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GLOBAL MACROECONOMIC EFFECTS OF EXITING FROM UNCONVENTIONAL MONETARY POLICY

by Pietro Cova*, Patrizio Pagano** and Massimiliano Pisani*

Abstract

This paper evaluates the international macroeconomic spillovers from the Eurosystem's expanded Asset Purchase Programme (APP) under alternative assumptions as regards (i) the unwinding of the asset positions accumulated under the APP and (ii) the normalization of the US monetary policy stance. We simulate a dynamic general equilibrium model of the world economy, calibrated to the Euro area (EA), the US, China, Japan, and the 'rest of the world' (RW). Our results are as follows. First, APP expansionary spillovers are dampened if the Eurosystem brings forward the unwinding of its bond holdings because of the lower increase in EA aggregate demand and, therefore, EA imports. The RW is the region most affected because it has the greatest trade integration with the EA. Second, if the US monetary authority announces that it will hold the policy rate constant for a shorter period of time – which dampens the increase in US aggregate demand and, therefore, US imports from the EA – then US spillovers to the EA, while still expansionary, as in the case of a slower normalization of the monetary policy stance, are more modest.

JEL Classification: E43, E44, E52, E58.
Keywords: DSGE models, open-economy macroeconomics, non-standard monetary policy, zero lower bound.

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* Bank of Italy, Directorate General for Economics, Statistics and Research.

** The World Bank.

1 Introduction[1]

There is a wide debate in the academic and policy circles, about how the design of the non-standard monetary policy measures (their duration, composition and size) would affect the effectiveness of the programme in restoring price stability.

The debate has focused also on the international effects of the non-standard measures. For two reasons. First, non-standard measures are rather novel and, therefore, there are not many theoretical and empirical contributions that evaluate their international effects. Second, there are growing concerns about the evolution of worldwide economic conditions, as risks of a slowdown in aggregate demand in both advanced and emerging countries are rising. Thus, non-standard monetary policy in the main worldwide regions, in particular the euro area (EA) and the U.S. (US), can become even more relevant for sustaining domestic and international economic conditions.

In this paper we evaluate the relationship between APP effectiveness, its duration and the role of international spillovers under alternative assumptions about (i) the unwinding of the asset positions accumulated under the APP and (ii) the normalization of the U.S. monetary policy stance. We simulate a large-scale multi-country dynamic general equilibrium model of the EA and the world economy, calibrated to the EA, China (CH), Japan (JP), the US, and the rest of the world (RW).[2] Building on a recent contribution by Canzoneri, Cumby, Diba and Lopez-Salido (2013, henceforth CCDLS), we define total liquidity as an aggregate of "narrow" money and sovereign bonds in an otherwise standard New Keynesian open economy model.[3] Different from CCDLS, we introduce demand for EA long-term sovereign bonds. In each country households (optimally) demand liquidity, which facilitates transactions for consumption purposes (thereby providing so called "liquidity services"). "Liquidity" is a combination of domestic narrow money balances (currency in circulation), and short- and long-term government bonds. In this way,

[1]We thank Martina Cecioni and participants at the 2016 Banca d'Italia workshop on "Unconventional monetary policy: effectiveness and risks" for useful comments. The opinions expressed are those of the authors and do not reflect views of the Bank of Italy or the World Bank. Any remaining errors are the sole responsibility of the authors.

[2]In what follows we will interchangeably use the expressions countries or regions when referring to the EA, CH, JP, US and RW.

[3]See CCDLS (2008) for a closed-economy analysis.

we relax the well known "Wallace neutrality" and make assets imperfect substitutes, since they differ for the amount of liquidity services they provide.[4] This framework allows to formalize the APP as purchases of long-term sovereign bonds by the EA monetary authority financed via narrow money injection. The model calibration, informed by the data, implies that narrow money is a more liquid asset than sovereign bonds, as the related parameter in the liquidity bundle is relatively large. Thus, the APP generates an increase in overall liquidity, as the monetary authority exchanges a more liquid asset (money) for a less liquid one (long-term sovereign bonds). The implied decrease in long-term rates and the increase in overall liquidity induce households to increase consumption, favoring an increase in aggregate demand and, thus, economic activity.

The model allows to evaluate the impact of the APP and other countries' monetary policy measures on the EA exchange rate, and trade flows and, therefore, on EA inflation. To capture their nontrivial role in international liquidity markets, we allow EA and US short- and long-term sovereign bonds to be internationally traded and to be a component of both domestic and other regions' liquidity.[5] To the opposite, it is assumed that CH, JP and RW government bonds are not internationally traded.

In all scenarios, the APP is simulated, as an exogenous increase in the purchases of long-term sovereign bonds by the EA monetary authority. The shock is calibrated so that it corresponds to quarterly purchases of euro 180 billion, that last from March 2015 to the end of September 2016 (7 quarters).

Moreover, during the initial 8 quarters, the EA short-term monetary policy rate remains constant at its baseline level, reflecting the commitment of the EA central bank to maintain an accommodative stance for a prolonged period. Thus, the constant monetary policy rate is not associated with the zero lower bound constraint, but should be interpreted as a deliberate policy choice (so called "forward guidance", FG from now, on policy rate). From quarter 9, the monetary policy rate is set according to the Taylor rule.

[4] See Wallace (1981).

[5] See Chinn and Frankel (2008), Devereux and Shi (2013) and Krishnamurthy and Vissing-Jorgensen (2012). We treat the EA as a single country in our model, alongside the CH, JP, US and the RW. Thus, the EA government bonds are meant to denote bonds denominated in euro issued by the (hypothetical) EA government.

Finally, the supply of long-term public debt is kept constant at its steady-state level.

We run the following scenarios. In the first, it is assumed that the Eurosystem central bank holds the purchased bonds to maturity, equal to 8 years on average (benchmark case). In the second scenario, the Eurosystem central bank sells long-term sovereign bonds immediately after the end of the purchasing period ("early-exit" case). In the third and fourth scenarios, on top of the (benchmark) APP, it is assumed that a positive demand shock stimulates the US economy. In one case, the US Federal Reserve (FED) keeps the US policy rate at its baseline level during the first year after the shock, instead of raising it to stabilize the economy (we label it "early normalization of the US monetary policy"). In the alternative scenario, the FED keeps the policy rate at its baseline level for three years ("late normalization of the US monetary policy").

Our results are as follows. First, in case of an early unwinding of asset holdings by the Eurosystem, the APP-related stimulus on inflation and aggregate demand is significantly dampened. The implied lower increase in EA imports reduces the expansionary spillovers to economic activity and inflation of other regions. Second, the region RW is the one affected the most, because it is the most trade-integrated with the EA. Third, if the US monetary authority announces a shorter period of constant policy rate – that dampens the increase in US aggregate demand following a domestic expansionary demand shock and, therefore, dampens exports to the US by the EA and other regions – then the expansionary spillovers from the US accommodative monetary policy to the EA are expansionary, but more modest. This being the case, it becomes even more crucially to correctly identify the appropriate point in time to exit EA non standard monetary policy measures.

Our paper relates to other contributions on unconventional monetary policy. Chen, Curdia, and Ferrero (2012) introduce preferred habitat theory for financial assets to evaluate the impact of US quantitative easing. They assume there is one type of households that can invest only in physical capital or in long-term sovereign bonds. Thus, the reduction in the long-term interest rate induces those households to increase investment in physical capital. Burlon, Gerali, Notarpietro and Pisani (2015) formalize the EA as a monetary union and evaluate the impact of APP on EA member countries on the basis of a framework as in Chen, Curdia and Ferrero (2012). Different from them, we assume 1) a representative agent having an explicit demand for liquidity, that provides consumption transaction services, and 2) that liquidity is a composite of narrow money, short- and long-term sovereign bonds.[6] The last assumption is more in line with Alpanda and Kabaka (2015), that introduce a composite liquidity bundle similar to ours in the utility function of the representative household. Alpanda and Kabaka (2015) evaluate the international spillover effects of large-scale asset purchases using a two-country dynamic stochastic general-equilibrium model. Differently from them, we explicitly introduce liquidity in a *multi-country* quantitative dynamic general equilibrium model. Cova, Pagano and Pisani (2014) use a framework similar to the one used in this paper to evaluate the international macroeconomic effects of changes in official reserves, while Cova, Pagano, and Pisani (2015) to evaluate the domestic macroeconomic effects of APP. Differently from those contributions, we evaluate the relation between the effectiveness of non-standard monetary policy measures and their unwinding (early exit), and its implications for stimulating the EA economy and its main trade and financial partners.

Finally, in the literature, to the best of our knowledge, there are no quantitative results available for domestic and international macroeconomic effects of the APP. The only exception is Burlon, Gerali, Notarpietro and Pisani (2015), that report nontrivial expansionary macroeconomic effects of the APP on the EA economy.[7]

The rest of the paper is organized as follows. Section 2 reports the main features of the model setup and the calibration. Section 3 contains the results. Finally, section 4 concludes.

2 Model setup

We build up and simulate a five-region New Keynesian dynamic general equilibrium model of the world economy, calibrated to the EA, CH, JP, US and RW.

Following the theoretical framework of CCDLS, in each country households'

[6] Our setup would be closer to the one in Chen, Curdia and Ferrero (2012) if we would allow for a transactions cost on investment in physical capital.

[7] Cova and Ferrero (2015) find non-negligible expansionary effects of APP on the Italian GDP by simulating the Bank of Italy quarterly model of the Italian economy.

liquidity includes not only domestic money, but also domestic and US government bonds. Different from CCDLS, we distinguish between short- and long-term government bonds, the latter formalized as perpetuities following Woodford (2001). It is also assumed that EA sovereign bonds are internationally traded and are a component of each region's liquidity.

As usual in dynamic open economy models, financial assets allow to smooth consumption over time and to share idiosyncratic risk across countries. The novelty of the framework we use is that it allows assets to be part of liquidity. They pay, as usual, an interest rate ("pecuniary" return). Moreover, they allow households to pay for transaction services when buying consumption goods. Thus, their yield embodies a liquidity premium, that reflects the non-pecuniary return of these transactions services.

The transactions technology makes assets imperfect substitutes, because each asset is different from the others for the amount of provided liquidity services. Thus, the households' portfolio problem is nontrivial and, thus, the distinction between EA short- and long-term sovereign bonds allows to formalize the APP. The resulting private sector demand interacts with 1) the monetary authority demand for unconventional monetary policy purposes and 2) the supply by the fiscal authority. They jointly determine the equilibrium interest rates and exchange rates in the global markets.

Households also trade a private bond at the international level, denominated in US dollars, that pays an interest rate which does not embody the aforementioned liquidity premium, as the bond does not offer transaction services. The bond allows for a proper calibration of countries' net foreign asset position (NFA) and, hence, to fully characterize the current account dynamics.[8]

Other features of the model are standard and in line with other existing New Keynesian multi-country general equilibrium models, based on nominal (price and wage) and real rigidities (habit in consumption, adjustment costs on investment and imports).[9] The model distinguishes between intermediate and final goods.

[8]While admittedly this is only a shortcut, in order to account for other asset classes that are riskier than government bonds and that affect countries' financial accounts, by and large US dollar-denominated debt still constitutes the most important component among private international assets and liabilities.

[9]The model is similar to the Euro area and the Global economy Model (EAGLE) developed

The former include both tradable and non-tradable goods, and are produced by monopolistic competitive firms, that set their prices to maximize profits subject to quadratic adjustment costs. Final goods are non-tradable, and are distinguished in private consumption, government consumption and investment goods. They are produced under perfect competition. In each region there is a continuum of households, that maximize lifetime utility subject to the budget constraint. The world economy size is normalized to 1. The size of each country corresponds to the size of households population and to the number of firms operating in each sector. Specifically, n^{EA}, n^{US}, n^{CH}, n^{JP} (n^{EA}, n^{US}, n^{CH}, $n^{JP} > 0$, $n^{EA}+n^{US}+n^{CH}+n^{JP} < 1$) are the sizes of EA, US, CH, JP, respectively. The size of RW is obtained subtracting other regions' sizes from 1.

