International spillovers of quantitative easing*

Marcin Kolasa†
Grzegorz Wesołowski‡

This draft: September, 2019

Abstract

This paper develops a two-country model with asset market segmentation to investigate the effects of quantitative easing implemented by the major central banks on a typical small open economy that follows independent monetary policy. The model is able to replicate the key empirical facts on emerging countries' response to large scale asset purchases conducted abroad, including inflow of capital to local sovereign bond markets, an increase in international comovement of term premia, and change in the responsiveness of the exchange rate to interest rate differentials. According to our simulations, quantitative easing abroad boosts domestic demand in the small economy, but undermines its international competitiveness and depresses aggregate output, at least in the short run. This is in contrast to conventional monetary easing in the large economy, which has positive spillovers to output in other countries. We also find that limiting quantitative easing spillovers might require policies that affect directly international capital flows, like purchasing assets by the small economy's central bank.

JEL: E44, E52, F41

Keywords: quantitative easing, international spillovers, bond market segmentation, term premia

*The authors would like to thank editor G.Lorenzoni and three anonymous referees for helpful suggestions to the earlier draft, and S.Benecka, M.Ca'Zorzi, J.Gali, P.Jacquinot, M.Jarociński, R.Kollmann, J.Linde, B.Maćkowiak, I.Presno, F.Romei, S.Schmitt-Grohe and U.Szczerbowicz for useful discussions. The paper also benefited from comments received at the CEF conference in New York, EEA-ESEM meeting in Lisbon, ESCB Research Cluster 1 workshop in Madrid, SNDE conference in Tokyo, NBP-BoL-CEBRA-CEPR conference "International Spillovers" in Warsaw, WGEM EAGLE Network meeting in Frankfurt, Dynare conference in Lausanne, RBA-BoC-RBNZ-NB-SR conference "Business Cycles in Small Open Economies" in Stockholm, and a seminar at the ECB. The views expressed herein are those of the authors and not those of Narodowy Bank Polski.

†SGH Warsaw School of Economics and Narodowy Bank Polski; E-mail: marcin.kolasa(at)sgh.waw.pl.

‡Narodowy Bank Polski; E-mail: grzegorz.wesolowski(at)nbp.pl.

1 Introduction

Following the financial turmoil in the second half of 2008 and after decreasing their short-term interest rates close to zero, the major central banks, notably the Federal Reserve, the European Central Bank and the Bank of England, implemented several rounds of non-standard policy measures. These measures included purchases of long-term assets, the scale of which was unprecedented in modern economic history. Figure 1 offers one way of documenting this process by showing that asset purchases in the United States, the United Kingdom and the euro area substantially lowered the share of long-term government bonds in total supply of consolidated public sector liabilities: by mid-2016 this share had decreased by over 10 percentage points as compared with 2009.

The primary goal of these operations, popularly referred to as quantitative easing (QE), was to reduce long-term interest rates and overcome the ongoing slump in economic activity. However, given the importance of monetary policy in the countries that implemented these programs for global financial cycles (as documented e.g. by Rey, 2013), the scale of asset purchases provoked a heated debate among policymakers on their net benefits to other economies. Some of them were expressing concerns about excessive currency appreciation in small open economies (SOEs) and possible imbalances in emerging markets, see e.g. Rajan (2016), and a speech by Per Jansson invoked in Bluwstein and Canova (2016). Others were stressing a favorable impact of quantitative easing on global demand, see e.g. Blanchard (2016), and speeches by Ben Bernanke and Mario Draghi quoted by Bhattarai et al. (2015) and Falagiarda et al. (2015).

The existing empirical evidence provides fairly strong support for the positive impact of quantitative easing on financial markets. A number of papers have confirmed a significant reduction of long-term yields in the economies that engaged in asset purchase programs, especially in the US economy, see e.g. Gagnon et al. (2011), Joyce et al. (2011), D'Amico et al. (2012), Baumeister and Benati (2013), Kiley (2014). On the other hand, Neely (2015), Fratzscher et al. (2013), Ahmed and Zlate (2014), Lim and Mohapatra (2016) and Tillmann (2016) all stress that quantitative easing by the Federal Reserve resulted in procyclical capital inflows into emerging markets and appreciation of their exchange rates. Falagiarda et al. (2015) find similar effects of the ECB non-standard monetary policy measures on Central and Eastern European countries that are tightly integrated with the euro area.

To illustrate the magnitude of capital inflows to sovereign bond markets in SOEs, we plot in Figure 2 the share of non-resident investors holdings in the outstanding bonds issued by emerging market governments (in their currencies). Since 2009, this share has increased by about 15 percentage points. It is important to note that this capital inflow into emerging economies' sovereign bond markets was not matched by offsetting capital outflows associated with other debt securities. As Figure 3 shows, a massive increase of this group of countries' international liabilities can be observed also for a broader category of debt securities that additionally cover government bonds issued in foreign markets and private debt securities. At the same time, the corresponding gross asset position expressed as a percentage of GDP remained flat, so the observed processes resulted in large net capital inflows. Naturally, flows of this type and scale must have affected asset prices. First, they impacted prices of long-term bonds issued by the recipient countries. As Figure 4 strikingly reveals, the comovement between the term premium on 10-year US treasuries and 10-year bonds issued by the governments of SOEs has significantly increased since 2009.

Second, massive capital flows driven by quantitative easing affected exchange rates. To illustrate this effect, we utilize the so-called Fama regressions (Fama, 1984). Table 1 reports the estimated slope on the interest rate differential and on its interaction with a QE dummy for bilateral exchange rates vis-a-vis the US dollar, estimated on a panel of data for 17 small open economies. As it has been documented many times in the literature, the coefficient in normal (pre-QE) times is far away from unity implied by the uncovered interest parity (UIP) condition, and statistically insignificant from zero at conventional levels. During the period of large scale asset purchases initiated by the Fed, the slope becomes significantly negative. This effect is observed both for advanced and emerging economies, but is stronger for the latter group.

Overall, the existing evidence suggests that, while there are strong reasons to believe that the reaction of financial markets to unconventional monetary policy contributed to revival in economic activity in countries pursuing quantitative easing, the net effect on other countries' output is not clear. On the one hand, improved economic conditions in countries engaged in asset purchases stimulate their demand for imports. Moreover, the induced world-wide compression of long-term yields should support spending in SOEs. On the other hand, this favorable impact can be offset by the exchange rate appreciation associated with increased capital inflows. Bhattarai et al. (2015) offer some support for the hypothesis that the net effect of quantitative easing pursued by major economies on output in other economies does not need to be positive. Using a VAR analysis, they fail to detect a significantly positive impact of the Fed non-standard measures on GDP in emerging markets, and some of their specifications actually suggest negative effects.

In this paper we contribute to this debate by proposing a model that helps understand and quantitatively analyze international spillovers of long-term asset purchase programs pursued by the major central banks, and in particular the capital flows that this type of unconventional policy generates. We build on the segmented asset markets framework considered by Andres et al. (2004), and more recently further developed by Chen et al. (2012). Our main modeling extension is to formulate this environment in an open economy, two-country setup. In the model we propose, agents can trade long-term bonds issued by the two governments so that changes in their supply trigger portfolio adjustments that have real effects on both economies.[1] Also, as recently advocated by Passari and Rey (2015), we define financial linkages in terms of gross rather than net international positions in assets.

We calibrate the two-country model to Poland, a typical small open economy pursuing independent conventional monetary policy and deeply integrated with the rest of the world, and a conglomerate of three big economies whose central banks engaged in long-term asset purchases during the last decade, namely the United States, the United Kingdom and the euro area. We next use this model to simulate the quantitative easing in the large economies. We find that the model is able to replicate the salient features of the data discussed above. In particular, it generates an inflow of foreign capital to the small economy's sovereign bond market that matches the data very well. In line with what we show in Figure 4, the model also implies very strong comovement of term premia in the two regions during the period of quantitative easing, but not necessarily in normal times. Finally, it correctly predicts the estimated downward shift in the slope of exchange rate projections on the interest rate differential (Fama regressions) during the period of QE.

According to our model-based simulations, quantitative easing abroad boosts domestic demand in the small economy, but strongly undermines its international competitiveness and depresses economic activity as measured with GDP, at least in the short run. This is in contrast to the effects of conventional monetary easing abroad, which positively affects the small economy's output. Our model is hence consistent with the empirical findings on conventional monetary policy spillovers (Mackowiak, 2007; Banerjee et al., 2016; Dedola et al., 2017; Iacoviello and Navarro, 2018) and unconventional ones (Bhattarai et al., 2015). From the model's perspective, the differences between these two forms of monetary accommodation are related to the size of international capital movements and exchange rate adjustments they induce. For a given magnitude of impact on the large economy's output, central bank asset purchases generate a much larger inflow of non-residents into sovereign long-term bond markets of other countries, resulting in a much sharper appreciation of their real exchange rates. In this sense, our model-based predictions support the concerns raised e.g. by Rajan (2016) about the impact of quantitative easing in advanced countries on emerging economies.

One way of interpreting our results is that the small economy's central bank by using only conventional policy can easily control the short end of the domestic yield curve, but is less powerful in affecting its long end. Therefore, following QE in the large economy that strongly depresses foreign long-term rates, the equalization of ex ante returns on home and foreign bonds is achieved mainly by exchange rate and term premium adjustment, the mirror image of which are massive capital inflows to the small economy. Indeed, our framework implies that limiting the negative impact of unconventional monetary policy spillovers is much easier with interventions that directly address the associated financial flows, like purchasing long-

[1] Bartocci et al. (2017) use a similar framework to study asset purchases by the ECB. However, they do not allow for international trade in long-term bonds, which is the key transmission mechanism in our model.

term bonds by the small economy. This outcome is consistent with Blanchard (2016), who calls for international coordination of large scale asset purchases.

The closest paper to ours is the recent work by Alpanda and Kabaca (2017), who develop a two-country model with portfolio balance effects to investigate international spillovers of large scale asset purchases in the US to the rest of the world. Similarly to ours, their model predicts capital inflows into the markets for long-term bonds issued by other economies. However, their simulations also feature offsetting capital flows, and in particular a massive increase in short-term US bond holdings by the rest of the world, which does not fit the experience of small open economies that we focus on. As a result, the net capital inflow to countries not engaged in quantitative easing is moderate, their trade balance does not deteriorate much, and its negative effect on output is easily dwarfed by a boost in domestic demand. Our model instead, in line with evidence from emerging markets, restricts international trade in short-term bonds, hence generating bigger net capital flows following QE abroad, whose negative effect on the domestic economy's international competitiveness is strong enough to result in a fall in its output. In this sense, our paper is also related to the recent literature highlighting the role of exchange rate adjustments and international financial flows, including the beggar-thy-neighbor effects, during the period of extremely low global interest rates (see e.g. Caballero et al., 2015; Eggertsson et al., 2016; Cook and Devereux, 2016; Haberis and Lipinska, 2012).

The rest of this paper is structured as follows. Section two presents the model and section three discusses its calibration. Section four offers a deeper discussion of the asset market segmentation in our model. The baseline QE scenario and its international spillovers are presented in section five. Section six compares QE spillovers to those associated with conventional monetary policy. The most important robustness checks are covered in section seven. Section eight concludes.

2 Model

We develop a two-country DSGE model where agents can trade long- and short-term government bonds. The world population is normalized to unity and the relative size of the domestic (small) economy is $\omega \in (0; 0.5)$. Each country is populated by two types of households, as well as final and intermediate goods producers that supply domestic and foreign markets. The government in each country controls the short-term interest rate, exogenous spending and the supply of long- and short-term bonds, both issued in local currency.

Similarly to Andres et al. (2004) and others who followed their modeling approach (e.g. Chen et al., 2012; Kiley, 2014; Alpanda and Kabaca, 2017), we introduce market segmentation between short- and long-term bonds in a parsimonious way. It allows us to analyze the impact of quantitative easing on macrovariables without modeling imperfect asset substitutability in detail.

As the model structure is largely symmetric, in what follows we focus on the problems faced by agents populating the home (small) economy, and discuss those related to foreign agents only when they are distinct. We also adopt a standard convention of indicating variables related to the foreign economy with an asterisk. A full list of equations defining the equilibrium in our model can be found in the Appendix.

2.1 Households

There are two types of households in our model, which we call restricted and unrestricted, and which we index with $j = \{r, u\}$.[2] The share of restricted households is $\omega_r \in (0; 1)$. Household types differ in two ways (see Table 2). First, they are distinguished by their access to bond markets. Restricted households trade only in long-term bonds, reflecting the observation that in the real world some agents hold mostly long-term assets (e.g. pension funds). Unrestricted households, in turn, conduct transactions in long-term bonds, both foreign and domestic, as well as in short-term bonds issued by their own country. Second, while trading in long-term bonds, unrestricted households have to pay transaction costs, whereas restricted households do not bear such expenses. As argued by Chen et al. (2012), since the latter type of agents specialize in trading only in long-term bonds and their investment horizon is likely to be longer, their transaction costs are believed to be minor.

2.1.1 Households in the small economy

Restricted agents in the small economy have access only to domestic long-term bonds, while unrestricted households can additionally trade in domestic short-term and foreign long-term bonds. Both types of households rent their 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.

A representative household of type j maximizes her lifetime utility that depends on consumption c_t^j and labor effort n_t^j

$$U_t^j = E_t \sum_{s=0}^{\infty} \beta_j^s \exp\{\varepsilon_{t+s}^d\} \left[\frac{(c_{t+s}^j)^{1-\sigma}}{1-\sigma} - \frac{(n_{t+s}^j)^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where ε_t^d is the preference shock, $\beta_j \in (0; 1)$ is the subjective discount factor, $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution and $\varphi > 0$ is the inverse of the Frisch elasticity of labor supply.

[2] We assign these names to be consistent with the previous literature, even though unrestricted households in our model are not allowed to hold all types of assets.

Following Woodford (2001), we model long-term bonds as perpetuities that pay an exponentially decaying coupon κ^s every period $s+1$ ($s \geq 0$) after the issuance, where $\kappa \in (0;1]$. Then the current price of a bond issued s periods ago is related to the price of currently issued bonds with $P_{L-s,t} = \kappa^s P_{L,t}$. This allows us to write the budget constraint of restricted households as (see Chen et al., 2012)

$$P_t c_t^r + P_{L,t} B_{H,L,t}^r + T_t^r = P_{L,t} R_{L,t} B_{H,L,t-1}^r + W_t n_t^r + D_t^r \tag{2}$$

where P_t is the aggregate price level, $B_{H,L,t}^r$ denotes bonds issued by the home government and held by home restricted households, and $R_{L,t} \equiv P_{L,t}^{-1} + \kappa$ is the gross yield to maturity on these bonds.

Unrestricted households additionally have access to domestic short-term bonds and long-term bonds issued by the foreign government. Whenever they trade in long-term bonds, unrestricted households are required to pay transaction costs. Their budget constraint can be written as

$$\begin{aligned} P_t c_t^u + B_{H,t}^u + (1+\zeta_{H,t}) P_{L,t} B_{H,L,t}^u + (1+\zeta_{F,t}) S_t P_{L,t}^* B_{F,L,t}^u + T_t^u = \\ R_{t-1} B_{H,t-1}^u + P_{L,t} R_{L,t} B_{H,L,t-1}^u + S_t P_{L,t} R_{L,t}^* B_{F,L,t-1}^u + W_t n_t^u + D_t^u + \Xi_t^u \end{aligned} \tag{3}$$

where R_t is the short-term interest rate controlled by the domestic monetary authority, S_t is the nominal exchange rate expressed as the home currency price of one unit of foreign currency, $B_{H,t}^u$ and $B_{H,L,t}^u$ stand for short and long-term domestic bond holdings, while $B_{F,L,t}^u$ denotes holdings of bonds issued by the foreign government, the price and yield to maturity of which are $P_{L,t}^*$ and $R_{L,t}^*$, respectively.

Unrestricted households are subject to two types of transaction costs related to trading in long-term bonds given by

$$\frac{1+\zeta_{h,t}}{1+\zeta_h} = \left(\frac{P_{L,t} b_{h,L,t}^u}{P_L b_{h,L}^u} \right)^{\xi_h} \tag{4}$$

for $h = \{H, F\}$, where $\xi_h > 0$, $b_{H,L,t}^u \equiv B_{H,L,t}^u / P_t$, and variables without time subscripts indicate their steady state values. These costs are external to an individual household (i.e. depend on aggregate positions) and rebated back in a lump sum fashion as Ξ_t^u.

2.1.2 Households in the large economy

Households in the large (foreign) economy are modeled analogously to presented above, except that restricted agents trade in both domestic and foreign long-term bonds.[3] Their

[3] This asymmetry in the structure of our model is only aimed to keep it simpler, and does not have any significant impact on our results, i.e. they are very similar if we allow also the home restricted agents to hold

budget constraint can be written as

$$P_t^* c_t^{r*} + P_{L,t}^* B_{F,L,t}^{r*} + (1+\Gamma_t^{r*})\frac{P_{L,t}}{S_t} B_{H,L,t}^{r*} + T_t^{r*} =$$
$$P_{L,t}^* R_{L,t}^* B_{F,L,t-1}^{r*} + \frac{P_{L,t}}{S_t} R_{L,t} B_{H,L,t-1}^{r*} + W_t^* n_t^{r*} + D_t^{r*} + \Xi_t^{r*} \tag{5}$$

where Γ_t^{r*} is an external adjustment cost given by

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

and rebated back as Ξ_t^{r*}, where $\kappa^{r*} > 0$ is the steady state proportion of restricted households' holdings of bonds issued by the small and large economies. This adjustment cost is introduced only to make the steady state portfolio problem of restricted households in the large economy determinate, and we parameterize it such that it does not affect the model dynamics, i.e. by setting ξ_r^* to a very low positive number.

