necessarily mirror those of asset purchases, because they may be occurring along different segments of the Phillips curve, and because they may imply different adjustment in short-term rates due to the asymmetry generated by the ELB.

We start the model-based part of the analysis by demonstrating that our framework accounts for key empirical regularities established using local projections. In particular, large scale asset purchases have a strong effect on the exchange rate but a relatively small impact on domestic aggregate demand compared to conventional monetary policy. This finding points to important non-substitutabilities between conventional and unconventional monetary policy, and means that long-term yields have to be increased notably more under QT compared to a conventional policy tightening to achieve commensurate effects on activity and inflation, in line with the findings in Kiley (2014). We also show that QE has significantly larger effects on domestic output than same-sized QT, while the inflation effects remain similar. The output effects of QE are elevated as it is deployed when the economy is at the ELB and the Phillips curve is flat, while broadly similar inflation responses are attributable to the Phillips curve steepening during recoveries.

[2] Put differently, the slope of the Phillips curve becomes state-dependent.

We then turn our attention to international spillovers. Our nonlinear structural model implies that exit from an extended period of monetary accommodation by a central bank in a large economy via QT may entail significantly more adverse international output spillovers than conventional tightening. When alternative exit strategies are scaled to generate the same impact on domestic inflation and output, our results suggest that tightening via QT causes an inflation-output tradeoff to emerge in other economies, whereas conventional policy tightening does not. This is because QT engenders a depreciation of the exchange rate in the recipient economy – which stimulates inflation and triggers a higher term-premium – which lowers output. The potential for QT in large economies to exacerbate inflation-output tradeoffs abroad is particularly strong under an emerging market calibration, in which a weaker exchange rate is passed-through to core CPI faster. We also show that foreign transmission of QT can be particularly strong to small open EMEs with fixed exchange rates, as, in this case, they need to markedly tighten policy rates to defend their pegs.

Our model-based finding that spillovers from advanced economy monetary policies – to both advanced and emerging market counterparts – can be quantitatively significant and crucially depend on which of the two monetary instruments is used as the primary tightening lever is an important contribution to a vibrant policy discussion (see e.g., Brainard, 2017; Brainard, 2017; Gilchrist et al., 2019; Brainard, 2017 or the Taper Tantrum-focused work of N'Diaye et al., 2014; N'Diaye et al., 2014, and Moriyama et al., 2014; Moriyama et al., 2014). Our results are also in line with empirical evidence of U.S. monetary policy affecting financial conditions in emerging market and developing economies (e.g., Rey, 2013; Kalemli-Ozcan, 2019; Alter and Elekdag, 2020; IMF, 2021), possibly even exceeding the effects of domestic interventions (Cecchetti et al., 2020). Strong spillovers have also been documented for balance sheet policies (Georgiadis and Jarocinski, 2023; Kolasa and Wesołowski, 2024), with notable cross country heterogeneity (Bowman et al., 2015; Caballero and Kamber, 2019). Our analysis is also related to the debate on which international transmission channels dominate. Curcuru et al. (2018) and Deng et al. (2022), for example, focus on the role of exchange rate effects, while Albagli et al. (2019) stress the importance of term premiums, particularly in the context of monetary policy spillovers. Our findings highlight the importance of both channels.

Overall – adopting a global perspective to policy normalization by large central banks – our results tend to favor conventional interest rate hikes over asset sales: both polices can achieve similar domestic objectives, but conventional policy tightening carries the benefit of smaller negative effects on other countries, especially emerging market economies. This conclusion is broadly in the spirit of the IMF's Integrated Surveillance Decision (ISD) framework, which leans towards alternatives with fewer negative spillovers.

The remainder of the paper is structured as follows: Section 2 discusses our empirical framework and the key results on conventional and LSAP transmission. Section 3 provides an overview of our model and calibration. Section 4 outlines the transmission mechanism of conventional and unconventional policies, while Section 5 focuses on the spillovers of exit strategies and discusses the robustness of our findings. Section 6 concludes.

2. Empirical Results

Our empirical results are based on local projections, with variable X_t at horizon h described by the following equations

$$X_{t+h} - X_{t-1} = c^h + \beta^h \epsilon_t + \sum_{j=1}^{P} d_p Z_{t-p} + u_{t+h} \tag{1}$$

$$var(u_{t+h}) = \Omega_h \tag{2}$$

where c is an intercept, ϵ denotes a vector of structural monetary policy shocks – described in more detail below – and Z denotes control variables for domestic US conditions and common international shocks. These controls include lags of the dependent variable ΔX_t, industrial production growth, PCE inflation, stock returns, change in the unemployment rate, the 10 year term premium, oil prices and OECD-wide industrial production and prices. As equation (2) shows, and as discussed below, we allow the forecast errors u_{t+h} to be heteroscedastic.

2.1. **Monetary Policy Shocks.** Our interest centers on conventional policy rate shocks and unconventional large scale asset sales. We use the proxies for these disturbances constructed from high frequency yield curve data by Lewis (2023), however we obtain broadly similar results when we use the shocks for these policy changes estimated by Swanson (2021).[3] Broadly, Swanson (2021) extends the analysis in Gurkaynak et al. (2005) to construct factors from intraday yield curve data that represent surprise changes in conventional monetary policy, LSAPs and forward guidance. These factors are rotations of principal components obtained from the high frequency yields. The

[3] The key associated results, alongside those based on the identification proposed in Jarociński (2024), can be found in Appendix B.

conventional policy shock is the factor that can load on the 3-month yield while the remaining factors are restricted to have no impact at the short-end. The LSAP shock is identified by placing a further restriction that the variance of this factor is as small as possible over the pre-2009 period.

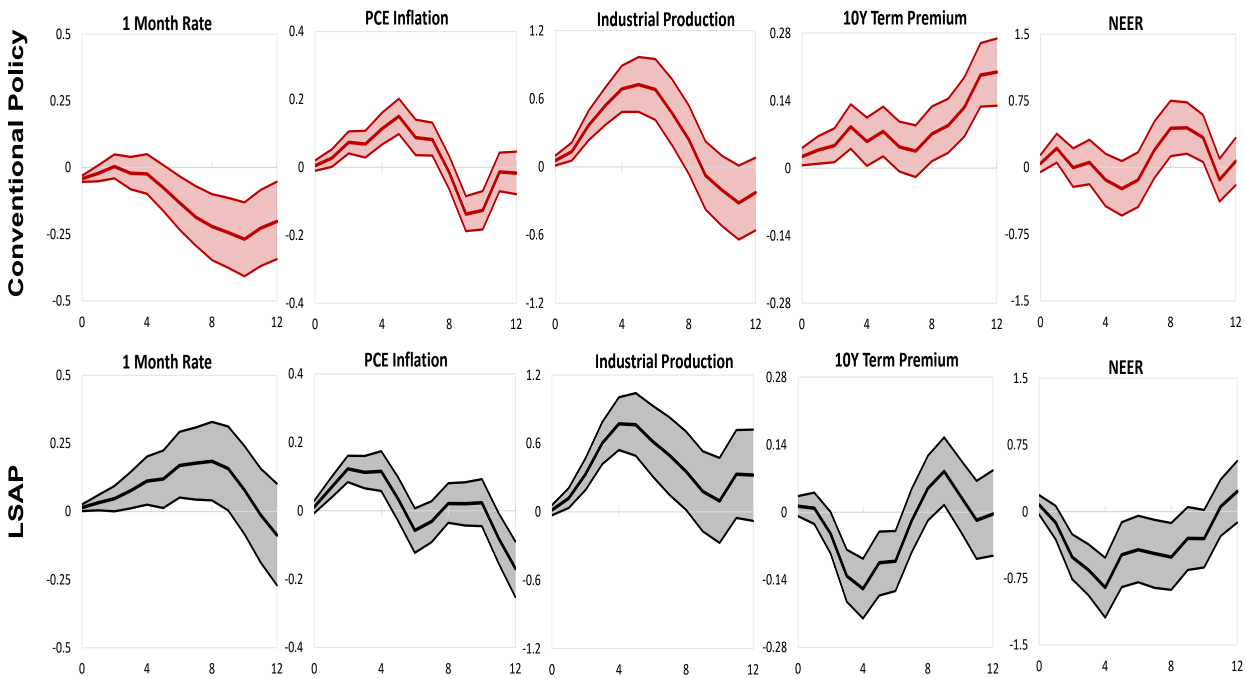
Lewis (2023) relaxes the assumption implicit in Swanson (2021), namely that the relationship between policy shocks and high frequency yields is constant over time. The announcement-specific relationship between the yields and shocks is estimated by exploiting heteroscedasticity in the intra-day yield curve data on monetary policy announcement days, precluding the need to impose the restrictions used by Swanson (2021). The shocks are then labeled using a historical decomposition – conventional monetary policy shocks are those that affect the first two Fed Fund future contracts while LSAP shocks shift either the 5 or 10-year yields and move S&P 500 in the opposite direction. Notably, Lewis (2023) also identifies forward guidance shocks and an information shock which we include as controls in the LP model. [4]

2.2. **Estimation and Specification.** Our sample is monthly and runs from 1996M1 to 2019M12, though, to facilitate comparisons to the quarterly DSGE model, we subsequently report results at a quarterly frequency. The lag length P is set to 12. We adopt a Bayesian approach to estimation and approximate the posterior distribution of the impulse response β^h using a Gibbs sampling algorithm. The forecast errors of the LP regression u_{t+h} follow student's t-distributions with degrees of freedom ν and variance Ω_h. As discussed in Geweke (1993) and Koop (2003), this assumption is equivalent to allowing for heteroscedasticity of an unknown form (more details on the prior distributions and the Gibbs algorithm are provided in Appendix C).

It is well known that the LP residuals are autocorrelated at horizons greater than 0. We deal with this issue through lag augmentation. Montiel Olea and Plagborg-Møller (2021) have demonstrated that heteroscedasticity-robust (frequentist) confidence intervals from LPs that control for lags of the regression variables have satisfactory coverage rates even without an explicit correction for serial correlation. Cloyne et al. (2022) show through a Monte-Carlo experiment that Montiel Olea and Plagborg-Møller (2021) results also extend to the Bayesian LP with student-t errors and that the error bands estimated via Gibbs sampling display good coverage rates even at long-horizons.

[4] In a related paper Jarociński (2024) identifies unconventional policy shocks by exploiting non-normality in the high frequency yield curve data. Georgiadis and Jarociński (2023) show that the Jarociński (2024) shocks produce impulse responses of US variables that are very similar to those obtained when the Swanson (2021) measures are used, and we also report key results based on this alternative identification scheme in Appendix B.

Figure 2. Conventional Policy vs LSAP Transmission



Note: This figure compares IRFs to a conventional monetary policy shock (red line and shaded areas in the top panels corresponding to the median and 68% error bands) to a large scale asset purchase shock (LSAP) (black lines and grey shaded areas in the bottom panels). All panels show quarterly responses to a one standard deviation expansionary shock in the US.

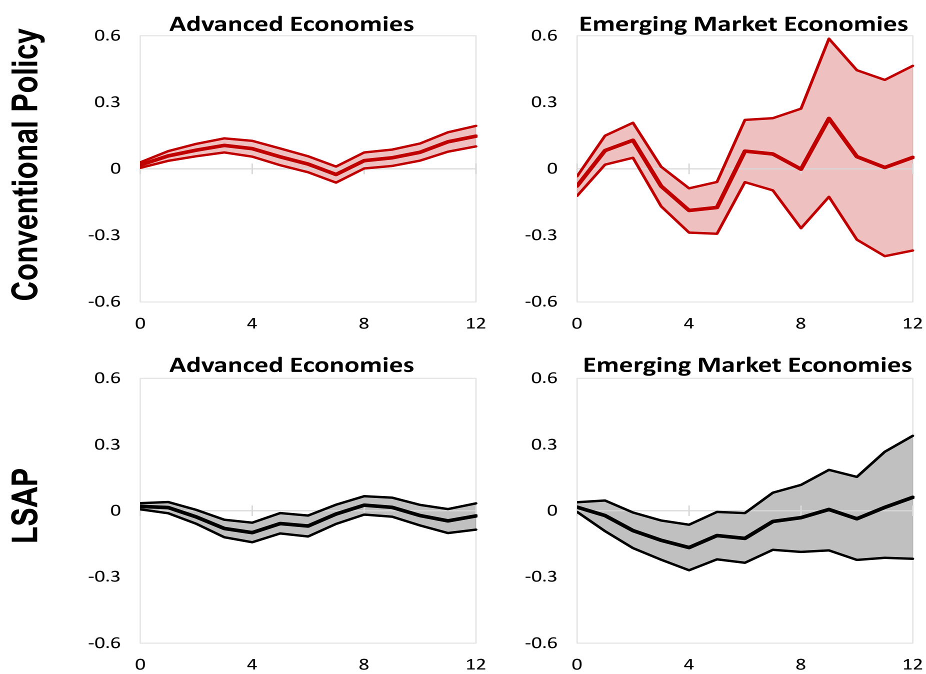
2.3. **Transmission of Conventional Monetary Policy and LSAPs.** Our key empirical findings are summarized in Figure 2, which compares IRFs to one standard deviation expansionary monetary policy shocks (top panels) to those from a large scale asset purchase (bottom panels).[5] As can be seen from the first column, looser conventional monetary policy is estimated to slowly decrease the level of the one-month interest rate, which contrasts with the somewhat positive and then insignificant responses to LSAPs. Despite these differences, both shocks are inflationary (column two) and have a positive effect on industrial production (a proxy for total output, which is unavailable at monthly frequency) shown in column three.[6] In our view, however, the most intriguing aspects of Figure 2, are presented in the final two columns. In line with the frequently-stated goal of large scale asset purchases being lower long term yields, the fourth column shows that

[5] Even though our paper is about "Exit Strategies", we recognize that the data is most informative about the effects of quantitative easing. Because our model suggests that QE and QT propagate differently, we have examined this possibility empirically. Appendix A reports IRFs from an empirical model which allows for asymmetries in transmission, and which is broadly consistent with the view that the stimulative effects of QE in a liquidity trap exceed the contractionary potential of QT during a tightening phase.

[6] Per Figure 10, reproduced in Appendix A, the similarities do not end there, with both shocks having a positive effect on employment and equity prices.

the ten year term premium decreases in response to LSAPs, but not following conventional policy tightening. In fact, had we normalized shocks to LSAPs and short-term policy rates based on their impact on long-term yields, LSAPs would be associated with a notably smaller impact on industrial production but a relatively large propagation to the nominal exchange rate.[7] Relatedly, the final column shows that expansionary LSAP shocks depreciate the dollar nominal effective exchange rate, whereas conventional interest rate hikes have a considerably more modest effect on the exchange rate path.[8]

Figure 3. Spillovers to 10-year Term Premiums



Note: This figure compares IRFs to a conventional monetary policy shock (red line and shaded areas in the top panels corresponding to the median and 68% error bands) to a large scale asset purchase shock (LSAP) (black lines and grey shaded areas in the bottom panels). All panels show quarterly responses to a one standard deviation expansionary shock in the US. Advanced Economies comprise an average of term-premiums in Australia, Canada, Norway, Sweden and the UK, while Emerging Market Economies consist of Chile, Mexico, Poland and Russia (see also body of the text for exact inclusion criteria).

[7] More broadly, the conventional shock increases the 10 year rate around FOMC meetings by 0.1 SD units on impact while the unconventional shock raises this variable by 0.24 SD units on impact. Therefore, the effect of conventional policy would be larger once scaled.

[8] Arguably, the latter result differs from some earlier studies, such as those of Christiano et al. (2005). Beyond differences in data ranges, frequencies and variables used in those studies, we attribute these discrepancies to the fact that – absent recent advances in identification techniques – researchers previously had no way of disentangling the effects of pure monetary shocks from those of information effects, e.g., of what central bank decisions revealed about the state of the economy, or the guidance they provided about the future conduct of policy.

The final pieces of the empirical puzzle that we inspect are related to spillovers of conventional policy and LSAPs to ten year term premiums in advanced and emerging market economies (Figure 3). Our full sample comprised estimates of ten year term premiums derived using the methodology proposed by Adrian et al. (2013) for 18 AEs and 14 EMEs.[9] We then restricted attention to a subset of countries, which, according to the latest IMF AREAERS report (published in 2022), were listed as inflation targeters with a de facto freely floating exchange rate. We subsequently averaged term premium estimates for the resulting AEs (Australia, Canada, Norway, Sweden and the UK) as well as the relevant subset of EMEs (Chile, Mexico, Poland and Russia), and we used our benchmark local projection to estimate the impact of policy shocks on these averages. Importantly, Figure 3 suggests that US LSAPs, in contrast to conventional policy, are successful at compressing 10-year term premiums in both advanced and emerging market economies. This result is in line with the effects of conventional policy and LSAPs at the daily frequency estimated by Georgiadis and Jarociński (2023)

In summary, the "stylized facts" that we will be interested in first replicating, and subsequently analyzing through the lens of the DSGE model, are that large scale asset purchase shocks mainly propagate through exchange rates and long-dated term premiums. Broadly in line with the findings reported in Kiley (2014), our empirical results also imply that quantitative easing in the United States has roughly 2.5 times smaller effects on domestic industrial production when we normalize by the shocks' impact on long rates. Expressed alternatively, central bank asset sales have considerably smaller effects on domestic demand than conventional policy shocks when normalized by their impact on long-term nominal yields. [10]

3. Model and Calibration

As alluded to in the introduction, the two-country DSGE model used in our analysis nests the one developed in Kolasa and Wesołowski (2020). We now provide an overview of its main elements, highlighting the key extensions along the way. Since the model structure is largely symmetric, in what follows we focus on problems faced by agents populating the home economy, except when foreign problems are non-trivially different. In all cases, foreign variables are indicated with an

[9] The data were kindly provided by Mustafa Caylan and Sheheryar Malik, who used them as inputs to IMFs Global Financial Stability Reports.

