Large-scale asset purchase program in the Euro area. A model-based evaluation*

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Abstract

This paper evaluates the domestic and international macroeconomic effects of purchases of long-term sovereign bonds by the Euro area (EA) central bank. To this end, we calibrate a five-country dynamic general equilibrium model of the world economy (EA, China, Japan, China and the rest of the world) . We assume that EA and US sovereign bonds are internationally traded as they provide liquidity services. The main results are as follows. First, sovereign bond purchases boost EA economic activity, as the measure increases liquidity and reduces the long-term interest rates. Second, macroeconomic effects on the other regions are expansionary and, for the rest of the world bloc, not negligible because of the relatively large trade and financial linkages with the EA. Finally, results are rather robust to changes in the assumption on the phasing-out of the EA non-standard monetary policy measures, the path of the short-term interest rate and the international exchange rate pass-through.

*PRELIMINARY AND INCOMPLETE. Please do not quote. The opinions expressed are those of the authors and do not reflect views of the Bank of Italy. Any remaining errors are the sole responsibility of the authors. Corresponding author: Massimiliano Pisani; Email:massimiliano.pisani@bancaditalia.it

1 Introduction

In January 2015 the European Central Bank (ECB) has announced the launch of an Expanded Asset Purchase Programme (EAPP), which consists of purchases of private securities and euro-denominated investment-grade securities issued by euro area (EA) governments and institutions in the secondary market.

The announcement of the EA EAPP has spurred a debate about their domestic and international macroeconomic effects.

This paper addresses these issues by quantitatively assessing the domestic and international macroeconomic effects of the EA EAPP and US tapering.

The analysis is performed by simulating a large-scale multi-country dynamic general equilibrium model calibrated to the EA, the US, China (CH), Japan (JP), and the rest of the world (RW).[1] Building on a recent contribution by Canzoneri, Cumby, Diba and Lopez-Salido (2013, henceforth CCDLS), we introduce demand for international liquidity in an otherwise standard New Keynesian open economy model. In all countries households optimally demand liquidity, which has domestic and international components and facilitates transaction for consumption purposes (thereby providing so called "liquidity services"). In each region, liquidity is a combination, according to a transaction technology, of domestic money balances issued by the local central bank, domestic government bonds, US short- and long-term government bonds, and EA short- and long-term government bonds (by assumption, Chinese, Japanese and RW government bonds are not internationally traded).[2]

We initially simulate the EAPP, formalized as an exogenous increase in the purchases of long-term sovereign bonds by the EA monetary authority, lasting xxx quarters and gradually phased out from xxx to xxx quarter. In the second scenario, the EAPP is accompanied by the US tapering, formalized as exogenous decrease in the purchases of long-term sovereign bonds by the US monetary authority, from quarter xxx to quarter xxx. Finally, we perform a sensitivity analysis by modifying

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

[2] We treat the EA as a single country in our model, alongside the US, CH and the RW. As such EA government bonds are meant to denote bonds denominated in euro issued by the (hypothetical) EA government.

the length of EA EAPP and US tapering. In all scenarios the US and EA (short-term) monetary policy rates are kept constant at the baseline level for xxx quarters. All simulations are run under perfect foresight. So there is no uncertainty, policies are fully credible and agents perfectly anticipate the future path of shocks (the only exception is the initial period, as the shock is initially unexpected).

Our main results are as follows. First, the EAPP has expansionary effects on EA economy. The reduction in long-term interest rates and the simultaneous increase in domestic liquidity favors aggregate demand for consumption and investment. Second, international spillovers are not sizeable. Exports towards the EA increase, because of the higher EA aggregate demand. Third, the main results are robust to changes in key parameters.