2.2 Firms

To introduce price stickiness and imperfect substitution between domestic and imported goods, we consider three stages of production. At the final stage, perfectly competitive final goods producers combine homogeneous home-made goods $y_{H,t}$ and imported goods $y_{F,t}$ according to the following technology

$$\tilde{y}_t = \left(\eta^{\frac{1}{\nu}} y_{H,t}^{\frac{\nu-1}{\nu}} + (1-\eta)^{\frac{1}{\nu}} y_{F,t}^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}} \tag{7}$$

where $\eta \in (0;1)$ is the home-bias parameter and $\nu > 0$ is the elasticity of substitution between domestic and imported goods.

At the previous production stage homogeneous goods are produced by perfectly competitive aggregators according to

$$y_{h,t} = \left(\int_0^1 y_{h,t}(i)^{\frac{1}{\mu}} di \right)^{\mu} \tag{8}$$

for $h = \{H, F\}$, where $\mu > 1$ controls the degree of substitution between intermediate inputs $y_{h,t}(i)$.

Intermediate inputs are produced by monopolistically competitive firms indexed by i that operate a linear production function in local labor

both domestic and foreign long-term bonds. See also the Appendix.

$$y_{H,t}(i) + y^*_{H,t}(i) = \exp\{\varepsilon^z_t\} n_t(i) - \phi \tag{9}$$

where ε^z_t is the productivity shock and ϕ is a fixed cost of production. These firms set their prices in the buyer's currency, separately for the domestic market and exports, in a staggered fashion that is similar to the Calvo scheme. More specifically, every period a firm operating in the domestic economy faces a fixed probability θ_H of price reoptimization for the domestic market and probability θ^*_H of price reset for exports. Firms that cannot reoptimize index their prices to steady state CPI inflation.

We assume that firms using local labor are owned by local restricted and unrestricted households in a proportion equal to their shares in population. The problem of reoptimizing firms is hence to maximize

$$E_t \sum_{s=0}^{\infty} (\theta_H)^s \Lambda_{t+s} \left(P_{H,t}(i)\, \pi^s - \frac{W_{t+s}}{\exp\{\varepsilon^z_{t+s}\}} \right) y_{H,t+s}(i) \tag{10}$$

$$E_t \sum_{s=0}^{\infty} (\theta^*_H)^s \Lambda_{t+s} \left(S_{t+s} P^*_{H,t}(i)\, (\pi^*)^s - \frac{W_{t+s}}{\exp\{\varepsilon^z_{t+s}\}} \right) y^*_{H,t+s}(i) \tag{11}$$

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 stochastic discount factor for nominal payoffs that is consistent with the assumed firm ownership structure, $P_{H,t}(i)$ is the price set by intermediate producer i for the domestic market, $P^*_{H,t}(i)$ is the price set for the foreign market, while $\pi_t \equiv P_t/P_{t-1}$ and $\pi^*_t \equiv P^*_t/P^*_{t-1}$ are the domestic and foreign inflation rates for final goods. This maximization problem is subject to the demand schedules consistent with aggregators' optimization sketched above.

2.3 Government

The monetary authority follows a Taylor-like feedback rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_r} \left[\left(\frac{\pi_t}{\pi}\right)^{\gamma_\pi} \left(\frac{y_t}{y}\right)^{\gamma_y} \right]^{1-\gamma_r} \exp\{\varepsilon^r_t\} \tag{12}$$

where ε^r_t is the monetary policy shock, $\gamma_r \in (0;1)$ controls the degree of interest rate smoothing, while γ_π and γ_y control, respectively, the strength of interest rate response to deviations of inflation from the target and to the output gap.

The fiscal authority sets exogenous spending on final goods $g_t \equiv g \exp\{\varepsilon^g_t\}$, where ε^g_t is the government spending shock, and finances it with lump sum taxes levied on households $T_t \equiv \omega_r T^r_t + (1-\omega_r) T^u_t$ and with net debt issuance. We assume that both types of households pay the same amount of taxes in per capita terms so that $T^r_t = T^u_t = T_t$. The government budget constraint is

$$B^g_{H,t} + P_{L,t}B^g_{H,L,t} + T_t = R_{t-1}B^g_{H,t-1} + P_{L,t}R_{L,t}B^g_{H,L,t-1} + P_t g_t \tag{13}$$

and the market value of total (short and long-term) government debt is

$$B^g_t = B^g_{H,t} + P_{L,t}B^g_{H,L,t} \tag{14}$$

Unless stated otherwise, the government of the small country keeps the real market value of debt $b^g_t \equiv B^g_t/P_t$ and its composition $\frac{B^g_{H,t}}{P_{L,t}B^g_{H,L,t}}$ constant. Total real debt of the large country b^{g*}_t is also fixed, but its composition may change according to the following rule

$$\frac{P^*_{L,t}b^{g*}_{F,L,t}}{P^*_L b^{g*}_{F,L}} = \left(\frac{P^*_{L,t-1}b^{g*}_{F,L,t-1}}{P^*_L b^{g*}_{F,L}}\right)^{\gamma^*_L} \exp\{\varepsilon^{L*}_t\} \tag{15}$$

where $\gamma^*_L > 0$ is a smoothing parameter and ε^{L*}_t is the quantitative easing shock.

2.4 Goods market clearing

We impose a set of market clearing conditions. Equilibrium on the goods market requires

$$\tilde{y}_t = \omega_r c^r_t + (1-\omega_r)c^u_t + g_t \tag{16}$$

and

$$y_t \equiv y_{H,t}\Delta_{H,t} + \frac{1-\omega}{\omega}y^*_{H,t}\Delta^*_{H,t} = \exp\{\varepsilon^z_t\}n_t - \phi \tag{17}$$

where $n_t \equiv \omega_r n^r_t + (1-\omega_r)n^u_t$ is aggregate labor input, y_t defines aggregate output while

$$\Delta_{H,t} = \int_0^1 \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{\frac{\mu}{1-\mu}} di \tag{18}$$

$$\Delta^*_{H,t} = \int_0^1 \left(\frac{P^*_{H,t}(i)}{P^*_{H,t}}\right)^{\frac{\mu^*}{1-\mu^*}} di \tag{19}$$

are the measures of price dispersion resulting from staggered pricing by intermediate goods producing firms.

Given our assumptions on market segmentation, the market clearing conditions for bonds issued by the home economy's government are

$$(1-\omega_r)B^u_{H,t} = B^g_{H,t} \tag{20}$$

$$\omega_r B^r_{H,L,t} + (1-\omega_r) B^u_{H,L,t} + \frac{1-\omega}{\omega}\omega^*_r B^{r*}_{H,L,t} + \frac{1-\omega}{\omega}(1-\omega^*_r) B^{u*}_{H,L,t} = B^g_{H,L,t} \tag{21}$$

Using these market clearing conditions together with the budget constraints of households and the government, as well as the zero-profit condition of the final goods producers and aggregators, we obtain the following law of motion for the small economy's net foreign assets position

$$A_t = R^*_{L,t}\frac{S_t}{S_{t-1}}\frac{P^*_{L,t}}{P^*_{L,t-1}}A^+_{t-1} - R_{L,t}\frac{P_{L,t}}{P_{L,t-1}}A^-_{t-1} + NX_t \tag{22}$$

where

$$A^+_t = (1-\omega_r) S_t P^*_{L,t} B^u_{F,L,t} \tag{23}$$

$$A^-_t = \frac{1-\omega}{\omega} P_{L,t}\left((1-\omega^*_r) B^{u*}_{H,L,t} + \omega^*_r B^{r*}_{H,L,t}\right) \tag{24}$$

$$NX_t = \frac{1-\omega}{\omega} S_t P^*_{H,t} y^*_{H,t} - P_{F,t} y_{F,t} \tag{25}$$

are, respectively, small economy's gross foreign assets, gross foreign liabilities and net exports.

2.5 Term premium

As in Chen et al. (2012), we define the term premium on long-term bonds as

$$TP_t = R_{L,t} - R^{EH}_{L,t} \tag{26}$$

where $R^{EH}_{L,t}$ is the counterfactual yield to maturity on a long-term bond in the absence of transaction costs, which we price using unrestricted households' stochastic discount factor, and κ^{EH} is such that this counterfactual bond has the same steady state duration D_L as the actual bond, i.e. the following must hold

$$D_L = \frac{R_L}{R_L - \kappa} = \frac{R^{EH}_L}{R^{EH}_L - \kappa^{EH}} \tag{27}$$

As shown by Chen et al. (2012), the term premium can be approximated up to first order as the discounted sum of expected values of transaction costs $\zeta_{H,t}$ associated with trade in domestic long-term bonds

$$TP_t \approx D_L^{-1}\sum_{s=0}^{\infty}\left(\frac{D_L - 1}{D_L}\right)^s E_t \zeta_{H,t+s} \tag{28}$$

Hence, fluctuations in the term premium essentially reflect the current and planned portfolio rebalancing decisions made by agents.

2.6 Exogenous shocks

The key driving force in our model are exogenous shifts in the composition of public debt in the large economy ε_t^{L*}. The model also features a set of standard shocks used in open economy DSGE models. These are the country pairs of shocks to productivity (ε_t^z and ε_t^{z*}), time preferences (ε_t^d and ε_t^{d*}), government spending (ε_t^g and ε_t^{g*}) and monetary policy (ε_t^r and ε_t^{r*}). All shocks are modeled as independent first-order autoregressions, except for monetary and quantitative easing shocks that we assume to be i.i.d.

3 Calibration

We calibrate our two-country model to a block of three big economies that engaged in quantitative easing during the last decade, namely the United States, the United Kingdom and the euro area (BIG3 henceforth) and Poland. Given the diversity across small open economies, picking their representative is not trivial. We motivate our choice of Poland as follows. First of all, it pursues independent monetary policy with a flexible exchange rate. Second, it is relatively free from idiosyncratic features characterizing many other emerging economies, and from which we abstract away in our model. Poland is not a resource rich economy, its public debt is relatively low and widely considered safe, it has not suffered from a banking crisis or a bust in the housing market. Finally, and most importantly given this paper's motivation, the experience of the Polish economy over the QE period fits almost perfectly the picture documented in Figures 2-4 for a larger group of small open economies.[4]

Following the standard practice, we set the parameters to match some key steady state proportions observed in the data or take them from the previous literature. Table 3 shows the calibrated parameter values while Table 4 presents the targeted steady state ratios. The time period is one quarter.

If we measure the country size with GDP in current US dollars, the relative size of the small economy ω is 0.014. The home bias parameter η is calibrated at 0.75 to capture the average share of imports in the Polish GDP, corrected for the import content of exports estimated by the OECD. The elasticity of substitution between domestically produced goods and imports is set to 3, which can be seen as a compromise between the micro and macro estimates found in the literature.

In our model the key transmission channel of international policy spillovers relies on gross

[4]Over the period covered by Figure 2, the share of foreign investors in the Polish sovereign debt market increased by 15 percentage points, compared to 14 percentage points calculated as the aggregate over 15 emerging economies considered in the figure. Over the last decade, the net inflow of foreign debt securities to Poland amounted to 7.5% of GDP, which is close to 9.2% of GDP for a median small open economy as shown in Figure 3. As regards comovement in the term premia documented in Figure 4, Jabłecki et al. (2016) noted that the one in Poland has been following almost one-to-one its counterpart in Germany since the outbreak of the Great Recession.

bond holdings and their adjustment. Hence, the crucial part of our calibration concerns the steady state composition of the bond portfolios held by agents in the small and large economy. Our targets for these proportions are based on the averages observed over the period 2004-2015, which are calculated by combining several data sources. The shares of sovereign bonds in quarterly GDP in Poland and in BIG3 are calibrated to 1.25 and 2.65, respectively. These values are derived using the nominal value of government debt securities reported by Eurostat (for Poland) and by the World Bank in its Quarterly Public Sector Debt Database (for the BIG3).[5] These databases also allow us to distinguish between long- and short-term bonds, where we follow Chen et al. (2012) and treat sovereign debt securities that mature in one year or less as short-term bonds. For the BIG3, the latter category also includes money holdings since these are very close substitutes of short-term safe debt securities when the policy rate is close to zero. This gives the share of long-term bonds in total sovereign bonds of 0.71 in Poland and 0.63 for the BIG3. The steady state share of resident holdings in total long-term bonds issued by the small economy is set to 0.76, which is in line with data published by the Polish Ministry of Finance. The ratio of foreign bonds to total bonds held by small economy's agents is calibrated at 0.05, reflecting average portfolio investment in foreign bonds by Polish residents according to the International Investment Position statistics published by the Polish central bank. Finally, we assume that the share of small economy's bonds in the long-term bond portfolio held by foreign households is the same for their two types, which pins down the value of κ^{r*} at 0.0018.

Another important group of parameters determine the degree of market segmentation and sensitivity of transaction costs, and hence the term premia, to adjustments in agents' portfolios. We set the share of restricted households ω_r and ω_r^* to 0.1 for both economies. While calibrating transaction costs on long-term bonds ξ_H and ξ_F, our primary goal is to make sure that, in response to a QE scenario that we describe in section 5, our model generates the reaction of bond prices in the large economy that is consistent with the results reported by Chen et al. (2012).[6] Given the potential importance of these parameters, we later confirm the robustness of our main results to their either smaller or asymmetric values. Finally, the smoothing coefficient in the debt composition rule for the large economy γ_L^* is calibrated at 0.99 to reflect high persistence of asset purchase programs.

The following parameters determine the steady state levels of the interest rates and bond prices, and hence the term premia and bond duration. We set the inflation targets π and π^* to 1.005 (2% annualized) so that they are consistent with those adopted by the three major central banks (the Fed, the Bank of England and the European Central Bank)

[5] In the World Bank database the time series on debt securities for Poland are only available from 2010, therefore we chose to complement this source with Eurostat data.

[6] Chen et al. (2012) estimate a reduction of the term premium by 10 bps following the LSAP II in the United States. However, the ultimate scale of this program (600 bn USD, i.e. 4% of the US GDP) is about three times smaller than in our case (12% of the combined GDP of the US, the UK and the euro area), so we target the fall in the term premium in the large economy by 30 bps.

and the average inflation rate in Poland since 2004. These, together with the discount factors for restricted and unrestricted households β_r and β_u, pin down the steady state long and short-term interest rates. We target them to match the US averages of 5.2% and 4%, respectively, and symmetrically between the two regions. Since long-term bonds are modeled as perpetuities, we need to specify their coupons κ and κ^*. We do it to match the duration of long-term bonds, which is equal to 3 years in Poland according to MoF (2015), and 7.5 years in the US according to Chen et al. (2012). The Calvo probability for domestic sales θ_H and θ_F^* are calibrated at 0.8, which implies higher price duration compared to US micro-data evidence, but results in the slope of the Phillips curve that is within the range reported in the empirical macro literature (Erceg and Linde, 2014).[7] We assume that the price duration for foreign sales is twice lower and set θ_H^* and θ_F to 0.6.

The remaining parameters are either relatively well-established in the literature or do not have important effects on our key results. The steady state government spending in both countries 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, price markups μ, interest rate rule coefficients γ_r, γ_π and γ_y, as well as their large economy counterparts, are all set to standard values considered in the DSGE literature. As explained before, we set the portfolio adjustment cost ξ_r^* to a small positive number that ensures determinacy, and at the same time does not affect significantly the model dynamics.

4 The role of asset market segmentation

In a model like ours, asset market segmentation plays a key role, therefore in this section we discuss it in more detail. In particular, we argue that our modeling choice is not only in line with the balance of payments statistics for the small open economies that we focus on, but also allows our model to account for the stylized QE spillover facts discussed in the introduction, namely substantial comovement in the term premia, direction and size of capital flows (both gross and net), and the slope in the Fama regressions.

As it was stated in section 2.1, there are four types of households and four types of bonds in our two-country world, but we do not allow any agent to trade all assets (recall Table 2). It is convenient to discuss separately two dimensions of asset segmentation in our model: across the term structure and across borders. The former, i.e. excluding restricted households from short-term bond markets and making unrestricted ones subject to transaction costs whenever they adjust their positions in long-term bonds, is borrowed from the previous literature and its role has been extensively discussed by Chen et al. (2012). These assumptions limit the

[7] Moderate slope of the Phillips curve helps avoid extreme reactions of inflation to small extensions in the forward guidance (Carlstrom et al., 2015), which is important for those of our simulations that assume a temporary policy rate peg that aims to mimic a binding zero lower bound constraint.

arbitrage between short-term and long-term bonds issued in a given currency, resulting in fluctuations in the term premia that have effects on real activity. Absent transaction costs, short and long-term bonds would become perfect substitutes under certainty equivalence, while allowing restricted households to trade short-term bonds would effectively eliminate transaction costs through arbitrage. What distinguishes our modeling approach from the existing literature and what is crucial to match the stylized facts from the introduction is the international aspect of segmentation.