[10] This result is consistent with the findings reported in Swanson (2023)

asterisk. Moreover, for any variable X_t: X denotes X_t's steady state and $x_t = X_t/P_t$ denotes its real value, where P_t is the aggregate price level.

Global population is normalized to unity and the relative size of the domestic economy is $\omega \in (0,1)$. Each country is populated by two types of households, as well as final and intermediate goods producers that supply domestic and foreign markets.

3.1. **Households.** The two types of households are labeled "restricted" and "unrestricted", and indexed with $j \in \{r, u\}$, respectively, with $\omega_r \in (0,1)$ denoting the share of restricted households.[11] Both types derive log-utility from consumption c^j, offer labor services to firms at the nominal wage rate W_t, receive dividends from monopolistically competitive firms D_t^j, and pay lump sum taxes T_t^j, with lifetime utility maximized by household of type j given by

$$U_t^j = \mathbb{E}_t^j \sum_{s=0}^{\infty} \beta_j^s \exp\{\varepsilon_{t+s}^d\} \left[\log(c_{t+s}^j) - \frac{(n_{t+s}^j)^{1+\varphi}}{1+\varphi} \right], \tag{3}$$

where ε_t^d is the preference shock, $\beta_j \in (0,1)$ is the subjective discount factor, and $\varphi > 0$ is the (inverse) Frisch elasticity of labor supply, and $\mathbb{E}_t^j$ indicates the expected value operator under the subjective expectations of type j households.

Regarding the latter, we deviate from rational expectations by following Gabaix (2020) and its open economy extension derived in Kolasa et al. (2022) and assuming that households can be myopic. More specifically, when anticipating the future, they shrink their expectations toward the economy's steady state. Formally, for any variable X_t that households of type j take as given during optimization, their perceived law of motion is

$$X_{t+1} - X = m_j \mathbb{G}^X (\mathbf{X}_t^s - \mathbf{X}^s, \epsilon_{t+1}), \tag{4}$$

where $\mathbf{X}_t^s$ is a vector of aggregate state variables, ϵ_t is a vector of innovations to stochastic processes driving the economy, $\mathbb{G}^X$ is the equilibrium aggregate policy function for variable X_t, and $0 \leq m_j \leq 1$ is a cognitive discounting parameter for agent j, with $m_j = 1$ corresponding to the standard case of rational expectations.

[11] These name choices are largely for consistency with previous literature (Andres et al., 2004; Chen et al., 2012; Kiley, 2014) even though, as per Table 1, "unrestricted" agents cannot hold all asset types.

Households can trade long term bonds, which, following Woodford (2001), we model as perpetuities paying an exponentially decaying coupon $1, \kappa, \kappa^2, \ldots$ starting in the period following issuance, where $\kappa \in (0,1]$. By absence of arbitrage, $P_{L-s,t}$, i.e., the current price of a long term bond issued s periods ago, then has to be related to the price of a newly issued perpetuity $P_{L,t}$ via $P_{L-s,t} = \kappa^s P_{L,t}$. A convenient implication is that we only need to keep track of the long term bond price issued contemporaneously, as prices of all past vintages can be easily recovered using the preceding formula.

With that as background, Table 1 provides an overview of permissible asset holdings, with its entries denoting *units* of the underlying short- or long-term bonds, respectively. As Table 1 makes clear, restricted households trade only in long-term bonds, which is meant to proxy for longer-horizon investors, such as pension funds. Relatedly, unrestricted households have to pay transaction costs to trade in those markets, with corresponding costs for specialized, "restricted" investors assumed to be negligible.[12]

Table 1. Asset Holding Notation

Bond Issuer:	Home	Foreign	Home	Foreign
Bond Type:	Short-term		Long-term	
Home unrestricted	$B^u_{H,t}$	-	$B^u_{H,L,t}$	$B^u_{F,L,t}$
Foreign unrestricted	-	$B^{u,\star}_{F,t}$	$B^{u,\star}_{H,L,t}$	$B^{u,\star}_{F,L,t}$
Home restricted	-	-	$B^r_{H,L,t}$	$B^r_{F,L,t}$
Foreign restricted	-	-	$B^{r,\star}_{H,L,t}$	$B^{r,\star}_{F,L,t}$

Note: An entry means that an agent has access to a given bond, with the symbol denoting time t holdings (units of the security), while a gray background indicates that these holdings are associated with transaction costs.

Letting $R_{L,t} \equiv P^{-1}_{L,t} + \kappa$ denote the gross yield to maturity on domestic long-term bonds, the restricted households' budget constraint becomes[13]

$$P_t c^r_t + \left[P_{L,t} B^r_{H,L,t}\right] + \left(1 + \Gamma^r_t\right)\left[S_t P^\star_{L,t} B^r_{F,L,t}\right] + T^r_t$$
$$= \left[P_{L,t} R_{L,t} B^r_{H,L,t-1}\right] + \left[S_t P^\star_{L,t} R^\star_{L,t} B^r_{F,L,t-1}\right] + W_t n^r_t + D^r_t + \Xi^r_t, \quad (5)$$

[12] For more on the rationale and merits of our chosen approach to introducing segmentation we refer the reader to Appendix D.

[13] The current period yield to maturity is, by definition, $R_{L,t}$ satisfying

$$P_{L,t} = \frac{1}{R_{L,t}} + \frac{\kappa}{R^2_{L,t}} + \frac{\kappa^2}{R^3_{L,t}} + \ldots \equiv \frac{1}{R_{L,t}}\left(\frac{1}{1 - \frac{\kappa}{R_{L,t}}}\right) \Longleftrightarrow R_{L,t} - \kappa = \frac{1}{P_{L,t}} \Longleftrightarrow R_{L,t} = P^{-1}_{L,t} + \kappa.$$

where the terms on the left hand side denote, respectively, expenditures on consumption, home and foreign long-term bond investment, as well as tax obligations, while the terms on the right hand side correspond to proceeds from sales of home and foreign long-term bonds purchased in the previous period, labor income, dividends from firm ownership, and lump-sum subsidies. In addition, S_t is the home nominal exchange rate, and Γ_t^r is an adjustment cost rebated lump-sum through Ξ_t^r and assumed to follow

$$1 + \Gamma_t^r = \exp\left\{\xi_r\left(\frac{S_t P_{L,t}^\star B_{F,L,t}^r}{P_{L,t} B_{H,L,t}^r} - \frac{s P_L^\star b_{F,L}^r}{P_L b_{H,L}^r}\right)\right\}. \tag{6}$$

This adjustment cost is introduced only to ensure determinacy of "restricted" agents' asset portfolios and we make it quantitatively negligible by setting ξ_r to a positive but very small number.

In line with Table 1, unrestricted agents additionally have access to domestic short-term bonds, trading in which requires paying upfront transaction costs $\zeta_{H,t}$ and $\zeta_{F,t}$, respectively. These considerations translate into the following, "unrestricted" budget constraint

$$\begin{aligned} &P_t c_t^u + \left[B_{H,t}^u\right] + \left[(1+\zeta_{H,t}) P_{L,t} B_{H,L,t}^u\right] + \left[(1+\zeta_{F,t}) S_t P_{L,t}^\star B_{F,L,t}^u\right] + T_t^u \\ &\qquad = \left[R_{t-1} B_{H,t-1}^u\right] + \left[P_{L,t} R_{L,t} B_{H,L,t-1}^u\right] + \left[S_t P_{L,t}^\star R_{L,t}^\star B_{F,L,t-1}^u\right] + W_t n_t^u + D_t^u + \Xi_t^u, \end{aligned} \tag{7}$$

where R_t is the short-term policy rate, and all the bond holding costs are rebated lump sum through Ξ_t^u and are assumed to satisfy

$$\frac{1+\zeta_{H,t}}{1+\zeta_H} = \left(\frac{P_{L,t} b_{H,L,t}^u}{P_L b_{H,L}^u}\right)^\xi \quad \text{and} \quad \frac{1+\zeta_{F,t}}{1+\zeta_F} = \left(\frac{P_{L,t} b_{F,L,t}^u}{P_L b_{F,L}^u}\right)^\xi,$$

with $\xi > 0$.

3.2. **Firms.** Perfectly competitive final goods producers combine homogeneous home-made goods $y_{H,t}$ and imported goods $y_{F,t}$ according to the following technology

$$\tilde{y}_t = \left(\eta^{\frac{1}{\nu}} y_{H,t}^{\frac{\nu-1}{\nu}} + (1-\eta)^{\frac{1}{\nu}} y_{F,t}^{\frac{\nu-1}{\nu}}\right)^{\frac{\nu}{\nu-1}}, \tag{8}$$

where $\eta \in (0,1)$ is the home-bias parameter, and $\nu > 0$ is the elasticity of substitution between domestic and imported goods. Inputs into final goods production are indexed by i and aggregated according to

$$\int_0^1 G\left(\frac{y_{H,t}(i)}{y_{H,t}}\right) di = 1, \tag{9}$$

for $h = \{H, F\}$, and where the Kimball aggregator is parameterized as in Dotsey and King (2005) by assuming

$$G(x) \equiv \frac{\phi}{1+\psi}\left[(1+\psi)x-\psi\right]^{\frac{1}{\phi}} - \frac{\phi}{1+\psi} + 1, \tag{10}$$

with $\psi \leq 0$. This specification implies that the steady state (gross) markup μ equals $\frac{\phi}{(1-\phi)(1+\psi)+\phi}$, and it nests the standard Dixit and Stiglitz (1977) aggregator for $\psi = 0$ (in which case we also have $\mu = \phi$).

Intermediate inputs are produced by monopolistically competitive firms indexed by i and operating a production function that is linear in labor

$$y_{H,t}(i) + y^{\star}_{H,t}(i) = \exp\{\varepsilon^z_t\} n_t(i) - f, \tag{11}$$

where ε^z_t denotes a productivity shock, and $f > 0$ is a fixed cost of production. Every period these firms face a fixed probability θ_H of domestic price reoptimization, and probability $\theta^{\star}_H$ of export price reset, with non-resetting firms indexing prices according to $P_{H,t}(i) = \pi^{\zeta}_{t-1}\pi^{1-\zeta}P_{H,t-1}(i)$ and $P^{\star}_{H,t}(i) = \left(\pi^{\star}_{t-1}\right)^{\zeta}(\pi^{\star})^{1-\zeta}P^{\star}_{H,t-1}(i)$, where $0 \leq \zeta \leq 1$. We additionally assume that marginal costs faced by firms are distorted by an exogenous shock ε^m_t, which can be interpreted as reflecting stochastic variation in proportional taxes levied on firms that are rebated back to them in a lump sum fashion.

Assuming no myopia and local firm ownership – by "restricted" and "unrestricted" agents and in proportion to their shares in the population – the problem of reoptimizing firms becomes to maximize

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\theta_H)^s \Lambda_{t+s}\left(P_{H,t}(i)\left(\pi_t...\pi_{t-1+s}\right)^{\zeta}\pi^{(1-\zeta)s} - \exp\{\varepsilon^m_{t+s} - \varepsilon^z_{t+s}\}W_{t+s}\right) y_{H,t+s}(i), \tag{12}$$

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\theta^{\star}_H)^s \Lambda_{t+s}\left(S_{t+s}P^{\star}_{H,t}(i)\left(\pi^{\star}_t...\pi^{\star}_{t-1+s}\right)^{\zeta}(\pi^{\star})^{(1-\zeta)s} - \exp\{\varepsilon^m_{t+s} - \varepsilon^z_{t+s}\}W_{t+s}\right) y^{\star}_{H,t+s}(i), \tag{13}$$

where $\Lambda_{t+s} \equiv P^{-1}_{t+s}[\omega_r\beta^s_r(c^r_t)^{-\sigma} + (1-\omega_r)\beta^s_u(c^u_t)^{-\sigma}]$ is the nominal stochastic discount factor, $P_{H,t}(i)$ is the price set by intermediate producer i for the domestic market, $P^{\star}_{H,t}(i)$ is the price set for the foreign market, while $\pi_t \equiv P_t/P_{t-1}$ and $\pi^{\star}_t \equiv P^{\star}_t/P^{*}_{t-1}$ are the domestic and foreign final good inflation rates.

3.3. **Government.** The fiscal authority operates subject to the following constraint

$$B^f_{H,t} + P_{L,t} B^f_{H,L,t} + T_t + \Phi^c_t = R_{t-1} B^f_{H,t-1} + P_{L,t} R_{L,t} B^f_{H,L,t-1} + P_t g_t,$$

i.e., it finances its expenditures by issuing long-term $B^f_{H,L,t}$, and short-term $B^f_{H,t}$ bonds, as well as through lump sum taxation T_t, with any holding-period profits made by the central bank on its asset portfolio Φ^c_t transferred back to the treasury. Government expenditures on final goods are assumed to follow $g_t \equiv g \exp\{\varepsilon^g_t\}$, where ε^g_t is the government spending shock. Taxes per capita are set equal across the two household types. In the baseline version of our model, the fiscal authority is assumed to keep the real market value of debt $b^f_t \equiv \left(P_{L,t} B^f_{H,L,t} + B^f_{H,t}\right) / P_t$ and its composition $\theta^L_t \equiv \left(P_{L,t} B^f_{H,L,t}\right) / \left(P_{L,t} B^f_{H,L,t} + B^f_{H,t}\right)$ constant.

The monetary authority conducts "conventional" monetary policy according to a Taylor-type feedback rule subject to the zero lower bound constraint

$$R_t = \max\left\{1, \tilde{R}_t\right\} \qquad \text{where} \qquad \tilde{R}_t = R^{\gamma}_{t-1} \left[R \left(\frac{\pi_t}{\pi}\right)^{\gamma_\pi} \left(\frac{y_t}{y}\right)^{\gamma_y} \right]^{1-\gamma} \exp\{\varepsilon^r_t\}, \tag{14}$$

with ε^r_t denoting the monetary policy shock, $\gamma_r \in (0, 1)$ controlling the degree of interest rate smoothing, and γ_π and γ_y determining, respectively, the strength of interest rate responses to deviations of inflation and output from their steady state values.

The central bank can also be active in the domestic bond market, i.e., it can take a position $B^c_{H,L,t}$ in long term bonds, financing it entirely by issuing reserves $B^c_{H,t}$ that pay interest R_t, and hence which – from the perspective of private agents – are indistinguishable from short term government bonds. We shall refer to $QE_t \equiv P_{L,t} B^c_{H,L,t} = B^c_{H,t}$ as the size of LSAP and we assume that it is driven by the following rule

$$QE_t \equiv \left(1 + (1 - \varrho)\left(\frac{P_{L,t}}{P_{L,t-1}} R_{L,t} - \frac{1}{P_{L,t-1}} - 1\right)\right) QE_{t-1} + \varepsilon^c_t, \tag{15}$$

where $0 \leq \varrho < 1$ is a parameter controlling the reinvestment strategy (see also Appendix F for detailed derivations and a comprehensive discussion).

The holding period profit associated with central bank asset purchases is

$$\Phi^c_t \equiv R_{t-1} B^c_{H,t-1} + P_{L,t} R_{L,t} B^c_{H,L,t-1}, \tag{16}$$

and, as highlighted above, we assume that it is fully transferred to the fiscal authority.

3.4. **Market Clearing Conditions.** Equilibrium in the goods market requires

$$\tilde{y}_t = \omega_r c_t^r + (1-\omega_r)c_t^u + g_t, \tag{17}$$

and

$$y_t \equiv y_{H,t}\Delta_{H,t} + \frac{1-\omega}{\omega} y_{H,t}^{\star}\Delta_{H,t}^{\star} = \exp\{\varepsilon_t^z\}n_t - f, \tag{18}$$

where $n_t \equiv \omega_r n_t^r + (1-\omega_r)n_t^u$ is aggregate labor input, y_t defines aggregate output, and

$$\Delta_{H,t} \equiv \frac{1}{1+\psi}\left(\int_0^1 \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{\frac{1}{1-\phi}} di\right)^{-\phi} \int_0^1 \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{\frac{\phi}{1-\phi}} di + \frac{\psi}{1+\psi}, \tag{19}$$

captures price dispersion arising on account of staggered price setting in the intermediate goods sector producing for domestic market, with the price dispersion index associated with export production $\Delta_{H,t}^{\star}$ defined analogously.

Complementing these, we also have market clearing conditions for bonds issued by the home economy's government, including central bank reserves

$$(1-\omega_r)B_{H,t}^u = B_{H,t}^f - B_{H,t}^c, \tag{20}$$

and

$$\omega_r B_{H,L,t}^r + (1-\omega_r)B_{H,L,t}^u + \frac{1-\omega}{\omega}\omega_r^{\star} B_{H,L,t}^{r\star} + \frac{1-\omega}{\omega}(1-\omega_r^{\star})B_{H,L,t}^{u\star} = B_{H,L,t}^f - B_{H,L,t}^c. \tag{21}$$

3.5. **Exogenous shocks.** The model dynamics is driven by stochastic shocks. These are the country pairs of shocks to productivity (ε_t^z and $\varepsilon_t^{z\star}$), markups (ε_t^m and $\varepsilon_t^{m\star}$), time preferences (ε_t^d and $\varepsilon_t^{d\star}$), government spending (ε_t^g and $\varepsilon_t^{g\star}$), conventional monetary policy (ε_t^r and $\varepsilon_t^{r\star}$), and central bank asset purchases (ε_t^c and $\varepsilon_t^{c\star}$). Unless otherwise stated, all shocks are modeled as independent first-order autoregressions.