Our paper relates to other contributions on the international liquidity and unconventional monetary policy. Chen, Curdia, and Ferrero (2012) introduce financial market segmentation to evaluate the impact of US quantitative easing. Alpanda and Kabaka (2015) evaluate the international spillover effects of large-scale asset purchases using a two-country dynamic stochastic general-equilibrium model with nominal and real rigidities, and portfolio balance effects. Burlon, Gerali, Notarpietro, and Pisani (2015) formalize the EA as a monetary union and evaluate the impact of EAPP on EA member countries on the basis of a framework as in Chen, Curdia and Ferrero (2012). Differently from them, we evaluate non-standard monetary policy measures on the EA economy and on its main trade and financial partners, by explicitly introducing liquidity in a multi-country quantitative dynamic general equilibrium model.

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 of the main simulations. 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, US, CH, JP and RW.

Crucially, EA and US government bonds are demanded by other governments and by domestic and foreign households. Governments fulfill currency reserve targets. Following the theoretical framework of CCDLS, in each country households' liquidity includes not only domestic money and government bonds, but also foreign government bonds. One is the US dollar-denominated short- and long-term bonds, issued by the US government; the other is the euro-denominated short- and long-term sovereign bonds, issued by the EA. Households make optimal choices between three types of assets: liquid domestic assets (money and domestic government bonds), liquid international assets (US and EA government bonds) and an illiquid international bond. As usual in dynamic open economy models, financial assets allow to smooth consumption over time and to share idiosyncratic risk across countries. The novelty is in liquid assets, that can be domestic or foreign. They are "liquid" because they enter into a composite transaction technology. They pay an interest rate and allow households to pay for transaction services when buying consumption goods. As such, their yield embodies a liquidity premium, that reflects the non-pecuniary return of these transactions services. The transaction technology makes assets imperfect substitutes and, hence, the households' portfolio problem not trivial. The resulting private sector demands interact with government demands and supplies of liquid assets so as to determine the equilibrium interest rates and exchange rates in the global markets.

The illiquid bond, denominated in US dollars, is issued by households and pays an interest rate which does not embody the aforementioned liquidity premium, as it does not offer any transaction services. The illiquid bond allows for a proper calibration of countries' net foreign asset position (NFA) and, hence, to fully characterize the current account dynamics.[3]

Other features of the model are more 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).[4] The model distinguishes between intermediate and final goods. The former are tradable and nontradable, and are produced under mo-

[3]While admittedly this is only a short cut, 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.

[4]The model is similar to the Euro area and the Global economy Model (EAGLE) developed by Gomes et al. (2012) and to the Global Economy Model (GEM) developed at the IMF (see Pesenti, 2008).

nopolistic competition by firms, that set their prices to maximize profits subject to quadratic adjustment costs. Final goods are nontradable, 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 budject constraint. 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} ($0 < n^{EA}$, n^{US}, n^{CH}, $n^{JP} < 1$) are the sizes of EA, US, CH, JP, respectively. The world economy size is normalized to 1. 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 US case. Where this is not the case, it will be explicitly stated.

2.1 Households and international liquidity

The US household j's intertemporal utility at time 0 is

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

where E is the expectation operator, $0 < \beta < 1$ is the discount rate, $C_t(j)$ is consumption of the final good and $N_t(j)$ measures household's labor effort. The term C_{t-1} reflects previous period's aggregate consumption and 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 $\chi > 0$. The budget constraint is

$$\begin{aligned}
& M_t(j) - M_{t-1}(j) + B^S_{US,t}(j) - R_{US,t-1} B^S_{US,t-1}(j) + B_{PR,t}(j) - \tilde{R}_{t-1} B_{PR,t-1}(j) \\
& + P^L_t B^L_{US,t}(j) - P^L_t B^L_{US,t-1}(j) \\
& + B^S_{EA,t}(j)/S_{EA,t} - R_{EA,t-1} B^S_{EA,t-1}(j)/S_{EA,t} \\
& + P^L_{EA,t} B^L_{EA,t}(j)/S_{EA,t} - P^L_t B^L_{EA,t-1}(j)/S_{EA,t} \\
& = W_t N_t(j) + r_{K,t} K_{t-1}(j) + D_t(j) - (1 + \tau_t(j)) P_t C_t(j) - P_{I,t} I_t(j) - TAX_t,
\end{aligned} \tag{2}$$