The key assumption we make is that unrestricted households cannot trade short-term bonds issued abroad.[8] This restriction is in line with the data for small open economies, indicating that short-term debt securities account only for a tiny proportion of international financial flows to these countries. In particular, according to the Coordinated Portfolio Investment Survey held by the IMF, the share of short-term instruments in this category is very small and stable (the median value moving between 2.2% and 5.2% over the period 2006-2018).[9] As regards foreign debt assets held by small open economies, their holdings are relatively small and stable (recall Figure 3), and, according to the sparse data on sectoral composition of asset holdings that are available, their short-term component is tiny.

Our market segmentation has important implications for the model dynamics. As we show in the Appendix, it implies the following long-term uncovered interest parity (UIP) condition

$$\mathbb{E}_t \left\{ \hat{P}_{L,t+1} - \hat{P}_{L,t} + \hat{R}_{L,t+1} - \hat{\pi}_{t+1} \right\} = \mathbb{E}_t \left\{ \hat{P}^*_{L,t+1} - \hat{P}^*_{L,t} + \hat{R}^*_{L,t+1} - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t \right\} \quad (29)$$

where hats over variables indicate log-deviations from the non-stochastic steady state. This equation simply postulates that, to the first order of approximation, expected one-period rates of return on home and foreign long-term bonds should be the same when expressed in the same (small economy's) currency. This further leads to the equalization of transaction costs (and hence of the term premia on bonds with the same duration, see equation (28)) on home and foreign long-term bonds within each country ($\zeta_{H,t} = \zeta_{F,t}$ and $\zeta^*_{H,t} = \zeta^*_{F,t}$), but not necessarily internationally (in general $\zeta_{H,t} \neq \zeta^*_{F,t}$). To study its role, it is instructive to look at the implied short-term UIP condition in our model

$$\mathbb{E}_t \left\{ \hat{R}_t - \hat{\pi}_{t+1} \right\} = \mathbb{E}_t \left\{ \hat{R}^*_t - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t \right\} + \zeta^*_{F,t} - \zeta_{H,t} \quad (30)$$

Compared to the standard UIP, equation (30) additionally features transaction costs associ-

[8]Another restriction we impose is not allowing home restricted households to hold foreign long-term bonds, see footnote 3. As we show in the Appendix, this restriction does not have direct consequences for the ability of our model to account for the stylized facts that we focus on in this section.

[9]We use data on total foreign debt securities, which is a broader category of assets that we use in our model as it includes both sovereign and private (e.g. corporate bonds) assets. In this way we avoid omitting in this discussion assets that can be considered close substitutes to sovereign bonds.

ated with trade in long-term bonds, which can be interpreted as an endogenous risk premium. The presence of this wedge also means that, in contrast to long-term bond holdings, expected rates of return on domestic and foreign short-term bonds in our model are not equalized, even under certainty equivalence.

This potentially appealing arbitrage at the short-term end of the yield curve would vanish if we did allow unrestricted agents (either home or foreign) to trade short-term bonds issued in the other economy as it would lead to perfect equalization of all transaction costs, also internationally ($\zeta_{H,t} = \zeta^*_{F,t}$). We now show that this would have important consequences for the model's ability to account for the key stylized facts associated with quantitative easing.

First, there would be perfect comovement between the term premia on home and foreign bonds of the same maturity, irrespective of the type of shocks hitting the two economies. Clearly, such a model would be inconsistent with evidence presented in Figure 4, which documented imperfect cross-country correlation of the term premia and its markedly increased synchronization after major central banks introduced QE.

Second, allowing for international trade in short-term bonds would also generate counterfactual cross-border capital flows during the analyzed episode. To see why, note that QE abroad shrinks the available supply of foreign long-term bonds, making the UIP wedge in equation (30) negative under our segmentation, which implies a positive return differential between foreign and home short-term bonds. Unleashing arbitrage forces by lifting the constraint on international trade in short-term bonds would hence lead to their massive outflow from the small economy in response to foreign QE. As we discuss later using the model simulations, this would nearly perfectly offset the capital inflow associated with trade in long-term bonds, making this prediction inconsistent with evidence presented in Figure 3.

Third, as it is clear by looking at equation (30), if all transaction costs were equal to each other, as it would be the case if we allowed for trade in short-term bonds, we would obtain the standard UIP condition without any risk premium. Hence, there would be no way of obtaining a marked shift in the slope of the Fama regressions that we documented in the introduction as it would be always equal to unity, irrespective of shocks driving the economies.

Let us now demonstrate that imposing our international asset market segmentation resolves or at least improves over these counterfactual predictions. We start with the cross-country synchronization of the term premia before and after QE. To this end, we look at the correlations between the term premia in the large and small economy as implied by our model, conditional on a shock type.[10] As the first column in Table 5 reveals, shocks affecting the composition of the large economy's bond supply imply very tight comovement between

[10] The calculations are based on the first-order approximation to the model equilibrium conditions. In line with evidence from estimated DSGE models in the literature, autoregressive shocks are allowed to exhibit considerable degree of inertia (we set their autoregressive coefficients to 0.9). Shocks of same type are assumed to have the same volatility in both countries.

the term premia. None of the standard business cycle disturbances can generate similarly high correlation, whereas productivity shocks imply even negative comovement. Moreover, when we allow the volatility of shocks in the small economy to be higher than in the large economy,[11] these correlations become even lower. Hence, we can conclude that our model is able to account for the observed increase in the cross-country term premia comovement during the period of quantitative easing compared to the per-crisis times.

As regards international capital flows, restricting their trade at the short end of the yield curve prevents their counterfactual outflow from the small economy by construction. Importantly, as we show later in the paper, it is feasible to feed an actual QE scenario into our model and generate the magnitudes of the flows that match the data very well.

We finally examine the empirical validity of the UIP condition (30). The second column in Table 5 presents the model-implied slope of the Fama regression, conditional on different types of shocks. The presence of an endogenous wedge that depends on transaction costs clearly improves the fit for standard business cycle shocks, driving the projection of the exchange rate change on the (short-term) interest rate differential away from unity towards zero.[12] Importantly, the slope becomes negative for government asset composition shocks, thus helping explain the empirical finding on its shift during the QE period.

5 Quantitative easing in the large economy

We are now ready to use our model to simulate a quantitative easing scenario in the large economy. We design it to mimic the evolution of the share of long-term bonds in the total supply of bonds issued by the BIG3 as in Figure 1 from 2009 through 2016, i.e. the central bank of the large economy buys domestic long-term sovereign bonds in exchange for short-term securities, reducing the share of the former in the private sector portfolio by nearly 10 percentage points. We assume that after 2016 this policy starts being withdrawn at the same pace as it was introduced so that by 2024 the composition of outstanding bonds is the same as before the crisis. The scenario is implemented using an appropriate sequence of shocks to ε_t^{L*} in equation (15).

A potentially important part of the simulation design regards the assumptions on agents' expectations about the ultimate shape of the QE program and reaction of the short-term interest rates. In this paper we do not attempt to model in detail how expectations of central bank actions are formed. Instead, we present four stylized variants that are aimed to span a wide spectrum of realistic cases. As we argue in the subsequent paragraphs, notwithstanding some differences, the main outcomes for the small economy hold in all variants (Figure 5).

[11] See e.g. Kolasa (2009) for evidence based on a two-country DSGE model estimated for Poland and the euro area.

[12] This improvement is consistent with Wesołowski (2018), who shows in an estimated DSGE model of a small open economy that a similarly derived risk premium improves the data fit.

As the baseline we assume that quantitative easing is unanticipated, but once it starts being implemented, the whole path of asset purchases is perfectly known to all agents. In the second variant we assume that the central bank in the large economy announces the whole path of quantitative easing one year in advance. Arguably, both are quite extreme as in reality there were several rounds of asset purchases implemented by the three large economies that we consider and, even though they might have been anticipated to some extent by the agents, their implementation was definitely not perfectly foreseen as of 2009. Therefore, in the third variant we consider the opposite extreme by assuming that agents are fully taken by surprise each quarter when the central bank announces a new round of asset purchases.[13] In all three variants we allow the short-term interest rates to respond endogenously in line with their feedback rules, also in the large economy. This choice is consistent with the tightening of conventional policy by the European Central Bank implemented in 2011. However, at least for some period included in our analysis, the binding zero lower bound (ZLB) was an important feature of the monetary policy conducted by the BIG3. Therefore, the fourth variant assumes that the short-term rate in the large economy is not allowed to respond. We combine it with the third scenario so that, every quarter the central bank in the large economy announces asset purchases and commits to keeping the short-term interest rates constant for one year.[14]

We now turn to analyze the outcomes of such defined four variants of the QE scenario for selected variables in both economies. Long and short-term bonds are imperfect substitutes, thus quantitative easing is not neutral for other macrovariables. In the baseline scenario, it drives down the term premium in the large economy by 30 bps on impact, stays below this level for about 6 years, and then gradually rises, coming back close to its steady state value several years before the asset purchase program is withdrawn. As a direct outcome of our calibration strategy explained in section 3, the magnitude of this response is consistent with that obtained by Chen et al. (2012) in a closed economy setup if one takes into account the differences in the size of the impulse, and within the bounds implied by the empirical literature they summarize. If we assume that agents do not fully realize the ultimate scale of QE, the reaction of the term premium is more gradual and delayed, but its trough is about the same as in the perfect foresight scenarios. In line with the previous studies, quantitative easing stimulates real activity in the implementing country, but the expansion in its output is sizable only when the short-term rate is at the ZLB.

As far as the response of the small economy is concerned, a lower term premium in the large economy induces its investors to search for yield abroad. As a consequence, the share of

[13] More specifically, we assume that quantitative easing is initially announced for a period of only two years, after which it is expected to be gradually withdrawn at the same pace as it was introduced. Then, every next period the program is extended by one more quarter, with the last extension announced two years before the program starts being withdrawn.

[14] The last announcement takes place when withdrawal of quantitative easing begins, meaning that the policy rate ends up being fixed for nine years.

non-residents in the small economy's long-term bond market increases by 10-13 percentage points after around 8 years, depending on the simulation variant. Both the scale and timing of this process match the data very well, as can be seen by comparing our simulation outcomes to Figure 2. The inflow of foreign capital into local bond markets is accompanied by a drop in the domestic term premium by 35-45 bps at its trough around 5-6 years after the program started. In this way the program is expansionary as lower long-term interest rates stimulate domestic demand. Furthermore, improved demand in the large economy supports small economy's exports. At the same time, however, the massive inflow of foreign capital leads to the persistent appreciation of its real exchange rate, which deteriorates price competitiveness and leads to a fall in the trade balance.

Irrespective at which of our four simulation variants one looks, the contractionary effect of exchange rate adjustment is strong enough to prevail over the expansionary channels and, at least in the short run, the reaction in the small economy's output is negative. As regards the response of consumer prices, it is positive if the whole QE path is perfectly anticipated as the appreciation of bond prices on impact is then stronger, which translates into a stronger increase in spending by small economy's households. If instead agents do not realize the full extent of the planned QE and its each extension takes them by surprise, the increase in absorption is more gradual and inflation falls because of exchange rate appreciation.

As indicated above, the obtained negative reaction of output in the small economy results from the massive capital inflows accompanied by the loss of international competitiveness, so it is important to verify that our model does not overemphasize this channel. First, we note that the magnitude of the exchange rate reaction that we obtain in our simulations is broadly in line with the empirical studies of international QE spillovers, see e.g. Fratzscher et al. (2013). As an additional validation of the exchange rate reaction, we test our model predictions against the so-called taper tantrum episode in 2013.[15] We simulate a taper tantrum shock by engineering a reciprocal QE scenario in the large economy, calibrating its size to match the term premium increase in the United States around Bernanke's talks (about 110 bps). The resulting nominal exchange rate depreciation in our model (4.5% if we assume a 4-quarter ZLB period) is very similar to that observed for emerging market currencies over the same period (3.9% drop in the JP Morgan EM FX index). Second, we compare the total net capital inflow generated by our model (2.5-3% of small economy's GDP) with the evidence from Figure 3 and conclude that, if anything, we underestimate the magnitude of net capital inflows to emerging economies during the QE period.

At this point it is instructive to highlight again the role of asset market segmentation in generating our results. As explained in section 4, if we allowed for cross-border trade in

[15] In his speech in May 2013, Chairman Bernanke suggested that the Fed might start reducing the size of monthly bond purchases, whereas in June 2013 he pointed to a possible QE taper in 2013 and the end of the program in 2014. Following these declarations, long-term interest rates and term premia grew worldwide, while the currencies of emerging market economies depreciated.

short-term bonds, the forces leading to equalization of the term premia in both economies would be even stronger, and hence we would still see a massive inflow of foreign capital into the small economy's long-term bond markets. However, this inflow would be nearly perfectly offset by the outflow of short-term bonds. As a result, the exchange rate adjustment would be very small and the reaction of output in the small economy would turn positive.[16]

6 Conventional versus unconventional monetary policy spillovers

Given the large literature on the effects of short-term interest rate changes in large economies, and most notably in the US, on smaller countries, a natural next step is to use our model to compare the effects of quantitative easing to a conventional monetary policy accommodation. Figure 6 plots the dynamic responses to an expansionary monetary policy shock, defined as a negative innovation to the monetary policy feedback rule given by equation (12), but written for the large economy, and compares them to the effects of quantitative easing. The latter is defined as a positive innovation to the rule describing composition of public debt in the large economy and given by equation (15), where the size of this innovation is chosen such that, assuming that the policy rate is kept constant for one year, the peak response of output in the large economy is the same as following conventional policy easing. In both cases the small economy follows a standard Taylor-like rule given by equation (12).

As regards standard monetary policy, the results are consistent with what is well documented in the literature, also in the context of spillovers on economic activity in emerging markets, see references in the introduction. Conventional monetary accommodation in the large economy boosts aggregate demand in this country, which leads to an increase in its output and demand for other countries' exports. As in the case of quantitative easing, appreciation of the exchange rate deteriorates the price competitiveness of the small economy. This time, however, even though the reaction of output in the large economy is the same by construction, the adjustment in the exchange rate is about three times weaker, and hence the net effect on the small economy's trade balance and GDP is positive. It is worth stressing that this positive spillover on output occurs despite lack thereof on absorption. The latter actually falls because imported inflation leads to some tightening of monetary policy. All in all, for the same scale for conventional and unconventional monetary accommodation in the

[16]This is the key reason making our results different from Alpanda and Kabaca (2017) whose model, in a similarly defined QE scenario in the US, predicts a massive increase in short-term US bond holdings by the rest of the world. As we showed in Figure 3, this did not happen to the group of small open economies that we focus on in this paper. However, it has to be noted that the perspective taken by this paper and ours is somewhat different. In Alpanda and Kabaca (2017) only the US engages in QE, and they focus on spillovers to the rest of the world, which is defined to include the remaining two economies from our BIG3 (euro area and UK), or countries whose exchange rate cannot be considered freely floating (e.g. China).

large economy, the former leads to an increase in GDP abroad, while the latter to its drop.

This result is important as the effects of asset purchase programs are sometimes presented in the empirical literature as equivalence of short-term interest rate cuts. For example, Gambacorta et al. (2014) use a back of the envelope calculation to express the impact of doubling of the central bank balance sheets on output as equivalent to a decrease in the policy rate by 300 bps. Our simulations suggest that an analogous way of thinking about international monetary policy spillovers is not valid, unless the recipient countries respond to QE abroad with similarly unconventional measures.

The key to understand this difference is the presence of arbitrage in international trade in long-term bonds and associated capital flows. It is convenient to reorganize the UIP condition for long-term bond holdings (29)

$$\mathbb{E}_t\left\{\hat{P}_{L,t+1}-\hat{P}_{L,t}+\hat{R}_{L,t+1}-\Delta\hat{S}_{t+1}\right\}=\mathbb{E}_t\left\{\hat{P}^*_{L,t+1}-\hat{P}^*_{L,t}+\hat{R}^*_{L,t+1}\right\} \tag{31}$$

so that, taking the perspective of a foreign investor, the left-hand side is the ex-ante one-period nominal return on home long-term bonds, while the right-hand side describes its counterpart for foreign bonds. The former is the sum of return on home bonds expressed in domestic currency and expected nominal exchange rate appreciation. This equation implies that any change in foreign long-term bond prices leads to equilibrium adjustments in home long-term bond prices and/or the nominal exchange rate. Which combination of the two actually materializes can be influenced by the reaction of the small economy's monetary authority.

Both standard and unconventional monetary expansion in the large economy lower the return on foreign long-term bonds. However, as Figure 6 shows, long-term rates in the large economy decline much more following QE compared to conventional monetary policy easing. In the former case, the short-term rate in the small economy does decrease, thus lowering domestic long-term rates. However, the scale of monetary policy accommodation produced by a standard Taylor rule like in equation (12) is not sufficient to equalize returns on foreign and domestic bonds. Therefore, a large change in foreign long-term bond prices generated by QE leads to a large exchange rate adjustment and a contemporaneous decrease in the home term premium that lowers the long-term interest rate. Both developments are a mirror reflection of a massive capital inflow to the small economy's bond markets as foreign agents search for yield abroad.