In what follows we report the key equations that define "international liquidity". As equations are similar across countries, we report only the EA case. Where this is not the case, it will be explicitly stated.[10]

2.1 Households and international liquidity

The generic EA household j's intertemporal utility at time 0 is

$$U_0(j) \equiv E_0 \Sigma_{t=0}^{\infty} \beta^t \left\{ \frac{\left(C_t(j) - \xi C_{t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_t(j)^{1+\chi}}{1+\chi} \right\}, \tag{1}$$

where E is the expectation operator, $0 < \beta < 1$ is the discount factor, C is consumption of the final good and N measures labor effort. The parameter $0 \leq \xi \leq 1$ accounts for external consumption habits. The intertemporal elasticity of substitution is $1/\sigma > 0$, and the inverse of the Frisch labor supply elasticity is $\chi > 0$.

by Gomes, Jacquinot and Pisani (2010) and to the Global Economy Model (GEM) developed at the IMF (see Pesenti, 2008).

[10]See the Appendix "The model" for a description of the other main equations.

The budget constraint is

$$
\begin{aligned}
& M_t(j) - M_{t-1}(j) \\
& + P_t^L B_t^{EA,L}(j) - \left(1 + \kappa P_t^L\right) B_{t-1}^{EA,L}(j) \\
& + B_t^{EA,S}(j) - R_{EA,t-1} B_{t-1}^{EA,S}(j) \\
& + S_t P_t^{US,L} B_t^{US,L}(j) - \left(1 + \kappa^{US} P_t^{US,L}\right) S_t B_{t-1}^{US,L}(j) \\
& + S_t B_t^{US,S}(j) - S_t R_{US,t-1} B_{t-1}^{US,S}(j) \\
& + S_t B_t^{PR}(j) - S_t R_{PR,t-1} B_{t-1}^{PR}(j) \\
& = W_t(j) N_t(j) + R_{K,t} K_{t-1}(j) + D_t(j) \\
& - (1 + \tau_t(j)) P_t C_t(j) - P_{I,t} I_t(j) - TAX_t(j) + TR_t(j) - AC_t^W(j), \qquad (2)
\end{aligned}
$$

where M is domestic narrow money holdings and $B^{EA,L}$ is the domestic long-term government bond and P^L its price. The long-term bond is formalized as a perpetuity, paying an exponentially decaying coupon κ ($0 < \kappa < 1$), in line with Woodford (2001). Its gross yield to maturity (our measure of long-term interest rate), is given by

$$R_{L,t} = \frac{1}{P_{L,t}} + \kappa. \qquad (3)$$

The term $B^{EA,S}$ represents the short-term government bond, expressed as a one-period bond for the sake of tractability. It pays the domestic (gross) monetary policy rate R_{EA}. The terms $B^{US,L}$ and $B^{US,S}$ represent household's holding of US long- and short-term sovereign bonds, respectively. The term $P^{US,L}$ is the price of the long-term bond in US dollars. The short-term bond pays the US (gross) monetary policy rate, R_{US}. Both bonds are multiplied by the nominal exchange rate S between the euro and the US dollar (number of euro per US dollar). Thus, their value is converted in euro terms. The term B^{PR} is EA household's holdings of the internationally traded bond that does not provide liquidity services, denominated in US dollar and paying the gross nominal interest rate R^{PR}.

On the right-hand-side W stands for the wage rate, $R_K K$ is the income from renting the stock of physical capital K to domestic firms at the rate R_K, D are dividends from ownership of domestic firms, τ is the transactions cost, P is the consumption price index, I is investment in physical capital and P_I the related price index, $TAX > 0$ are lump-sum taxes, $TR > 0$ are lump-sum transfers associated with money injections. Finally, the term AC^W is the quadratic adjustment cost paid by the household to change its nominal (sticky) wage.

As in Schmitt-Grohé and Uribe (2004) and CCDLS, the transactions cost is proportional to consumption, with a factor of proportionality that is an increasing function of velocity:

$$\tau_t(j) = \begin{cases} \left(\frac{A}{v_t(j)}\right)(v_t(j) - \bar{v})^2 & \text{for} \quad v_t(j) > \bar{v} \\ 0 & \text{for} \quad v_t(j) \leq \bar{v} \end{cases}, \tag{4}$$

where $\bar{v}$ is the satiation level of velocity and $A > 0$ is a cost parameter. Velocity depends in turn on consumption C and overall liquidity $\tilde{M}$ holdings according to the relation

$$v_t(j) = \frac{C_t(j)}{\tilde{M}_t(j)}. \tag{5}$$

The overall liquidity $\tilde{M}_t$ is a nested CES bundle, which includes not only holdings of domestic narrow money M, but also domestic government bonds B^{EA} (composed by domestic short- and long-term bonds, $B^{EA,S}$ and $B^{EA,L}$ respectively) and US government bonds (B^{US}, composed by short- and long-term bonds, $B^{US,S}$ and $B^{US,L}$respectively):

$$\tilde{M}_t(j) = \left(\zeta_1^{\frac{1}{\lambda_1}} M_t(j)^{\frac{\lambda_1-1}{\lambda_1}} + \zeta_2^{\frac{1}{\lambda_1}} B_t^{EA}(j)^{\frac{\lambda_1-1}{\lambda_1}} + (1-\zeta_1-\zeta_2)^{\frac{1}{\lambda_1}} \left(S_t B_t^{US}(j)\right)^{\frac{\lambda_1-1}{\lambda_1}}\right)^{\frac{\lambda_1}{\lambda_1-1}} \tag{6}$$

$$B_t^{EA}(j) = \left(\theta^{\frac{1}{\lambda_2}} B_t^{EA,S}(j)^{\frac{\lambda_2-1}{\lambda_2}} + (1-\theta)^{\frac{1}{\lambda_2}} \left(P_t^L B_t^{EA,L}(j)\right)^{\frac{\lambda_2-1}{\lambda_2}}\right)^{\frac{\lambda_2}{\lambda_2-1}}, \tag{7}$$

$$B_t^{US}(j) = \left(\omega^{\frac{1}{\lambda_3}} B_t^{US,S}(j) + (1-\omega)^{\frac{1}{\lambda_3}} \left(P_t^{US,L} B_t^{US,L}(j)\right)^{\frac{\lambda_3-1}{\lambda_3}}\right)^{\frac{\lambda_3}{\lambda_3-1}}, \tag{8}$$

where US government bonds, denominated in US dollars, are appropriately converted in euro terms by the bilateral nominal exchange rate S. The parameters ζ_1, ζ_2 ($\zeta_1, \zeta_2 > 0$, $1-\zeta_1-\zeta_2 < 1$) measure the relevance of respectively EA money and domestic government bonds in facilitating transactions. The US government bond characterizes the international component of the EA liquidity holdings. Similarly, the parameters $\theta, \omega \in (0,1)$ measure the relevance of EA and US short-term bonds, respectively ($1-\theta$ and $1-\omega$ measure the relevance of EA and US long-term bonds, respectively). Parameters $\lambda_1, \lambda_2, \lambda_3 > 0$ represent elasticities of substitution among assets in the corresponding bundle. As reported in section 2.4, our calibration implies that narrow money is a more liquid asset than sovereign bonds, as the related parameter in the liquidity bundle is relatively large. Thus, the APP generates an increase in overall liquidity, as the monetary authority exchanges a more liquid asset (money) for a less liquid one (long-term sovereign bonds).

The transactions cost allows sovereign bonds to directly affect the intertemporal cost of consumption. *Ceteris paribus*, a higher amount of sovereign bonds' holdings today reduces the transaction cost today and favors current relative to future consumption. [11]

Household's optimality conditions with respect to consumption C, domestic narrow money M, domestic (EA) short- and long-term government bonds, $B^{EA,S}$ and $B^{EA,L}$ respectively, and US short- and long-term government bond, $B^{S,US}$ and $B^{L,US}$ respectively, are given by the following equations:

$$\left(C_t(j) - \xi C_{t-1}\right)^{-\sigma} = \Lambda_t(j)\left[1 + 2A\left(v_t(j) - \bar{v}\right)\right], \tag{9}$$

$$1 - A\left[\left(v_t(j)\right)^2 - (\bar{v})^2\right] \times \zeta_1^{\frac{1}{\lambda_1}} \left(\frac{\tilde{M}_t(j)}{M_t(j)}\right)^{\frac{1}{\lambda_1}} = E_t\left[\beta \frac{\Lambda_{t+1}(j)}{\Lambda_t(j)} \frac{P_t}{P_{t+1}}\right], \tag{10}$$

$$\begin{aligned} 1 - A\left[\left(v_t(j)\right)^2 - (\bar{v})^2\right] \zeta_2^{\frac{1}{\lambda_1}} \theta^{\frac{1}{\lambda_2}} \left(\frac{\tilde{M}_t(j)}{B_t^{EA}(j)}\right)^{\frac{1}{\lambda_1}} \left(\frac{B_t^{EA}(j)}{B_t^{EA,S}(j)}\right)^{\frac{1}{\lambda_2}} &= \\ = R_t E_t\left[\beta \frac{\Lambda_{t+1}(j)}{\Lambda_t(j)} \frac{P_t}{P_{t+1}}\right], \end{aligned} \tag{11}$$

[11] Thus, the transaction cost is observationally equivalent to an always binding liquidity constraint, where in each period consumption has to be equal to the amount of overall available liquidity, including the sovereign bonds.

$$1 - A\left[\left(v_t\left(j\right)\right)^2 - \left(\bar{v}\right)^2\right]\zeta_2^{\frac{1}{\lambda_1}}\left(1-\theta\right)^{\frac{1}{\lambda_2}}\left(\frac{\tilde{M}_t\left(j\right)}{B_t^{EA}\left(j\right)}\right)^{\frac{1}{\lambda_1}}\left(\frac{B_t^{EA}\left(j\right)}{P_t^L B_t^{EA,L}\left(j\right)}\right)^{\frac{1}{\lambda_2}} =$$

$$= E_t\left[\beta\frac{\Lambda_{t+1}\left(j\right)}{\Lambda_t\left(j\right)}\frac{1+\kappa P_{t+1}^L}{P_t^L}\frac{P_t}{P_{t+1}}\right], \quad (12)$$

$$1 - A\left[\left(v_t\left(j\right)\right)^2 - \left(\bar{v}\right)^2\right] \times$$

$$\times\left(1-\zeta_1-\zeta_2\right)^{\frac{1}{\lambda_1}}\omega^{\frac{1}{\lambda_3}}\left(\frac{\tilde{M}_t\left(j\right)}{S_t B_t^{US}\left(j\right)}\right)^{\frac{1}{\lambda_1}}\left(\frac{B_t^{US}\left(j\right)}{B_t^{S,US}\left(j\right)}\right)^{\frac{1}{\lambda_2}} =$$

$$= R_t^{US} E_t\left[\beta\frac{\Lambda_{t+1}\left(j\right)}{\Lambda_t\left(j\right)}\frac{P_t}{P_{t+1}}\frac{S_{t+1}}{S_t}\right], \quad (13)$$

$$1 - A\left[\left(v_t\left(j\right)\right)^2 - \left(\bar{v}\right)^2\right] \times$$

$$\times\left(1-\zeta_1-\zeta_2\right)^{\frac{1}{\lambda_1}}\left(1-\omega\right)^{\frac{1}{\lambda_3}}\left(\frac{\tilde{M}_t\left(j\right)}{S_t B_t^{US}\left(j\right)}\right)^{\frac{1}{\lambda_1}}\left(\frac{B_t^{US}\left(j\right)}{P_t^{US,L} B_t^{US,L}\left(j\right)}\right)^{\frac{1}{\lambda_2}} =$$

$$= E_t\left[\beta\frac{\Lambda_{t+1}\left(j\right)}{\Lambda_t\left(j\right)}\frac{1+\kappa P_{t+1}^{US,L}}{P_t^{US,L}}\frac{S_{t+1}}{S_t}\frac{P_t}{P_{t+1}}\right], \quad (14)$$

where Λ is the marginal value of wealth.[12] Eq. (9) states that the marginal value of wealth is lowered by the transactions costs. Eq. (10) states that in equilibrium the current value of money holdings, which yield zero pecuniary returns, but provide transaction services (the left-hand-side of the equation), should be equal to the present value of the return on saving (the right-hand-side of the equation) – the stochastic discount factor. Similarly, eq. (11) shows that the presence of a liquidity premium, decreasing in the stock of government bonds outstanding (left-hand-side), determines the spread between the interest rate on short-term government bonds and that on a risky asset (right-hand-side). Thus, the latter show that, due to the presence of transactions services, interest rates differ from a standard model in which assets are perfect substitutes. A similar intuition applies to the other above reported first order conditions. These liquidity premia are affected by the size of the asset stocks outstanding in each period. Given demand for overall liquidity, demand for a specific liquid asset is directly proportional to the asset's capability of facilitating transaction costs (measured by its weight in the transaction technology) and its "pecuniary" return. At the margin, expected

[12]The remaining first order conditions are not shown for brevity and are available upon request.

returns of different assets are equated, taking into account the transaction services provided by each asset. The transaction cost is relevant for multiple assets to have a nontrivial role in households' choices. Without the transaction cost, indeed, assets would be perfectly substitutable, and the increase in bonds purchases would not have real effects. For the nominal exchange rate determination, combining the linearized versions of the optimality conditions with respect to domestic and US government bonds shows that there is a departure from the standard uncovered interest parity condition (UIP), due to the imperfect substitutability between domestic and foreign bonds.