where M is domestic money holdings, B^S is domestic short-term (one period) government bond holdings paying the (gross) monetary policy rate R, [[[[[$B^L$and P^L are respectively the US long-term sovereign bond and its price,]]]]]] B_{PR} is the (short-term) illiquid bond paying the interest rate $\tilde{R}$, and B_{EA}/S_{EA} is the dollar amount of euro government bonds earning the interest rate R_{EA} (S_{EA} is the nominal exchange rate of the euro vis-à-vis the US dollar, defined as number of euros per one dollar). Finally, B^L_{EA} and P^L_{EA} are respectively the EA long-term sovereign bond and its price. 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 with P_I the related price index, TAX are lump-sum taxes. All bonds are nominal, riskless and have a one-period maturity.

As in CCDLS, the transactions cost is proportional to consumption, with a factor of proportionality that is an increasing function of velocity:

$$\tau_t(J) = \begin{cases} \left(\frac{A}{v_t(j)}\right)(v_t(j) - \bar{v})^2 & \text{for} \quad v_t(j) > \bar{v} \\ 0 & \text{for} \quad v_t(j) \leq \bar{v} \end{cases}, \tag{3}$$

where $\bar{v}$ is the satiation level of velocity and $A > 0$ is a cost parameter. Velocity depends in turn on consumption and "effective" money holdings

$$v_t(j) = \frac{C_t(j)}{\tilde{M}_t(j)}. \tag{4}$$

The variable "effective" money holdings $\tilde{M}_t$ is a nested bundle, which includes not only money holdings M, but also domestic government bonds B_{US} and EA government bonds B_{EA}:

$$\begin{aligned} \tilde{M}_t(j) &= M_t(j)^{\zeta_1} B_{US,t}(j)^{\zeta_2} \left(B_{EA,t}(j)/S_{EA,t}\right)^{1-\zeta_1-\zeta_2} \\ B_{US,t}(j) &= B^S_{US,t}(j)^{\upsilon} B^L_{US,t}(j)^{1-\upsilon} \\ B_{EA,t}(j) &= B^S_{EA,t}(j)^{\theta} B^L_{EA,t}(j)^{1-\theta}, \end{aligned} \tag{5}$$

where EA government bonds, denominated in euros, are appropriately converted in dollars via the bilateral nominal exchange rate S_{EA}. The parameters $\zeta_1, \zeta_2 \in [0,1]$ measure the relevance of respectively US money and domestic government bonds in facilitating transactions relative to the EA government bonds. The latter characterizes the international component of the US "effective" money holdings. Similarly, the parameter $\nu, \theta \in [0,1]$ measure the relevance of US and EA short-term bonds, respectively ($1 - \upsilon$ and $1 - \theta$ measure the relevance of US and EA long-term bonds, respectively).

As the implied first order condition are rather standard, they are not shown for brevity.[5] 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 rate of return. At the margin, expected returns of different assets are equated, taking into account the transaction services provided by each asset. In particular, combining the linearized versions of the two optimality conditions with respect to domestic and EA 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 "effective" liquidity hold for households in regions other than the US. Effective money holdings of EA households include domestic money, government bonds and, as international liquidity component, US government bonds. The "effective" money holdings of RW and CH households include not only domestic government bonds and money, but also, as international components of liquidity, both US and EA government bonds:

$$\tilde{M}_t(j) = M_t(j)^{\zeta_1} B_t(j)^{\zeta_2} \left(S_t B_{US,t}(j)\right)^{\zeta_3} \left(\frac{S_t}{S_{EA,t}} B_{EA,t}(j)\right)^{1-\zeta_1-\zeta_2-\zeta_3}, \tag{6}$$

where the bilateral nominal exchange rates with respect to the US dollar and the euro are denoted respectively by S and S_{EA}, and the parameter $\zeta_3 \in [0,1]$ accounts for the weight of US government bonds in CH and RW households' "effective" money or liquidity holdings.