Since the differences between spillovers of conventional monetary policy and QE hinge on the size of capital flows and exchange rate appreciation, we investigate whether this result holds under alternative economic policies in the small economy that are targeted to counteract at least one of them. So far we have assumed that the monetary authority in the small economy was following a standard Taylor-like rule. In response to a QE shock considered above, it generated a drop in the short-term interest rate in the small country by about 30 bps annually, see Figure 6, and despite that its output contracted. Given the discussion above, let us now assume that the short-term interest rate in the small economy also directly responds to exchange rate movements as follows

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_r} \left[\left(\frac{\pi_t}{\pi}\right)^{\gamma_\pi} \left(\frac{y_t}{y}\right)^{\gamma_y} \left(\frac{S_t}{S_{t-1}}\right)^{\gamma_s}\right]^{1-\gamma_r} \exp\{\varepsilon_t^r\} \tag{32}$$

where $\gamma_s > 0$.

The dashed line in Figure 7 plots the extreme case of such a policy, in which γ_s is large enough to virtually prevent any nominal exchange rate adjustment after QE abroad. It illustrates that, to some extent, this policy succeeds in that it substantially moderates the trough in output contraction, and even generates a very short-lived boom. However, the fall in the short-term rate that is needed to achieve this outcome is very large and hence this policy is a viable option only for those central banks which are sufficiently far from the effective lower bound on the nominal interest rates. Importantly, the inflow of capital to the small economy is not much different from the baseline case. This is because the required fall in the short-term rates increases spending by households in the small economy, which boosts the demand for imports, and hence the moderation in output contraction is not achieved by a reduction in external imbalances, but mainly by a stronger increase in absorption, the side effect of which is higher inflation.

The limited ability of conventional monetary policy that uses the short-term rate as an instrument to affect capital inflows is not very surprising, given that it does not affect much the term premium. One can expect that policies directly affecting the relative supply of tradable long-term versus nontradable short-term assets, and hence the term premia, should be more effective. We consider two types of such interventions that could be possibly used by the small economy.

The first one simply replicates quantitative easing implemented abroad, i.e. the central bank in the small economy buys home long-term sovereign bonds in exchange for home short-term securities, reducing the share of the former in the private sector portfolio in a way that perfectly tracks the change in composition of foreign bonds. The second policy is a currency intervention, implemented as a purchase of foreign long-term bonds by the small economy's central bank in quantity that ensures constant nominal exchange rate. To differentiate this policy from quantitative easing, we assume that this purchase is financed with issuance of both short-term and long-term bonds denominated in the home currency, keeping their proportion fixed at its steady-state level. As in the case of quantitative easing in the large economy, both interventions are conducted in a way that keeps the real value of consolidated public sector net liabilities constant, so that the considered policies only affect their structure but not the total amount.

The outcomes are depicted as two additional lines in Figure 7. Both policies are effective at preventing the inflow of capital to the small economy as both reduce the term premium in the small economy so that the equalization of the rates of return on domestic and foreign long-term bonds is achieved without sharp exchange rate appreciation. The model mechanism that leads to this outcome boils down to purchasing tradable long-term assets from the market and selling short-term ones to home private agents (unrestricted households), thus depressing the term premium in this country.[17] The two non-standard interventions also manage to turn the negative output spillover into a positive one, and this is despite we allow for endogenous tightening of conventional policy, which cools down a boom in absorption. Importantly, the magnitude of asset purchases by the small economy's central bank needed to achieve these outcomes is not unreasonable. In the case of quantitative easing, this is guaranteed by construction as, compared to QE abroad, the intervention by the small economy is automatically scaled down by the country size and depth of its bond market. While the currency intervention looks fairly large, peaking at about 23 percent of the small economy's GDP, this magnitude does not stand out given the past experience of small open economies that engaged in this type of actions.[18]

Summing up, our analysis shows that international spillovers associated with conventional and unconventional monetary policy are qualitatively different, and hence require different reactions in the recipient countries that want to mitigate their effects. While a decrease in the foreign short-term interest rate is expansionary for the economies that follow a standard monetary policy rule, the consequences of quantitative easing implemented abroad for output are negative unless counteracted with unconventional measures.

7 Robustness checks

In this section we show that our assessment of international spillovers of unconventional monetary is robust to a number of modeling choices and assumptions underlying our simulations.

In our benchmark model agents' financial decisions do not affect the economies' productive capacity. We now modify the setup by including physical capital as the second production factor and allowing for its endogenous accumulation.[19] The outcomes are presented as dashed lines in Figure 8. We find that allowing for capital accumulation reduces the impact

[17] The currency intervention even reverses the direction of international capital flows, suggesting that the central bank could allow for some nominal appreciation of the local currency before starting intervening if the goal is only to dampen the inflow.

[18] After the QE introduction by the BIG3, exchange rate interventions of the Czech and Swiss central banks have heavily contributed to an expansion in their their balance sheets, increasing them from about 20% of GDP before the crisis to respectively around 60% and 120% in 2018. This expansion accelerated to about 20 percentage points in each case when one of these central banks announced a currency ceiling.

[19] We implement this extension as in Chen et al. (2012). Full details of the extended model are available upon request.

of quantitative easing on the term premia (and thus on bond prices) in both economies as investment in non-financial assets offers to the agents an additional way of transferring their wealth intertemporally. Since this type of investment is assumed to affect the productive capacity, its expansion affects positively output in both countries. As a result, GDP of the small economy eventually rises above the level observed before quantitative easing abroad started, but only after about four years.[20]

Another possible concern is related to fiscal policy. Asset market segmentation breaks the Ricardian equivalence and hence assuming constant total public debt is not innocuous. We now replace this assumption with a tax rule borrowed from Chen et al. (2012)

$$T_t^* = G_t^* + P_t^* \Phi^* \left(\frac{P_{L,t-1}^* B_{H,L,t-1}^{g*}}{P_L^* B_{H,L}^{g*}} \right)^{\gamma_T^*} \tag{33}$$

where $\gamma_T^* > 0$ and Φ^* is a normalizing constant ensuring that this equation holds in the steady state. Dotted lines in Figure 8 plot our QE scenario with γ_T^* set to 1.3 as estimated by Chen et al. (2012). Since quantitative easing reduces the supply of long-term bonds in the large economy, this rule leads to a decrease in taxes levied on its households during this period, and hence an expansion in total debt. For a given path of the composition of public debt as assumed in our scenario, this means a lower reduction in the supply of long-term bonds. As a result, the effect on bond prices in the foreign economy is attenuated, and so are the international spillovers. However, the difference relative to the baseline scenario is not large, and it disappears almost completely if we do the comparison for the same absolute supply of long-term bonds rather than for their share in total public debt.[21]

We next check to what extent our results depend on some assumptions regarding the values of calibrated parameters. In a model like ours, two crucial parameters that govern the response of the term premium and its transmission to other macroeconomic variables are the share of restricted households and transaction cost curvature. Recall that our calibration strategy for this block of parameters was to treat both countries symmetrically, set the share of restricted households to some reasonable value, and calibrate the transaction costs such that we obtain the response of the term premium in the large economy that is consistent with the earlier studies. If we stick to this strategy, then our results are robust to moderate changes in the degree of market segmentation. In particular, resetting the share of restricted households to 0.05, i.e. the posterior median in Chen et al. (2012), and appropriate rescaling of the transaction costs leaves our main results broadly unchanged.

A more interesting case is what happens under asymmetric segmentation. It might be

[20]One can conjecture that the mitigating effect of the presence of non-financial investment on the drop in the small economy's output following QE abroad would be weaker if we allowed some of it to be not directly related to the productive capacity, e.g. residential investment or purchase of other durables.

[21]This finding is consistent with Duszak (2018), who reports very small quantitative deviations from the Ricardian equivalence in this class of models.

argued that in emerging economies the degree of bond market segmentation is larger than in developed countries, so as an alternative we consider a higher value of ω_r equal to 0.2. On the other hand, it might be also interesting to see what happens if there is no segmentation in the small economy, so we also consider the case of ω_r approaching zero. The outcomes of these two robustness checks are plotted in Figure 9. With higher bond market segmentation in the small economy, quantitative easing abroad generates a stronger inflow of capital to local bond markets. The consumption boom is bigger, but the exchange rate appreciates more sharply and the fall in output is even deeper than under our baseline parametrization. At the same time, the comovement of the term premia in both economies is still very high. Under no segmentation in the small economy, the reactions are weaker, but they do not disappear completely. This is because international trade and financial linkages tie the small open economy to developments abroad, while cross-border trade in long-term bonds still leads to high synchronization in the term premia, affecting intertemporal decisions of home unconstrained agents.

One of our paper's key messages are the negative spillovers of quantitative easing on other economies' output. One might be concerned that this finding crucially depends on the parametrization of the trade block in our model. In particular, one of the key parameter could be the price elasticity of demand for imports ν. Some papers suggest that a lower value of this parameter helps achieve a better fit to the international business cycle, see Bodenstein (2010) for a review. Therefore, we check how our results change if we assume a Cobb-Douglas form of the final goods basket by picking $\nu = \nu^* \approx 1$. We also examine the sensitivity of our main findings to the degree of exchange rate pass-through, and hence the strength of the expenditure switching channel, by considering higher values of Calvo stickiness whenever firms in both countries supply foreign markets, i.e. $\theta_H^* = \theta_F = 0.9$, which is well above the estimates typically reported in the DSGE literature. As can be seen from Figure 10, none of our qualitative results hinge on the parametrization of the trade block. As regards the magnitude of the responses, non-negligible differences relative to our baseline scenario concern only the case of low elasticity of substitution between home goods and imports as it implies a lower inflow of capital and weaker response of the term premium in the small economy, but a stronger appreciation of its exchange rate.

Finally, even though our model defines asset holdings in gross terms and bonds issued in both economies are denominated in different currencies, in our discussion we have omitted the role of wealth effects associated with exchange rate movements due to currency mismatches. The reason is that, since our calibration implies only a small share of foreign bonds in total bonds held by households in the small economy (5%), these wealth effects are not quantitatively important. This low share is quite typical for the group of small open economies, but there are some exceptions. Most notably, the ratio of foreign debt securities to GDP in Israel at the beginning of the QE period was about ten times higher than in

Poland according to the IMF data. Therefore, as our last robustness check we reparametrize our model to account for this case, and plot the outcomes as the last line in Figure 10. If households hold more long-term assets denominated in foreign currency, exchange rate appreciation hurts their balance sheets. However, this negative effect is roughly compensated by a positive one associated with a larger increase in foreign bond prices relative to domestic ones.

Overall, we can conclude that our main findings are robust to the alternative assumptions considered in this section.

8 Conclusions

We have developed a two-country DSGE model with segmented asset markets and used it to quantitatively analyze international spillovers of large scale asset purchase programs pursued in some large economies in the aftermath of the Great Recession. We showed that this framework can replicate key empirical facts observed in small economies pursuing independent monetary policy during the period of quantitative easing abroad. First, it accurately mimics the inflow of foreign capital to small economies' sovereign bond markets. Second, it accounts for the very strong cross-country comovement of the term premia during the period of quantitative easing, but not necessarily during normal times. Third, it is able to produce a downward shift in the slope of exchange rate projections on the interest rate differential during the period of QE as identified by the Fama regressions.

Notwithstanding the positive effects of QE implemented by the major central banks on asset prices worldwide, such programs tend to strongly undermine international price competitiveness of other economies that do not respond by taking similar unconventional measures. As a result, even though domestic demand in a typical small open economy improves, the net impact on its GDP is likely to be negative, at least in the short run. This is in contrast to the effects of conventional monetary easing abroad, which positively affects other economies' output. The reason for this difference are massive capital inflows and currency appreciation following QE abroad.

Two caveats to our results should be born in mind, however. Firstly, quantitative easing spillovers do not need to be uniform across countries since they may be dependent on factors that are hard to include in our framework, such as institutions. As pointed out by Fratzscher et al. (2013), strong domestic institutions in small countries affect risk pricing and may insulate these economies from QE spillovers. Secondly, we abstract from non-productive investment and macroeconomic imbalances (credit booms, asset bubbles) that might emerge in a small economy experiencing a substantial inflow of capital. Their presence could enhance the response of GDP in the short run at the cost of a downturn in the medium term. We leave this issue for future research.

References

Adrian, Tobias, Richard K. Crump, and Emanuel Moench (2013) 'Pricing the term structure with linear regressions.' *Journal of Financial Economics* 110(1), 110–138

Ahmed, Shaghil, and Andrei Zlate (2014) 'Capital flows to emerging market economies: A brave new world?' *Journal of International Money and Finance* 48(PB), 221–248

Alpanda, Sami, and Serdar Kabaca (2017) 'International Spillovers of Large-Scale Asset Purchases.' Working Paper, Bank of Canada, July

Andres, Javier, J. David Lopez-Salido, and Edward Nelson (2004) 'Tobin's imperfect asset substitution in optimizing general equilibrium.' *Journal of Money, Credit and Banking* 36(4), 665–90

Banerjee, Ryan, Michael B. Devereux, and Giovanni Lombardo (2016) 'Self-oriented monetary policy, global financial markets and excess volatility of international capital flows.' *Journal of International Money and Finance* 68(C), 275–297

Bartocci, Anna, Lorenzo Burlon, Alessandro Notarpietro, and Massimiliano Pisani (2017) 'Macroeconomic effects of non-standard monetary policy measures in the euro area: the role of corporate bond purchases.' Temi di discussione (Economic working papers) 1136, Bank of Italy, Economic Research and International Relations Area, September

Baumeister, Christiane, and Luca Benati (2013) 'Unconventional Monetary Policy and the Great Recession: Estimating the Macroeconomic Effects of a Spread Compression at the Zero Lower Bound.' *International Journal of Central Banking* 9(2), 165–212

Bhattarai, Saroj, Arpita Chatterjee, and Woong Yong Park (2015) 'Effects of US quantitative easing on emerging market economies.' Globalization and Monetary Policy Institute Working Paper 255, Federal Reserve Bank of Dallas, November

Blanchard, Olivier (2016) 'Currency Wars, Coordination, and Capital Controls.' NBER Working Papers 22388, National Bureau of Economic Research, Inc, July

Bluwstein, Kristina, and Fabio Canova (2016) 'Beggar-Thy-Neighbor? The International Effects of ECB Unconventional Monetary Policy Measures.' *International Journal of Central Banking* 12(3), 69–120

Bodenstein, Martin (2010) 'Trade elasticity of substitution and equilibrium dynamics.' *Journal of Economic Theory* 145(3), 1033–1059

Caballero, Ricardo J., Emmanuel Farhi, and Pierre-Olivier Gourinchas (2015) 'Global Imbalances and Currency Wars at the ZLB.' NBER Working Papers 21670, National Bureau of Economic Research, Inc, October

Carlstrom, Charles T., Timothy S. Fuerst, and Matthias Paustian (2015) 'Inflation and output in New Keynesian models with a transient interest rate peg.' *Journal of Monetary Economics* 76(C), 230–243

Chen, Han, Vasco Curdia, and Andrea Ferrero (2012) 'The Macroeconomic Effects of Large-scale Asset Purchase Programmes.' *Economic Journal* 122(564), F289–F315

Cook, David, and Michael B Devereux (2016) 'Exchange rate flexibility under the zero lower bound.' *Journal of International Economics* 101(C), 52–69

D'Amico, Stefania, William English, David Lopez-Salido, and Edward Nelson (2012) 'The Federal Reserve's Large-scale Asset Purchase Programmes: Rationale and Effects.' *Economic Journal* 122(564), F415–F446

Dedola, Luca, Giulia Rivolta, and Livio Stracca (2017) 'If the Fed sneezes, who catches a cold?' *Journal of International Economics* 108(S1), 23–41

Duszak, Anna (2018) 'Does the Way of Financing Quantitative Easing Programmes Matter?' *Central European Journal of Economic Modelling and Econometrics* 10(2), 101–131

Eggertsson, Gauti B., Neil R. Mehrotra, Sanjay R. Singh, and Lawrence H. Summers (2016) 'A Contagious Malady? Open Economy Dimensions of Secular Stagnation.' *IMF Economic Review* 64(4), 581–634

Erceg, Christopher, and Jesper Linde (2014) 'Is There A Fiscal Free Lunch In A Liquidity Trap?' *Journal of the European Economic Association* 12(1), 73–107

Falagiarda, Matteo, Peter McQuade, and Marcel Tirpak (2015) 'Spillovers from the ECB's non-standard monetary policies on non-euro area EU countries: evidence from an event-study analysis.' Working Paper Series 1869, European Central Bank, November

Fama, Eugene F. (1984) 'Forward and spot exchange rates.' *Journal of Monetary Economics* 14(3), 319–338

Fratzscher, Marcel, Marco Lo Duca, and Roland Straub (2013) 'On the international spillovers of US quantitative easing.' Working Paper Series 1557, European Central Bank, June