3.6. **Calibration.** In our two-country setup, the foreign economy is always assumed to be large and represent the US. The calibration of the smaller, home country comes in two flavors and is meant to proxy either an advanced economy (AE), or an emerging market (EM). Broadly, apart from being smaller, the advanced economy is calibrated symmetrically to the foreign one. Conversely, and as discussed in detail below, the emerging market economy features larger pass-through from exchange rates to inflation, in line with the estimates provided by Brandao-Marques et al. (2021), and more

Table 2. Calibrated Parameters

Parameter	Symbol)	Value
Size of the small economy	ω	0.01
Share of restricted households	ω_r	0.15
Inv. Frisch elasticity of labor supply	φ	2
Discount factor, unrestricted households	β_u	0.99875
Discount factor, restricted households	β_r	0.9975
Cognitive discounting, unrestricted households	m_u	0.95
Cognitive discounting, restricted households	m_r	1
Steady-state inflation	π	1.005
Long-term bond duration	$D = \frac{\pi\beta_r^{-1}}{\pi\beta_r^{-1}-\kappa}$	40
Transaction cost on long-term bonds	ξ	0.015
Price markup	$\mu = \frac{\phi}{(1-\phi)(1+\psi)+\phi}$	1.15
Kimball parameter	ψ	-12
Calvo probability for domestic production	θ_H, $\theta_F^\star$	0.75
Calvo probability for home exports (AE, EME)	$\theta_H^\star$	0.667, 0.88
Calvo probability for home imports (AE, EME)	θ_F	0.667, 0.5
Price indexation in home economy (AE, EME)	ζ	0, 0.75
Price indexation in foreign economy	$\zeta^\star$	0
Elast. of subst. between home and foreign goods	ν	0.8
Home-bias	η	0.75
Interest rate smoothing	γ	0.9
Interest rate response to inflation	γ_π	2
Interest rate response to output gap	γ_y	0.125
Reinvestment strategy	ϱ	0.5525

sticky export prices denominated in foreign currency. These two features align the EM calibration with the dominant currency paradigm (Gopinath et al., 2020). Moreover, we assume that inflation in EMs has a higher degree of intrinsic persistence. Overall, the calibration for the emerging market economy implies that its policymakers face a more difficult monetary trade-off, in line with the discussion in Adrian et al. (2021b). Following standard practice, we either set parameters to match key steady state proportions observed in the data, or we rely on extant literature. Table 2 shows the values we adopted, with Table 3 presenting the targeted steady state ratios. The time period throughout corresponds to a quarter.

The home bias parameter η in the small country is calibrated at 0.75 to capture the typical degree of import penetration in many open economies. The relative home country size ω is set to 0.01, which, together with the assumed balanced trade in the steady state, implies that the foreign economy can be considered approximately closed. The elasticity of substitution between domestically produced goods and imports is set to 0.8, reflecting low sensitivity of trade volumes to changes in relative prices that is typically found in the data.

Table 3. Targeted Steady State Ratios

Steady state ratio	Expression	Value
Government consumption to GDP	$\frac{g}{y}$	0.2
Public debt to GDP	$\frac{b^f}{y}$	2.5
Net foreign assets to GDP	$\frac{P_L[\omega_r(b^r_{H,L}+b^r_{F,L})+(1-\omega_r)(b^u_{H,L}+b^u_{F,L})-b^f_{H,L}]}{y}$	0
Long-term bonds to total bonds	$\theta_L = \frac{P_L b^f_{H,L}}{b^f}$	0.5
Central bank assets (QE)	$P_L b^c_{H,L} = b^c_H$	0
Home long-term bonds held by residents	$\frac{\omega_r b^r_{H,L}+(1-\omega_r)b^u_{H,L}}{b^f_{H,L}}$	0.75

An important part of our calibration concerns the structure of the bond market. We set the steady state share of sovereign bonds in quarterly GDP to 2.5, which is close to what was observed in many countries before the Covid-19 pandemic. We also assume that central bank holdings of government bonds were initially zero. The share of long-term bonds in total sovereign bond issuance is calibrated at 0.5 and their duration is set at 10 years. These choices imply that the effective duration of outstanding public debt is close to 5 years. The steady state share of resident holdings in total long-term bonds issued by the small economy is calibrated at 0.75. We also assume that the portfolio of long-term bonds held by restricted and unrestricted households exhibits the same degree of home bias. Since balanced trade implies zero net foreign assets, the assumptions listed above are sufficient to pin down the steady state bond holdings by each type of agents in the two economies.

Another important group of parameters determines the degree of bond market segmentation. This is governed by the share of restricted households ω_r, which we set to 0.15, and the sensitivity of transaction costs to changes in bond holdings by unrestricted households ξ, which we calibrate at 0.015. In line with market practice, we assume that maturing assets held by the central bank are partially reinvested, which we achieve by setting the runoff parameter ϱ to 0.5525. These choices allow us to generate the response of the term premium and output to LSAP in the large economy that is consistent with empirical evidence for the US (see also Section 4). We use the US average levels of inflation, short-term rates and long-term rates (and hence also the term premiums) to pin down, respectively, the inflation target π at 1.005 (2% annualized), the discount factor of unrestricted households β_u at 0.99875, and that of restricted agents β_r at 0.9975.

Given the focus of our study, the crucial part of calibration concerns parameters governing inflation dynamics, especially in response to monetary policy actions. We allow for a modest degree of cognitive myopia by setting the corresponding discounting parameter of unrestricted households m_u to 0.95. Compared to papers that estimate this parameter within a DSGE framework (see, e.g., Gust et al., 2022; Kolasa et al., 2022; Brzoza-Brzezina et al., 2022), our choice implies a rather small deviation from rational expectations, which, however, turns out to be sufficient to make the potency of forward guidance small when the economy is in a deep liquidity trap. To account for state-dependence in the slope of the Phillips curve, we follow Harding et al. (2021) and set the Kimball curvature parameter ψ to -12. The Calvo probabilities for domestic sales θ_H and $\theta_F^\star$ are calibrated at 0.75, consistent with the empirical evidence on average price duration.

As alluded to before, some of our calibration choices depend on whether we consider an advanced or emerging small economy. In the former case, we keep the Calvo probabilities for prices of internationally traded goods symmetric by setting them to 0.667, thus allowing for a bit smaller degree of nominal rigidity compared to domestic production. When we instead assume that the small country is an EM, we introduce an asymmetry by allowing for a high degree of stickiness in EM's export prices ($\theta_H^\star = 0.88$) and a significantly faster exchange rate pass through to its import prices ($\theta_F = 0.5$). Moreover, while we assume no intrinsic inflation persistence in the foreign and small AE economy, we set the dynamic price indexation parameter ζ to 0.75 when we deal with the EM case.

The remaining parameters are relatively well-established in the literature. The steady state government spending is set to 20% of GDP, roughly in line with the long-run averages observed in the data. The elasticity of intertemporal substitution σ, the Frisch elasticity of labor supply φ, and price markups μ are all set to typical values used in New Keynesian models. The monetary policy rule coefficients γ, γ_π and γ_y also reflect typical values used in the DSGE literature.

3.7. **Solution.** To preserve nonlinearities associated with the Kimball aggregator and effective lower bound constraint, we do not linearize the model before solving it. To deal with behavioral discounting, which is not tractable in a fully non-linear setting, we proceed as follows. We first derive the linearized first-order conditions describing the decisions of behavioral agents. In an open economy setting these yield aggregate Euler conditions in which the forward looking terms are multiplied by the cognitive discounting parameter m, with an additional additive term that depends on agents' asset holdings (which, for reasons discussed in Kolasa et al. (2022), is very small). Guided by these considerations, we approximate the relevant first-order conditions in the non-linear model with formulas that, after linearization, yield equations that match the linear derivations, up to the above mentioned quantitatively small term. We solve the resulting model using the extended path approach of Fair and Taylor (1983).

4. Transmission of Asset Purchases and Interest Rate Policy in the Model

4.1. **Comparing the Effects of QT and Conventional Tightening.** We start our analysis by comparing the transmission channels of quantitative tightening and conventional interest rate hikes. To that effect, we first observe that, in the model, the macroeconomic effects of asset purchases depend on the impact they have on the term structure of interest rates. It is therefore instructive to examine a linearized arbitrage condition linking the expected one-period rate of return from holding long-term bonds to the risk-free interest rate on one-period bonds

$$\mathbb{E}_t^u \hat{R}_{L,t+1}^1 = \hat{R}_t + \zeta_F \hat{B}_{L,t}^u, \tag{22}$$

where $R_{L,t}^1 \equiv \frac{P_{L,t}}{P_{L,t-1}} R_{L,t}$ and hats indicate log-deviations from the steady state. As Equation (22) makes clear, transaction costs – captured by the final term on the right hand side – effectively drive a wedge between the two rates of return.[14] These costs are an increasing function of long-term bond holdings of unrestricted agents (i.e., of those who can hold both types of assets). It follows that, for a given short-term policy rate, asset sales by the central bank increase the supply of long-term bonds available to private agents and so increase the associated expected return. Intertemporal smoothing then implies that the consumption of restricted agents (i.e., those exclusively trading long-term bonds) falls. Note that, unless the short term rate R_t moves, intertemporal decisions made by unrestricted agents are not affected by changes in the term premiums. Consequently, the effect of LSAPs on aggregate output will crucially depend on the share of restricted households in the population.

[14] To first order, the current and expected future transaction costs are related to the term premium via the following equation: $\hat{TP}_t = \frac{\zeta_F}{D} \sum_{s=0}^{\infty} (\frac{D-1}{D})^s \mathbb{E}_t \hat{B}_{L,t+s}^u$. See also Chen et al. (2012).

The second key equilibrium relationship in the model, particularly important for international spillovers of monetary policy, is associated with portfolio choices of unrestricted agents, and is best summarized by the linearized "long-UIP" condition

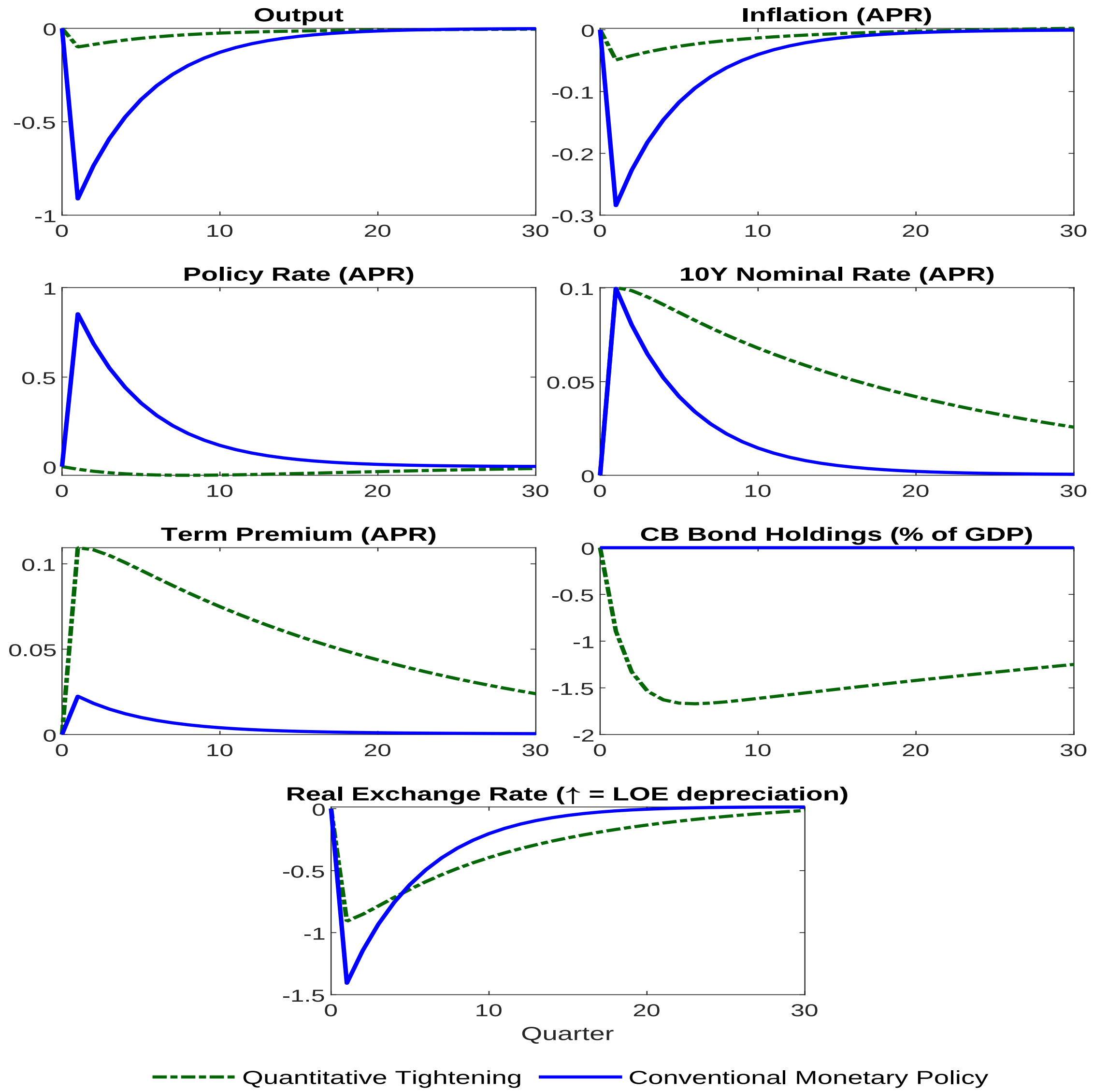
$$\mathbb{E}_t^u \hat{R}_{L,t+1}^1 = \mathbb{E}_t \hat{R}_{L,t+1}^{1,*} + \mathbb{E}_t \Delta \hat{S}_{t+1}, \tag{23}$$

which postulates the equalization of one-period holding returns on long-term bonds denominated in different currencies, with S_t denoting the nominal exchange rate. Its immediate implication is that an increase in the expected return on long-term bonds issued by one country, possibly associated with quantitative tightening conducted by the central bank, must generate an increase in the other country's expected bond return or expected exchange rate depreciation. Expressed alternatively, the exchange rate of the country implementing QT will tend to appreciate on impact. Notably, the exact extent to which the increase in long-term rates translates into domestic appreciation and an increase in foreign long-term rates depends on the policies endogenously pursued by the neighboring central bank. For example, in the case in which the monetary authority operates an exchange rate peg, the effects of foreign QT would be fully transmitted to domestic long-term rates. If, on the other hand, the central bank adopted a standard Taylor-type instrument rule, our model implies that a 100bp hike in foreign long-term rates would increase the same maturity domestic rates by about 35bp, which is close to what is implied by the local projections presented in Section 2 for advanced economies that follow a flexible exchange rate regime.

To show the basic workings of the model under our baseline parameterization, Figure 4 compares the effects of a short-term policy shock and quantitative tightening in the large economy, both sized to provide a 10-basis point increase in the long-term nominal rate. In the former case, this increase reflects a persistent rise in the short-term rate, while in the latter case it is driven by an increase in the term premium. It also turns out that the scale of foreign monetary policy accommodation implied by a standard Taylor rule proves insufficient to equalize foreign and domestic bond returns. Accordingly, the change in large economy long-term bond prices generated by QT leads to a sizable exchange rate adjustment and a contemporaneous increase in other countries' term premium that increases their long-term interest rates. Both developments are a mirror reflection of a large capital outflow from the small economy's bond markets as investors search for higher yields.

Crucially, the model matches key aspects of the IRFs derived and documented in Section 2. Adopting a similar on-impact normalization, here by the ten year rate, we find that unconventional

Figure 4. Effects of Balance Sheet and Short-Term Policy Rate Tightening in the Large Open Economy (LOE)



Note: This figure compares IRFs to quantitative tightening (dashed green line) to those corresponding to a conventional monetary policy tightening (solid blue line). Both types of intervention are scaled to ensure a 10bp increase in the large economy 10Y nominal interest rate. All variables are plotted as deviations from their steady states.

monetary policy has smaller effects on output than interest rate interventions. Quantitative tightening also has little impact on the policy rate and is associated with a more persistent appreciation. In summary, compared to short-term policy rate hikes, large scale asset selloffs have a relatively small impact on domestic aggregate demand, but affect the exchange rate and term premiums more strongly in the medium to long-run.[15]

Our calibrated model suggests that policy rate hikes lower output by about 1 percent, and inflation by 0.3 percent. These effects are also broadly consistent with VAR and DSGE evidence for euro area and the US, albeit admittedly a bit too frontloaded for inflation and output. The latter arguably occurs because we abstract from real rigidities such as habit persistence and gradual nominal wage adjustment, as well as intrinsic persistence in the pricing equations. For quantitative tightening, a 1.5 percent sell-off of CB bond holdings affects output by an order of magnitude less, although the long-term nominal rate increases more persistently. The effects on inflation are also smaller, though in line with the US estimates of Chung et al. (2012), albeit slightly below the median estimates in Fabo et al. (2021).