Similar expressions for budget constraints, transaction costs and liquidity hold for households in regions other than the EA. Liquidity holdings of US households include domestic money, government bonds and, as international component, EA government bonds. The liquidity holdings of CH, JP, and RW households include not only domestic money and government bonds, but also, as international components, both US and EA government bonds. For example, in the case of the generic RW household j, overall liquidity $\tilde{M}$ is defined as

$$\tilde{M}_t(j) = \left(\begin{array}{c} \zeta_1^{\frac{1}{\lambda_1}} M_t(j)^{\frac{\lambda_1-1}{\lambda_1}} + \zeta_2^{\frac{1}{\lambda_1}} B_t(j)^{\frac{\lambda_1-1}{\lambda_1}} + \zeta_3^{\frac{1}{\lambda_1}} \left(S_t^{RW} B_t^{US}(j) \right)^{\frac{\lambda_1-1}{\lambda_1}} \\ + (1-\zeta_1-\zeta_2-\zeta_3)^{\frac{1}{\lambda_1}} \left(\frac{S_t^{RW}}{S_t} B_t^{EA}(j) \right)^{\frac{\lambda_1-1}{\lambda_1}} \end{array} \right)^{\frac{\lambda_1}{\lambda_1-1}} \quad (15)$$

where the term S^{RW} is the nominal exchange rate of the RW currency against the US dollar (units of RW currency per US dollar). A similar bundle holds for CH and JP households.[13]

[13]Our "representative" country-specific liquidity portfolio can be thought as a synthesis of different strategies of liquidity management, followed by investors that are rather different in terms of preferences and available financial technologies. We choose not to model this type of heterogeneity to keep the model parsimonious.

2.2 Public sector supply and demand of (international) liquidity

In each region a standard Taylor rule holds for the gross (short-term) monetary policy rate:

$$\log\left(R_t/\bar{R}\right) = \rho_R \log\left(R_{t-1}/\bar{R}\right) + (1-\rho_R)\,\varphi_\pi \log\left(\Pi_t/\bar{\Pi}\right) + (1-\rho_R)\varphi_{GDP}\log(GDP_t/GDP_{t-1}), \tag{16}$$

where an upper-bar "$^-$" denotes steady-state values of variables, $\rho_R > 0$ is a parameter capturing inertia in the monetary policy conduct, φ_π and φ_{GDP} are the parameters measuring respectively the response of the policy rate to deviations of the (gross) domestic inflation rate Π from its target $\bar{\Pi}$ and to the GDP growth rate. As in standard New Keynesian models, the central bank sets the short-term interest rate on domestic (short-term) government bonds by appropriately changing the amount of money supply.

The EA monetary authority implements the APP by buying EA long-term sovereign bonds in the secondary market. In each period, the amount of purchased sovereign bonds by the central bank, $B^L_{CB,t}$, is exogenously set through an appropriate shock.

The budget constraint of the fiscal authority is

$$B^{G,S}_t + P^L_t B^{G,L}_t = R_{t-1}B^{G,S}_{t-1} + \left(1+\kappa P^L_t\right) B^{G,L}_{t-1} + P_t G_t - TAX_t + TR_t, \tag{17}$$

where $B^{G,S}$ is the supply of domestic short-term government bonds, $B^{G,L}_t$ is the supply of long-term government bonds ($B^{G,S}_t$, $B^{G,L}_t > 0$ represent short- and long-term public debt, respectively). The term G_t denotes public consumption, TAX_t is lump-sum taxes and TR_t lump-sum transfers. Public consumption is assumed to be exogenous and is kept constant at its steady-state level.

Lump-sum taxes guarantee fiscal solvency according to the fiscal rule

$$TAX_t - \overline{TAX} = \varphi_b\left(B^{G,S}_{t-1} - \bar{B}^{G,S}\right), \tag{18}$$

where $\overline{TAX}$ is the tax steady-state level, φ_b is a parameter that determines the tightness of the fiscal policy rule, i.e. the speed at which the short-term debt is returned to the target (steady-state) level, $\bar{B}^{G,S}$. Similarly in CCDLS, the parameter φ_b is assumed to be larger than the steady-state value of the real interest rate paid by the short-term government bond, to guarantee that the primary surpluses move to stabilize the debt. The supply of long-term sovereign bonds is exogenously set.

2.3 Bond market clearing conditions

For the EA short-term government bond, the (world-wide) market clearing condition is

$$\begin{aligned} & \int_0^{n^{EA}} B_t^{EA,S}(j)\,dj + \int_{n^{EA}}^{n^{US}} B_t^{EA,S}(j)\,dj + \\ & \int_{n^{US}}^{n^{CH}} B_t^{EA,S}(j)\,dj + \int_{n^{CH}}^{n^{JP}} B_t^{EA,S}(j)\,dj + \int_{n^{JP}}^{1} B_t^{EA,S}(j)\,dj \\ = \; & B_t^{S,G}. \end{aligned} \tag{19}$$

Correspondingly, the market clearing of the EA long-term government bond is

$$\begin{aligned} & \int_0^{n^{EA}} B_t^{EA,L}(j)\,dj + \int_{n^{EA}}^{n^{US}} B_t^{EA,L}(j)\,dj + \\ & \int_{n^{US}}^{n^{CH}} B_t^{EA,L}(j)\,dj + \int_{n^{CH}}^{n^{JP}} B_t^{EA,L}(j)\,dj + \int_{n^{JP}}^{1} B_t^{EA,L}(j)\,dj \\ & + B_{CB,t}^{L} \\ = \; & B_t^{L,G}, \end{aligned} \tag{20}$$

where B_{CB}^{L} represents the purchases of EA long-term sovereign bonds by the EA monetary authority. Similar conditions hold for US short- and long-term sovereign bonds.

CH, JP and RW government issue short-term and long-term government bonds to domestic households. The corresponding market clearing conditions for CH are

$$B^{S,G}_{CH,t} = \int_{n^{US}}^{n^{CH}} B^{S}_{CH,t}(j)\,dj, \tag{21}$$

$$B^{L,G}_{CH,t} = \int_{n^{US}}^{n^{CH}} B^{L}_{CH,t}(j)\,dj. \tag{22}$$

Similar conditions hold for JP and RW sovereign bonds.

Finally, the market clearing condition for the bond denominated in US dollars that does not provide liquidity services is

$$\begin{aligned} & \int_{0}^{n^{EA}} B^{PR}_{EA,t}(j)\,dj + \int_{n^{EA}}^{n^{US}} B^{PR}_{US,t}(j)\,dj \\ & + \int_{n^{US}}^{n^{CH}} B^{PR}_{CH,t}(j)\,dj + \int_{n^{CH}}^{n^{JP}} B^{PR}_{JP,t}(j)\,dj + \int_{n^{JP}}^{1} B^{PR}_{RW,t}(j)\,dj \\ = \; & 0. \end{aligned} \tag{23}$$

The conditions make clear the interaction between the central bank, the fiscal authority and households when the APP is implemented. EA central banks' purchases of domestic long-term sovereign bonds is an asset demand shock. For a given supply of EA government bonds, the shock affects the long-term interest rate and hence the (optimal) demand of households for each asset. As a result a new market equilibrium, characterized by new equilibrium interest rates, exchange rates and, hence, real allocations is achieved.

2.4 Calibration

We fully match all reported empirical ratios by appropriately adjusting parameters of the model. Parameters in the production functions, consumption and investment baskets are set to exactly match the observed "great ratios" (2012 averages) and trade flows. Moreover, similarly to CCDLS, we calibrate the parameters of transactions costs and the transactions technology to match key monetary and fiscal ratios. Remaining parameters are set to values in line with theoretical and quantitative contributions of a fully estimated version of the ECB New Area Wide

Model (NAWM, see Christoffel, Coenen and Warne 2008), the IMF Global Economy Model (GEM, see Laxton 2008 and Pesenti 2008) and the Eurosystem Euro Area and Global Economy Model (EAGLE, see Gomes, Jacquinot and Pisani 2010).

Table 1 reports the model implied great ratios for the five regions.

Table 2 shows the preference and technology parameters. Preferences are the same across households of different regions. The habit parameter is set to 0.85, the intertemporal elasticity of substitution to 1.0 and the Frisch elasticity to 0.50. We further assume a quarterly depreciation rate of capital to 0.02, consistently with an annual depreciation rate of 8%.

As for the final goods, the degree of substitutability between domestic and imported tradables is higher than that between tradables and non-tradables, consistently with the existing literature. We set the (long-run) elasticity of substitution between tradables and non-tradables to 0.5 and the long-run elasticity between domestic and imported tradables to 2.5.

Table 3 reports real and nominal rigidities. For real rigidities, parameters of the adjustment costs on investment changes are set to 3.5 in all countries. For nominal rigidities, we set the Rotemberg (1982) price and wage adjustment parameters in the tradable and non-tradable sectors to 400. This value for quadratic adjustment costs in prices is roughly equivalent to a four-quarter contract length under Calvo-style pricing, as highlighted, among others, by Faruquee, Laxton and Muir (2007).

Table 4 reports the values of the elasticity of substitution among assets in the liquidity bundle, the elasticity of substitution among imported goods and the steady-state international trade linkages. Parameters λ_1, λ_2 and λ_3 in eqs. (6)-(8) are set to 1 in every region, in line with CCDLS ("Cobb-Douglas" calibration).

The weight of domestic tradable goods in the consumption and investment tradable baskets is different across countries, to match multilateral import-to-GDP ratios. In particular, we rely on the United Nations' Commodity Trade Statistics (COMTRADE) data on each region's imports of consumer and capital goods, to derive a disaggregated steady-state matrix delineating the pattern and composition of trade for all regions' exports and imports. We then set the weights of bilateral imports to match this trade matrix, reported in Table 4. It is interesting to highlight that trade with the RW region clearly dominates trade patterns for all the other countries, and in particular for EA.

Table 5 contains price and wage markup values. We identify the non-tradable and tradable intermediate sectors in the model with the services and manufacturing sectors in the data, respectively. In each region the markup in the non-tradable sector is higher than that in the tradable sector and labor market, which we instead assume to be equal. Our values are in line with other existing similar studies, such as Bayoumi, Laxton and Pesenti (2004), Faruqee, Laxton and Muir (2007). Many, if not all, of these studies refer to Jean and Nicoletti (2002) and Oliveira Martins and Scarpetta (1999) for estimates of markups.