Gagnon, Joseph, Matthew Raskin, Julie Remache, and Brian Sack (2011) 'The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases.' *International Journal of Central Banking* 7(1), 3–43

Gambacorta, Leonardo, Boris Hofmann, and Gert Peersman (2014) 'The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis.' *Journal of Money, Credit and Banking* 46(4), 615–642

Haberis, Alex, and Anna Lipinska (2012) 'International policy spillovers at the zero lower bound.' Bank of England working papers 464, Bank of England, October

Iacoviello, Matteo, and Gaston Navarro (2018) ' Foreign effects of higher U.S. interest rates.' *Journal of International Money and Finance*

Jabłecki, Juliusz, Andrzej Raczko, and Grzegorz Wesołowski (2016) 'Negative bond term premia - a new challenge for Polish conventional monetary policy.' In *Inflation mechanisms, expectations and monetary policy,* ed. Bank for International Settlements, vol. 89 of *BIS Papers chapters* (Bank for International Settlements) pp. 303–315

Joyce, Michael A. S., Ana Lasaosa, Ibrahim Stevens, and Matthew Tong (2011) 'The Financial Market Impact of Quantitative Easing in the United Kingdom.' *International Journal of Central Banking* 7(3), 113–161

Kiley, Michael T. (2014) 'The Aggregate Demand Effects of Short- and Long-Term Interest Rates.' *International Journal of Central Banking* 10(4), 69–104

Kolasa, Marcin (2009) 'Structural heterogeneity or asymmetric shocks? Poland and the euro area through the lens of a two-country DSGE model.' *Economic Modelling* 26(6), 1245–1269

Lim, Jamus Jerome, and Sanket Mohapatra (2016) 'Quantitative easing and the post-crisis surge in financial flows to developing countries.' *Journal of International Money and Finance* 68(C), 331–357

Mackowiak, Bartosz (2007) 'External shocks, U.S. monetary policy and macroeconomic fluctuations in emerging markets.' *Journal of Monetary Economics* 54(8), 2512–2520

MoF (2015) 'Public Debt in Poland.' Annual Report, Polish Ministry of Finance

Neely, Christopher J. (2015) 'Unconventional monetary policy had large international effects.' *Journal of Banking & Finance* 52(C), 101–111

Passari, Evgenia, and Helene Rey (2015) 'Financial Flows and the International Monetary System.' *Economic Journal* 584, 675–698

Rajan, Raghuram G. (2016) ‘Towards Rules of the Monetary Game.’ Working Papers id:10373, eSocialSciences, March

Rey, Helene (2013) ‘Dilemma not trilemma: the global cycle and monetary policy independence.’ *Proceedings - Economic Policy Symposium - Jackson Hole* pp. 1–2

Tillmann, Peter (2016) ‘Unconventional monetary policy and the spillovers to emerging markets.’ *Journal of International Money and Finance* 66(C), 136–156

Wesołowski, Grzegorz (2018) ‘Do long-term interest rates drive gdp and inflation in small open economies? evidence from poland.’ *Applied Economics* 50(57), 6174–6192

Woodford, Michael (2001) ‘Fiscal Requirements for Price Stability.’ *Journal of Money, Credit and Banking* 33(3), 669–728

Tables and figures

Table 1: Fama regressions

	All countries	Emerging markets	Advanced economies
IR	-0.035	0.165	-0.861
	(0.418)	(0.418)	(0.466)
$IR * QE$	-1.468	-2.080	-1.086
	(0.422)	(0.524)	(0.424)

Note: The reported coefficients come from a panel regression with fixed effects - a specification favored by a robust version of the Hausman test. The dependent variable is the monthly change in the exchange rate vis-a-vis the US dollar. IR is the lagged interest rate differential while QE indicates a QE dummy (zero until the end of 2008 and one afterwards). The additional regressors are QE dummy and VIX. Robust and clustered standard errors in parenthesis. The estimation sample covers the period from February 2000 to August 2018 and currencies of 17 economies: Australia, Canada, Czechia, Hungary, Indonesia, Israel, South Korea, Mexico, Norway, New Zealand, Philippines, Poland, Romania, Russia, South Africa, Sweden and Switzerland.

Table 2: Asset market segmentation in the model

	Short-term		Long-term	
	Home	Foreign	Home	Foreign
Home unrestricted	$+$		$\oplus$	$\oplus$
Foreign unrestricted		$+$	$\oplus$	$\oplus$
Home restricted			$+$	
Foreign restricted			$+$	$+$

Note: A plus means that an agent has access to a given asset and a circle around it indicates that trading in this asset is subject to transaction costs.

Table 3: Calibrated parameters

Parameter	Value
Size of the small economy; ω	0.014
Share of restricted households; ω_r, ω_r^*	0.1
Inv. elasticity of intertemporal substitution; σ, σ^*	2
Inv. Frisch elasticity of labor supply; φ, φ^*	2
Discount factor, unrestricted households; β^u, β^{u*}	0.992
Discount factor, restricted households; β^r, β^{r*}	0.995
Coupon; κ, κ^*	0.929, 0.979
Transaction cost on long-term bonds (unrestricted households); ξ_H, ξ_F	0.015
Portfolio adjustment cost (large economy's restricted households); ξ_r^*	10^{-5}
Calvo probability for domestic production; θ_H, θ_F^*	0.8
Calvo probability for exports; θ_H^*, θ_F	0.6
Price markup; μ, μ^*	1.15
Elasticity of substitution btw. home and imported goods; ν, ν^*	3
Home-bias; η	0.75
Steady-state inflation; π, π^*	1.005
Interest rate smoothing; γ_r, γ_r^*	0.9
Interest rate response to inflation; γ_π, γ_π^*	2
Interest rate response to output gap; γ_y, γ_y^*	0.125
Smoothing parameter in debt composition;γ_L^*	0.99

Table 4: Targeted steady state ratios

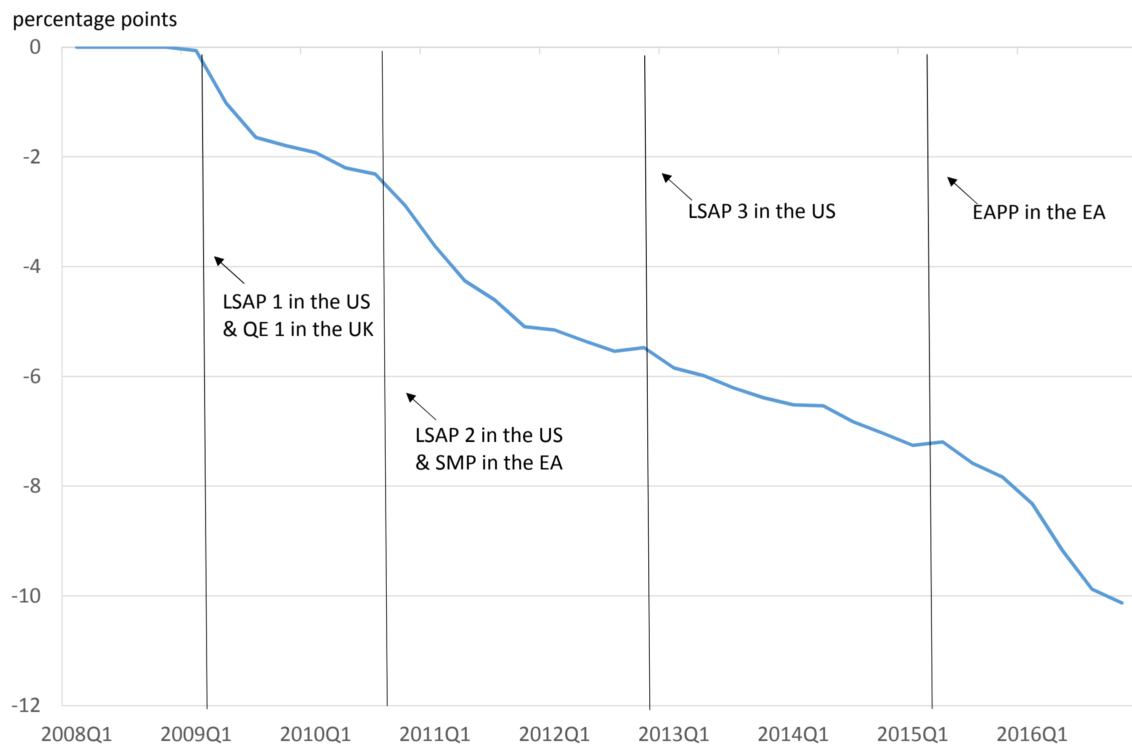
Steady state ratio	Value
Share of government spending in GDP; $\frac{g}{y}$, $\frac{g^*}{y^*}$	0.2
Share of government bonds in GDP; $\frac{b^g+P_L b^g_{H,L}}{y}$, $\frac{b^{g*}+P^*_L b^{g*}_{H,L}}{y^*}$	1.25, 2.65
Share of long-term bonds in total bonds; $\frac{P_L b^g_{H,L}}{b^g+P_L b^g_{H,L}}$, $\frac{P^*_L b^{g*}_{H,L}}{b^{g*}+P^*_L b^{g*}_{H,L}}$	0.71, 0.65
Share of residents in small economy's long-term bonds; $\frac{P_L(\omega_r b^r_{H,L}+(1-\omega_r)b^u_{H,L})}{b^g_{H,L}}$	0.76
Share of foreign bonds in small country's portfolio; $\frac{(1-\omega_r)sP^*_L b^u_{F,L}}{\omega_r P_L b^r_{H,L}+(1-\omega_r)(sP^*_L b^u_{F,L}+P_L b^u_{H,L})}$	0.05

Table 5: Conditional moments implied by the model

Shock	Correlation btw. term premia	Fama regression slope
QE in large economy ε_t^{L*}	0.95	-0.56
Productivity; ε_t^{z}, ε_t^{z*}	-0.31	0.75
Time preference; ε_t^{d}, ε_t^{d*}	0.20	0.76
Government spending; ε_t^{g}, ε_t^{g*}	0.22	0.77
Monetary policy; ε_t^{r}, ε_t^{r*}	0.66	0.92

Note: The moments are calculated using the first-order approximation to the model equilibrium conditions. The inertia of productivity, time preference, government spending and risk premium shocks are all set to 0.9. QE and monetary shocks are assumed to be i.i.d.

Figure 1: QE impact on the share of long-term government bonds (excluding central bank holdings) in total public sector liabilities in the US, UK and EA

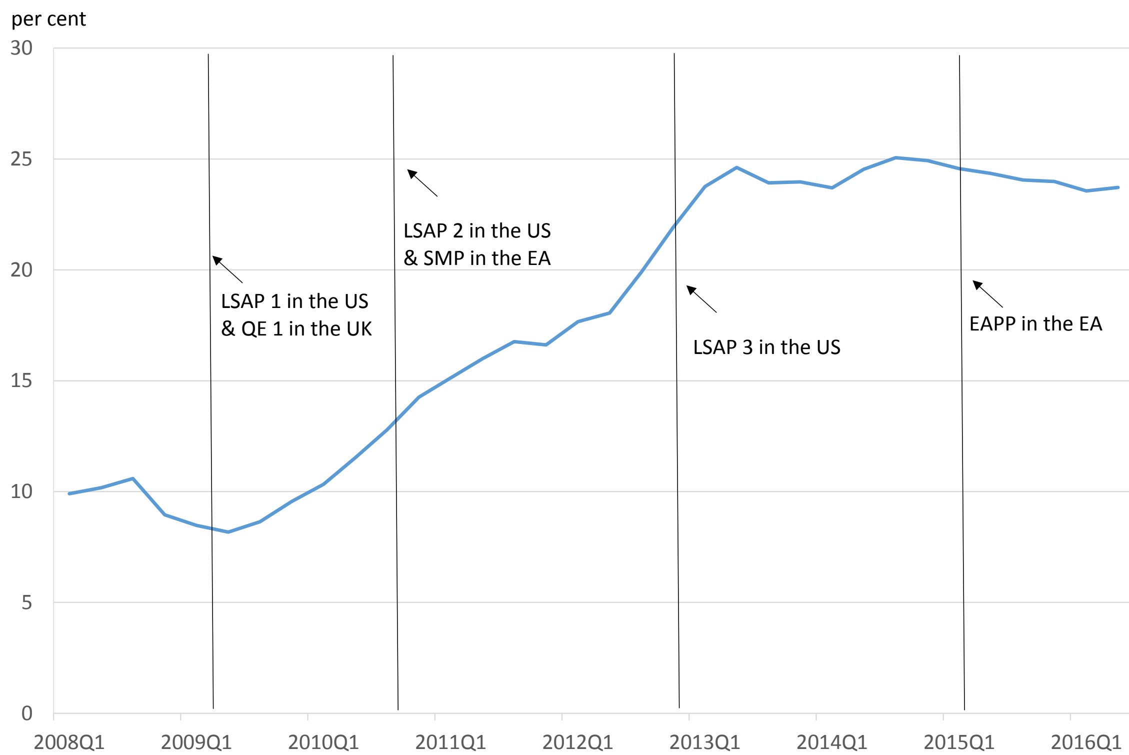


Note: The presented QE impact is calculated as the difference between (i) the share of long-term bonds in total public sector liabilities (that we call bonds in what follows) issued in the BIG3 countries (United States, United Kingdom and euro area), excluding central bank holdings, and (ii) the share of long-term bonds including central bank holdings in total bonds issued by the BIG3 governments. Central bank asset purchases reduce the outstanding amount of long-term bonds, but do not impact the total government debt - when a central bank buys long-term bonds, it creates new central bank reserves, replacing de facto long-term public liabilities with short-term ones. Short-term debt comprises short-term government bonds, as well as central bank short-term interest-bearing liabilities and cash in circulation. Both long and short-term bonds are calculated as a sum of outstanding bonds in the BIG3.

Source: World Bank, central bank web pages, authors' calculations.

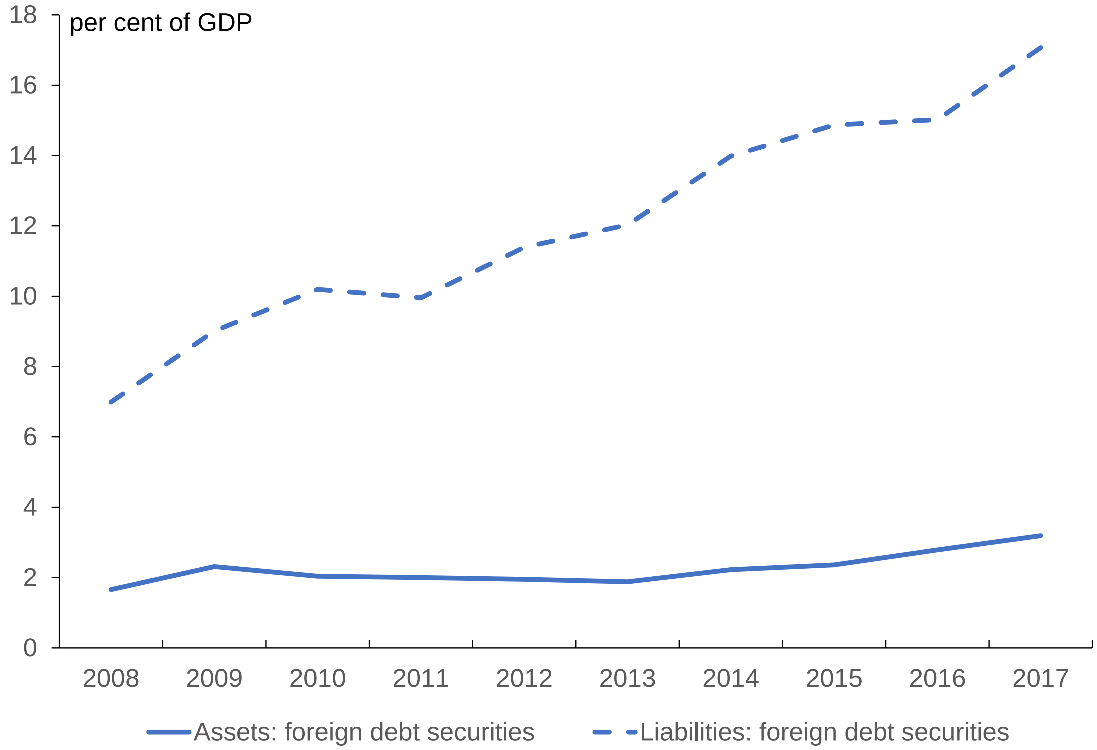
Memo: LSAP - Large-Scale Asset Purchases; SMP - Securities Markets Programme; EAPP - Expanded Asset Purchase Programme.