In the context of our model, the larger output effects of conventional policy compared to QT reflect the fact that 85 percent of consumers are assumed to be financially unconstrained and hence respond relatively more strongly to changes in the short-term policy rate than the term premium-driven changes in the long rate. Even so, an important implication of Figure 4 is that the real exchange rate responds quite strongly to QT. This finding is driven by Equation (23), which stipulates that the exchange rate is primarily driven by the long-term interest rate differential. Since QT has a more persistent influence on the long-term nominal rate, it therefore exerts a relatively large lingering effect on the real exchange rate. As the next section will show, the sizeable exchange rate impact of QT documented here will play an important role in the international propagation of alternative exit strategies.

4.2. **Effects of Forward Guidance and QE in a Liquidity Trap.** Figure 4 studies the effects of large scale asset selloffs when the economy is at the steady state. But since our model features important nonlinear mechanisms, and since Figure 4 does not consider the impact of the ELB, we therefore now focus on the effects of QE in a severe recession.

To generate an adverse scenario, we assume both economies in the model are exposed to negative demand shocks (i.e., the discount factor shock ε_t^d in equation 3), which drives output well below potential and inflation persistently below the central bank's inflation target, so that

[15] If the "conventional" exchange rate response seems large, this is mainly because, and in contrast to the empirical results, the scaling is not by output or inflation but by the long rate. Expressed alternatively, were we to engineer a similar on-impact output contraction, the corresponding "conventional" exchange rate IRF would appear insignificant compared to its LSAP counterpart.

the policy rate becomes constrained by the ELB for an extended period. The adverse scenario is shown by the dotted red lines in Figure 5. The figure also reports two additional simulations. First, a green dashed line shows the effects of a credible forward guidance commitment by the central bank to keep the policy rate lower for longer – at the ELB for almost 5 years – in order to provide additional stimulus and nudge inflation faster back to target. Finally, the solid blue lines show the additional boost and term-premium compression due to large scale asset purchases of long-term bonds totalling almost 20 percent of baseline GDP. The size of the QE program is not optimized, but allows the central bank to close the output gap after three years and raises inflation during the forecast horizon notably.

Figure 5. Effects of Forward Guidance and QE

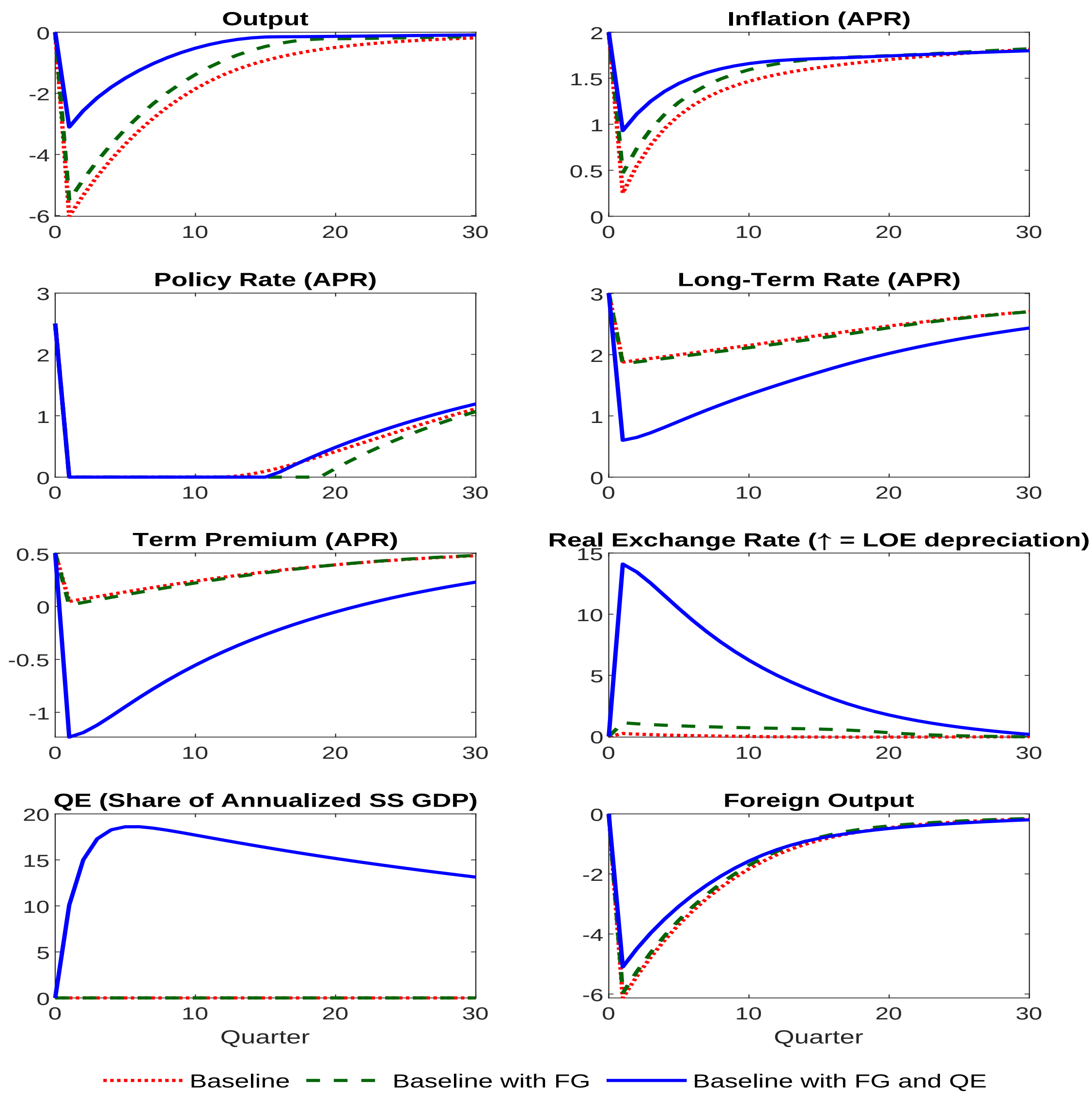


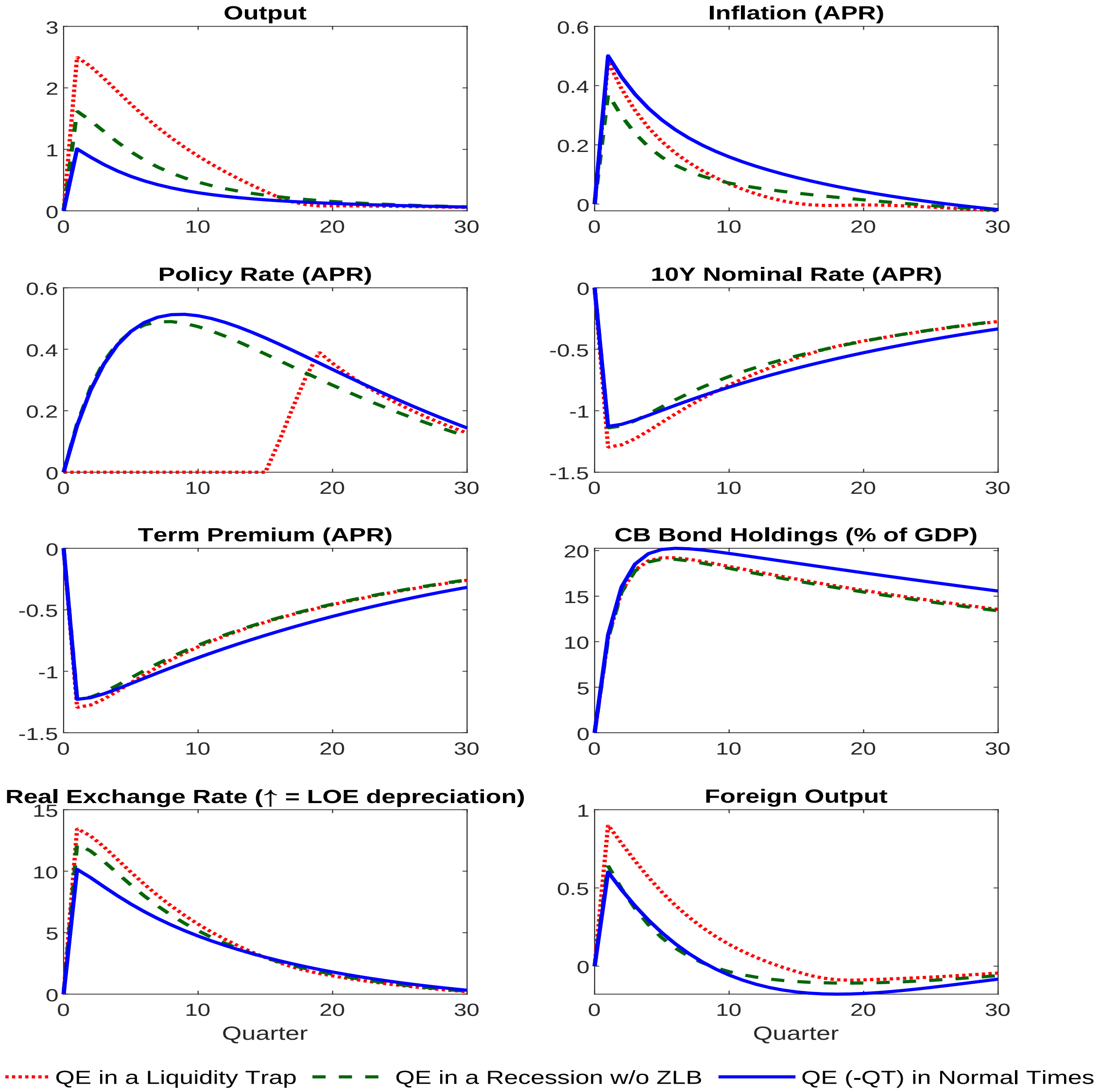
Figure 5 clearly demonstrates that the combination of cognitive discounting and Kimball aggregation effectively eliminates the forward guidance puzzle discussed in Del Negro et al. (2012). Comparing the red dotted and green dashed lines, it is evident that if the economy is exposed to an adverse demand shock, which causes the policy rate to become constrained by the effective lower bound for an extended period (here about three years), then promising to keep rates at the ELB for an even longer period has very small stimulative effects on the economy.

The relative inefficacy of forward guidance leaves open the question of what the central bank could do to provide more material stimulus to the economy in such circumstances? According to our model, and as shown in Figure 5, by efficiently reducing term-premiums and long-term yields, large scale asset purchases retain their potency. For that reason, QE can be argued to be a "policy lever of last resort" for a central bank faced with a protracted liquidity trap. An important insight from the figure is that QE in the large source economy is not a beggar-thy-neighbor policy. Although the exchange rate of the small recipient economy appreciates, its output expands since stronger foreign demand and lower term-premiums dominate the drag on net exports driven by the stronger exchange rate.

4.3. **Comparing the Effects of QE and QT.** With these results in mind, we now compare the transmission of quantitative easing (QE) and quantitative tightening (QT) in our model. We will show that QE, which we assume is undertaken in a recession when the ELB is expected to bind for an extended period, has notably larger domestic effects than QT, which is done when the economy faces a more favorable outlook, and the policy rate is not pinned at the effective lower bound. As we will demonstrate, this greater efficacy in part reflects the ELB, but also the state-dependent slope of the Phillips curve.

To that effect, the red dotted lines in Figure 6 show the marginal impact of QE when the economy is in a recession, while the solid blue lines show the effects of QT (with the sign flipped so that the results can be more easily compared to QE) in the vicinity of the steady state. More specifically, the red dotted line is calculated as the difference between the blue solid line ("Baseline with FG and QE") and the green dashed line ("Baseline with FG") in Figure 5, and hence shows the partial QE impact in a recessionary ELB scenario. The blue solid line, in turn, is simply taken

Figure 6. Effects of QE and QT



Note: All interventions are scaled to ensure a 20% real increase in CB long-term bond holdings at the 2-year horizon.

from Figure 4, with the shock re-sized to ensure identical CB bond holdings around their peak, at the two-year horizon.[16]

As can be seen from the upper left panel of Figure 6, QE has a notably larger transmission to domestic output compared to QT, while the impact on inflation is similar. The larger impact on output most obviously reflects constraints on interest rate policy, characteristic of a recession

[16] The figure makes apparent slight differences in the path of central bank real bond holdings in the two experiments, despite an identical CB reinvestment strategy. These reflect differences in the path of inflation (as we're plotting real holdings), but also differences in revaluation, with prices of long term bonds held by the central bank approximately inversely related to the long run yields (which, like inflation, evolve endogenously in all scenarios). See also Appendix G for more details.

and liquidity trap, but there's more to these differences. To show that most clearly, we added a dashed green line, which is identical to the red, *except* that we relax the assumption that the ELB is a binding constraint. We see that the output impact is larger in the recession, with the inflation impact smaller than in the vicinity of the steady state. Balancing the larger output stimulus and smaller inflation impetus, the central bank hikes rates broadly in line with the course of action pursued close to the steady state.

These differences are almost entirely accounted for by the Kimball aggregator, which, as discussed in Harding et al. (2021, 2023), implies a state-dependent slope of the Phillips curve, with a low slope in a downturn and a higher slope during an economic recovery.[17] This implies that when the central bank is undertaking QE in a recession, it has a relatively larger impact on output than inflation, because the slope of the Phillips curve is low. In contrast, when it is normalizing policy, similar changes would be associated with larger effects on inflation relative to output because of the steepening of the Phillips curve in the corresponding business cycle phase.

5. International Spillovers from Central Bank Exit Strategies

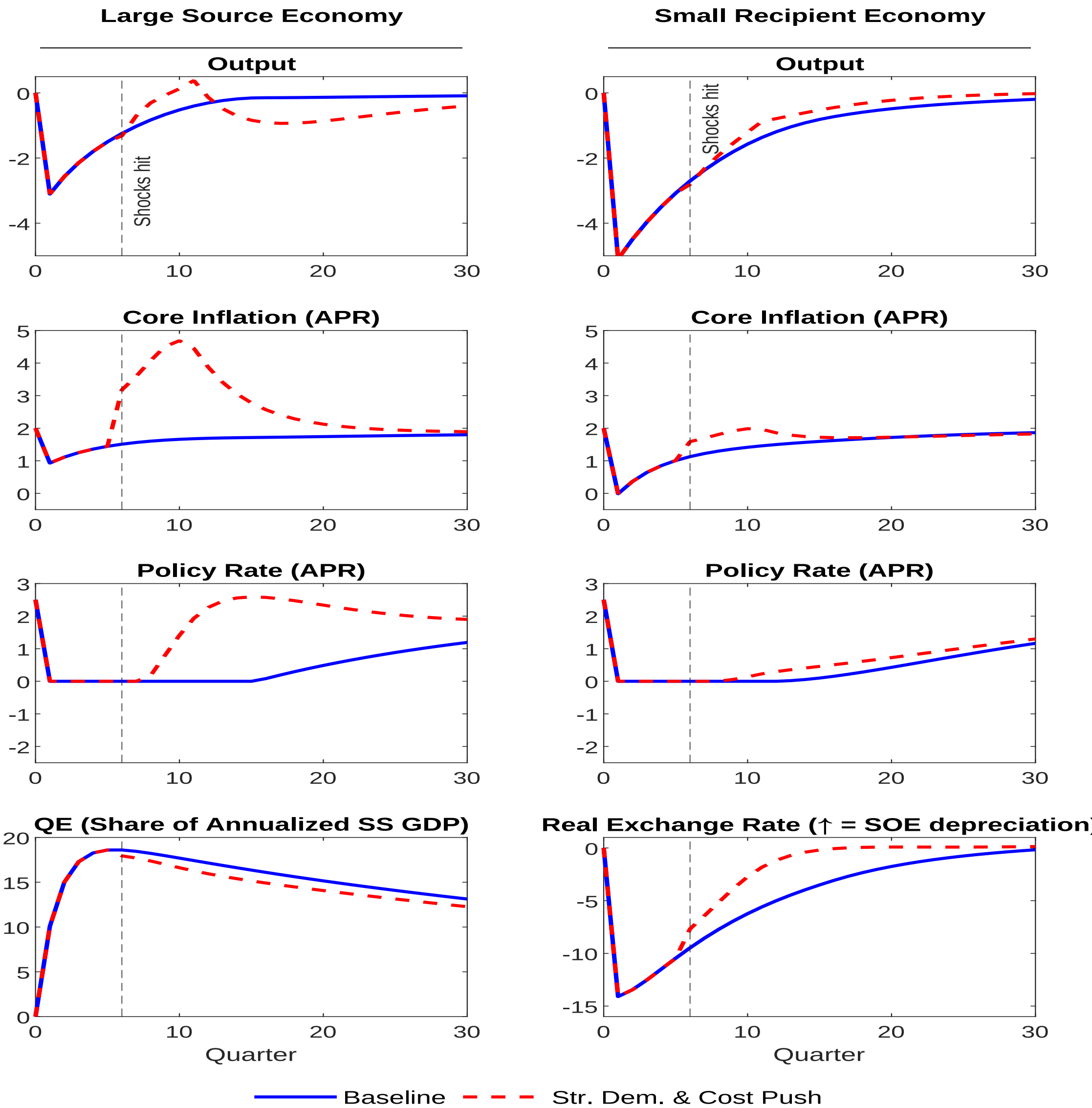
We now move on to discuss international spillovers of alternative exit strategies. Building on the scenario with QE and FG in Figure 5, we add a mix of unanticipated positive demand and adverse supply shocks, which provides a rationale for the large economy central bank to materially tighten its policy stance. We then discuss how this tightening affects the recipient small open economy, assumed to allow its exchange rate to float freely, as part of a flexible inflation targeting regime (which we proxy using a standard interest rate rule). As a final experiment, we demonstrate the sensitivity of spillovers to the recipient economy's exchange rate regime, by showing how spillovers would be affected if its central bank chose to use interest rate policy to implement an exchange rate peg.