Table 6 reports the parameters of the policy rules. For monetary policy rules, the interest rate reacts to the its lagged value (inertial component of the monetary policy), gross inflation and output growth (see eq. 16). For fiscal policy, the parameter governing the speed of speed of adjustment of short-run public debt is assumed equal across countries and allows to stabilize the short-run debt in the long run (long-run debt is exogenous and kept constant at its steady-state level in every region).

Table 7 shows the ratios (% of GDP) for the different asset stocks that enter into the model: currency in circulation, total general government debt levels and, in the case of the US and the EA, for foreign private holdings of government debt issued in US dollars and in euros. The ratios are matched by calibrating the parameters affecting the transactions technology, which involves money and government bonds held by private agents. Following CCDLS we first compute the asset ratios using the data available on currency in circulation, total general government debt levels and, for the United States and the EA, on foreign private holdings of government debt issued in US dollars and in euros. The specific data sources used to compute these stocks are reported in the Appendix "Data". Second, we use these asset ratios, together with the steady state level of transactions costs (τ in eq. 4), which we set as in CCDLS to 0.8% of consumption, and with our choice of the liquidity premium, to jointly pin down the parameters entering the transactions costs and transactions technology (i.e. the cost parameters A, the satiation levels of velocity v, and the shares of the various assets – denoted above by ζ and ω – in the definition of the liquidity balances, $\tilde{M}$). We match asset shares by maturity distribution. We consider as "short-term" ("long-term") those outstanding bonds having residual maturity up to (greater than) 1 year.

In our model the yield curve on sovereign bonds is composed by two "points", one representing the short-term sovereign bond and its return, the other the long-term sovereign bonds and its return. Short- and long-term interest rates are endogenously determined by market clearing conditions, given the calibrated values for bond holdings. The short-term interest rate is around 3% in every region, the long-term interest rate is around 4%. The duration of the long-term bonds is set to 6.5 years.

3 Results

3.1 Simulated scenarios

In all scenarios, the APP is simulated as an exogenous increase in the purchases of long-term sovereign bonds by the EA monetary authority. The shock is calibrated so that it corresponds to quarterly purchases of euro 180 billion that last from March 2015 to the end of September 2016 (7 quarters). During the initial 8 quarters, the EA short-term monetary policy rate is constant at its baseline level $\bar{R}$ (see Taylor rule, eq. 16), reflecting the commitment of the EA central bank to maintain an accommodative stance for a prolonged period (EA FG). Thus, the constant monetary policy rate is not associated with the zero lower bound constraint, but should be interpreted as a deliberate policy choice. From quarter 9, the monetary policy rate is set according to the Taylor rule, that kicks in and becomes active. Finally, the supply of long-term public debt is kept constant at its steady-state level.

We run the following simulations.

In the first scenario, It is assumed that the EA central bank holds the purchased bonds to maturity (benchmark case).

In the second scenario, the EA central bank sells long-term sovereign bonds immediately at the end of the purchasing period ("early-exit" case).

In the third and fourth scenarios, on top of the APP, it is assumed that a positive demand shock stimulates the US economy. In one case, the FED keeps the US policy rate at its baseline level during the first year after the shock, instead of raising it to stabilize the economy (we label it "early normalization of US monetary policy"). In the alternative scenario, the FED keeps the policy rate at its baseline level during the first three years ("late normalization of US monetary policy"). In quarter 5 and 13 the FED resumes to set the policy rate according to the Taylor rule, respectively.

All simulations are run under perfect foresight. Therefore, there is no uncertainty, policies are announced by the monetary authority, fully credible and households and firms perfectly anticipate the future.[14]

3.2 Benchmark simulation: domestic (EA) effects

The EA long-term interest rate declines following the increase in long-term bond purchases by the EA monetary authority (the long-term rate is measured by the yield-to-maturity, see eq. 3).

The low long-term interest rate is an incentive to substitute the most liquid asset – domestic narrow money – and the EA short-term sovereign bond, whose relative pecuniary return has increased, for EA long-term sovereign bonds. Overall liquidity $\tilde{M}$ increases.

Fig. 1 reports the responses of the main EA macroeconomic variables. Both EA GDP and inflation increase. The reduction in the transaction cost – associated with the increase in liquidity – induces households to increase consumption. Firms increase production to match the higher demand, by augmenting labor. The implied higher marginal productivity of capital favors the increase in investment. Higher aggregate demand induces higher inflation. Given that the central bank does not increase the short-term term interest rate, the persistent increase in inflation favors the reduction in the real interest rates, that further stimulate aggregate demand. Higher activity stimulates imports, while higher prices have a negative effect on international competitiveness, partially compensated in the short-run by the nominal (and real) exchange rate depreciation. Overall, exports do not greatly change, in particular in the short run.

[14] In particular, there is no premium associated with inflation risk.

3.3 Early exit from bond holdings

We consider the case of an "early exit from sovereign bond holdings". In this alternative scenario, the EA monetary authority starts to gradually sell the purchased bonds from quarter eight (thus, immediately after the end of the purchasing period).

Figure 2 compares the results of the benchmark and early-exit cases. In the early-exit case, households and firms anticipate that the amount of most liquid narrow money are going to be reduced and increased for a relatively short amount of time, respectively. Thus, they increase demand for consumption and investment to a lower extent than in the benchmark scenario. Consistent with the more muted increase in aggregate demand, the increase in EA labor and imports increase is lower, and, more crucially, the increase in inflation is mitigated as well. Given the smaller injection of narrow money, the EA currency depreciates to a lower extent (bottom panel), limiting the price competitiveness gain of EA export (whose increase is small) and the increase in inflation, in particular the imported component.

Figure 3 reports, for the two scenarios, the spillovers to the region RW. Spillovers in the early-exit case are smaller than spillovers in the benchmark scenario. Under early exit, EA aggregate demand increases to a relatively low extent. Thus, Home imports increase to a low extent as well, implying a modest stimulus to the RW production of tradable goods (which are exported to the EA). The small expansionary impulse implies that in the RW labor and, thus, consumption and investment, increase to a low extent. Inflation, as a consequence, modestly increases as well.

Figure 4 reports the spillovers to the US economy. Qualitatively, they are similar to those to the RW. The smaller the increase in EA imports of US goods, the smaller the stimulating effect on the US production and, thus, on US households' income and aggregate demand. In each scenario, the spillovers to US are smaller than the spillovers to the RW. The reason is the different degree of trade integration, because the EA-RW (bilateral) trade is larger than the EA-US trade.

Overall, the central bank announcement to hold long-term sovereign bonds for a relatively short amount of time limits the (short-term) effectiveness of the APP in stimulating the EA economy and favoring the price stability, and, thus, limits the size of the implied international spillovers.

3.4 Normalization of US monetary policy

We now consider two alternative strategies of the normalization of the US monetary policy in correspondence of an expansionary aggregate demand shock affecting the US economy. In one case, the FED commits to keep the short-term policy rate constant at its baseline level during the first year, instead of raising it to stabilize the economy (early normalization of the US monetary policy), in the other during the first three years (late normalization of the US monetary policy). The EA central bank, as in the previous scenarios, implements the APP and keep the policy rate constant during the first two years.

Figure 5 shows the results for the main US variables. The more the monetary policy rate is kept constant at its baseline level, the more the aggregate demand shock is amplified. The reason is the larger drop in the US real interest rate, associated with the larger increase in expected inflation, when the nominal interest rate is constant for three years. Aggregate demand for consumption and investment increases relatively more, favoring a larger increase in imports.

Figure 6 reports the effects on the EA economy. Spillovers are rather contained. EA GDP does not greatly change. If anything, it slightly increases relatively more when the US interest rate is kept constant during the initial three years. The reason is the larger increase in US aggregate demand, which favors EA exports towards the US to a larger extent. Interestingly, when comparing the two scenarios, in the case of the late normalization of US monetary policy the additional expansionary effect of US aggregate demand more than counterbalances the additional euro exchange rate depreciation (the US dollar appreciates to a lower extent, because the US policy rate starts to increase later than in the case of the early normalization of US monetary policy).

Figure 7 reports the effects on the RW. Qualitatively, spillovers to the RW are similar to those to the EA, as they are expansionary. The only difference is the real exchange rate against the US dollar. It does not depreciates, as the euro does, but appreciates, because in the RW the interest rate is increased by the monetary authority to stabilize the economy. The appreciation is larger in the late-normalization than in the early-normalization case, because the US policy rate starts to increase later in the former than in the latter case. However, the RW exports increase more in the late-normalization case, because of the larger increase in US aggregate demand. Quantitatively, the results do not greatly change across the two scenarios, with RW GDP increasing more in the late-normalization case, favored by the larger exports towards the US.

Overall, spillovers to the EA associated with alternative stances of the US monetary policy are rather small. The additional stimulus associated with the US expansion can give a limited contribution to improve economic conditions and favor price stability in the EA. A US-based stimulus to the EA economy can hardly substitute for a domestic (EA-based) stimulus. This result suggests the relevance of properly designing EA non-standard monetary policy measures, to maximize its effectiveness, and in particular of properly calibrating the announced timing of the measures' unwinding.

4 Conclusions

Our results suggest that an early exit from the APP, by severely dampening its effectiveness in stimulating the EA economy, dampens the EA aggregate demand and, therefore, EA imports. The expansionary international spillovers are, therefore, reduced. If the US monetary authority announces a shorter period of constant policy rate, then the spillovers from the US to the EA are expansionary, as in the case of a longer period of constant policy rate, but more modest. This being the case, it becomes even more crucially to correctly identify the appropriate point in time to exit EA non standard monetary policy measures.

The obtained results suggest further extension of the work. First, in addition to EA and US monetary policy decisions, the measures implemented by Japan and the Chinese exchange rate regime can be simulated too, to get a complete picture of the impact of cross-country monetary policy. Second, the role of cross-country monetary policy coordination can be explored. We leave these issues for future research.

Table 1: Steady state national accounts (% of GDP)

	EA	US	CH	JP	RW
Private consumption	54.3	58.5	38.8	55.1	56.7
Investment	20.0	15.0	40.0	20.0	20.0
Public consumption	20.0	20.0	20.0	20.0	20.0
Imports	23.8	14.3	22.2	14.8	19.2
Consumption goods	13.1	7.8	10.3	8.2	11.1
Investment goods	10.7	6.5	11.9	6.6	8.1
Share of world GDP	14.1	21.1	14.9	9.2	40.7

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 2: Households and Firms Behavior

	EA	US	CH	JP	RW
Households					
Subjective discount factor	0.995	0.995	0.995	0.995	0.995
Depreciation rate	0.02	0.02	0.02	0.02	0.02
Intertemporal elasticity of substitution	1.00	1.00	1.00	1.00	1.00
Habit persistence	0.85	0.85	0.85	0.85	0.85
Inverse of the Frisch elasticity of labor	2.00	2.00	2.00	2.00	2.00
Tradable Intermediate Goods					
Bias toward capital	0.40	0.40	0.50	0.40	0.40
Non-tradable Intermediate Goods					
Bias toward capital	0.35	0.35	0.45	0.35	0.35
Final consumption goods					
Substitution btw domestic and imp. goods	2.50	2.50	2.50	2.50	2.50
Bias toward domestic goods	0.52	0.83	0.34	0.67	0.77
Substitution btw tradables and non-trad.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.50	0.50	0.60	0.50	0.50
Final investment goods					
Substitution btw domestic and imp. goods	2.50	2.50	2.50	2.50	2.50
Bias toward domestic goods	0.28	0.59	0.24	0.47	0.60
Substitution btw tradables and nontr.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.50	0.50	0.70	0.50	0.50

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 3: Real and nominal rigidities