Figure 2: Share of foreign investors in sovereign bond markets of emerging economies



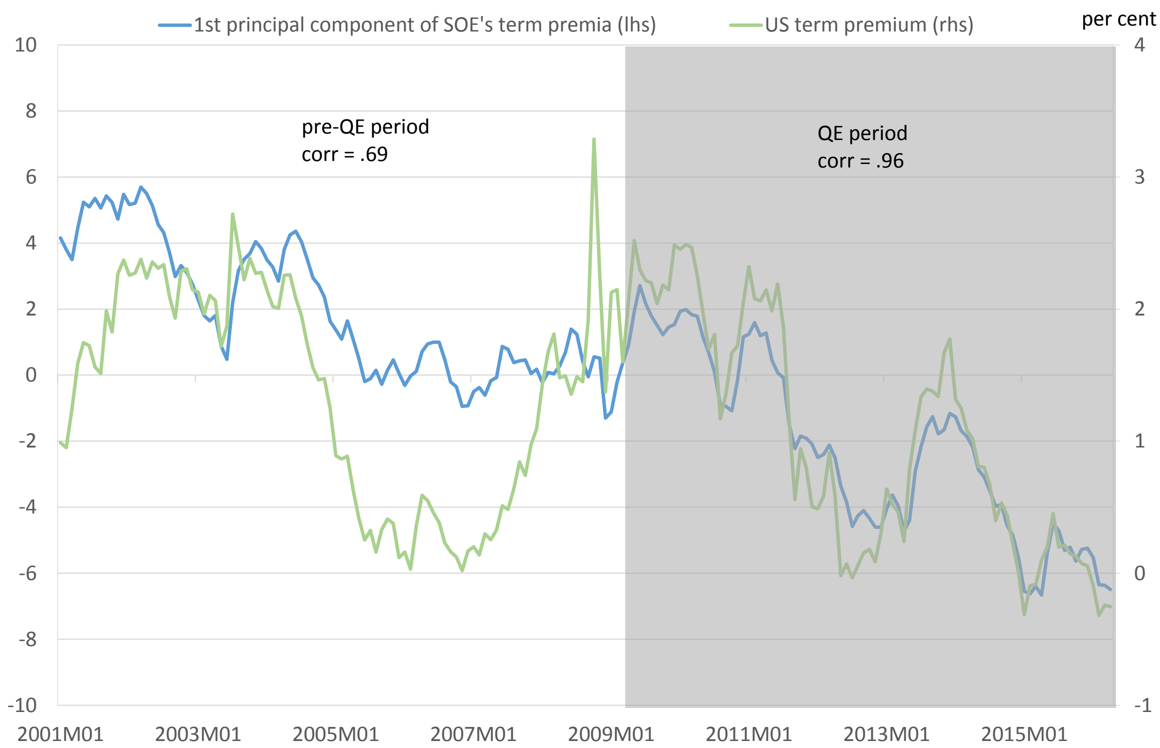
Note: This plot presents the share of bonds issued by the emerging economies' governments held by non-residents. The emerging economies included are: Brazil, Colombia, Czech Republic, Hungary, Indonesia, Israel, Malaysia, Mexico, Peru, Poland, Russia, South Africa, South Korea, Thailand, Turkey. Source: Credit Suisse. For exact definitions, calculation and data sources, see Credit Suisse monthly note ”Emerging Markets: Non-residents' holdings in local currency government bonds”.
Memo: LSAP - Large-Scale Asset Purchases; SMP - Securities Markets Programme; EAPP - Expanded Asset Purchase Programme.

Figure 3: Median financial position in debt securities of emerging economies



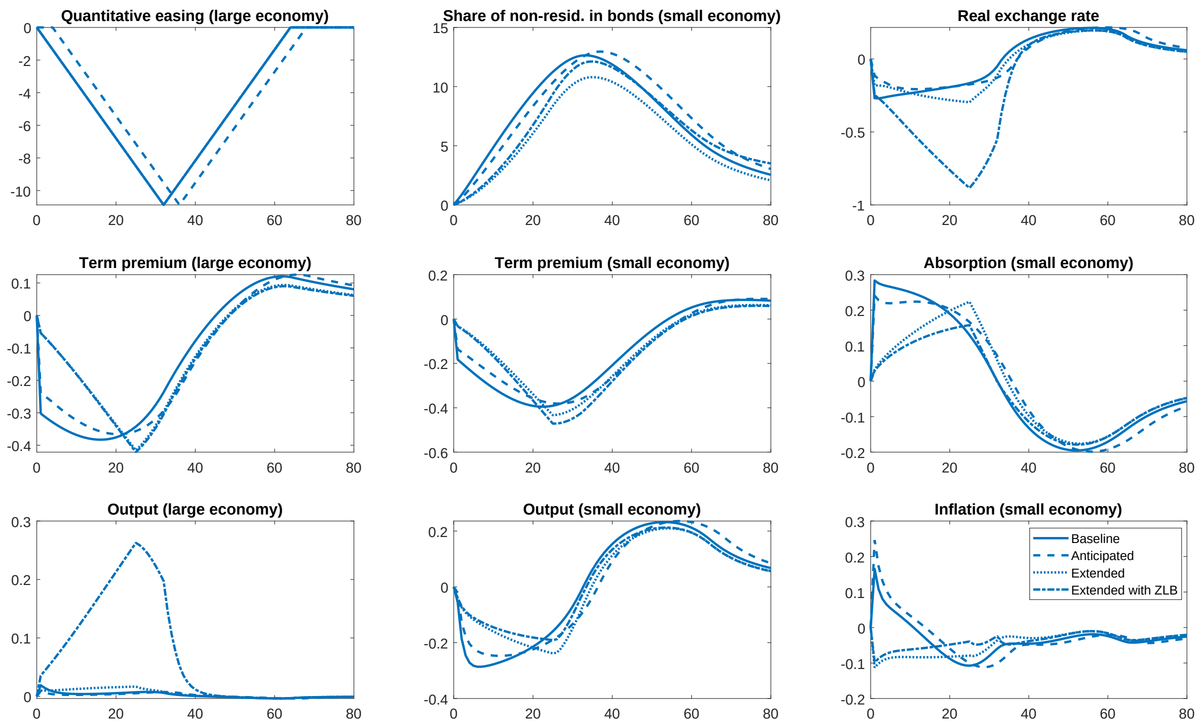
Note: This figure presents the asset and liability sides of the international investment position in foreign debt securities, both expressed relative to GDP, for the median economy of the same group of countries as in Figure 2. Source: International Monetary Fund statistics.

Figure 4: Term premium on 10-year bonds in the US and small open economies



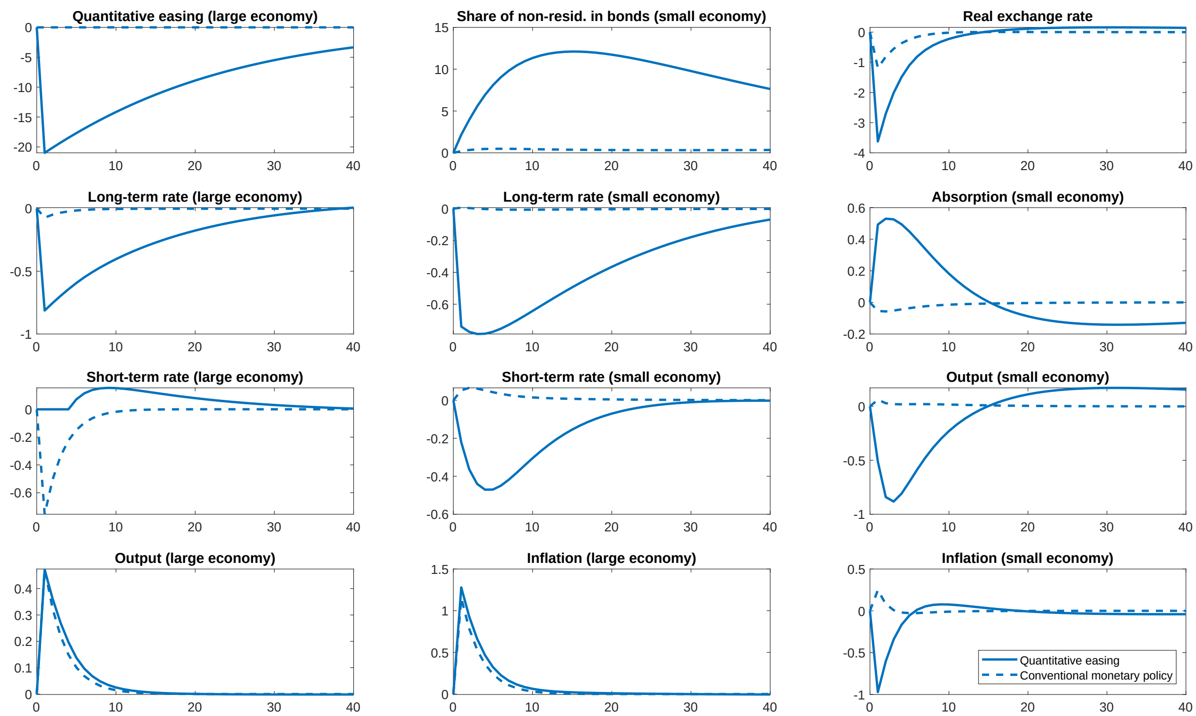
Note: This plot presents the 10-year term premium in the United States and the first principal component of 10-year term premia in small open economies (SOEs). SOEs comprise: Australia, Canada, Chile, Czech Republic, Hong Kong, Hungary, Indonesia, Israel, Japan, South Korea, Malaysia, New Zealand, Norway, Philippines, Poland, Singapore, South Africa, Sweden, Turkey. The term premia in SOEs were calculated based on the Adrian et al. (2013) model. Source: Bloomberg, New York Fed, authors' calculations.

Figure 5: Effects of quantitative easing in the large economy



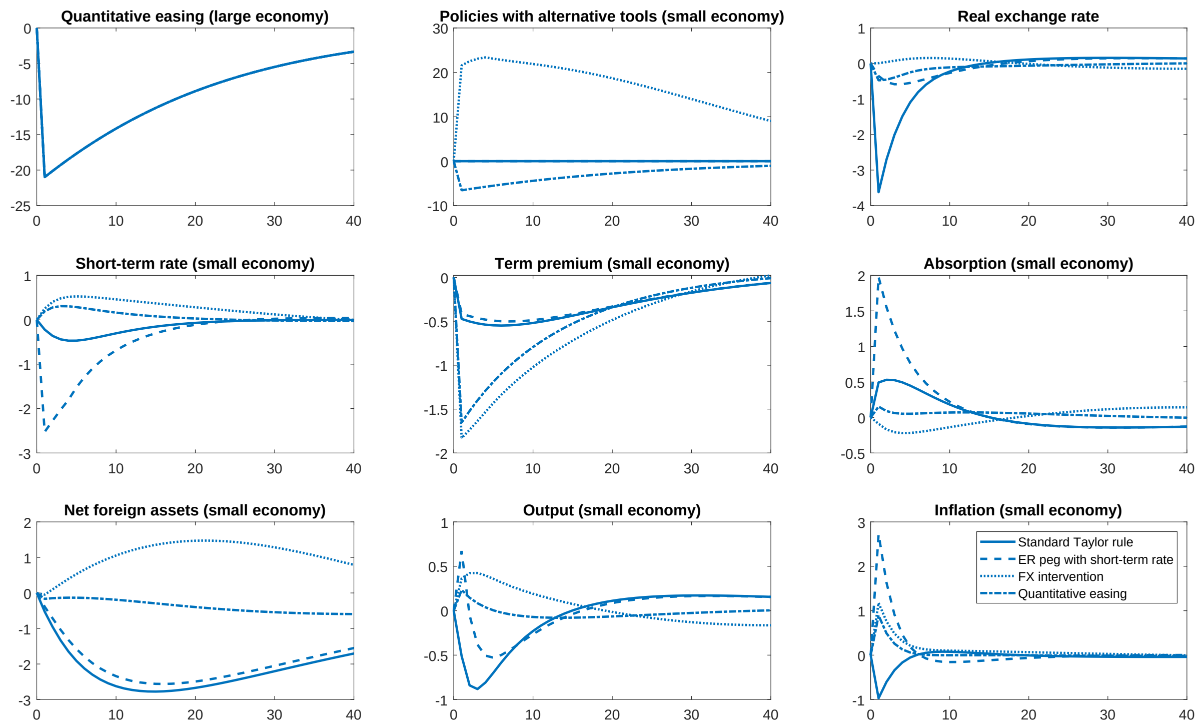
Note: This figure presents the effects of quantitative easing in the large economy, calibrated to mimic the evolution of the share of long-term bonds in total large economy's government debt as in Figure 1, and assuming that it will be withdrawn at the same pace as it was implemented. The first three variants consider the cases when: the whole QE program is announced at the moment of implementation (Baseline), announced one year before implementation (Anticipated) or announced for a period of two years and subsequently extended every quarter by another quarter (Extended). In all of them, the short-term nominal interest rates are allowed to respond endogenously in both countries. The last variant (Extended with ZLB) is the same as the third one, but additionally assumes that the short-term interest rate in the large economy is expected to stay constant for one year after every announcement. All responses are in percent deviations from the steady state. The responses of the term premium and inflation are annualized.

Figure 6: Conventional and unconventional monetary policy easing in the large economy



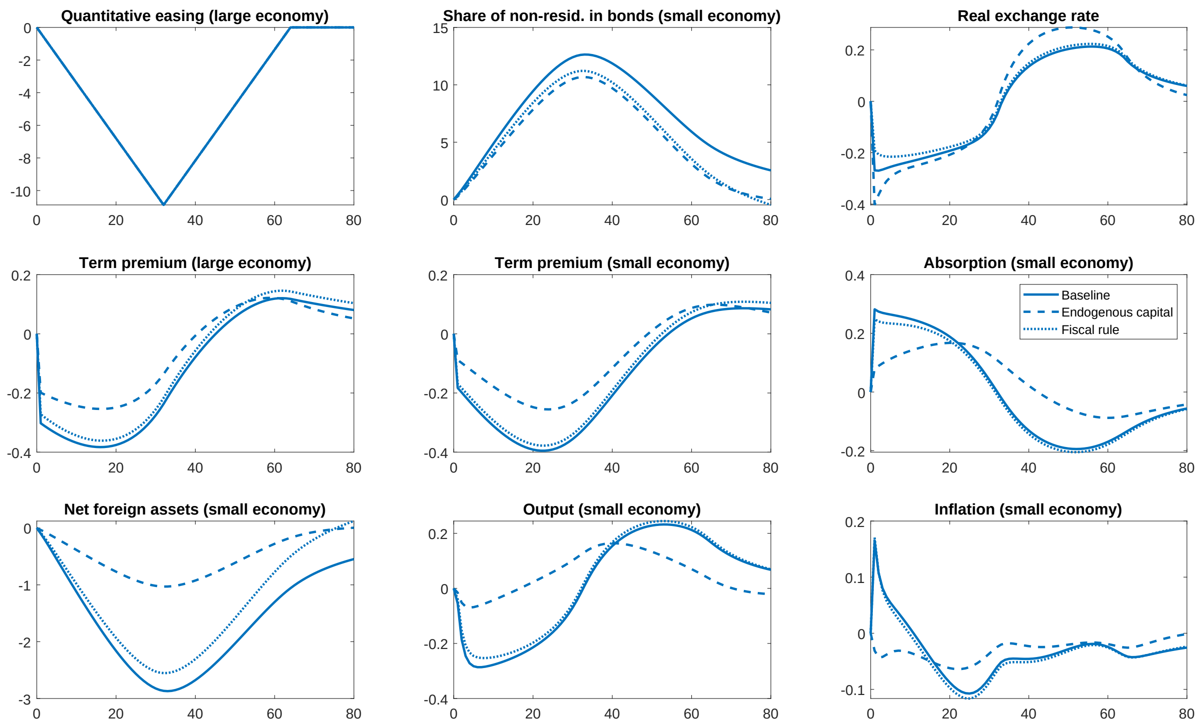
Note: This figure presents the effects of conventional and unconventional monetary policy in the large economy. The former is defined as a shock of 1 percentage point (annualized) to the monetary feedback rule. The latter is a shock to the composition of public debt, the magnitude of which is calibrated such that it generates the same peak reaction of output in the large economy, assuming that the short-term interest rate in this country is fixed for two years. All responses are in percent deviations from the steady state. The responses of the term premium, interest rates and inflation are annualized.