5.1. **The Inflation Surge Scenario.** In this section we provide more details on the stronger activity and inflation boom scenario that we use to study the spillover effects of alternative exit strategies. Layered on top of the baseline simulation in Figure 5 (with QE and FG; solid blue lines), a mix of unanticipated positive demand and cost-push shocks hits the large source economy in the

[17] See also Appendix I, which separately quantifies the role of cognitive discounting and Kimball aggregation.

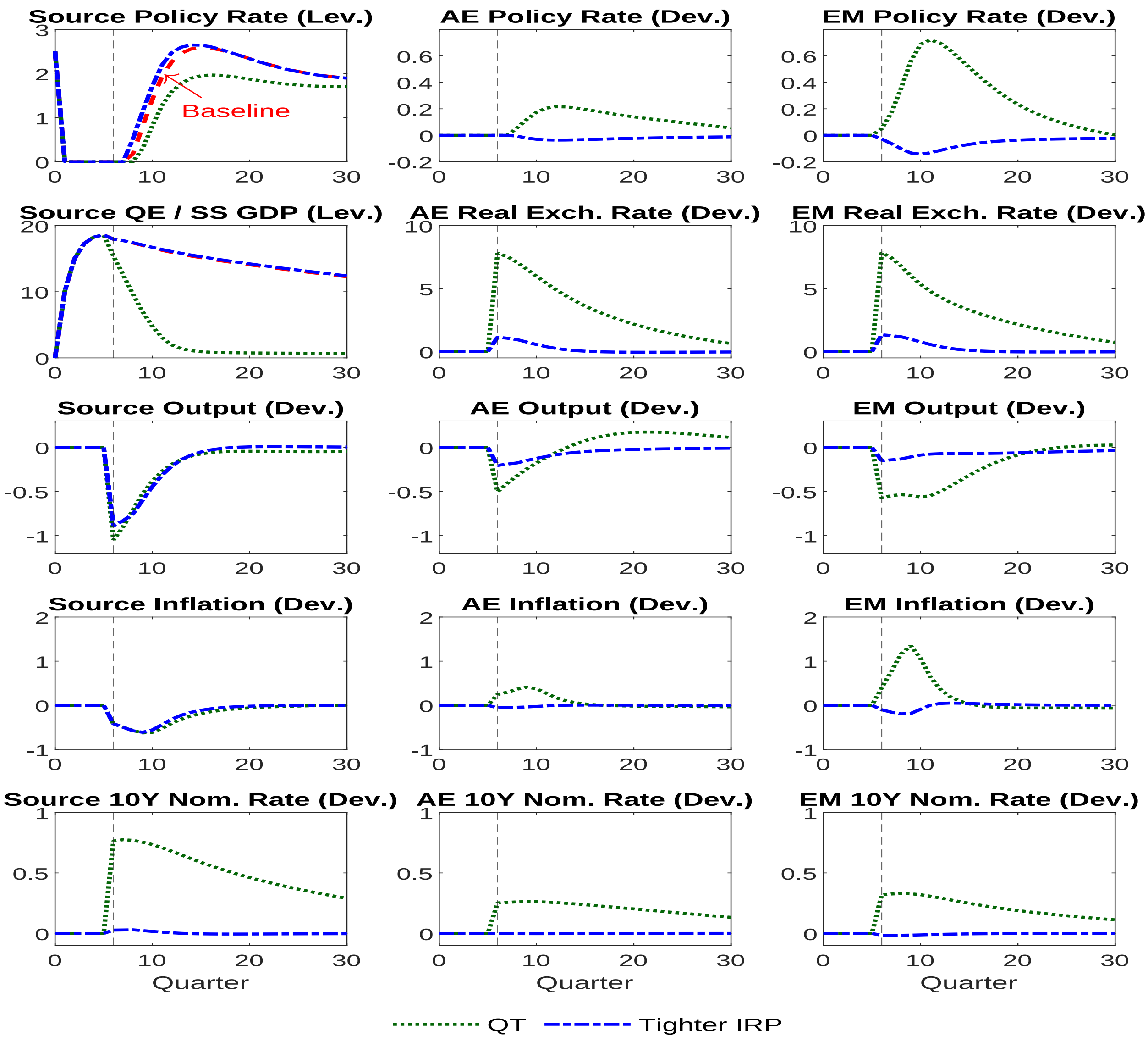
sixth quarter (marked using vertical black lines), with the corresponding trajectories depicted using the red-dashed line in Figure 7. No shocks are assumed to hit the small recipient economy.

Figure 7. Baseline with Unexpected Positive Cost Push and Demand Shocks



These unanticipated shocks cause inflation to surge in the large source economy, and the stronger demand causes output to expand in the short run and contract slightly thereafter (relative to the no shock baseline). As the red dashed lines make clear, the Taylor rule in such circumstances calls for lift-off from the effective lower bound in period eight, two quarters after the occurrence of the unanticipated shock. Since the QE portfolio is exogenous w.r.t. economic developments, the bottom left panel shows that the scenario is associated with a very gradual runoff of the source central bank's bond purchases, which we arrive at by setting the runoff parameter ϱ to 0.5525. The value of the central bank's QE portfolio relative to steady state GDP falls somewhat, because bond prices fall when short- and long-term (not shown) yields rise.

Figure 8. Effects of Alternative Exit Strategies



5.2. **Spillovers from Alternative Exit Strategies.** As strongly suggested by the sizeable overshoot of inflation, the source country central bank can improve on domestic outcomes by pursuing a tighter policy stance. In this section we therefore compare the implications of the large economy effecting a contraction through QT combined with a smaller conventional interest rate hike, to sole reliance on short-term interest rates and allowing its QE portfolio to gradually decline (ceasing reinvestments and holding to maturity).

Figure 8 presents the impact on the large source economy as well as advanced and emerging market recipients.[18] In the top two panels in the left column, the red-dashed lines illustrate the scenario with strong demand and adverse cost push shocks, i.e., the red-dashed lines in Figure 7. The figure also includes paths under two alternative exit strategies: the green dotted line shows a more rapid asset sell-off combined with a smaller short-term interest rate hike, where blue dash-dotted lines show the strategy based solely on conventional policy rate hikes.[19] Importantly, apart from the two upper-left panels, the green and blue lines depict the deviations between the baseline scenario and the alternative tightening strategies. As shown by the third and fourth panels in the left column, the two contractionary monetary strategies are sized to generate the same deviations of inflation and output from their baseline trajectories in the large source economy.

By comparing the results for AEs and EMs, we observe that both exit strategies lower recipient country output. Importantly, however, tightening via short-term policy rates is associated with smaller adverse output effects compared to the QT case, especially so in EMs. As most readily seen by inspecting the middle and right panels in the second row, this occurs because the short-term policy rate tightening entails a notably smaller exchange rate depreciation and smaller increase in term-premiums than QT. Overall, and since both these policies achieve similar source economy objectives, our results therefore suggest using interest rates as the primary instrument for policy tightening on account of notably smaller international spillovers.

The preceding results may seem surprising particularly when compared to those in Figure 4. As alluded to previously, however, the results can be squared by recognizing that the alternative interventions depicted in Figure 8 are sized to give the same impact on *output* and *inflation* in the large source economy. And because the short-term policy rate affects output and inflation by more than LSAPs, larger asset sell-offs are required in the source economy. Accordingly, generating the same inflation and output paths in Figure 8 leads to larger long-term interest rate differentials, which tends to weaken the exchange rate and increase the term-premium more in recipient economies, particularly under the emerging market economy calibration of our model.

[18] The evolution of large source economy variables is largely unaffected by the recipient country calibration due to the relatively small size of the recipient economy.

[19] Under quantitative tightening the central bank combines asset sales with an endogenously less aggressive short-term policy rate path.

In turn, the relatively weaker EM exchange rate acts to exacerbate inflationary pressures, which causes the emerging market economy CB to tighten its policy stance more aggressively, translating into more notable output reductions under QT. Another source of negative spillovers from quantitative tightening is the larger transmission to long-term rates via term premiums. This is evident from the bottom row of Figure 8, where the middle and right panels show that long-term yields in AEs and EMs rise notably more following QT compared to conventional tightening.

5.3. **The Role of Policy Conduct in Recipient Economies.** So far, we have assumed that the small advanced and emerging market economies follow the same interest policy rules as that of the large source economy. This is meant to proxy flexible inflation targeting with no explicit exchange rate stabilization motive. Since spillovers of short-term interest rate hikes and QT hinge on the size of capital flows and exchange rate depreciation, we now investigate how our findings depend on the small recipient economy's exchange rate regime.

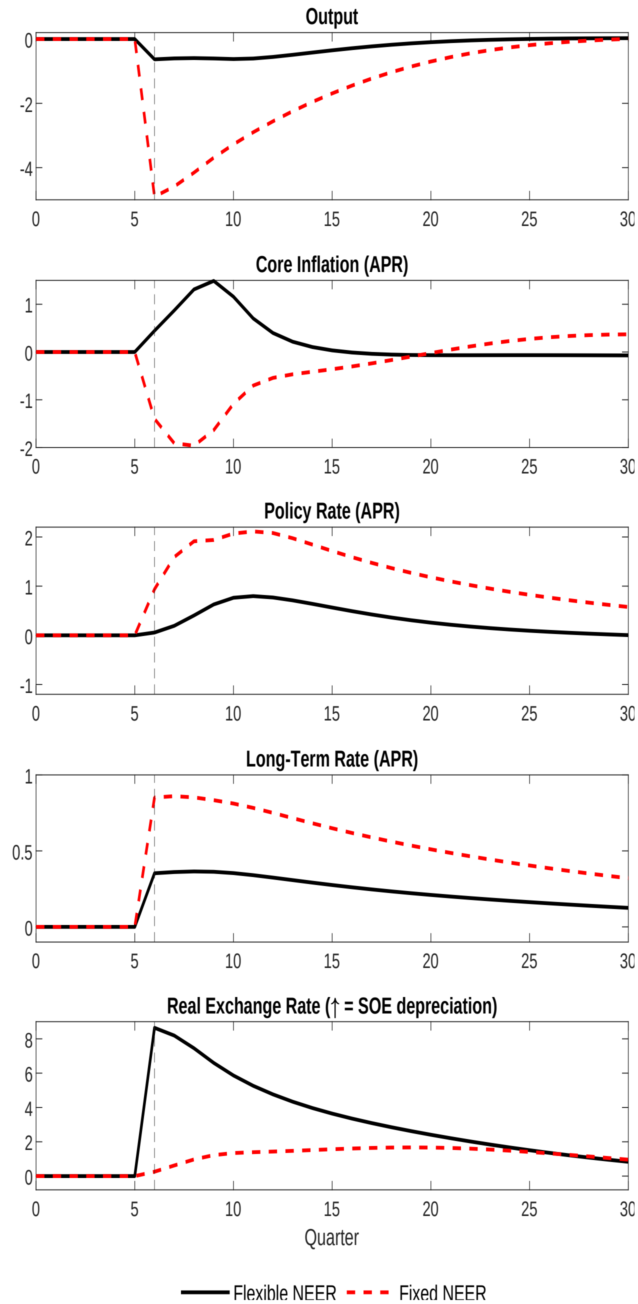
To that effect, in Figure 9, we study spillovers for alternative exchange rate regimes, purposefully restricting our attention to the emerging market calibration, as this is where heavily managed or even fixed exchange rate regimes are most commonly observed. The left (right) column of Figure 9 depicts spillovers for the same sized large source economy QT (interest rate policy tightening) as previously, with the black line in both columns corresponding to the baseline interest rate rule analyzed in Figure 8.[20] In addition, the red dashed line in Figure 9 reports results for a fixed nominal effective exchange rate (NEER) policy in the recipient economy, which is solely implemented via the short-term interest rate.

The figure shows that the much larger policy tightening needed to maintain the exchange rate peg leads to a large economic contraction relative to the flexible exchange rate case. This especially pertains to the QT exit strategy, in which case the central bank in the recipient economy needs to tighten the policy rate much more, which leads to higher long-term yields, a very strong economic contraction and persistent fall in core inflation. The persistent fall in core inflation eventually induces the same real depreciation of the recipient economies' currency, but much more gradually than with a standard flexible inflation targeting arrangement with a flexible NEER.

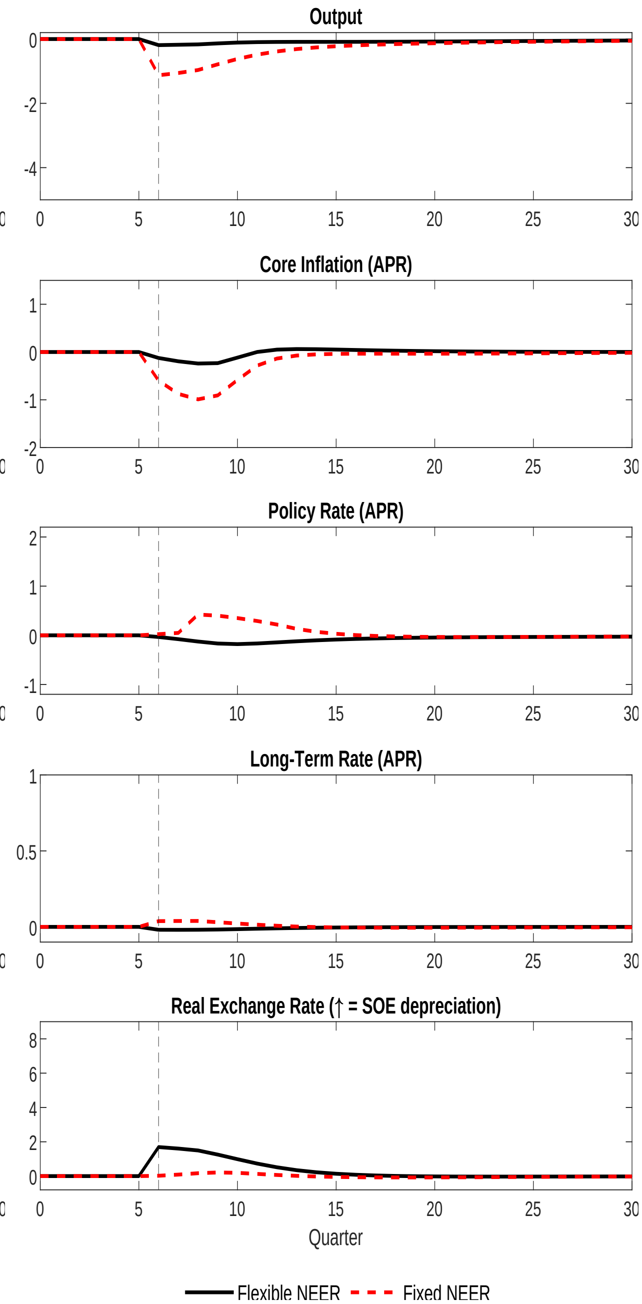
Overall, and in light of our findings in Figure 8, and specifically that QT is associated with larger depreciationary pressure on the EM exchange rate, it comes as no surprise that spillovers

[20] The black lines hence directly correspond to the green dotted lines in the QT case and the blue, dash-dotted lines in the tighter interest rate policy case in Figure 8, respectively.

Figure 9. Exit Spillovers to EMs with Alternative Nominal Effective Exchange Rate (NEER) Regimes



(a) Quantitative Tightening



(b) Tightening via Short Rate

from QT are more marked under a fixed exchange rate regime than under the baseline flexible NEER policy. By and large, however, the results in Figure 9 are also a stark reminder of the potential costs associated with a fixed exchange rate regime when the economy is exposed to large asymmetric foreign shocks.

6. Conclusions

We have provided empirical evidence on the domestic and international transmission of QE and conventional short-term interest rate policy. This evidence suggests that QE and conventional interest rate cuts propagate differently domestically. In particular, QE has a relatively greater impact on the real exchange rate and term premium even when both policies are normalized to have similar effects on domestic inflation and output.

Based on this evidence, we developed a two-country New Keynesian model with segmented asset markets, where a fraction of agents is directly exposed to long-rates on account of only trading long-dated treasury securities, which makes LSAP a potentially powerful tool. To address the forward guidance puzzle and account for the missing deflation puzzle and the post-pandemic inflation surge, we incorporate cognitive discounting and convexities in price-setting. These modifications – introduced to enhance empirical realism – create a unique role for QE when the central bank's policy rate is expected to be at the ELB for an extended period. In particular, the central bank cannot meaningfully stimulate the economy using forward guidance in a long-lived liquidity trap. But large scale asset purchases (QE) can effectively provide stimulus.

An additional important insight is that QE is associated with notably larger domestic output effects than QT. QE is a potent tool to stimulate output under the assumption that it is primarily deployed when inflation is well below the central bank's inflation target and the policy rate is expected to remain at the ELB for a protracted period. QT, on the other hand, is used when inflation is higher and short-term policy rates adjust, which dampens its impact. Despite this, the transmission to domestic inflation is similar, since inflation is more sensitive to policy changes outside of a liquidity trap.