	EA	US	CH	JP	RW
Real Rigidities					
Investment adjustment	3.50	3.50	3.50	3.50	3.50
Nominal Rigidities					
Households					
Wage stickiness	400	400	400	400	400
Manufacturing					
Price stickiness (domestically produced goods)	400	400	400	400	400
Price stickiness (imported goods)	400	400	400	400	400
Services					
Price stickiness	400	400	400	400	400

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 4: International linkages (% GDP)

	EA	US	CH	JP	RW
Substitution between assets in the liquidity bundle	1.00	1.00	1.00	1.00	1.00
Substitution between consumption imports	2.50	2.50	2.50	2.50	2.50
Imported consumption goods from					
EA	...	1.1	1.0	0.8	3.4
US	0.9	...	0.8	0.7	4.3
CH	1.3	1.4	...	1.8	2.5
JP	0.3	0.5	0.9	...	0.9
RW	10.5	4.9	7.6	5.9	...
Substitution between investment imports	2.50	2.50	2.50	2.50	2.50
Imported investment goods from					
EA	...	0.8	1.1	0.4	2.9
US	0.9	...	0.9	0.6	1.7
CH	1.2	1.3	...	1.4	2.7
JP	0.3	0.4	1.3	...	0.9
RW	8.4	4.0	8.6	4.3	...
Net foreign assets (%yearly GDP)	−17.6	−27.4	21.0	57.3	5.3
Net foreign assets (%yearly GDP) (1)	−0.4	13.3	−6.5	23.0	−9.9
Financial intermediation cost function (ϕ_1)	0.15	...	0.15	0.15	0.15
Financial intermediation cost function (ϕ_2)	0.3	...	0.3	0.3	0.3

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world. (1) net of private and official holdings of USD and EUR government bonds

Table 5: (Gross) Price and wage markups

	EA	US	CH	JP	RW
Manufacturing (tradables) price markup	1.20	1.20	1.20	1.20	1.20
Services (non-tradables) price markup	1.30	1.30	1.30	1.30	1.30
Wage markup	1.20	1.20	1.20	1.20	1.20

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 6: Monetary and fiscal policy

	EA	US	CH	JP	RW
Inflation target	1.02	1.02	1.02	1.02	1.02
Interest rate inertia	0.87	0.87	0.87	0.87	0.87
Interest rate sensitivity to inflation gap	1.70	1.70	1.70	1.70	1.70
Interest rate sensitivity to output growth	0.10	0.10	0.10	0.10	0.10
Lump-sum tax sensitivity to debt gap	0.60	0.60	0.60	0.60	0.60

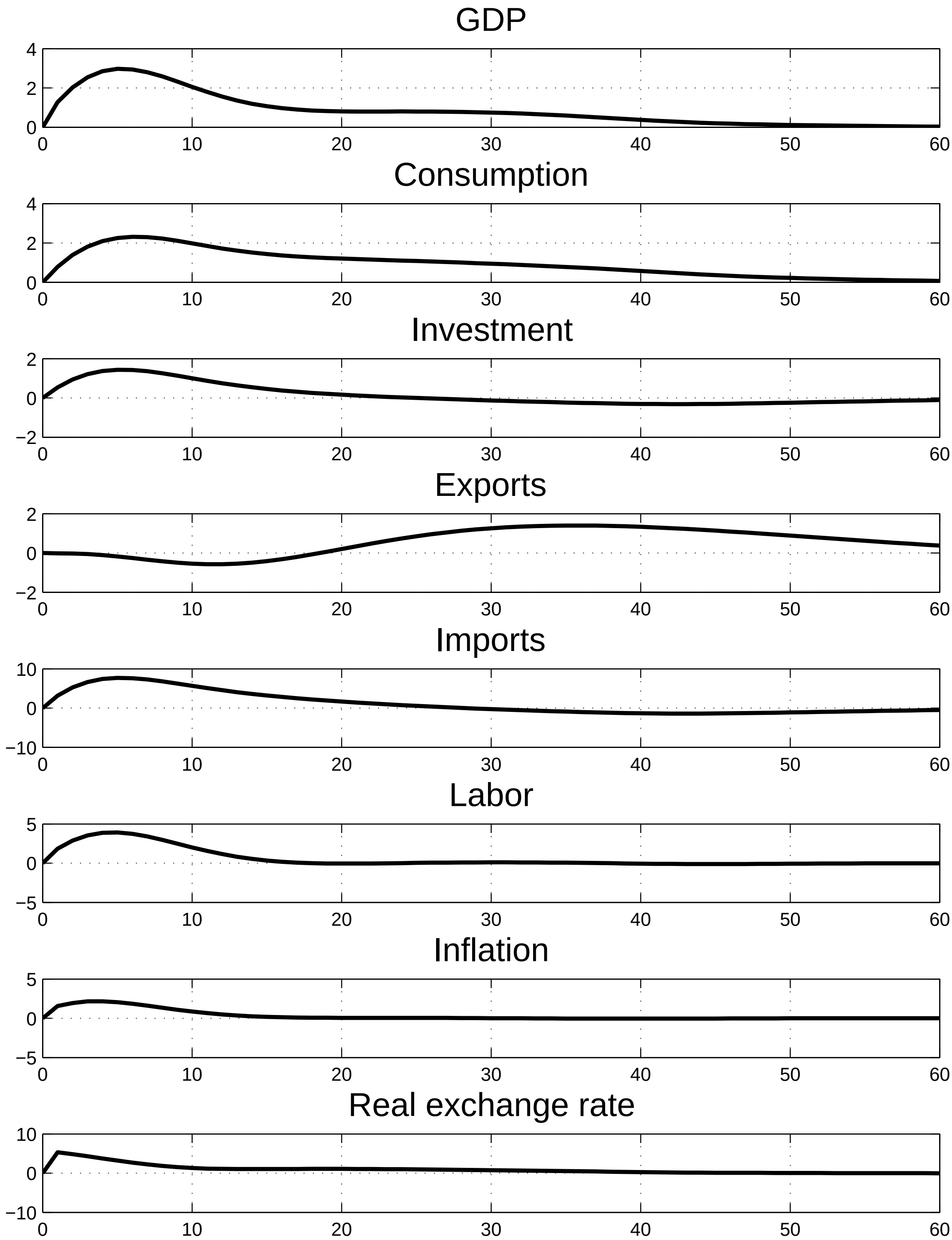
Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 7: Asset ratios (% of annualized GDP)

	EA	US	CH	JP	RW
Private agents					
Currency in circulation	8	6	12	15	8
USD govt bond holdings	2	23	5	7	3
EUR govt bond holdings	67	1	4	6	2
Total govt. debt	93	75	26	201	81
Share of long-term govt. debt, % of total debt	85	69	83	94	83

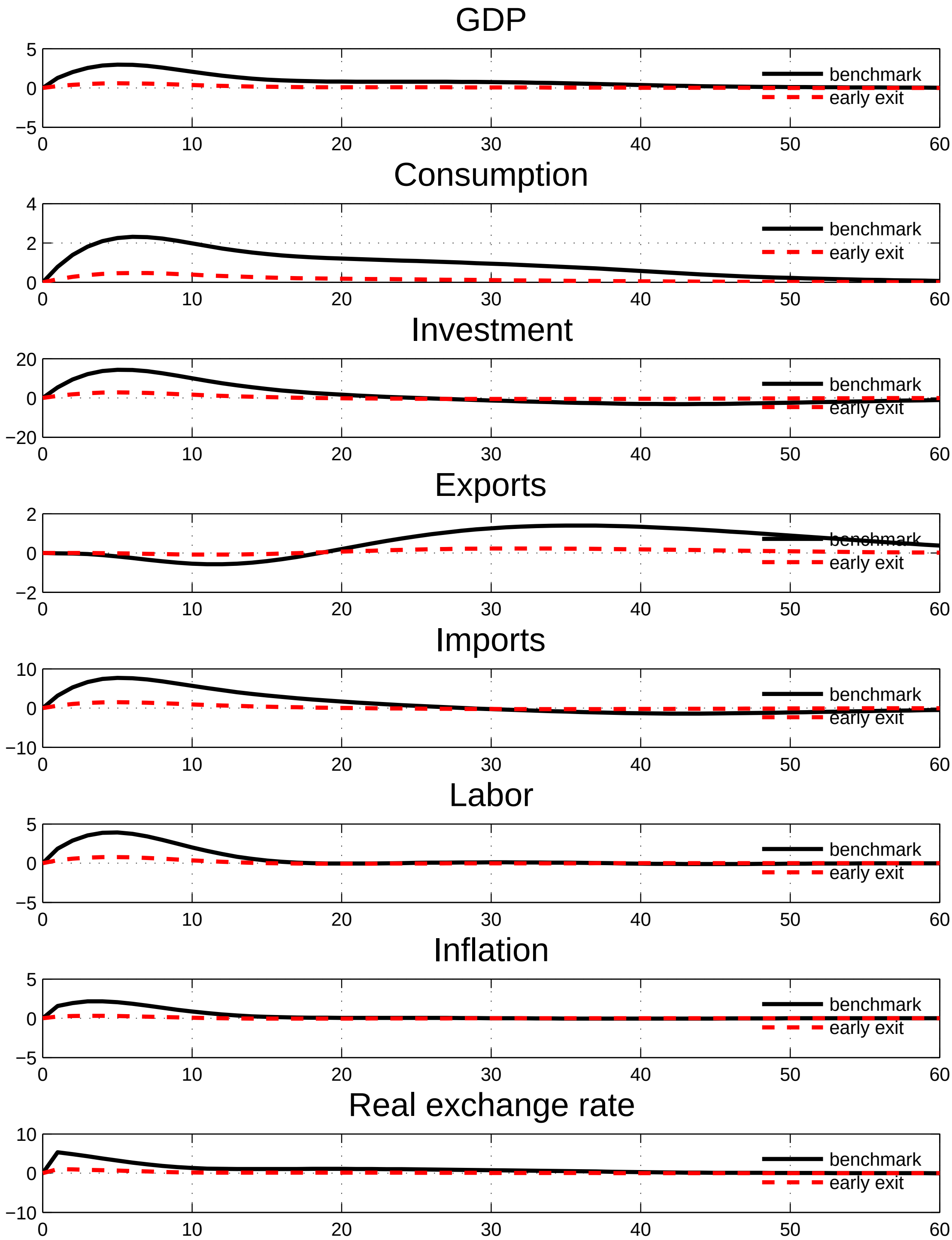
Notes: EA=euro area; US=United States; CH=China; RW=Rest of the world. Private holdings of US government bonds for CH are set as the average of private holdings for JP and RW. Long-term bonds are those with maturities greater than 1 year. For CH and RW, shares of long-term bonds are set to the average of EA, US and JP. Sources: Department of the Treasury, Federal Reserve Bank of New York, Board of Governors of Federal Reserve System Foreign Portfolio Holdings of US Securities (April 2013), ECB The International Role of the Euro (July 2013), IMF Fiscal Monitor (October 2014), IMF International Financial Statistics (October 2014).

Figure 1: EA APP . EA macroeconomic variables.