Figure 7: Monetary policy responses in the small economy to unconventional monetary policy shock in the large economy



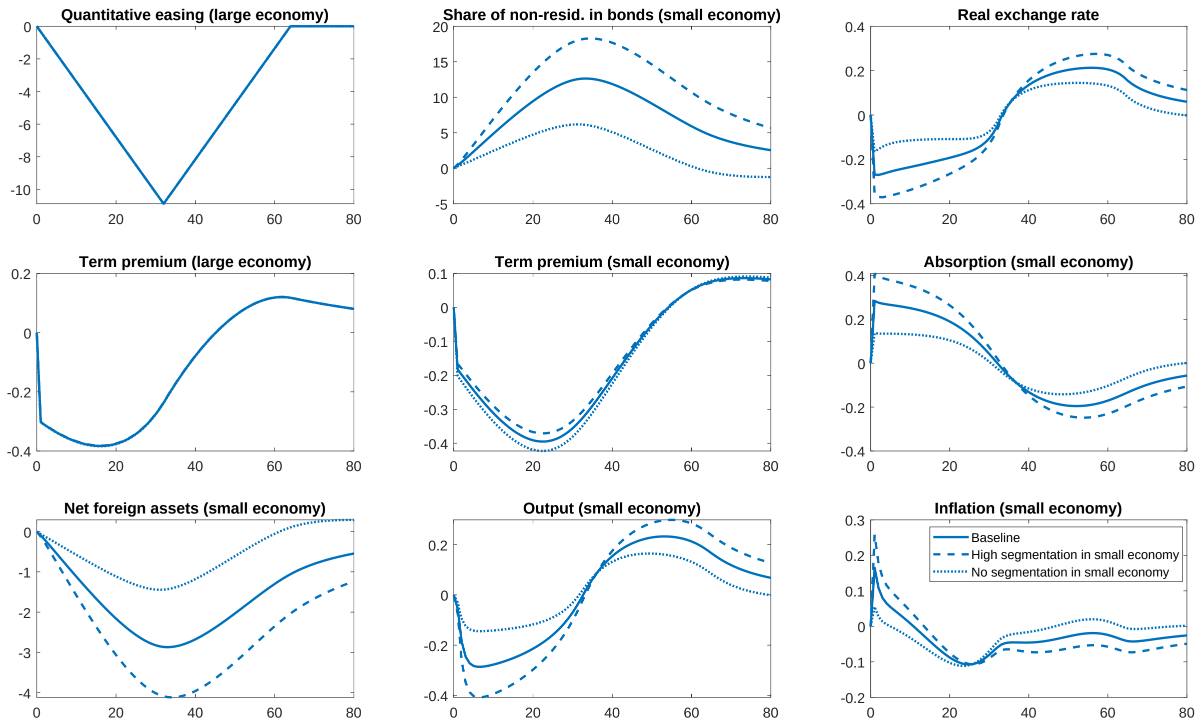
Note: This figure presents the impact of the baseline and three alternative monetary policy reactions in the small economy when the large economy is hit by a QE shock. In the baseline (solid line), the reaction is given by the Taylor rule (12) and calibration as in the paper. The dashed line presents the effects of perfect stabilization of the nominal exchange rate using the short-term rate. The dotted line presents the outcomes of FX interventions that achieve the same objective. Dash-dotted line shows the case when the small economy mimics QE implemented abroad. As in the previous figure, the QE shock in the large economy is calibrated to generate the same peak reaction of output in the large economy as the 1 percentage point (annualized) shock to the monetary feedback rule. All responses are in percent deviations from the steady state. The alternative policies (FX interventions, QE) are expressed as percent of steady state annual GDP, while net foreign assets is related to current annual GDP. The responses of the interest rates, term premium and inflation are annualized.

Figure 8: Effects of quantitative easing in the large economy: extended models



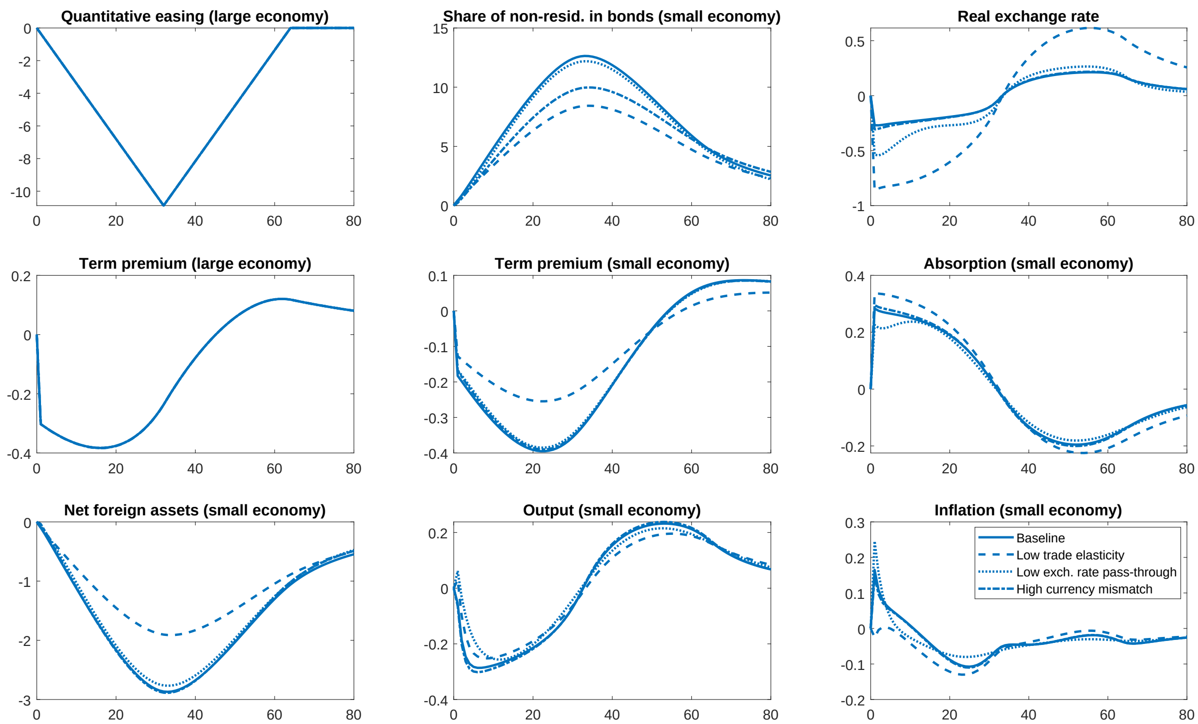
Note: This figure presents the effects of quantitative easing in the large economy for the baseline and two alternative modelling assumptions: two-factor production function with endogenous capital formation, and a fiscal rule for taxes instead of fixed total debt. All responses are in percent deviations from the steady state. Net foreign assets are expressed as percent of annual GDP. The responses of the term premium and inflation are annualized.

Figure 9: Effects of quantitative easing in the large economy - role of market segmentation and transaction costs



Note: This figure presents the effects of quantitative easing in the large economy for the baseline and two alternative parametrizations: high bond market segmentation in the small economy ($\omega_r = 0.2$) and no bond market segmentation in the small economy ($\omega_r \to 0$). All responses are in percent deviations from the steady state. Net foreign assets are expressed as percent of annual GDP. The responses of the term premium and inflation are annualized.

Figure 10: Effects of quantitative easing in the large economy - role of trade elasticity and exchange rate pass-through



Note: This figure presents the effects of quantitative easing in the large economy for the baseline and three alternative parametrizations: low trade elasticity ($\nu = \nu^* \approx 1$), low exchange rate pass-through ($\theta_H^* = \theta_F = 0.9$) and ten times higher steady-state share of foreign bonds in the small economy's household portfolio. All responses are in percent deviations from the steady state. Net foreign assets are expressed as percent of annual GDP. The responses of the term premium and inflation are annualized.

Appendix

A.1 List of model equations

The following equations describe the equilibrium in our two-country model. Small letters for variables defined in the main text indicate their real counterparts.

A.1.1 Households

Marginal utility

$$\lambda_t^r = \exp\{\varepsilon_t^d\}(c_t^r)^{-\sigma} \tag{A.1}$$

$$\lambda_t^{r*} = \exp\{\varepsilon_t^{d*}\}(c_t^{r*})^{-\sigma^*} \tag{A.2}$$

$$\lambda_t^u = \exp\{\varepsilon_t^d\}(c_t^u)^{-\sigma} \tag{A.3}$$

$$\lambda_t^{u*} = \exp\{\varepsilon_t^{d*}\}(c_t^{u*})^{-\sigma^*} \tag{A.4}$$

$$\lambda_t = \omega_r \lambda_t^r + (1-\omega_r)\lambda_t^u \tag{A.5}$$

$$\lambda_t^* = \omega_r^* \lambda_t^{r*} + (1-\omega_r^*)\lambda_t^{u*} \tag{A.6}$$

Bond prices

$$P_{L,t} = \frac{1}{R_{L,t} - \kappa} \tag{A.7}$$

$$P_{L,t}^* = \frac{1}{R_{L,t}^* - \kappa^*} \tag{A.8}$$

Restricted households' budget constraint

$$c_t^r + P_{L,t} b_{H,L,t}^r + t_t^r = P_{L,t} \frac{R_{L,t}}{\pi_t} b_{H,L,t-1}^r + w_t n_t^r + d_t^r \tag{A.9}$$

$$\begin{gathered} c_t^{r*} + P_{L,t}^* b_{F,L,t}^{r*} + s_t^{-1} P_{L,t} b_{H,L,t}^{r*} + t_t^{r*} = \\ P_{L,t}^* \frac{R_{L,t}^*}{\pi_t^*} b_{F,L,t-1}^{r*} + s_t^{-1} P_{L,t} \frac{R_{L,t}}{\pi_t} b_{H,L,t-1}^{r*} + w_t^* n_t^{r*} + d_t^{r*} \end{gathered} \tag{A.10}$$

Unrestricted households' budget constraint

$$\begin{gathered} c_t^u + b_{H,t}^u + P_{L,t} b_{H,L,t}^u + s_t P_{L,t}^* b_{F,L,t}^u + t_t^u = \\ \frac{R_{t-1}}{\pi_t} b_{H,t-1}^u + P_{L,t} \frac{R_{L,t}}{\pi_t} b_{H,L,t-1}^u + s_t P_{L,t}^* \frac{R_{L,t}^*}{\pi_t^*} b_{F,L,t-1}^u + w_t n_t^u + d_t^u \end{gathered} \tag{A.11}$$

$$\begin{gathered} c_t^{u*} + b_{F,t}^{u*} + s_t^{-1} P_{L,t} b_{H,L,t}^{u*} + P_{L,t}^* b_{F,L,t}^{u*} + t_t^{u*} = \\ \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1}^{u*} + s_t^{-1} P_{L,t} \frac{R_{L,t}}{\pi_t} b_{H,L,t-1}^{u*} + P_{L,t}^* \frac{R_{L,t}^*}{\pi_t^*} b_{F,L,t-1}^{u*} + w_t^* n_t^{u*} + d_t^{u*} \end{gathered} \tag{A.12}$$

Consumption-leisure choice

$$(n_t^r)^{\varphi} = \lambda_t^r w_t \tag{A.13}$$

$$(n_t^{r*})^{\varphi*} = \lambda_t^{r*} w_t^* \tag{A.14}$$

$$(n_t^u)^{\varphi} = \lambda_t^u w_t \tag{A.15}$$

$$(n_t^{u*})^{\varphi*} = \lambda_t^{u*} w_t^* \tag{A.16}$$

Restricted households' optimal bond holdings

$$\lambda_t^r P_{L,t} = \beta^r \mathbb{E}_t \left\{ \lambda_{t+1}^r P_{L,t+1} \frac{R_{L,t+1}}{\pi_{t+1}} \right\} \tag{A.17}$$

$$\lambda_t^{r*} P_{L,t}^* = \beta^{r*} \mathbb{E}_t \left\{ \lambda_{t+1}^{r*} P_{L,t+1}^* \frac{R_{L,t+1}^*}{\pi_{t+1}^*} \right\} \tag{A.18}$$

$$\lambda_t^{r*}(1+\Gamma_t^{r*}) s_t^{-1} P_{L,t} = \beta^{r*} \mathbb{E}_t \left\{ \lambda_{t+1}^{r*} s_{t+1}^{-1} P_{L,t+1} \frac{R_{L,t+1}}{\pi_{t+1}} \right\} \tag{A.19}$$

Unrestricted households' optimal bond holdings

$$\lambda_t^u = \beta^u \mathbb{E}_t \left\{ \lambda_{t+1}^u \frac{R_t}{\pi_{t+1}} \right\} \tag{A.20}$$

$$\lambda_t^u (1+\zeta_{H,t}) P_{L,t} = \beta^u \mathbb{E}_t \left\{ \lambda_{t+1}^u P_{L,t+1} \frac{R_{L,t+1}}{\pi_{t+1}} \right\} \tag{A.21}$$

$$\lambda_t^u s_t (1+\zeta_{F,t}) P_{L,t}^* = \beta^u \mathbb{E}_t \left\{ \lambda_{t+1}^u s_{t+1} P_{L,t+1}^* \frac{R_{L,t+1}^*}{\pi_{t+1}^*} \right\} \tag{A.22}$$

$$\lambda_t^{u*} = \beta^{u*} \mathbb{E}_t \left\{ \lambda_{t+1}^{u*} \frac{R_t^*}{\pi_{t+1}^*} \right\} \tag{A.23}$$

$$\lambda_t^{u*} s_t^{-1} (1+\zeta_{H,t}^*) P_{L,t} = \beta^{u*} \mathbb{E}_t \left\{ \lambda_{t+1}^{u*} s_{t+1}^{-1} P_{L,t+1} \frac{R_{L,t+1}}{\pi_{t+1}} \right\} \tag{A.24}$$

$$\lambda_t^{u*} (1+\zeta_{F,t}^*) P_{L,t}^* = \beta^{u*} \mathbb{E}_t \left\{ \lambda_{t+1}^{u*} P_{L,t+1}^* \frac{R_{L,t+1}^*}{\pi_{t+1}^*} \right\} \tag{A.25}$$

Transaction costs

$$\frac{1+\zeta_{H,t}}{1+\zeta_H} = \left(\frac{P_{L,t} b_{H,L,t}^u}{P_L b_{H,L}^u} \right)^{\xi_H} \tag{A.26}$$

$$\frac{1+\zeta_{H,t}^*}{1+\zeta_H^*} = \left(\frac{P_{L,t} b_{H,L,t}^{u*}}{P_L b_{H,L}^{u*}} \frac{s}{s_t} \right)^{\xi_H} \tag{A.27}$$

$$\frac{1+\zeta_{F,t}}{1+\zeta_F} = \left(\frac{P_{L,t}^* b_{F,L,t}^u}{P_L^* b_{F,L}^u} \frac{s_t}{s} \right)^{\xi_F} \tag{A.28}$$

$$\frac{1+\zeta^*_{F,t}}{1+\zeta^*_F} = \left(\frac{P^*_{L,t} b^{u*}_{F,L,t}}{P^*_L b^{u*}_{F,L}}\right)^{\xi_F} \tag{A.29}$$

$$1+\Gamma^{r*}_t = \exp\left\{\xi^*_r \left(\frac{P_{L,t} B^{r*}_{H,L,t}}{S_t P^*_{L,t} B^{r*}_{F,L,t}} - \kappa^{r*}\right)\right\} \tag{A.30}$$

A.1.2 Firms

Final goods basket

$$\tilde{y}_t = \left[\eta^{\frac{1}{\nu}} \left(y_{H,t}\right)^{\frac{\nu-1}{\nu}} + (1-\eta)^{\frac{1}{\nu}} \left(y_{F,t}\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} \tag{A.31}$$

$$\tilde{y}^*_t = \left[\eta^{*\frac{1}{\nu^*}} \left(y^*_{H,t}\right)^{\frac{\nu^*-1}{\nu^*}} + (1-\eta^*)^{\frac{1}{\nu^*}} \left(y^*_{F,t}\right)^{\frac{\nu^*-1}{\nu^*}}\right]^{\frac{\nu^*}{\nu^*-1}} \tag{A.32}$$

Optimal composition of final goods basket

$$y_{H,t} = \eta \left(p_{H,t}\right)^{-\nu} \tilde{y}_t \tag{A.33}$$

$$y_{F,t} = (1-\eta) \left(p_{F,t}\right)^{-\nu} \tilde{y}_t \tag{A.34}$$

$$y^*_{H,t} = \eta^* \left(p^*_{H,t}\right)^{-\nu^*} \tilde{y}^*_t \tag{A.35}$$

$$y^*_{F,t} = (1-\eta^*) \left(p^*_{F,t}\right)^{-\nu^*} \tilde{y}^*_t \tag{A.36}$$

Real price indices

$$p_{H,t}^{\frac{1}{1-\mu}} = \theta_H \left(p_{H,t-1}\frac{\pi}{\pi_t}\right)^{\frac{1}{1-\mu}} + (1-\theta_H)\left(\tilde{p}_{H,t}\right)^{\frac{1}{1-\mu}} \tag{A.37}$$

$$p_{F,t}^{\frac{1}{1-\mu^*}} = \theta_F \left(p_{F,t-1}\frac{\pi}{\pi_t}\right)^{\frac{1}{1-\mu^*}} + (1-\theta_F)\left(\tilde{p}_{F,t}\right)^{\frac{1}{1-\mu^*}} \tag{A.38}$$

$$p_{H,t}^{*\frac{1}{1-\mu}} = \theta^*_H \left(p^*_{H,t-1}\frac{\pi^*}{\pi^*_t}\right)^{\frac{1}{1-\mu}} + (1-\theta^*_H)\left(\tilde{p}^*_{H,t}\right)^{\frac{1}{1-\mu}} \tag{A.39}$$

$$p_{F,t}^{*\frac{1}{1-\mu^*}} = \theta^*_F \left(p^*_{F,t-1}\frac{\pi^*}{\pi^*_t}\right)^{\frac{1}{1-\mu^*}} + (1-\theta^*_F)\left(\tilde{p}^*_{F,t}\right)^{\frac{1}{1-\mu^*}} \tag{A.40}$$