In the simulation scenarios, households change their overall asset holdings and

[5] They are reported in the working paper version. See Cova et al. (2014).

the holdings of different assets in response to the bonds purchases by the monetary authorities, so as to smooth consumption and to equalize expected returns. In the case of liquid assets, returns do include also the liquidity services associated with the transaction costs. The transaction cost is relevant for international liquidity to have a non trivial role for consumption and asset allocation choices and to make assets imperfect substitutes. Without the transaction cost, indeed, assets would be perfectly substitutable, and the increase in bonds purchases would not have real effects.

2.2 Public sectors supply and demand of (international) liquidity

In each economy a standard Taylor rule holds (an upper-bar "$^-$" denotes steady-state values of variables) for the gross monetary policy rate:

$$\log\left(R_t/\bar{R}\right) = \rho_R \log\left(R_{t-1}/\bar{R}\right) + (1-\rho_R)\,\varphi_\pi \log\left(\Pi_t/\bar{\Pi}\right) + (1-\rho_R)\varphi_{GDP}\log(GDP_t/GDP_{t-1}), \tag{7}$$

where $\rho_R > 0$ is a parameter capturing inertia in the monetary policy conduct, while φ_π and φ_{GDP} are the parameters measuring respectively the response of the policy rate to deviations of the domestic inflation rate 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 government bonds by appropriately changing the amount of money supply.

The government's budget constraint is

$$M_t + B^{G,S}_{US,t} + P_t B^{G,L}_{US,t} = M_{t-1} + R_{t-1} B^{G,S}_{US,t-1} + P_t B^{G,L}_{US,t-1} + P_t G_t - TAX_t, \tag{8}$$

where B^G is the supply of US short-term government bonds, $B^G_{L,t}$ is the supply of US long-term government bonds, TAX_t is lump-sum taxes and G_t denotes public consumption, which is assumed to be exogenous and is kept constant at its initial steady state level. In the case of the EA, the government's budget constraint accounts for the stock of official reserves in US government bonds. CH and RW hold reserves in euro and US government bonds.

Lump-sum taxes are set according to the following fiscal rule (that guarantees fiscal solvency):

$$TAX_t - \overline{TAX} = \varphi_b \left(B_{t-1}^{G,S} - \bar{B}^{G,S} \right), \tag{9}$$

where $\varphi_b > 0$ 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 level. The supply of long-term bond is exogenously set.

For the EA, the US and Japan it is assumed that the "zero lower bound" holds. The monetary policy authority sets the short-term gross interest rate according to the Taylor rule when it choose not to keep the policy rate constant at the zero level. Thus, the following equation holds:

$$\log\left(R_t/\bar{R}\right) = \max\left(1, \rho_R \log\left(R_{t-1}/\bar{R}\right) + (1-\rho_R)\,\varphi_\pi \log\left(\Pi_t/\bar{\Pi}\right) + (1-\rho_R)\varphi_{GDP} \log(GDP_t/GDP_{t-1} \tag{10}$$

2.3 Bond market clearing conditions

For the US short-term government bond

$$\begin{aligned} & B_{US,t}^{S,G} + \int_0^{n^{EA}} B_{US,t}^S(j)\,dj + \int_{n^{EA}}^{n^{US}} B_{US,t}^S(j)\,dj + \\ & \int_{n^{US}}^{n^{CH}} B_{US,t}^S(j)\,dj + \int_{n^{CH}}^{n^{JP}} B_{US,t}^S(j)\,dj + \int_{n^{JP}}^{1} B_{US,t}^S(j)\,dj \\ = \; & 0, \end{aligned} \tag{11}$$

where $0 < n^{US} < 1$ is the size of US population (the world population is normalized to one), $B_{US,t}$ is US government bond holdings of the representative household in US, $B_{US,t}^J$ is US government bond holdings of representative household in EA, CH and RW. Correspondingly, the market clearing of the US long-term government bond is

$$
\begin{aligned}
& B^{L,G}_{EA,t} + \int_0^{n^{EA}} B^L_{US,t}(j)\,dj + \int_{n^{EA}}^{n^{US}} B^L_{US,t}(j)\,dj \\
& + \int_{n^{US}}^{n^{CH}} B^L_{US,t}(j)\,dj + \int_{n^{CH}}^{n^{JP}} B^L_{US,t}(j)\,dj + \int_{n^{JP}}^{1} B^L_{US,t}(j)\,dj \\
= \;& 0. \qquad (12)
\end{aligned}
$$

CH, JP and RW government issue only short-term government to domestic households. The corresponding market clearing condition for CH is[6]

$$
B^G_{J,t} = \int_{n^{US}}^{n^{CH}} B_{EA,t}(j)\,dj. \qquad (13)
$$

Similar conditions hold for JP and RW sovereign bonds.