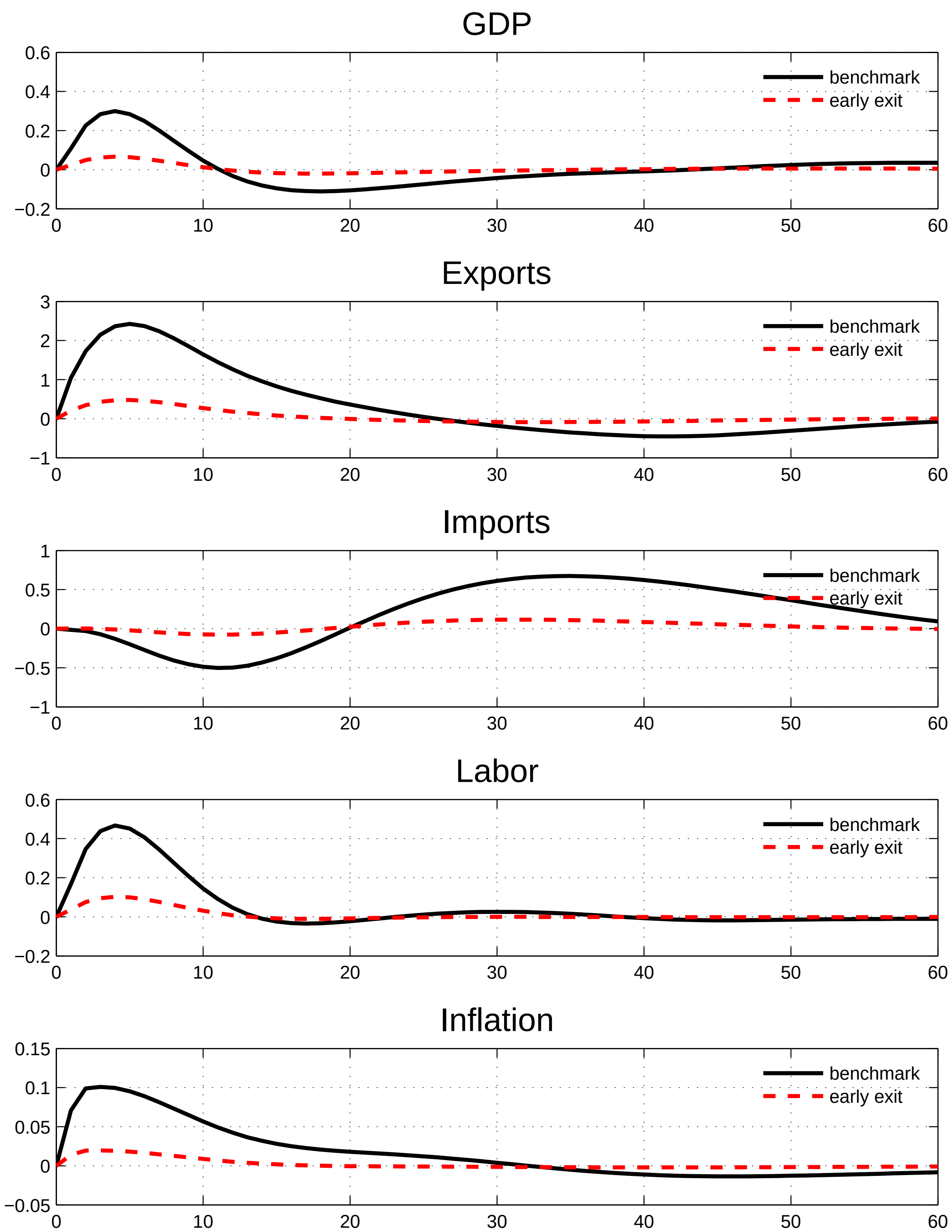
Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 2: EA APP and early-exit. EA macroeconomic variables.



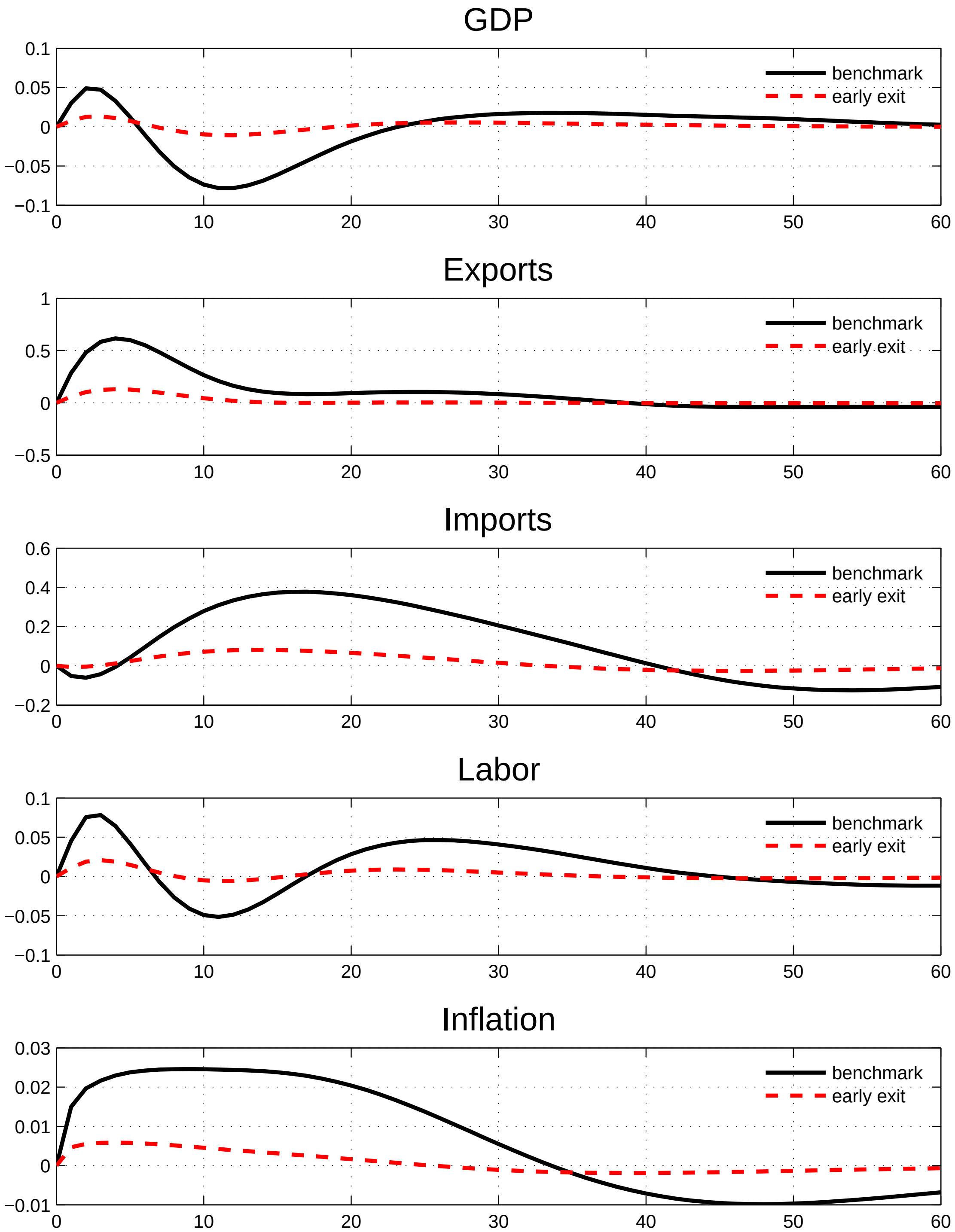
Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 3: EA APP and early exit. RW macroeconomic variables.



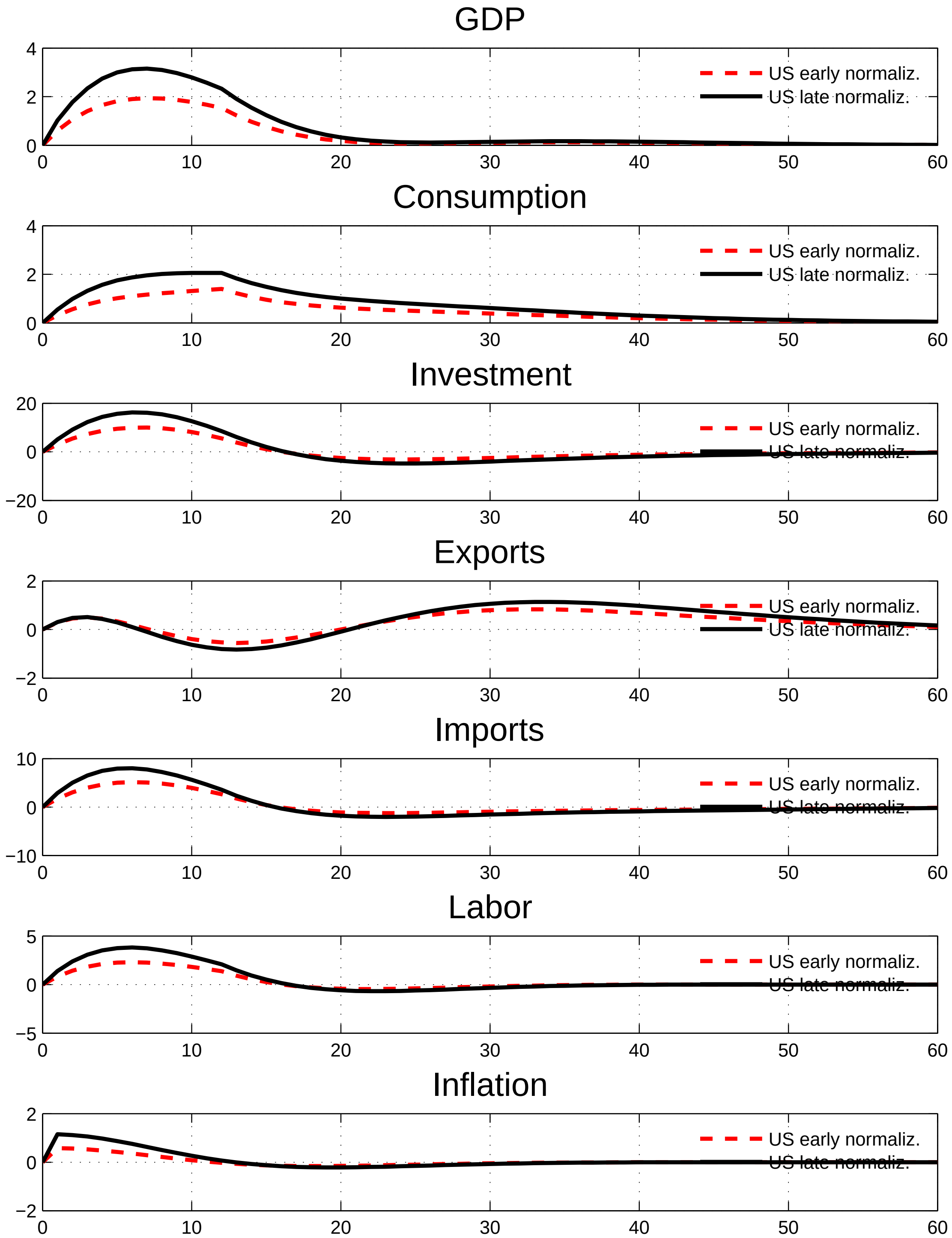
Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 4: EA APP and early exit. US macroeconomic variables.