The model implies that central bank exit from an extended period of monetary accommodation in major economies via QT tightening may entail significantly larger adverse output spillovers then exit via conventional short-term interest rate increases. Tightening via QT causes an inflation and output tradeoff to emerge in the foreign recipient economy, whereas a conventional policy tightening does not. This occurs because QT generates a depreciation of the recipient economy real exchange rate which stimulates inflation. But is also triggers a higher term-premium, which lowers output. The potential for QT in large, advanced economies to exacerbate inflation-output tradeoffs in foreign recipient economies is particularly strong under an EME calibration featuring larger pass-through to core CPI inflation. We also show that foreign transmission of QT can be particularly strong to small open emerging market economies with fixed exchange rates, as they then need to notably tighten policy rates to defend their exchange rate pegs. Given these findings, it is reassuring that central banks in large advanced economies have adopted a gradual approach to unwinding their long-term asset portfolios.

All told, our results demonstrate that the international transmission of alternative approaches to monetary policy normalization are not isomorphic, and that they engender different reactions in neighboring economies. Our analysis of the propagation of conventional short-term policy rate hikes and QT shows that spillover size can vary markedly depending on the monetary framework of the "recipient" economy. We also quantify the effects of the two types of monetary contractions on both advanced and emerging market economies highlighting the importance of transmission via the exchange rate and term premiums. Our results emphasize international benefits of conventional tightening, and they are a stark reminder of sizeable costs associated with exchange rate stabilization in the face of large and asymmetric foreign shocks.

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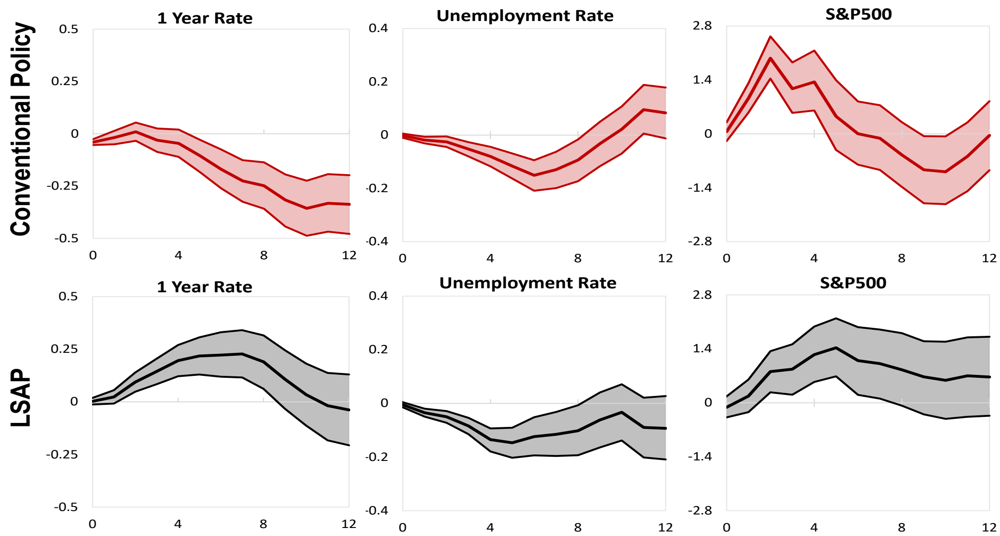
Online Appendices

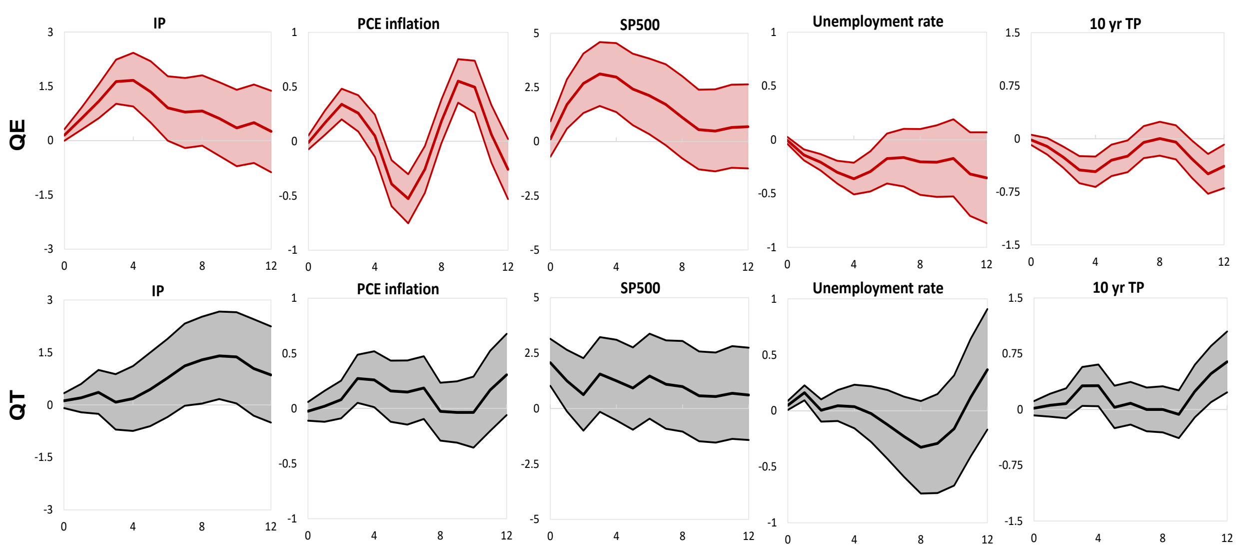
Appendix A. Additional Empirical Results

Figure 10. Conventional Policy vs LSAP Transmission



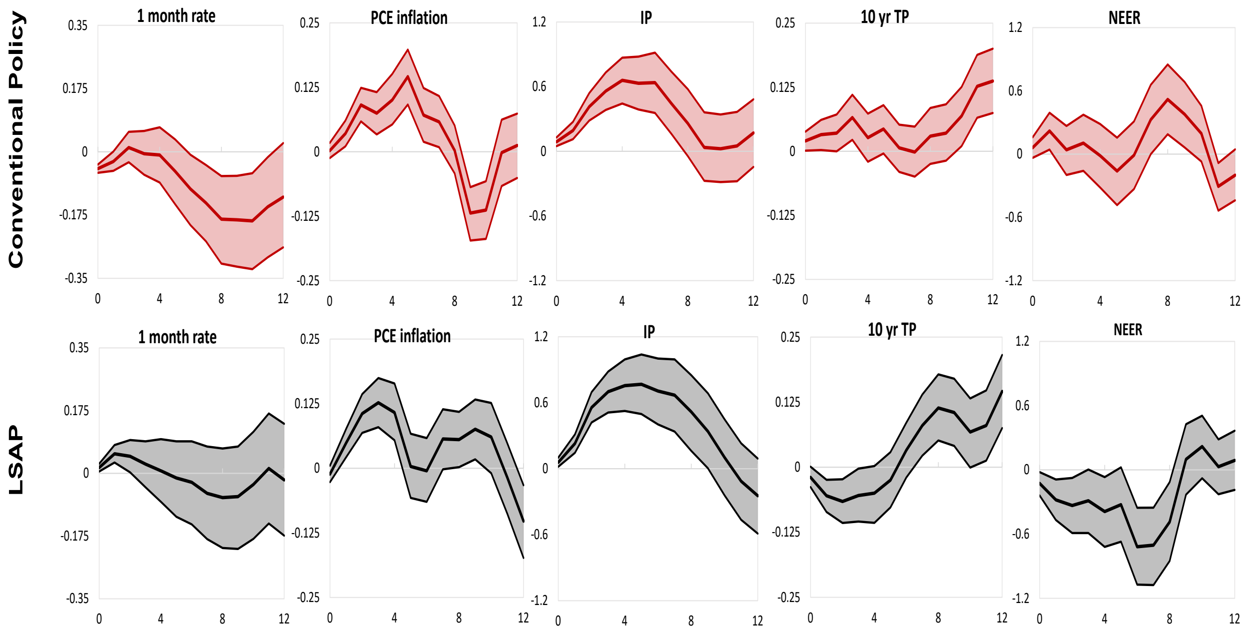
Note: This figure compares IRFs to a conventional monetary policy shock (red line and shaded areas in the top panels corresponding to the median and 68% error bands) to a large scale asset purchase shock (LSAP) (black lines and grey shaded areas in the bottom panels). All panels show quarterly responses to a one standard deviation expansionary shock in the US.

Figure 11. Asymmetries in QE and QT transmission



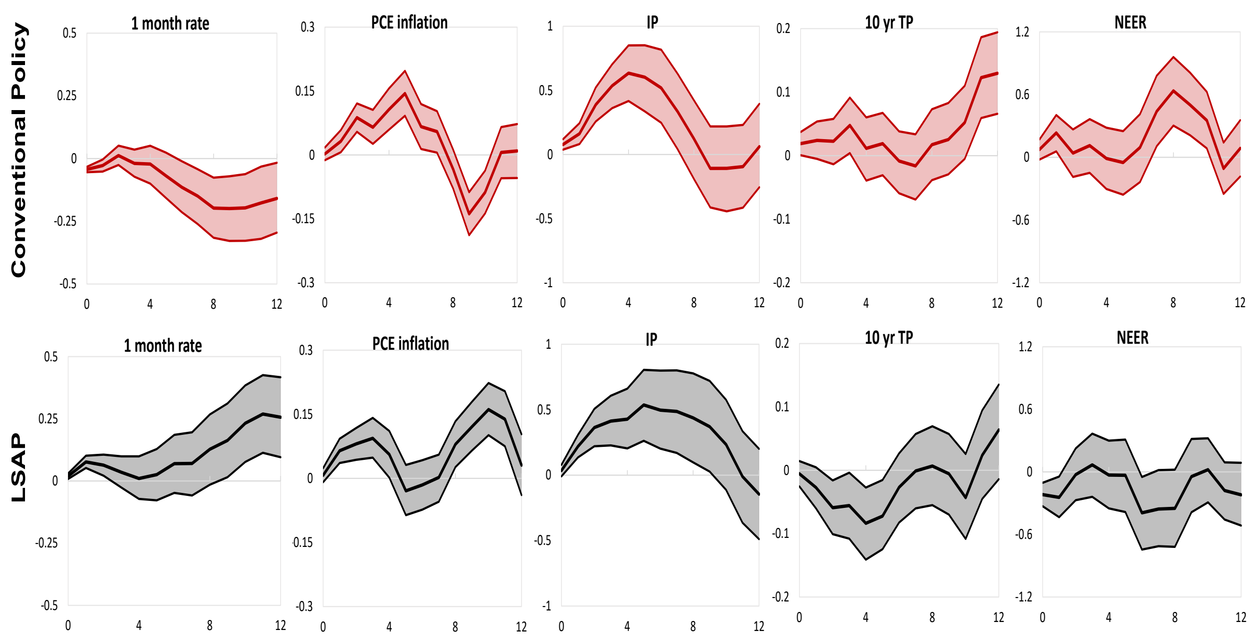
Note: This figure compares IRFs from a local projection with quadratic terms, i.e., allowing for asymmetric transmission, to 1 SD expansionary (QE) and contractionary (QT) shocks.

Figure 12. Policy Transmission: Identification à la Swanson (2021).



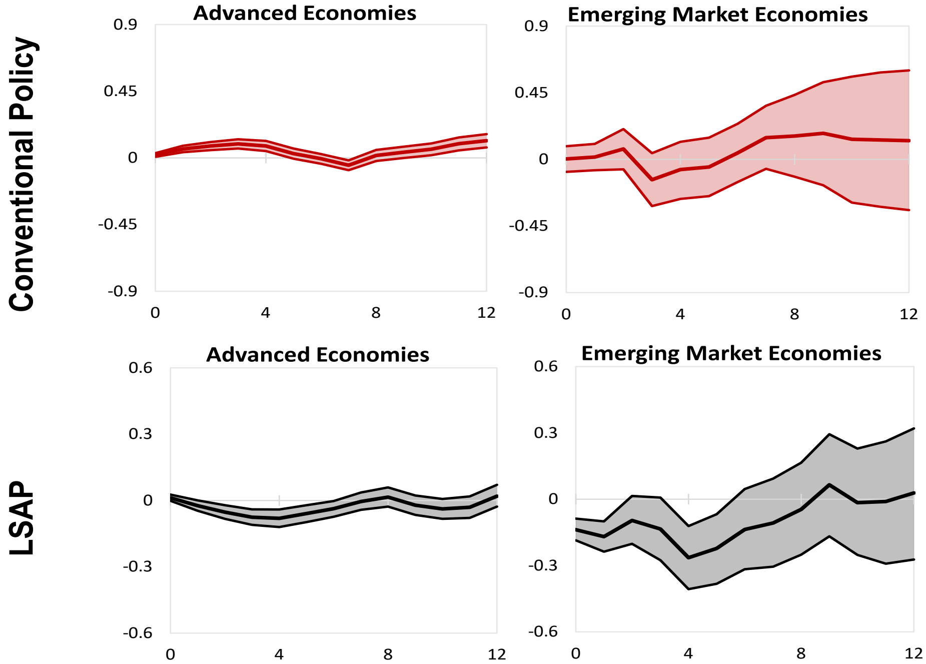
Note: This figure reproduces IRFs in Figure 2 except using the alternative identification of Swanson (2021) for the LSAP shock.

Figure 13. Policy Transmission: Identification à la Jarociński (2024).



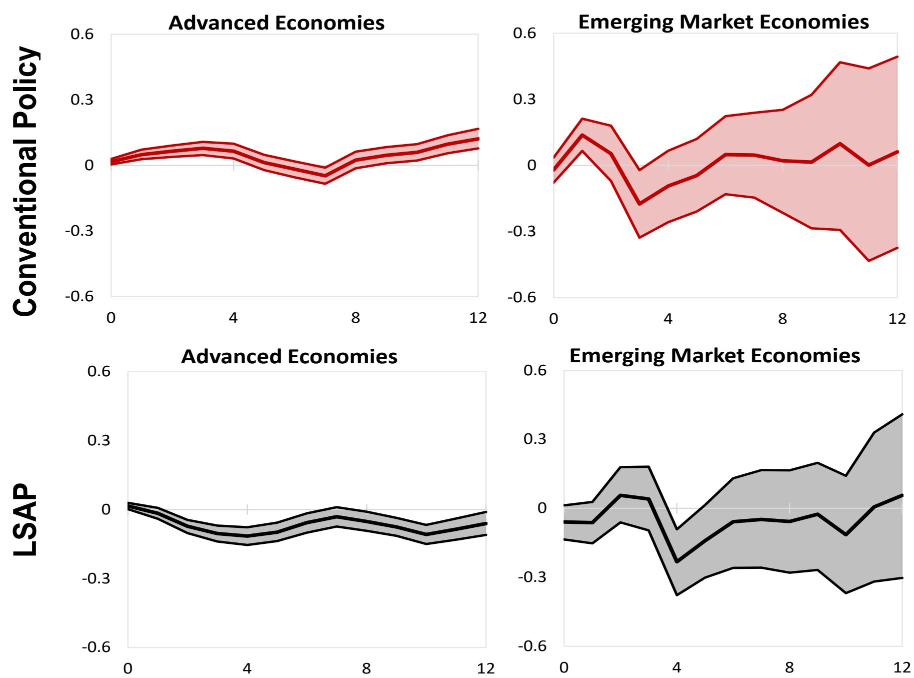
Note: This figure reproduces IRFs in Figure 2 except using the alternative identification of Jarociński (2024) for the LSAP shock.

Figure 14. 10Y Term Premium Spillovers: Swanson (2021) Identification



Note: This figure reproduces IRFs in Figure 3 except using the alternative identification of Swanson (2021) for the LSAP shock.

Figure 15. 10Y Term Prem. Spillovers: Jarociński (2024) Identification



Note: This figure reproduces IRFs in Figure 3 except using the alternative identification of Jarociński (2024) for the LSAP shock.

Appendix C. Estimation Details

The empirical model is defined as:

$$X_{t+h} - X_{t-1} = c^h + \beta^h \epsilon_t + \sum_{j=1}^{P} d_p Z_{t-p} + u_{t+h} \tag{A.1}$$

$$var(u_{t+h}) = \Omega_h \tag{A.2}$$

$$\Omega_h = \frac{\sigma^2}{\lambda_t} \tag{A.3}$$

Note that $\frac{1}{\lambda_t}$ denotes the time-varying volatility of the disturbances u_{t+h}. Geweke (1993) shows that assuming a Gamma prior for λ_t of the form $P(\lambda) = \prod_{t=1}^{T} P(\lambda_t) = \prod_{t=1}^{T} \Gamma(1, \nu)$ leads to scale mixture of normal distributions for the residuals (here $\Gamma(a, b)$ denotes a Gamma distribution with mean a and degrees of freedom b). As shown in Geweke (1993), this is equivalent to assuming that the residuals u_{t+h} follow a Student's t-distribution with degrees of freedom equal to ν.