Finally, the market clearing condition for the illiquid bond denominated in US dollars, which is traded internationally by households, is

$$
\begin{aligned}
& \int_0^{n^{EA}} B_{PR,t}(j)\,dj + \int_{n^{EA}}^{n^{US}} B_{PR,t}(j)\,dj \\
& + \int_{n^{US}}^{n^{CH}} B_{PR,t}(j)\,dj + \int_{n^{CH}}^{n^{JP}} B_{PR,t}(j)\,dj + \int_{n^{JP}}^{1} B_{PR,t}(j)\,dj \\
= \;& 0. \qquad (14)
\end{aligned}
$$

Market clearing conditions make clear the interaction between the central bank, the government and households. Central banks' purchases of long-term sovereign bonds is a demand shock . For a given supply of EA and US government bonds, the shock affects the interest rate and hence the optimal asset demand of households. As a result a new market equilibrium, characterized by new equilibrium interest rates, exchange rates and, hence, real allocations is achieved.

[6] Note that there are also government bond holdings held by domestic public institutions (e.g. the US government bonds on the Federal Reserve balance sheet). These intra-governmental holdings do not show up in the consolidated government budget constraints, but they obviously matter for the respective bond market clearing conditions. As explained in more detail in the Appendix (available upon request), we do account for the intra-governmental holdings in the calibration, but we do not add them as separate variables to save on notation.

2.4 Equilibrium

2.5 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 et al. 2008), the IMF Global Economy Model (Pesenti 2008) and the Eurosystem Euro Area and Global Economy Model (EAGLE, Gomes et al. 2012). To further validate the model, we have run monetary policy and public consumption shocks. Responses of the main macroeconomic variables are in line with those of the fully estimated NAWM and EAGLE.[7]

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

[7] Parameter values and responses, not reported to save on space. Parameter values are reported in the working paper version (see Cova et al. (2014). Responses are available on request. They suggest that the model has a rather plausible dynamics.

costs in prices is roughly equivalent to a four-quarter contract length under Calvo-style pricing, as highlighted, among others, by Faruquee et al. (2007).

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 note that trade with the RW region clearly dominates trade patterns for all the other countries.

Note that due to the presence of USD and EUR government bonds that provide transactions services internationally and act as official reserves we report both *overall* NFA positions – the standard measure that includes both the outstanding net stocks in the reserve currency bonds and in the other "riskier" components of the NFA – and a *net* measure of the NFA which includes only privately issued assets. These two different measures of the NFA position show that the US is a net debtor in government bonds and a net creditor in privately-issued assets: its overall NFA position amounts to a deficit of 27% relative to GDP, whereas the corresponding net measure which excludes government bonds from its international assets and liabilities exhibits a 13.3% surplus. China's net position in privately-issued "risky" assets is instead negative: the overall position exhibits a surplus of 21%, whereas the NFA excluding private and official holdings of USD and EUR sovereign bonds reveals a 6.5% deficit. A similar picture emerges for the RW bloc when comparing the two different NFA measures. Finally, the EA exhibits a balanced position when excluding government bond positions from its NFA measurement (-0,4% vs. -17.6%), while Japan's creditor status is more than halved (23%), compared to its overall NFA position (57%). The values chosen for the parameters governing the dynamics of these "non-liquid" components of the NFA, ϕ_1 and ϕ_2, are reported at the end of this table.

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 et al. (2004), Faruqee et al. (2007), Everaert and Schule (2008). 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 equation). For fiscal policy, the parameter governing the speed of speed of adjustment of public debt is assumed equal across countries and allows to stabilize the debt in the long run.