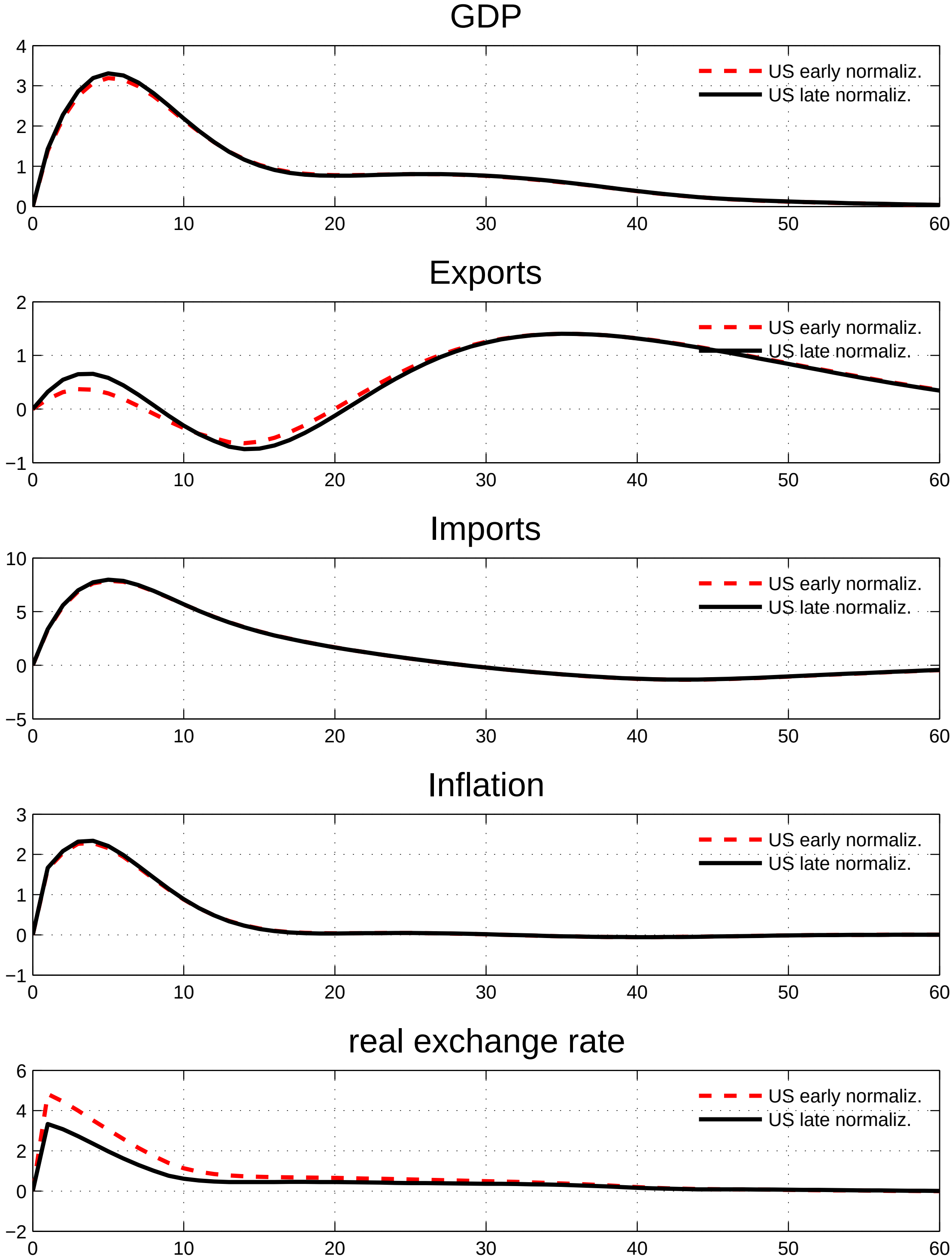
Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 5: US monetary policy normalization and EA APP. US variables.



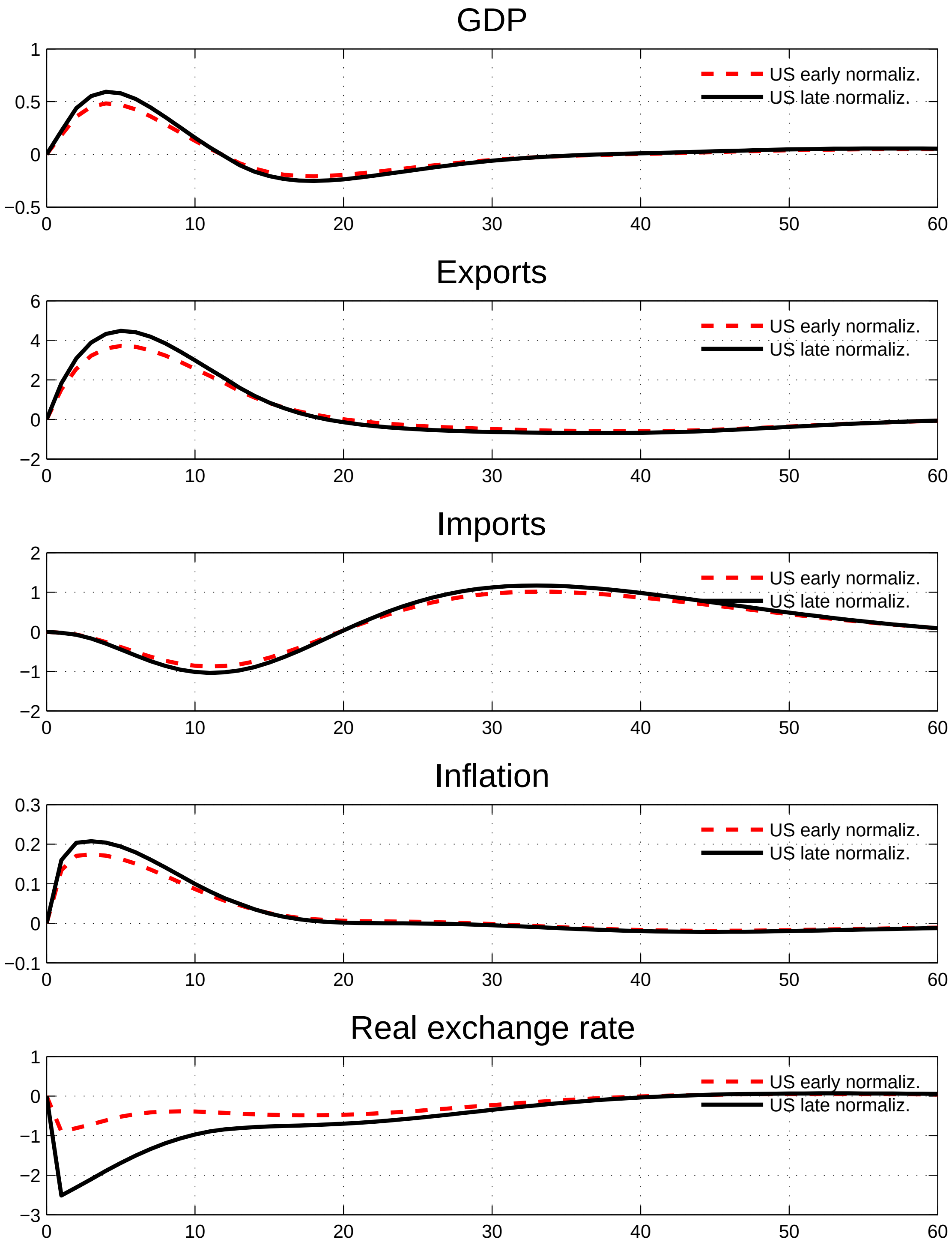
Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 6: US monetary policy normalization and EA APP. EA variables.



Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Figure 7: US monetary policy normalization and EA APP. RW variables.



Notes: Horizontal axis, quarters; vertical axis, % deviations from the steady state. For inflation, annualized percentage point deviations from the steady state.

Appendix: Data sources

We rely on several data sources in order to compute the different asset holdings that characterize the model. In particular, money balances held by households are computed as 2001-2012 averages using the variable "Currency in circulation" from the IMF's *International Financial Statistics* database. Data on foreign private and official holdings of US government bonds is taken from the April 2013 issue on *Foreign Portfolio Holdings of US Securities.*[15] The outstanding holdings refer to June 2012. We include both short- and long-term debt issued both by the Treasury and by the Government-sponsored Agencies. The latter have been taken over or placed into conservatorship by the U.S. Treasury in September 2008, and as such should command a liquidity premium equal or, at least, very close to that on U.S. Treasury bonds. As the information provided for China only refers to the aggregate holdings, with no distinction between private and official holdings being available, we assume that the entire holdings are official, except for a small part which we arbitrarily assume is being held by private households: alternatively, we would have needed to modify the model in order to set private Chinese household holdings of US bonds equal to zero, but this would have added some complications to our calibration procedure. Foreign holdings of euro denominated government bonds are computed from Tables A1 and A2 in *The International Role of the Euro*, July 2013, ECB. As we have no information on the different types of holders, we apply the same percentage shares used for US government bonds, taken from the aforementioned publication, to compute private versus official holdings of euro denominated government bonds. Finally, data on domestic holdings of government bonds are computed by combining the IMF's *Fiscal Monitor* database and the information on the different types of holders (private vs. official) reported in Andritzky (2012).

[15]See Department of the Treasury, the Federal Reserve Bank of New York, and the Board of Governors of the Federal Reserve System (2013).

Appendix: The Model

In this Appendix we report a detailed description of the model except for fiscal and monetary policies and households' optimization problems, which are reported in the main text.[16]

There are five blocs, Home, US (*), CH (China, **), JP (Japan, ***), and RW (rest of the world, ****). In what follows we illustrate the Home economy. The structure of each of the other four regions is similar and to save on space we do not report it.

Final consumption and investment goods

There is a continuum of symmetric Home firms producing nontradable final consumption under perfect competition. Each firm producing the consumption good is indexed by $x \in (0, n]$, where the parameter $0 < n < 1$ measures the size of Home economy. Firms in the other regions are similarly indexed (the size of the world economy is normalized to 1, so $n + n^* + n^{**} + n^{***} + n^{****} = 1$). The CES production technology used by the generic firm x is

$\frac{\rho_A - 1}{\rho_A}$

$$A_t(x) \equiv \left(a_{TA}^{\frac{1}{\phi_A}} \left(a_{HA}^{\frac{1}{\rho_A}} Q_{HA,t}(x)^{\frac{\rho_A-1}{\rho_A}} + (1-a_{HA})^{\frac{1}{\rho_A}} \left(\sum_{i=1}^{C-1} a_{IMPA,i}^{\frac{1}{\rho_{IMP}}} Q_{IMPA,i,t}(x)^{\frac{\rho_{IMP}-1}{\rho_{IMP}}} \right)^{\frac{\rho_{IMP}}{\rho_{IMP-1}}} \right)^{\frac{\rho_A}{\rho_A-1}\frac{\phi_A-1}{\phi_A}} + (1-a_{TA})^{\frac{1}{\phi_A}} Q_{NA,t}(x)^{\frac{\phi_A-1}{\phi_A}} \right)^{\frac{\phi_A}{\phi_A-1}}$$

where Q_{HA}, Q_{IMPA}, and Q_{NA} are bundles of respectively tradable intermediate goods produced in the Home country, tradable intermediate goods produced in one among the other four regions and imported by Home, and nontradable intermediate goods produced in the Home country. The parameter $\rho_A > 0$ is the elasticity of substitution between tradable goods and $\phi_A > 0$ is the elasticity of substitution between tradable and nontradable goods. The parameter a_{HA} $(0 < a_{HA} < 1)$ is the

[16] For a detailed description of the main features of the model see also [?].

weight of the Home tradable, the parameter $a_{IMP,i}$ ($0 < a_{IMP,i} < 1$, $\sum_{i=1}^{C-1} a_{IMPA,i}$) the weight of the generic imported tradable from country i, and the parameter a_{TA} ($0 < a_{TA} < 1$) the weight of tradable goods.

The production of investment good is similar. There are symmetric Home firms under perfect competition indexed by $y \in (0, n]$. Output of the generic Home firm y is

$$E_t(x) \equiv \left(\begin{array}{l} a_{TE}^{\frac{1}{\phi_A}} \left(\begin{array}{l} a_{HE}^{\frac{1}{\rho_E}} Q_{HE,t}(x)^{\frac{\rho_E - 1}{\rho_E}} \\ + (1 - a_{HE})^{\frac{1}{\rho_E}} \left(\sum_{i=1}^{C-1} a_{IMPE,i}^{\frac{1}{\rho_{IMP}}} Q_{IMPE,t}(x)^{\frac{\rho_{IMP}-1}{\rho_{IMP}}} \right)^{\frac{\rho_{IMP}}{\rho_{IMP}-1}} \end{array} \right)^{\frac{\rho_E}{\rho_E - 1} \frac{\phi_E - 1}{\phi_E}} \\ + (1 - a_{TE})^{\frac{1}{\phi_E}} Q_{NE,t}(x)^{\frac{\phi_E - 1}{\phi_E}} \end{array} \right)^{\frac{\phi_E}{\phi_E - 1}} .$$

Finally, we assume that public expenditure C^g is composed by nontradable intermediate goods only.