Priors. We employ the following prior distributions:

- We set a hierarchical prior for λ_t and ν (see Koop (2003)):

$$P(\lambda_t) = \Gamma(1, \nu) \tag{A.4}$$

$$P(\nu) = \Gamma(\nu_0, 2) \tag{A.5}$$

  Note that the prior for ν is an exponential distribution, which is equivalent to a Gamma distribution with 2 degrees of freedom. We set $\nu_0 = 20$.
- The prior for the regression coefficients $B^h = [c^h, \beta^h, d_1, \ldots, d_P]$ is normal:$P(B) \sim N(B_0, \Sigma_{B0})$. We set B_0 to zero while Σ_{B0} is a diagonal matrix with diagonal elements equal to 10.
- The prior for σ^2 is inverse Gamma: $IG(\theta_0, T_0)$ where $\theta_0 = 0.0001$ and $T_0 = 1$

Gibbs Sampler. We use a Gibbs sampling algorithm to approximate the posterior distribution. The algorithm is based on the samplers presented in Geweke (1993) and Koop (2003). In each iteration, the algorithm samples from the following conditional posterior distributions (Ξ denotes all other parameters):

- $G(\lambda_t|\Xi)$: The conditional posterior distribution for λ_t is derived in Geweke (1993). As shown in Koop (2003) this posterior density is a gamma distribution with mean $(\nu+1)/\frac{1}{\sigma}u_t^2+\nu$ and degrees of freedom $\nu+1$.
- $G(\nu|\Xi)$: The conditional posterior distribution of ν is non-standard (see Koop (2003)) and given as:

$$G(\nu|\Xi) \propto \left(\frac{\nu}{2}\right)^{\frac{T\nu}{2}} \Gamma\left(\frac{\nu}{2}\right)^{-T} \exp\left(-\left(\frac{1}{\nu_0}+0.5\sum_{t=1}^{T}\left[\ln\left(\lambda_t^{-1}\right)+\lambda_t\right]\right)\nu\right) \tag{A.6}$$

  As in Geweke (1993) we use the Random Walk Metropolis Hastings Algorithm to draw from this conditional distribution. More specifically, we draw $\nu^{new}=\nu^{old}+g^{1/2}\epsilon$ with $\epsilon\sim N(0,1)$. The draw is accepted with probability $\frac{G(\nu^{new}|\Xi)}{G(\nu^{old}|\Xi)}$ with g chosen to keep the acceptance rate around 40%.
- $G(\sigma^2|\Xi)$: With a draw of λ_t in hand, the residuals can be transformed as $e_t=u_t\times\lambda_t^{0.5}$. The conditional posterior of σ^2 is inverse Gamma with scale parameter $e'e+\theta_0$ and degrees of freedom $T+T_0$.
- $G(B^h|\Xi)$: After a GLS transformation, the LP reverts to a linear regression model with a known error variance. Let $y_t=\frac{X_{t+h}-X_{t-1}}{\Omega_h^{0.5}}$ and $x_t=\frac{z_t}{\Omega_h^{0.5}}$, where z_t denotes all regressors and $\Omega_h=\frac{\sigma^2}{\lambda_t}$. The conditional posterior for B^h is Normal with variance $V=\left(\Sigma_{B0}^{-1}+x'x\right)^{-1}$ mean $V\left(\Sigma_{B0}^{-1}B_0+x'y\right)$

This Gibbs sampler is applied to the regression in equation A.1 at each horizon h. We approximate the posterior by using $10,000$ iterations with a burn-in of $5,000$.

Appendix D. The Role of Asset Market Segmentation

This appendix briefly discusses the role of asset market segmentation, both across borders as well as maturities. The role of the latter, i.e., of preventing restricted households from trading in short-term bonds and subjecting unrestricted ones to portfolio adjustment costs has been extensively discussed by Chen et al. (2012) and Kolasa and Wesołowski (2020). In essence, limiting arbitrage between short- and long-term bonds results in fluctuations in term premiums that have effects on real activity. Expressed alternatively, without the trading restrictions certainty equivalence would make short and long-term bonds perfectly substitutable, with restricted households then able to circumvent portfolio adjustment costs.

The international aspect, first introduced and studied in Kolasa and Wesołowski (2020), is arguably more important, as it allows our model to match stylized facts on cross-border aspects of segmentation. Here, the key assumption is that unrestricted households cannot trade short-term bonds issued abroad. This, however, is broadly in line with the IMFs Coordinated Portfolio Investment Survey, which shows that short-term debt securities have a fairly stable market share typically oscillating below 5%, with foreign debt assets held by small open economies even less quantitatively relevant. In addition, restricting asset trade at the short end of the yield curve prevents counterfactual surges into the small economy, and generally helps the model generate realistic magnitudes of capital flows.

Appendix E. Term Premium and Duration

Typically, the 10Y term premium denotes the difference between the yield on a 10 year bond and the expected yield on a series of short term bonds. In a world with no uncertainty or adjustment costs, there would be no term premium, meaning that the yield on long term bonds would have to equal the expected yield of investing short term. Since the expected yield on the hypothetical long-term bond would equal the expected return on short term bonds, therefore we can define the term premium as

$$TP_t = R_{L,t} - R_{L,t}^{EH},$$

where $R_{L,t}^{EH}$ is the counterfactual yield to maturity on a longer-term bond in the absence of transaction costs. Duration, in turn, is, by definition, equal to

$$D \equiv \frac{\sum_{s=1}^{+\infty} \frac{\kappa^{s-1} s}{R^s}}{P}$$

where R is the yield to maturity, and where, for a consol $R - \kappa = \frac{1}{P}$. Substituting the former into the numerator we end up with

$$D \equiv (R - \kappa) \sum_{s=1}^{+\infty} \frac{\kappa^{s-1} s}{R^s}.$$

Since

$$\sum_{s=1}^{+\infty} \frac{\kappa^{s-1}s}{R^s} = \frac{1}{R}\sum_{s=1}^{+\infty} s\left(\frac{\kappa}{R}\right)^{s-1},$$

therefore, letting $x \equiv \kappa/R$, we obtain

$$\frac{1}{R}\sum_{s=1}^{+\infty} sx^{s-1} = \frac{1}{R}\sum_{s=1}^{+\infty}\frac{d}{dx}x^s = \frac{1}{R}\frac{d}{dx}\sum_{s=1}^{+\infty}x^s = \frac{1}{R}\frac{d}{dx}\frac{x}{1-x} = \frac{1}{R}\frac{1}{(1-x)^2}.$$

Substituting back in for x we arrive at the formula used in the paper, i.e.,

$$D \equiv (R-\kappa)\left(\frac{1}{R}\frac{1}{\left(1-\frac{\kappa}{R}\right)^2}\right) = (R-\kappa)\,\frac{R^2}{R\,(R-\kappa)^2} = \frac{R}{R-\kappa}.$$

Appendix F. The Government and Central Bank Balance Sheets

This section focuses on the interplay of unconventional monetary policy and conventional fiscal policy, both of which potentially entail issuance and purchases of local currency, long- and short-term bonds. In contrast to Kolasa and Wesołowski (2020), who proceed under the assumption of a consolidated government balance sheet, we account for the two policies separately, distinguishing issuance for fiscal purposes – superscript f – from issuance by the central bank – superscript c – and using the superscript g to denote the "consolidated" government fiscal position. This distinction facilitates a discussion of alternative central bank exit strategies, as it helps differentiate effects due to changes in fiscal plans from those induced by quantitative tightening. Finally, since the domestic central bank is assumed not to partake in unconventional monetary policy, therefore the ensuing discussion focuses only on the large, source economy.

Unconventional Monetary Policy. The CB balance sheet can be written as:

Table A.1. Central Bank Balance Sheet

Assets	Liabilities
$\tilde{B}^{c,\star}_{F,t}$	$\tilde{B}^{cp,\star}_{F,t}$
$P_{L,t}B^{c,\star}_{F,L,t}$	

This is because the large economy central bank is assumed to be active in its domestic asset market, i.e., it can take positions $\tilde{B}^{c,\star}_{F,t}$ in short term bonds, and $B^{c,\star}_{F,L,t}$ in long term bonds. These positions are entirely financed by issuing central bank commercial paper $\tilde{B}^{cp,\star}_{F,t}$, which constitutes 100% of central bank liabilities, and which – from the perspective of private agents – is indistinguishable from short term government bonds.

Because of the perfect substitutability between central bank commercial paper and short term treasuries, purchases of the latter only affect the size of the CB balance sheet but not the quantity of short term assets outstanding.[21] For that reason we will only focus on purchases of long term assets and will "net out" shorter term assets, defining

$$B^{c,\star}_{F,t} \equiv \tilde{B}^{c,\star}_{F,t} - \tilde{B}^{cp,\star}_{F,t}.$$

This leads to the simplified CB balance sheet:

Table A.2. Consolidated Central Bank Balance Sheet

Assets	Liabilities
$P_{L,t}B^{c,\star}_{F,L,t}$	$B^{c,\star}_{F,t}$

It also accounts for simplified definitions of government debt outstanding

$$B^{g,\star}_{F,t} \equiv B^{f,\star}_{F,t} - B^{c,\star}_{F,t}, \qquad B^{g,\star}_{F,L,t} \equiv B^{f,\star}_{F,L,t} - B^{c,\star}_{F,L,t}.$$

Importantly, because $B^{c,\star}_{F,t} = P_{L,t}B^{c,\star}_{F,L,t}$ therefore we shall refer to $P_{L,t}B^{c,\star}_{F,L,t}$ as the size of QE.[22] Relatedly, the holding period profits associated with unconventional monetary policy equal[23]

$$\Phi^{c,\star}_t \equiv R^\star_{t-1}B^{c,\star}_{F,t-1} + P^\star_{L,t}R^\star_{L,t}B^{c,\star}_{F,L,t-1}.$$

[21] The total quantity of short and long term government securities (i.e., $B^{g,\star}_{F,t}$ and $B^{g,\star}_{F,L,t}$, respectively) equals

$$\begin{aligned} B^{g,\star}_{F,t} &\equiv B^{f,\star}_{F,t} - \tilde{B}^{c,\star}_{F,t} + \tilde{B}^{cp,\star}_{F,t} \\ B^{g,\star}_{F,L,t} &\equiv B^{f,\star}_{F,L,t} - B^{c,\star}_{F,L,t}. \end{aligned}$$

The first of these equations immediately implies that purchases of short term assets $\tilde{B}^{c,\star}_{F,t}$ financed by issuing commercial paper $\tilde{B}^{cp,\star}_{F,t}$ leave government supplied short-term bonds $B^{g,\star}_{F,t}$ unchanged.

[22] Expressed alternatively, the model will be mute on the maturity composition of CB assets, because, in principle, we could have netted out any quantity of short term treasuries. In addition, since the central bank is assumed to purchase long-term treasuries when intervening, therefore the size and maturity composition of government debt determines the maximum size of unconventional stimulus. While intriguing, the potential implications of such considerations for optimal issuance policies are beyond the scope of our paper.

[23] Since $\forall t : B^{c,\star}_{F,L,t} \geq 0 \Rightarrow \forall t : B^{c,\star}_{H,t-1} \leq 0$, i.e., if $\Phi^{c,\star}_t$ is *negative* then the central bank has made operating losses.

To keep matters simple, we assume that any QE "carry costs" are fully rebated to the treasury and that losses are rebated lump sum as well. As a consequence, the central bank budget constraint becomes

$$P^{\star}_{L,t}B^{c,\star}_{F,L,t} + B^{c,\star}_{F,t} = R^{\star}_{t-1}B^{c,\star}_{F,t-1} + P^{\star}_{L,t}R^{\star}_{L,t}B^{c,\star}_{F,L,t-1} - \Phi^{c,\star}_{t},$$

or alternatively

$$P^{\star}_{L,t}B^{c,\star}_{F,L,t} + B^{c,\star}_{F,t} = 0,$$

which states that the central bank starts every period with a "clean" balance sheet.

Runoff, Revaluation and Reinvestment. We now formally define runoff and reinvestment, the first or which describes the mechanical phenomenon of assets maturing and leaving the central bank balance sheet, while the second essentially pins down the baseline investment strategy of the central bank that we shall analyze deviations from.

In our model, if the central bank purchased $P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}$ worth of consols, then at the start of the following period it would have a coupon worth $B^{c,\star}_{F,L,t-1}$ and a stock of assets with a market value of $\kappa P^{\star}_{L,t}B^{c,\star}_{F,L,t-1}$.[24] Mechanically, the change in value of long term assets Ψ_t thus equals

$$\Psi_t \equiv \kappa^{\star}P^{\star}_{L,t}B^{c,\star}_{F,L,t-1} - P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1},$$

i.e., it can be written as a combination of runoff and revaluation, as follows

$$\underbrace{\Psi_t}_{\text{"passive" change in portfolio value}} = \underbrace{-B^{c,\star}_{F,L,t-1}}_{\text{runoff}} + \underbrace{\left(\kappa^{\star}P^{\star}_{L,t}B^{c,\star}_{F,L,t-1} - P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1} + B^{c,\star}_{F,L,t-1}\right)}_{\text{revaluation}},$$

where runoff is defined as being negative, as it tends to decrease the, typically positive, value of long term bonds held by the central bank . Exploiting $R^{\star}_{L,t} \equiv \left(P^{\star}_{L,t}\right)^{-1} + \kappa^{\star}$, we can then simplify

[24] A potentially helpful way of thinking about the consol is as a portfolio of zero coupon bonds with exponentially decaying nominal face value. Under that interpretation, it becomes clear that run-off would simply be equal to the face value of the first coupon, or $-B^{c,\star}_{F,L,t-1}$.

the expression for the revaluation component as

$$\left(1+\kappa^{\star}P^{\star}_{L,t}\right)B^{c,\star}_{F,L,t-1}-P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}=P^{\star}_{L,t}\left(\frac{1}{P^{\star}_{L,t}}+\kappa^{\star}\right)B^{c,\star}_{F,L,t-1}-P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}$$

$$=\left(P^{\star}_{L,t}R^{\star}_{L,t}-P^{\star}_{L,t-1}\right)B^{c,\star}_{F,L,t-1}=\left(\Pi^{\star}_{L,t}R^{\star}_{L,t}-1\right)P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1},$$

which shows that positive inflation and yield to maturity will translate into positive *nominal* revaluation. Similarly, we can also express run-off in terms of the original value of the long term bond portfolio to arrive at

$$\underbrace{\Psi_t}_{\text{"passive" change in LT portfolio value}} = \Bigg(\underbrace{-\frac{1}{P^{\star}_{L,t-1}}}_{\text{runoff}}+\underbrace{\Pi^{\star}_{L,t}R^{\star}_{L,t}-1}_{\text{revaluation}}\Bigg)P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}.$$

Of course, typically, the central bank will also have a reinvestment strategy in place to counterbalance run-off and revaluation, and it may occasionally wish to deviate from that strategy. To capture such considerations, yet still keep the analysis tractable, we assume that the passive reinvestment strategy is expressed as a share of runoff and revaluation, and that it is governed by parameter ϱ, i.e., that total reinvestment Θ_t is given by

$$\underbrace{\Theta_t}_{\text{total reinvestment}} \equiv \underbrace{\varrho\left(\frac{1}{P^{\star}_{L,t-1}}-\Pi^{\star}_{L,t}R^{\star}_{L,t}+1\right)P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}}_{\text{passive reinvestment}}+\underbrace{\epsilon^{c,\star}_t}_{\text{active reinvestment}}.$$

Collecting terms, the expression for the evolution of the value of the central bank's portfolio becomes

$$\begin{aligned}P^{\star}_{L,t}B^{c,\star}_{F,L,t} &= \underbrace{P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}}_{\text{previous value}}+\underbrace{\Psi_t}_{\text{mechanical change in value of QE portfolio}}+\underbrace{\Theta_t}_{\text{passive and active reinvestment}}\\ &= \left(1+(1-\varrho)\left(-\frac{1}{P^{\star}_{L,t-1}}+\Pi^{\star}_{L,t}R^{\star}_{L,t}-1\right)\right)P^{\star}_{L,t-1}B^{c,\star}_{F,L,t-1}+\epsilon^{c,\star}_t,\end{aligned}$$

which confirms that with ϱ set to one, and absent active reinvestment $\epsilon^{c,\star}_t=0$, the nominal value of the long term bond portfolio would stay constant.[25] We conclude by presenting a real equivalent

[25] Conversely, with ϱ set to zero, corresponding to no reinvestment, the value of the portfolio would decrease at its fastest possible rate (barring active asset sales).

of the above expression, which we obtain by dividing through by $P_t^\star$ and simplifying to arrive at

$$P_{L,t}^\star b_{F,L,t}^{c,\star} = \frac{\left(1 + (1-\varrho)\left(-\frac{1}{P_{L,t-1}^\star} + \Pi_{L,t}^\star R_{L,t}^\star - 1\right)\right)}{\Pi_t^\star} P_{L,t-1}^\star b_{F,L,t-1}^{c,\star} + \frac{\epsilon_t^{c,\star}}{P_t^\star}.$$

This relationship confirms that positive inflation acts to erode the real value of the central banks' portfolio, even if the nominal value of debt outstanding is held fixed (i.e., even if ϱ is equal to one).[26]

Fiscal Policy. The fiscal authority operates subject to the following constraint

$$B_{F,t}^f + P_{L,t}^\star B_{F,L,t}^f + T_t^\star + \Phi_t^{c,\star} = R_{t-1}^\star B_{F,t-1}^f + P_{L,t}^\star R_{L,t}^\star B_{F,L,t-1}^f + P_t^\star g_t^\star,$$

i.e., it finances its expenditures by issuing long-term $B_{F,L,t}^f$, and short-term $B_{F,t}^f$ bonds, as well as through lump sum taxation $T_t^\star$ and any holding-period profits made by the central bank on its asset portfolio $\Phi_t^{c,\star}$, since we assume these are transferred back to the treasury. As the expression makes clear, the total amount requiring financing is a sum of the value of maturing obligations $R_{t-1}^\star B_{F,t-1}^f + P_{L,t}^\star R_{L,t}^\star B_{F,L,t-1}^f$ as well as government expenditures $P_t^\star g_t^\star$, with the total market value of outstanding government debt given by

$$B_t^f \equiv B_{F,t}^f + P_{L,t}^\star B_{F,L,t}^f.$$

Government expenditures on final goods are assumed to follow $g_t \equiv g \exp\{\varepsilon_t^g\}$, where ε_t^g is the government spending shock. Taxes per capita are set equal across the two household types, which implies that they are levied in proportion to the restricted and unrestricted households' population shares ω_r and $1-\omega_r$, respectively. In addition, in the baseline version of our model, the fiscal authority of the large country is assumed to keep the real market value of debt $b_{F,t}^f \equiv B_{F,t}^f / P_t^\star$ and its composition $\theta^L \equiv \left(P_{F,t}^\star B_{F,L,t}^f\right) / \left(P_{L,t}^\star B_{F,L,t}^f + B_{F,t}^f\right)$ constant.[27]