Table 7 shows the ratios for the different asset stocks that enter into the model: currency in circulation, total general government debt levels and, in the case of the United States 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 ratios reported in Table 7 (i.e. $M^J/B^J, M^J/B^{R_i,J}$ where $J = EA, US, CH, JP, RW$ and $R_i = EA, US$) using the data available on currency in circulation, total general government debt levels and, for the United States and the euro area, 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. Second, we use these asset ratios, together with the transactions costs (τ), 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^J, the satiation levels of velocity v^J, and the shares of the various assets – denoted above by ζ and ω – in the definitions of the effective transactions balances, $\tilde{M}^J$). We also compute foreign official holdings of US and EA government bonds to calibrate separately the stocks of foreign official reserves ($B_G^{R_i,J}$). These values are also reported in Table 7.

Finally, we set the discount factor so that the steady-state annualized real interest rate on risky (or "non-liquid") assets, i.e. the CCAPM rate, is about 7%. Given this choice for the risky rate we then set the yield on the government bonds, which in our model command an endogenous liquidity premium, such that the resulting steady state liquidity premia on government bonds – assumed to be equal across all regions – amounts to 3.6 percentage points.[8]

3 Results

In what follows we simulate the model to assess the macroeconomic implications of an exogenous increase in EA long-term bond purchases by the EA monetary authorities, respectively.

The EAPP is formalized 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 overall monthly purchases of 60 billion euros that last from March 2015 to the end of September 2016 (seven quarters). The phasing out is assumed to be gradual over 2 years. The short-term monetary policy rate is assumed to be constant for 8 quarters, reflecting the commitment of the central bank to maintain an accommodative stance for a prolonged period (as such, the constant monetary policy rate is not due to the ZLB constraint, but should be interpreted as a deliberate policy choice).

All simulations start are run under perfect foresight. Therefore, there is no uncertainty, policies are fully credible and households and firms perfectly anticipate the future.

3.1 Benchmark simulation

Figure 1 reports the responses of the main EA financial variables. The EA long-term interest rate declines following the increase in long-term bond purchases by the EA monetary authority. The decline is rather persistent, the interest rate returns to its baseline level after 5 years. The low long-term interest rate induce households to substitute the more liquid assets – domestic money – for the long-term sovereign bonds, whose return has decreased, and for the US dollar-denominated bonds. Similarly, households increase their holdings of short-term

[8] While this value is admittedly too high for Japan, it seems consistent with the average values for liquidity premia reported for the other countries in our model, as can be seen, e.g., in Table 5.5 of the World Development Indicators published by the World Bank.

bonds, that are relatively more liquid and whose return has increased relative to that of long-term bonds. Overall liquidity increases, in a rather persistent way. Figure 2 reports the responses of the main EA macroeconomic variables. EA GDP and inflation increase. The reduction in the transaction cost–associated with the increase in liquidity – and the simultaneous reduction in long-term interest rates induce 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 and the long-term rate decreases, the persistent increase in inflation favors the reduction in the real interest rates, that further stimulate aggregate demand. Higher aggregate demand induces imports to increase. Higher inflation as a negative competitive effect on international price competitiveness, partially compensated in the short-run by the nominal exchange rate depreciation. Overall, exports do not greatly change in the short run, while imports increase following the increase in EA aggregate demand for consumption and investment.

The largest cross-country spillover effects of the EAPP are those on the RW economy and are reported in Figure 3. Spillovers towards the other regions are qualitatively similar but smaller.[9] RW GDP and inflation slightly increase, driven by the higher exports towards the EA. The RW monetary authority increases the policy rate to stabilize the economy. Households substitute domestic short-term bonds, Euro-denominated short-term bonds and US-dollar denominated bonds, whose return has increased, for Euro-denominated long-term bonds an domestic money. Overall liquidity decreases. The implied increase in the transaction cost, jointly with the increase in the domestic and US interest rate, induce households to reduce consumption and investment in physical capital. Imports decrease, following the decrease in aggregate demand. Finally, and consistent with the relatively large increase in the RW interest rate, the RW exchange rate appreciates against the US dollar (the appreciation partially counterbalances the positive effect of higher EA aggregate demand on RW exports).