Intermediate goods

Demand

Bundles used to produce the final consumption goods are CES indexes of differentiated intermediate goods, each produced by a single firm under conditions of monopolistic competition:

$$Q_{HA}(x) \equiv \left[\left(\frac{1}{n} \right)^{\theta_T} \int_0^n Q(h, x)^{\frac{\theta_T - 1}{\theta_T}} dh \right]^{\frac{\theta_T}{\theta_T - 1}}, \tag{24}$$

$$Q_{NA}(x) \equiv \left[\left(\frac{1}{n} \right)^{\theta_N} \int_0^n Q(i, x)^{\frac{\theta_N - 1}{\theta_N}} di \right]^{\frac{\theta_N}{\theta_T - 1}}, \tag{25}$$

$$Q_{IMPA,US,t}(x) \equiv \left[\left(\frac{1}{n^*} \right)^{\theta_T} \int_n^{n+n^*} Q(g, x)^{\frac{\theta_T - 1}{\theta_T}} dg \right]^{\frac{\theta_T}{\theta_T - 1}}, \tag{26}$$

where firms in the Home tradable and nontradable sectors are respectively indexed by $h \in (0, n]$ and $x \in (0, n]$, while Home firms in the sector importing US goods are indexed by g. A similar indexation holds for firms in sectors importing from CH, JP, RW. Parameters θ_T, $\theta_N > 1$ are respectively the elasticity of substitution across brands in the tradable and nontradable sectors. The prices of the nontradable intermediate goods are denoted $p(i)$. Each firm x takes these prices as given when minimizing production costs of the final good. The resulting demand for nontradable intermediate input i is

$$Q_{A,t}(i,x) = \left(\frac{1}{n}\right)\left(\frac{P_t(i)}{P_{N,t}}\right)^{-\theta_N} Q_{NA,t}(x), \tag{27}$$

where $P_{N,t}$ is the cost-minimizing price of one basket of local intermediates:

$$P_{N,t} = \left[\int_0^n P_t(i)^{1-\theta_N} \, di\right]^{\frac{1}{1-\theta_N}}. \tag{28}$$

We can derive $Q_A(h,x)$, $Q_A(f,x)$, $C_A^g(h,x)$, $C_A^g(f,x)$ in a similar way. Firms y producing the final investment goods have similar demand curves. Aggregating over x and y, it can be shown that total demand for nontradable intermediate good i is

$$\begin{aligned} & \int_0^n Q_{A,t}(i,x)\,dx + \int_0^n Q_{E,t}(i,y)\,dy + \int_0^n C_t^g(i,x)\,dx \\ = & \left(\frac{P_t(i)}{P_{N,t}}\right)^{-\theta_N} \left(Q_{NA,t} + Q_{NE,t} + C_{N,t}^g\right), \end{aligned}$$

where C_N^g is public sector consumption. Home demands for (intermediate) domestic and imported tradable goods can be derived in a similar way.

Supply

The supply of each Home nontradable intermediate good i is denoted by $N^S(i)$:

$$N_t^S(i) = \left((1-\alpha_N)^{\frac{1}{\xi_N}} L_{N,t}(i)^{\frac{\xi_N-1}{\xi_N}} + \alpha^{\frac{1}{\xi_N}} K_{N,t}(i)^{\frac{\xi_N-1}{\xi_N}}\right)^{\frac{\xi_N}{\xi_N-1}}. \tag{29}$$

Firm i uses labor $L^p_{N,t}(i)$ and capital $K_{N,t}(i)$ with constant elasticity of input substitution $\xi_N > 0$ and capital weight $0 < \alpha_N < 1$. Firms producing intermediate goods take the prices of labor inputs and capital as given. Denoting W_t the nominal wage index and R^K_t the nominal rental price of capital, cost minimization implies that

$$L_{N,t}(i) = (1-\alpha_N)\left(\frac{W_t}{MC_{N,t}(i)}\right)^{-\xi_N} N^S_t(i) \tag{30}$$

and

$$K_{N,t}(i) = \alpha\left(\frac{R^K_t}{MC_{N,t}(i)}\right)^{-\xi_N} N^S_t(i)$$

where $MC_{N,t}(n)$ is the nominal marginal cost:

$$MC_{N,t}(i) = \left((1-\alpha)W_t^{1-\xi_N} + \alpha\left(R^K_t\right)^{1-\xi_N}\right)^{\frac{1}{1-\xi_N}}. \tag{31}$$

The productions of each Home tradable good, $T^S(h)$, is similarly characterized.

Price setting in the intermediate sector

Consider now profit maximization in the Home nontradable intemediate sector. Each firm i sets the price $p_t(i)$ by maximizing the present discounted value of profits subject to the demand constraint and the quadratic adjustment costs,

$$AC^p_{N,t}(i) \equiv \frac{\kappa^p_N}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 Q_{N,t},$$

which is paid in unit of sectorial product $Q_{N,t}$ and where $\kappa^p_N \geq 0$ measures the degree of price stickiness. The resulting first-order condition, expressed in terms of domestic consumption, is

$$p_t(i) = \frac{\theta_N}{\theta_N - 1} mc_t(i) - \frac{A_t(i)}{\theta_N - 1}, \tag{32}$$

where $mc_t(i)$ is the real marginal cost and $A_t(i)$ contains terms related to the presence of price adjustment costs:

$$\begin{aligned} A_t(i) \;&\approx\; \kappa_N^p \frac{P_t(i)}{P_{t-1}(i)} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right) \\ &\quad -\beta \kappa_N^p \frac{P_{t+1}(i)}{P_t(i)} \left(\frac{P_{t+1}(i)}{P_t(i)} - 1 \right) \frac{Q_{N,t+1}}{Q_{N,t}}. \end{aligned}$$

The above equations clarify the link between imperfect competition and nominal rigidities. When the elasticity of substitution θ_N is very large and hence the competition in the sector is high, prices closely follow marginal costs, even though adjustment costs are large. To the contrary, it may be optimal to maintain stable prices and accommodate changes in demand through supply adjustments when the average markup over marginal costs is relatively high. If prices were flexible, optimal pricing would collapse to the standard pricing rule of constant markup over marginal costs (expressed in units of domestic consumption):

$$p_t(i) = \frac{\theta_N}{\theta_N - 1} mc_{N,t}(i). \tag{33}$$

Firms operating in the intermediate tradable sector solve a similar problem. We assume that there is market segmentation. Hence the firm producing the brand h chooses $p_t(h)$ in the Home market, and a price in each of the other 4 regions ($p_t^*(h)$ $p_t^{**}(h)$, $p_t^{***}(h)$, $p_t^{****}(h)$) to maximize the expected flow of profits (in terms of domestic consumption units),

$$E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left[\begin{array}{c} p_\tau(h)\, y_\tau(h) + \frac{p_\tau^*(h)}{rer^*} y_\tau^*(h) + \frac{p_\tau^{**}}{rer^{**}}(h)\, y_\tau^{**}(h) \\ + \frac{p_\tau^{***}}{rer^{***}}(h)\, y_\tau^{***}(h) + \frac{p_\tau^{****}}{rer^{****}}(h)\, y_\tau^{****}(h) \\ -mc_{H,\tau}(h) \left(y_\tau(h) + y_\tau^*(h) + y_\tau^{**}(h)\, y_\tau^{***}(h)\, y_\tau^{****}(h) \right) \end{array} \right],$$

subject to quadratic price adjustment costs similar to those considered for nontradable goods and standard demand constraints. Each term "rer" represents bilateral exchange rate between Home currency and the currency of the considered importing country. The term E_t denotes the expectation operator conditional on the information set at time t, $\Lambda_{t,\tau}$ is the appropriate discount rate, and $mc_{H,t}(h)$ is the real marginal cost. The first order conditions with respect to $p_t(h)$, $p_t^*(h)$,

$p_t^{**}(h)$,$p_t^{***}(h)$, and $p_t^{****}(h)$ are

$$p_t(h) = \frac{\theta_T}{\theta_T - 1} mc_t(h) - \frac{A_t(h)}{\theta_T - 1}, \quad (34)$$

$$p_t^*(h) = \frac{\theta_T}{\theta_T - 1} \frac{mc_t}{rer^*}(h) - \frac{A_t^*(h)}{\theta_T - 1}, \quad (35)$$

$$p_t^{**}(h) = \frac{\theta_T}{\theta_T - 1} \frac{mc_t}{rer^{**}}(h) - \frac{A_t^{**}(h)}{\theta_T - 1}, \quad (36)$$

$$p_t^{***}(h) = \frac{\theta_T}{\theta_T - 1} \frac{mc_t}{rer^{***}}(h) - \frac{A_t^{***}(h)}{\theta_T - 1}, \quad (37)$$

$$p_t^{****}(h) = \frac{\theta_T}{\theta_T - 1} \frac{mc_t}{rer^{****}}(h) - \frac{A_t^{****}(h)}{\theta_T - 1}, \quad (38)$$

where θ_T is the elasticity of substitution of intermediate tradable goods, while $A(h)$ and $A^*(h)$ involve terms related to the presence of price adjustment costs:

$$\begin{aligned} A_t(h) &\approx \theta_T - 1 + \kappa_H^p \frac{P_t(h)}{P_{t-1}(h)} \left(\frac{P_t(h)}{P_{t-1}(h)} - 1 \right) \\ &\quad -\beta \kappa_H^p \frac{P_{t+1}(h)}{P_t(h)} \left(\frac{P_{t+1}(h)}{P_t(h)} - 1 \right) \frac{Q_{H,t+1}}{Q_{H,t}}, \\ A_t^*(h) &\approx \theta_T - 1 + \kappa_H^{p*} \frac{P_t^*(h)}{P_{t-1}^*(h)} \left(\frac{P_t^*(h)}{P_{t-1}^*(h)} - 1 \right) \\ &\quad -\beta \kappa_H^{p*} \frac{P_{t+1}^*(h)}{P_t^*(h)} \left(\frac{P_{t+1}^*(h)}{P_t^*(h)} - 1 \right) \frac{Q_{H,t+1}^*}{Q_{H,t}^*}, \end{aligned}$$

where κ_H^p, κ_H^{p*} respectively measure the degree of Home tradable nominal price rigidity in the Home country and in the US. Similar equations hold for CH, JP, RW.

Labor Market

In the case of firms in the nontradable intermediate sector, the labor input $L_N(i)$ is a CES combination of differentiated labor inputs supplied by domestic agents and defined over a continuum of mass equal to the country size ($j \in [0, n]$):

$$L_{N,t}(i) \equiv \left(\frac{1}{n}\right)^{\frac{1}{\psi}} \left[\int_0^n L_t(i,j)^{\frac{\psi-1}{\psi}} dj\right]^{\frac{\psi}{\psi-1}}, \tag{39}$$

where $L(i,j)$ is the demand of the labor input of type j by the producer of good i and $\psi > 1$ is the elasticity of substitution among labor inputs. Cost minimization implies that

$$L_t(i,j) = \left(\frac{1}{n}\right) \left(\frac{W_t(j)}{W_t}\right)^{-\psi} L_{N,t}(j), \tag{40}$$

where $W(j)$ is the nominal wage of labor input j and the wage index W is

$$W_t = \left[\left(\frac{1}{n}\right) \int_0^n W_t(h)^{1-\psi} dj\right]^{\frac{1}{1-\psi}}. \tag{41}$$

Similar equations hold for firms producing intermediate tradable goods. Each household is the monopolistic supplier of a labor input j and sets the nominal wage facing a downward-sloping demand obtained by aggregating demand across Home firms. The wage adjustment is sluggish because of quadratic costs paid in terms of the total wage bill,

$$AC_t^W = \frac{\kappa_W}{2} \left(\frac{W_t}{W_{t-1}} - 1\right)^2 W_t L_t, \tag{42}$$

where the parameter $\kappa_W > 0$ measures the degree of nominal wage rigidity and L_t is the total amount of labor in the Home economy.

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