Optimal reset prices

$$\tilde{p}_{H,t} = \mu \frac{\Omega_{H,t}}{\Upsilon_{H,t}} \tag{A.41}$$

$$\Omega_{H,t} = \lambda_t \frac{w_t}{\exp\{\varepsilon^z_t\}} p_{H,t}^{\frac{\mu}{\mu-1}} y_{H,t} + \beta\theta_H \mathbb{E}_t \left(\frac{\pi}{\pi_{t+1}}\right)^{\frac{\mu}{1-\mu}} \Omega_{H,t+1} \tag{A.42}$$

$$\Upsilon_{H,t} = \lambda_t p_{H,t}^{\frac{\mu}{\mu-1}} y_{H,t} + \beta\theta_H \mathbb{E}_t \left(\frac{\pi}{\pi_{t+1}}\right)^{\frac{1}{1-\mu}} \Upsilon_{H,t+1} \tag{A.43}$$

$$\tilde{p}_{F,t} = \mu^* \frac{\Omega_{F,t}}{\Upsilon_{F,t}} \tag{A.44}$$

$$\Omega_{F,t} = \lambda_t^* \frac{w_t^*}{\exp\{\varepsilon_t^{z*}\}} p_{F,t}^{\frac{\mu^*}{\mu^*-1}} y_{F,t} + \beta^* \theta_F \mathbb{E}_t \left(\frac{\pi}{\pi_{t+1}} \right)^{\frac{\mu^*}{1-\mu^*}} \Omega_{F,t+1} \tag{A.45}$$

$$\Upsilon_{F,t} = \lambda_t^* s_t^{-1} p_{F,t}^{\frac{\mu^*}{\mu^*-1}} y_{F,t} + \beta^* \theta_F \mathbb{E}_t \left(\frac{\pi}{\pi_{t+1}} \right)^{\frac{1}{1-\mu^*}} \Upsilon_{F,t+1} \tag{A.46}$$

$$\tilde{p}_{H,t}^* = \mu \frac{\Omega_{H,t}^*}{\Upsilon_{H,t}^*} \tag{A.47}$$

$$\Omega_{H,t}^* = \lambda_t \frac{w_t}{\exp\{\varepsilon_t^z\}} p_{H,t}^{*\frac{\mu}{\mu-1}} y_{H,t}^* + \beta \theta_H^* \mathbb{E}_t \left(\frac{\pi^*}{\pi_{t+1}^*} \right)^{\frac{\mu}{1-\mu}} \Omega_{H,t+1}^* \tag{A.48}$$

$$\Upsilon_{H,t}^* = \lambda_t s_t p_{H,t}^{*\frac{\mu}{\mu-1}} y_{H,t}^* + \beta \theta_H^* \mathbb{E}_t \left(\frac{\pi^*}{\pi_{t+1}^*} \right)^{\frac{1}{1-\mu}} \Upsilon_{H,t+1}^* \tag{A.49}$$

$$\tilde{p}_{F,t}^* = \mu^* \frac{\Omega_{F,t}^*}{\Upsilon_{F,t}^*} \tag{A.50}$$

$$\Omega_{F,t}^* = \lambda_t^* \frac{w_t^*}{\exp\{\varepsilon_t^{z*}\}} p_{F,t}^{*\frac{\mu^*}{\mu^*-1}} y_{F,t}^* + \beta^* \theta_F^* \mathbb{E}_t \left(\frac{\pi^*}{\pi_{t+1}^*} \right)^{\frac{\mu^*}{1-\mu^*}} \Omega_{F,t+1}^* \tag{A.51}$$

$$\Upsilon_{F,t}^* = \lambda_t^* p_{F,t}^{*\frac{\mu^*}{\mu^*-1}} y_{F,t}^* + \beta^* \theta_F^* \mathbb{E}_t \left(\frac{\pi^*}{\pi_{t+1}^*} \right)^{\frac{1}{1-\mu^*}} \Upsilon_{F,t+1}^* \tag{A.52}$$

Dividends

$$d_t = p_{H,t} y_{H,t} + \frac{1-\omega}{\omega} s_t p_{H,t}^* y_{H,t}^* - w_t n_t \tag{A.53}$$

$$d_t^* = \frac{\omega}{1-\omega} p_{F,t} y_{F,t} \frac{1}{s_t} + p_{F,t}^* y_{F,t}^* - w_t^* n_t^* \tag{A.54}$$

$$d_t^r = \omega_r d_t \tag{A.55}$$

$$d_t^u = (1-\omega_r) d_t \tag{A.56}$$

$$d_t^{r*} = \omega_r^* d_t^* \tag{A.57}$$

$$d_t^{u*} = (1-\omega_r^*) d_t^* \tag{A.58}$$

A.1.3 Government

Monetary policy rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\gamma_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\gamma_\pi} \left(\frac{y_t}{y} \right)^{\gamma_y} \right]^{1-\gamma_r} \exp\{\varepsilon_t^r\} \tag{A.59}$$

$$\frac{R_t^*}{R^*} = \left(\frac{R_{t-1}^*}{R^*}\right)^{\gamma_r^*} \left[\left(\frac{\pi_t^*}{\pi^*}\right)^{\gamma_\pi^*} \left(\frac{y_t^*}{y^*}\right)^{\gamma_y^*}\right]^{1-\gamma_r^*} \exp\{\varepsilon_t^{r*}\} \tag{A.60}$$

Government budget constraint

$$b_{H,t}^g + P_{L,t} b_{H,L,t}^g + t_t = \frac{R_{t-1}}{\pi_t} b_{H,t-1}^g + P_{L,t} \frac{R_{L,t}}{\pi_t} b_{H,L,t-1}^g + g \exp\{\varepsilon_t^g\} \tag{A.61}$$

$$b_{F,t}^{g*} + P_{L,t}^* b_{F,L,t}^{g*} + t_t^* = \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1}^{g*} + P_{L,t}^* \frac{R_{L,t}^*}{\pi_t^*} b_{F,L,t-1}^{g*} + g^* \exp\{\varepsilon_t^{g*}\} \tag{A.62}$$

Total government debt

$$b_{H,t}^g + P_{L,t} b_{H,L,t}^g = b_H^g + P_L b_{H,L}^g \tag{A.63}$$

$$b_{F,t}^{g*} + P_{L,t}^* b_{F,L,t}^{g*} = b_F^{g*} + P_L^* b_{F,L}^{g*} \tag{A.64}$$

Composition of government debt

$$P_{L,t} b_{H,L,t}^g = P_L b_{H,L}^g \tag{A.65}$$

$$\frac{P_{L,t}^* b_{F,L,t}^{g*}}{P_L^* b_{F,L}^{g*}} = \left(\frac{P_{L,t-1}^* b_{F,L,t-1}^{g*}}{P_L^* b_{F,L}^{g*}}\right)^{\gamma_L^*} \exp\{\varepsilon_t^{L*}\} \tag{A.66}$$

A.1.4 Aggregation and market clearing

Aggregate labor

$$n_t = \omega_r n_t^r + (1-\omega_r) n_t^u \tag{A.67}$$

$$n_t^* = \omega_r^* n_t^{r*} + (1-\omega_r^*) n_t^{u*} \tag{A.68}$$

Goods market clearing

$$\tilde{y}_t = \omega_r c_t^r + (1-\omega_r) c_t^u + g_t \tag{A.69}$$

$$\tilde{y}_t^* = \omega_r^* c_t^{r*} + (1-\omega_r^*) c_t^{u*} + g_t^* \tag{A.70}$$

Aggregate production function

$$y_t = \exp\{\varepsilon_t^z\} n_t - \phi_t \tag{A.71}$$

$$y_t^* = \exp\{\varepsilon_t^{z*}\} n_t^* - \phi_t^* \tag{A.72}$$

Aggregate output

$$y_t = y_{H,t} \Delta_{H,t} + \frac{1-\omega}{\omega} y_{H,t}^* \Delta_{H,t}^* \tag{A.73}$$

$$y_t^* = \frac{\omega}{1-\omega} y_{F,t} \Delta_{F,t} + y_{F,t}^* \Delta_{F,t}^* \tag{A.74}$$

Price dispersion

$$\Delta_{H,t} = \left(\frac{p_{H,t}}{p_{H,t-1}}\right)^{\frac{\mu}{\mu-1}} \theta_H \Delta_{H,t-1} \left(\frac{\pi}{\pi_t}\right)^{\frac{\mu}{1-\mu}} + (1-\theta_H) \left(\frac{\tilde{p}_{H,t}}{p_{H,t}}\right)^{\frac{\mu}{1-\mu}} \tag{A.75}$$

$$\Delta^*_{H,t} = \left(\frac{p^*_{H,t}}{p^*_{H,t-1}}\right)^{\frac{\mu}{\mu-1}} \theta^*_H \Delta^*_{H,t-1} \left(\frac{\pi^*}{\pi^*_t}\right)^{\frac{\mu}{1-\mu}} + (1-\theta^*_H) \left(\frac{\tilde{p}^*_{H,t}}{p^*_{H,t}}\right)^{\frac{\mu}{1-\mu}} \tag{A.76}$$

$$\Delta_{F,t} = \left(\frac{p_{F,t}}{p_{F,t-1}}\right)^{\frac{\mu^*}{\mu^*-1}} \theta_F \Delta_{F,t-1} \left(\frac{\pi}{\pi_t}\right)^{\frac{\mu^*}{1-\mu^*}} + (1-\theta_F) \left(\frac{\tilde{p}_{F,t}}{p_{F,t}}\right)^{\frac{\mu^*}{1-\mu^*}} \tag{A.77}$$

$$\Delta^*_{F,t} = \left(\frac{p^*_{F,t}}{p^*_{F,t-1}}\right)^{\frac{\mu^*}{\mu^*-1}} \theta^*_F \Delta^*_{F,t-1} \left(\frac{\pi^*}{\pi^*_t}\right)^{\frac{\mu^*}{1-\mu^*}} + (1-\theta^*_F) \left(\frac{\tilde{p}^*_{F,t}}{p^*_{F,t}}\right)^{\frac{\mu^*}{1-\mu^*}} \tag{A.78}$$

Aggregate taxes

$$t_t = \omega_r t^r_t + (1-\omega_r) t^u_t \tag{A.79}$$

$$t^*_t = \omega^*_r t^{r*}_t + (1-\omega^*_r) t^{u*}_t \tag{A.80}$$

Short-term bond market clearing

$$(1-\omega_r) b^u_{H,t} = b^g_{H,t} \tag{A.81}$$

$$(1-\omega^*_r) b^{u*}_{F,t} = b^{g*}_{F,t} \tag{A.82}$$

Long-term bond market clearing

$$\omega(1-\omega_r) b^u_{H,L,t} + (1-\omega)(1-\omega^*_r) b^{u*}_{H,L,t} + \omega\omega_r b^r_{H,L,t} + (1-\omega)\omega^*_r b^{r*}_{H,L,t} = \omega b^g_{H,L,t} \tag{A.83}$$

$$\omega(1-\omega_r) b^u_{F,L,t} + (1-\omega)(1-\omega^*_r) b^{u*}_{F,L,t} + (1-\omega)\omega^*_r b^{r*}_{F,L,t} = (1-\omega) b^{g*}_{F,L,t} \tag{A.84}$$

A.2 Asset market segmentation and transaction costs

In this Appendix we show how our assumed asset market segmentation determines international comovement in transaction costs, and hence in the term premia. In this presentation we use first-order accurate approximation to the Euler equations describing asset holdings by households, with hats over variables indicating log-deviations from the steady state. We also ignore adjustment cost Γ_t^{r*} as it was introduced in the model only to render foreign restricted households' portfolio determinate in the steady state, and is calibrated to be very small.

A.2.1 Baseline model

To first order, the Euler equations for foreign restricted households (A.18) and (A.19) gives the following long-term UIP condition

$$\mathbb{E}_t \left\{ \hat{P}^*_{L,t+1} - \hat{P}^*_{L,t} + \hat{R}^*_{L,t+1} - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t \right\} = \mathbb{E}_t \left\{ \hat{P}_{L,t+1} - \hat{P}_{L,t} + \hat{R}_{L,t+1} - \hat{\pi}_{t+1} \right\} \tag{A.85}$$

which is equation (29) in the main text. Combining the Euler equations associated with long-term bond holdings by home unrestricted households (A.21) and (A.22) yields

$$\mathbb{E}_t \left\{ \hat{P}^*_{L,t+1} - \hat{P}^*_{L,t} + \hat{R}^*_{L,t+1} - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t - \zeta_{F,t} \right\} = \mathbb{E}_t \left\{ \hat{P}_{L,t+1} - \hat{P}_{L,t} + \hat{R}_{L,t+1} - \hat{\pi}_{t+1} - \zeta_{H,t} \right\} \tag{A.86}$$

and by proceeding similarly for foreign unrestricted households using equations (A.24) and (A.25) we obtain

$$\mathbb{E}_t \left\{ \hat{P}^*_{L,t+1} - \hat{P}^*_{L,t} + \hat{R}^*_{L,t+1} - \hat{\pi}^*_{t+1} - \zeta^*_{F,t} \right\} = \mathbb{E}_t \left\{ \hat{P}_{L,t+1} - \hat{P}_{L,t} + \hat{R}_{L,t+1} - \hat{\pi}_{t+1} - \hat{s}_{t+1} + \hat{s}_t - \zeta^*_{H,t} \right\} \tag{A.87}$$

Comparing these three equations yields

$$\zeta_{H,t} = \zeta_{F,t} \tag{A.88}$$

$$\zeta^*_{H,t} = \zeta^*_{F,t} \tag{A.89}$$

This segmentation hence implies equalization of transaction costs (and hence the term premia for the same maturity) associated with home and foreign long-term bonds within each country, but not necessarily across borders.

To study international comovement in these costs, we can combine the Euler equations associated with home short-term and long-term bonds held by home unrestricted households (A.20) and (A.21)

$$\mathbb{E}_t \left\{ \hat{P}_{L,t+1} - \hat{P}_{L,t} + \hat{R}_{L,t+1} \right\} = \hat{R}_t + \zeta_{H,t} \tag{A.90}$$

and similarly combine the Euler equations associated with foreign short-term and long-term bonds held by foreign unrestricted households (A.23) and (A.25)

$$\mathbb{E}_t \left\{ \hat{P}^*_{L,t+1} - \hat{P}^*_{L,t} + \hat{R}^*_{L,t+1} \right\} = \hat{R}^*_t + \zeta^*_{F,t} \tag{A.91}$$

These equations simply state that home (foreign) transaction costs can be interpreted as a wedge between the one-period expected rate of return on home (foreign) short-term and long-term bonds. They are linked to each other via the long-term UIP condition (A.85). In particular, if we combine it with equations (A.90)-(A.91), we obtain the risk-augmented short-term UIP condition

$$\mathbb{E}_t \left\{ \hat{R}_t - \hat{\pi}_{t+1} \right\} = \mathbb{E}_t \left\{ \hat{R}^*_t - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t \right\} + \zeta^*_{F,t} - \zeta_{H,t} \tag{A.92}$$

which is equation (30) in the main text, and which we test against the data using the Fama regressions.

A.2.2 Relaxing restrictions on trade in short-term bonds

If we allow home unrestricted agents to trade in foreign short-term bonds, we would have an additional Euler equation

$$\lambda^u_t s_t = \beta \mathbb{E}_t \left\{ \lambda^u_{t+1} s_{t+1} \frac{R^*_t}{\pi^*_{t+1}} \right\} \tag{A.93}$$

Combining it with equation (A.20) describing home short-term bond holdings yields, up to first order

$$\mathbb{E}_t \left\{ \hat{R}_t - \hat{\pi}_{t+1} \right\} = \mathbb{E}_t \left\{ \hat{R}^*_t - \hat{\pi}^*_{t+1} + \hat{s}_{t+1} - \hat{s}_t \right\} \tag{A.94}$$

which is a standard UIP condition that does not feature any risk premia.

If we compare this additional equilibrium condition with equation (A.92), we immediately obtain

$$\zeta_{H,t} = \zeta^*_{F,t} \tag{A.95}$$

which, together with equalities (A.88)-(A.89) implies

$$\zeta_{H,t} = \zeta_{F,t} = \zeta^*_{H,t} = \zeta^*_{F,t} \tag{A.96}$$

Given the definitions of the term premia (28), we hence have their perfect equalization across borders.

It can be easily shown that exactly the same outcomes can be obtained if we instead (or additionally) allow for trade in home short-term bonds by foreign unrestricted agents.

A.2.3 Allowing home restricted agents to trade foreign long-term bonds

In our baseline model we allow foreign restricted agents to trade in long-term bonds issued in both countries, but exclude domestic restricted households from foreign long-term bond markets. Relaxing this restriction yields the following additional Euler equation

$$\lambda_t^r s_t P_{L,t}^* = \beta \mathbb{E}_t \left\{ \lambda_{t+1}^r s_{t+1} P_{L,t+1}^* \frac{R_{L,t+1}^*}{\pi_{t+1}^*} \right\} \tag{A.97}$$

If we combine it with equation (A.17) that describes the equilibrium choice of home long-term bonds by home restricted agents, we obtain a long-term UIP condition that, up to first order of approximation, is identical to equation (A.85), already implied by our baseline model. Hence, this model extension does not have any direct effects on the international comovement in transaction costs and term premia.