[26] See also Appendices H and G for a more detailed discussion of the underlying considerations.
[27] In general, one can show that letting

$$\forall t : \frac{B_{F,t}^f}{P_t^\star} \equiv b^{f,\star} \quad \text{and} \quad \forall t : \frac{P_{L,t}^\star B_{F,L,t}^f}{P_{L,t}^\star B_{F,L,t}^f + B_{F,t}^f} \equiv \theta^L$$

implies

$$g_t^\star - \tau_t^\star = \frac{B_{F,t-1}^f}{P_t^\star}\left[\Pi_t^\star - \left(\left(1-\theta^L\right) R_{t-1}^\star + \theta^L \Pi_{L,t}^\star R_{L,t}^\star\right)\right].$$

Appendix G. Extended Model Equations

For completeness, we now outline how the asset market specification of our model differs from the setup used in Kolasa and Wesołowski (2020). First, we note that nothing changes in the recipient economy, where we continue to assume that the CB does not implement QE, and where we continue not to explicitly model the CB balance sheet (i.e., we only have g variables but no decomposition into f nor c ones). While in the source economy we continue to use g for the (consolidated government) bond position, we introduce four additional variables capturing short and long-term fiscal positions $b^{f,\star}_{F,t}$ and $b^{f,\star}_{F,L,t}$ respectively as well as the short and long term central bank positions $b^{c,\star}_{F,t}$ and $b^{c,\star}_{F,L,t}$. For the fiscal side of the economy, we simply copy the equations from the home economy, implicitly assuming that the real size of the budget is constant and that the treasury issues debt targeting a fixed maturity split of assets issued. This immediately gives us two equations for $b^{f,\star}_{F,t}$ and $b^{f,\star}_{F,L,t}$: i) the equation for the debt composition becomes

$$\frac{\frac{b^{f,\star}_{F,L,t}}{R^{\star}_{L,t}-\kappa^{\star}}}{b^{f,\star}_{F,t}+\frac{b^{f,\star}_{F,L,t}}{R^{\star}_{L,t}-\kappa^{\star}}}=\frac{\frac{b^{f,\star}_{F,L}}{R^{\star}_{L}-\kappa^{\star}}}{b^{f,\star}_{F}+\frac{b^{f,\star}_{F,L}}{R^{\star}_{L}-\kappa^{\star}}},$$

while the equation for the size of the fiscal deficit can be written as

$$b^{f,\star}_{F,t}+\frac{b^{f,\star}_{F,L,t}}{R^{\star}_{L,t}-\kappa^{\star}}=b^{f,\star}_{F}+\frac{b^{f,\star}_{F,L}}{R^{\star}_{L}-\kappa^{\star}}.$$

For the central bank balance sheet evolution we also get two equations. The first is the "self-financing" assumption

$$P^{\star}_{L,t}B^{c,\star}_{F,L,t}+B^{c,\star}_{F,t}=0\Longleftrightarrow\frac{b^{c,\star}_{F,L,t}}{R^{\star}_{L,t}-\kappa^{\star}}=-b^{c,\star}_{F,t},$$

while the second is the real, non-linear QT specification discussed previously

$$P^{\star}_{L,t}b^{c,\star}_{F,L,t}=\frac{\left(1+(1-\varrho)\left(-\frac{1}{P^{\star}_{L,t-1}}+\Pi^{\star}_{L,t}R^{\star}_{L,t}-1\right)\right)}{\Pi^{\star}_{t}}P^{\star}_{L,t-1}b^{c,\star}_{F,L,t-1}+\frac{\epsilon^{c,\star}_{t}}{P^{\star}_{t}},$$

We thus see that if inflation exceeds the average rate of return on government debt (i.e., if government debt is deflated away) then the fiscal authority can run a primary fiscal deficit and still keep real debt constant. If, however, the average rate of return on government debt exceeds inflation, then the government will have to run a primary surplus to eventually start paying-off real interest accrual on its debt.

which can be equivalently rewritten as

$$\frac{b^{c,\star}_{F,L,t}}{R^\star_{L,t}-\kappa^\star}=\frac{\left(1+(1-\varrho)\left(\kappa^\star-R^\star_{L,t-1}+\left(\frac{R^\star_{L,t-1}-\kappa^\star}{R^\star_{L,t}-\kappa^\star}\right)R^\star_{L,t}-1\right)\right)}{\Pi^\star_t}\frac{b^{c,\star}_{F,L,t-1}}{R^\star_{L,t-1}-\kappa^\star}+\varepsilon^{c,\star}_t,$$

and where $\varepsilon^{c,\star}_t$ is a real, unconventional monetary policy shock.[28]

Appendix H. The Linear Run-Off Specification

In some circumstances having a linear expression for the run-off on the central bank's portfolio can be instructive. To derive one, we start by defining a variable called $\mathcal{CB}^\star_t$ which captures the size of the long-term bond position on the CBs balance sheet, and which follows

$$\mathcal{CB}^\star_t=\frac{(1-(1-\varrho)(\phi_t+\varphi_t))}{\Pi^\star_t}\mathcal{CB}^\star_{t-1}+\varepsilon^{c,\star}_t,$$

where $\varepsilon^{c,\star}_t\equiv\epsilon^{c,\star}_t/P^\star_t$ is the real value of the "unscheduled" long-term bond purchases, and where ϕ_t and φ_t denote runoff and revaluation respectively[29]

$$\phi_t\equiv-\frac{1}{P^\star_{L,t-1}},\qquad\text{and}\qquad\varphi_t\equiv\frac{R^\star_{L,t}}{\Pi^\star_{L,t}}-1.$$

Linearizing this equation around a steady state with no unconventional monetary policy yields

$$\mathcal{CB}^\star_t\approx\underbrace{\frac{(1-(1-\varrho)(\phi+\varphi))}{\Pi^\star}}\mathcal{CB}^\star_{t-1}+\varepsilon^{c,\star}_t,$$

which is essentially an AR(1) specification for the size of the central bank's balance sheet, and where ϕ,φ and $\Pi^\star$ denote steady state runoff, revaluation and inflation, respectively.

Of course, even though ϱ is a "free" policy parameter, ϕ and φ are not, and they can be expressed in terms of structural parameters. Using,

$$R^\star_{L,t}\equiv\frac{1}{P^\star_{L,t}}+\kappa^\star\qquad\text{and}\qquad DUR^\star_L\equiv\frac{R^\star_L}{R^\star_L-\kappa^\star},$$

[28] For reference, in steady state this implies that

$$\frac{1+(1-\varrho)\left(\kappa^\star-R^\star_{L,t-1}+\left(\frac{R^\star_{L,t-1}-\kappa^\star}{R^\star_{L,t}-\kappa^\star}\right)R^\star_{L,t}-1\right)}{\Pi^\star_t}=\frac{1+(1-\varrho)(\kappa^\star-1)}{1.005}=\frac{0.982+0.018\varrho}{1.005},$$

which confirms that runoff is efficiently pinned down by long-bond duration.

[29] Both are expressed as shares of the $t-1$ long term portfolio value.

we have that

$$\phi \equiv -\frac{1}{P_L^\star} - \kappa^\star + \kappa^\star = \frac{-R_L^\star + \kappa^\star}{R_L^\star} R_L^\star = -\frac{R_L^\star - \kappa^\star}{R_L^\star} R_L^\star = -\frac{R_L^\star}{DUR_L^\star},$$

where DUR_L denotes the consol duration, and where φ is given by

$$\varphi \equiv \frac{R_L^\star}{\Pi_L^\star} - 1.$$

Appendix I. The Impact of Cognitive Discounting and Kimball Preferences

Figure 16. Effects of Forward Guidance and QE: No Cognitive Discounting

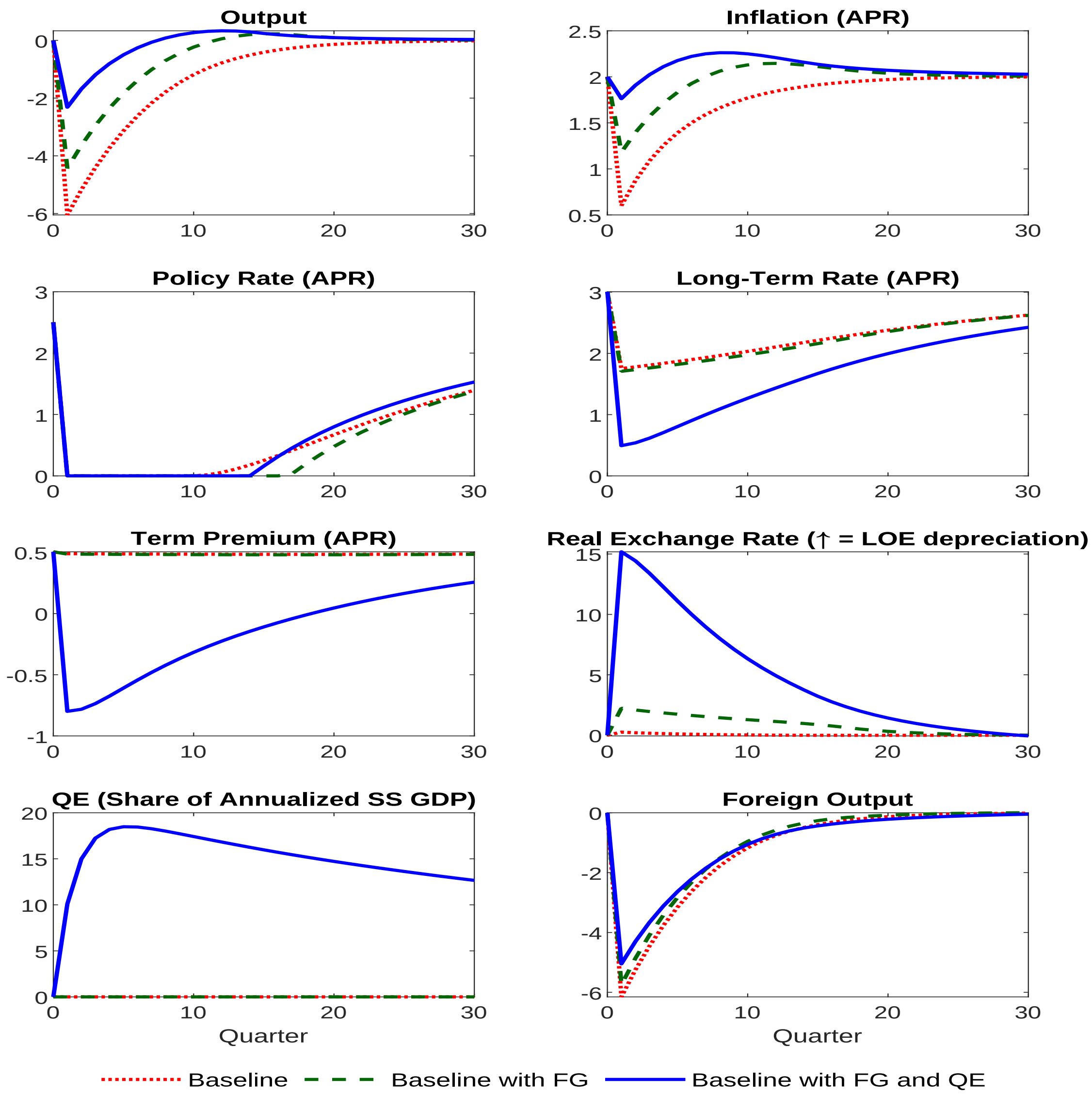
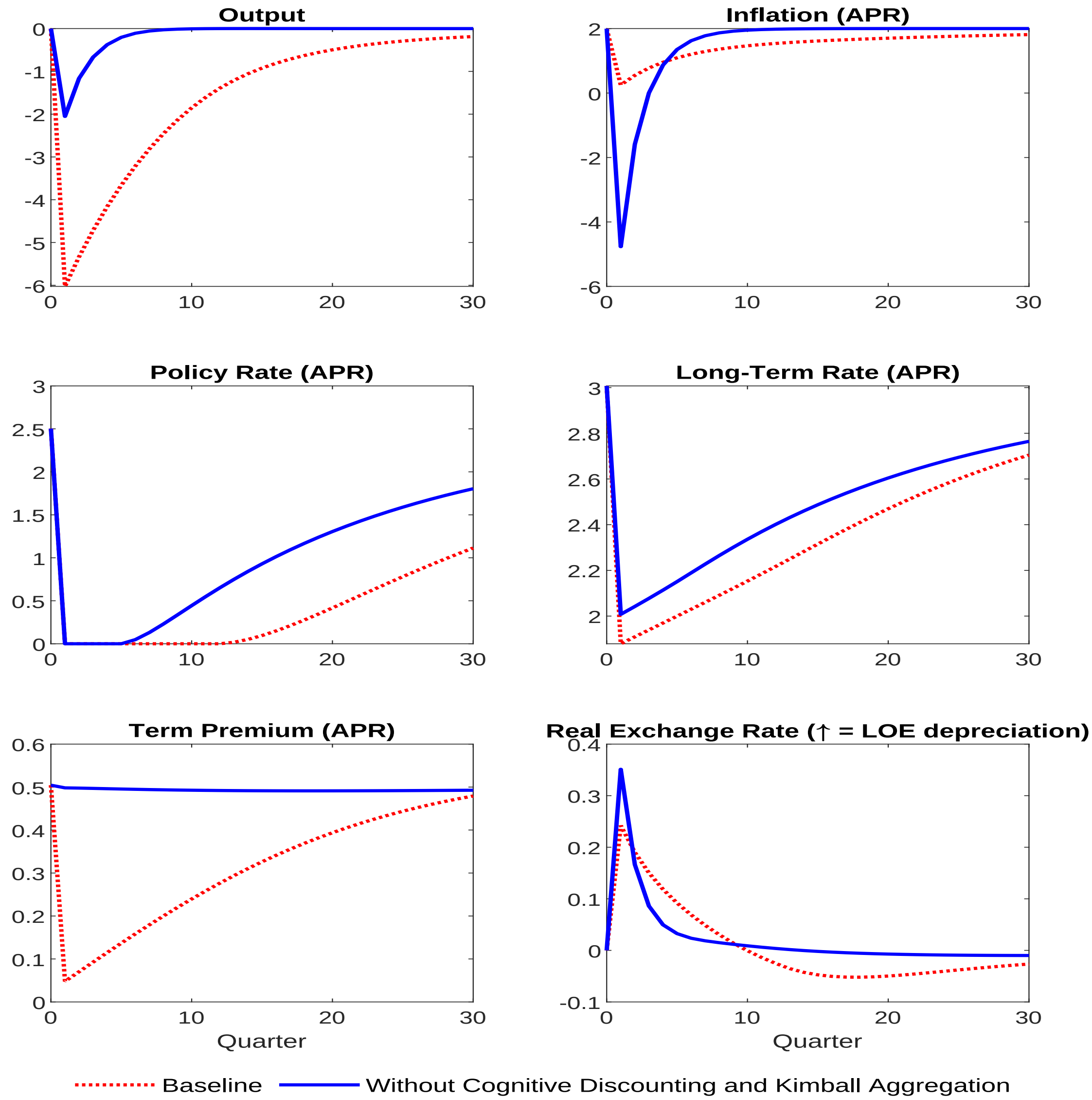


Figure 17. Baseline With and Without Cognitive Discounting And Kimball Aggregation



In this final appendix we parse out the impact of our assumptions about cognitive discounting and Kimball aggregation on the monetary transmission mechanism. To that effect, Figure 16 plots the equivalent of Figure 5, except that both of these features are switched off.

There are several interesting aspects of the corresponding "rational" simulations. First of all, if we use output as a metric, the economy with no cognitive discounting proves somewhat more resilient, with over 50% larger demand shocks required to generate a 6% on impact output contraction, though the latter is accompanied by considerably larger disinflation.[30] Crucially, and

[30] See also Kolasa et al. (2022) for a comprehensive discussion of the impact of behavioral discounting in an open economy setting.

as alluded to previously, forward guidance in this economy is almost as potent as large scale asset purchases, which occurs even though the central bank only promises to keep rates lower for six rather than seven periods.[31] In contrast to QE, however, and despite its greater efficacy, forward guidance has a much smaller impact on term premiums, the long-term rate and the exchange rate.

Importantly, and as shown in Figure 17, while cognitive discounting helps mute the forward guidance puzzle, it is Kimball aggregation that plays a bigger role in shaping our baseline. In particular, without Kimball aggregation, the fall in inflation depicted in the top right panel of Figure 16 would be markedly larger for identical underlying shocks. Accordingly, Figure 17 helps underscore the fact that Kimball aggregation, as well as the state-dependent slope of the Phillips curve that it gives rise to, are crucial for muting the fall in inflation relative to that of output.

[31] Forward guidance is implemented "endogenously", i.e., by assuming that the central bank targets the shadow interest rate, which becomes strictly positive slightly quicker than under cognitive discounting.

PUBLICATIONS

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