Overall, the increase in RW savings does finance the boom in EA aggregate demand.

[9] They are available upon request.

3.2 The role of the constant short-term interest rate

To further explain the transmission mechanism, we relax the assumption of constant interest rate, which holds in the benchmark scenario. In the alternative scenario, when the EAPP is implemented the EA short-term interest rate is set according to the Taylor rule.

Figure 4 compare the results for the main financial variables. The EA short-term interest rate now increases. The EAPP has a stimulating effect on the EA economy. Thus, the short-term interest rate increases to stabilize inflation and GDP. This implies that the monetary authority increases by a smaller amount the money in the system when rising the policy rate. Given that money is the most important component of liquidity, the latter increases to a lower extent than in the benchmark case. The increase in the short-term interest rate is an incentive for households to substitute short-term domestic bonds for long-term bonds.Thus, in equilibrium their price increase to a lower extent (the long-term interest rate decreases to a lower extent). Moreover, EA households try to reduce the loss in overall liquidity by reducing their holding of US bonds to a lower extent,inducing a lower increase in the related interest rates. The allocation across different bonds does not greatly change with respect to the benchmark case, because relative pecuniary returns are similar across the two scenarios. Finally, the increase in the EA short-term rate limits the depreciation of the EA real exchange rate.

Figure 5 reports the results for the main macroeconomic variables. Not surprisingly, the stimulating effects of the EAPP on GDP and its main components are smaller if the short-term interest rate is increased instead of being held constant at its baseline values while the non-standard monetary policy measures are implemented. It is however interesting to note that the macroeconomic effects are stimulating and are not extremely small. This suggests that EAPP provides a non-negligible expansionary contribution to the response of the macroeconomic variables in the benchmark scenario.

4 Conclusions

We have evaluated the domestic and cross-country macroeconomic effects of the EA EAPP by simulating a multi-country dynamic general equilibrium model. Our results suggest that the programme has real expansionary effects, as it persistently reduces the interest rates.

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* published jointly by the Department of the Treasury, the Federal Reserve Bank of New York, and the Board of Governors of the Federal Reserve System. 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).

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Table 1: Steady state national accounts (percent)

	EA	US	CHN	JAP	RW
Private consumption	54.3	58.5	38.8	55.1	56.7
Liquidity-constrained	13.7	13.7	24.2	13.8	13.8
Forward-looking	40.6	44.8	14.6	41.4	42.9
Private investment	20.0	15.0	40.0	20.0	20.0
Public expenditure	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
Public debt (% of yearly GDP)	92.8	102.7	26.1	238.0	80.8
Share of world GDP	14.1	21.1	14.9	9.2	40.7

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

Table 2: Households and Firms Behavior

	EA	US	CHN	JAP	RW
Households					
Subjective discount factor	0.9901	0.9901	0.9901	0.9901	0.9901
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; CHN=China; JAP=Japan; RW=Rest of the world.

Table 3: Real and nomianl rigidities

	EA	US	CHN	JAP	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; CHN=China; JAP=Japan; RW=Rest of the world.

Table 4: International linkages (percent of GDP)

	EA	US	CHN	JP	RW
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
CHN	1.3	1.4	...	1.8	2.5
JAP	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
CHN	1.2	1.3	...	1.4	2.7
JAP	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 ($\phi_1; \phi_2$)	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$

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

Table 6: Monetary and fiscal policy

	EA	US	CHN	JAP	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

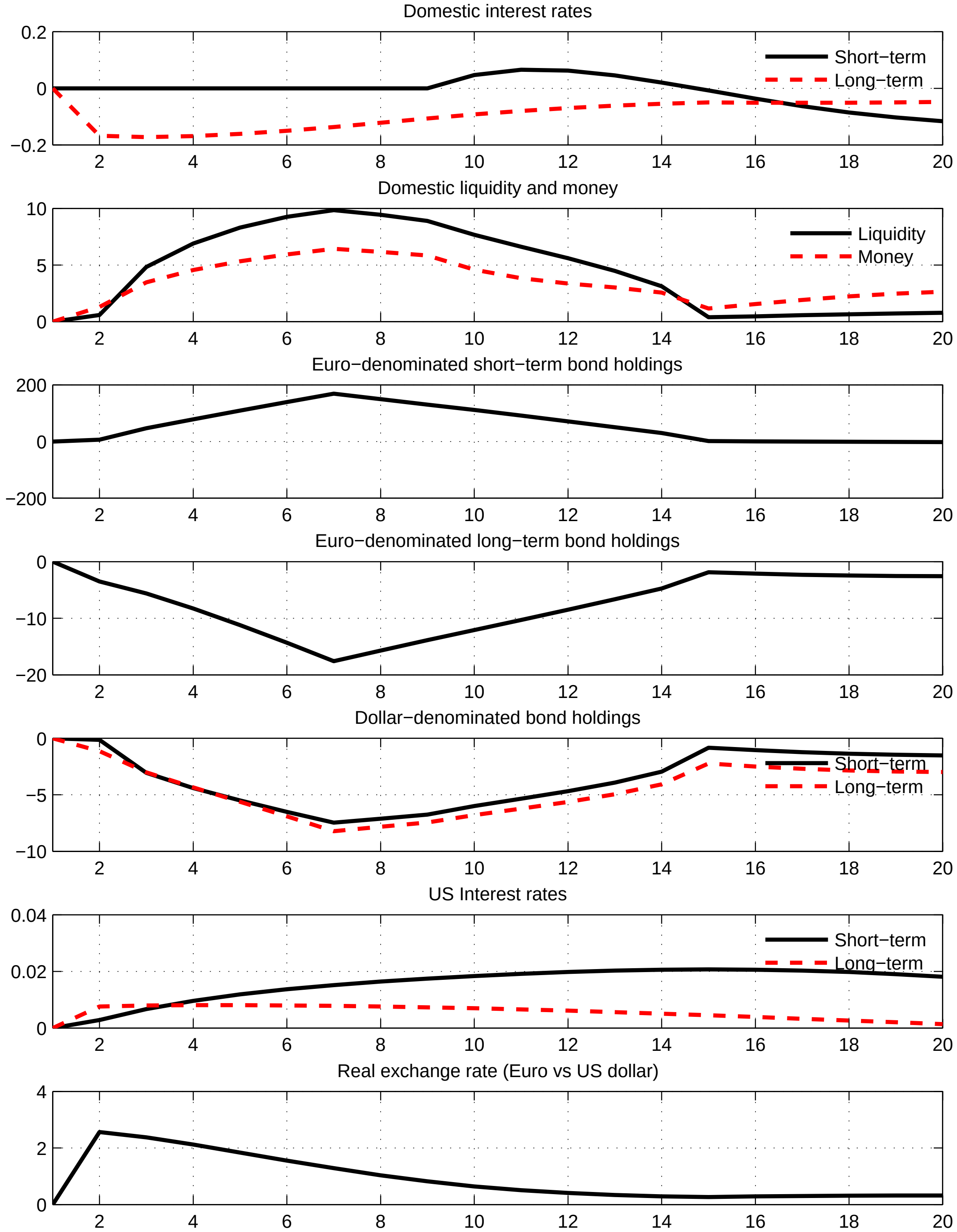
Note: EA=euro area; US=United States; CHN=China; JAP=Japan; RW=Rest of the world.

Table 7: Asset ratios

	US	EA	CHN	JAP	RW
Private agents					
curr. in circ./domestic govt bond holdings	0.27	0.22	0.48	0.06	0.19
curr. in circ./USD govt bond holdings	...	8.39	2.53	2.22	4.86
curr. in circ./EUR govt bond holdings	8.77	...	3.14	2.70	6.21
Official holdings					
of USD govt bonds (% of GDP)	...	3.87	16.40	16.00	6.80
of EUR govt bonds (% of GDP)	0.51	...	8.05	5.56	2.42

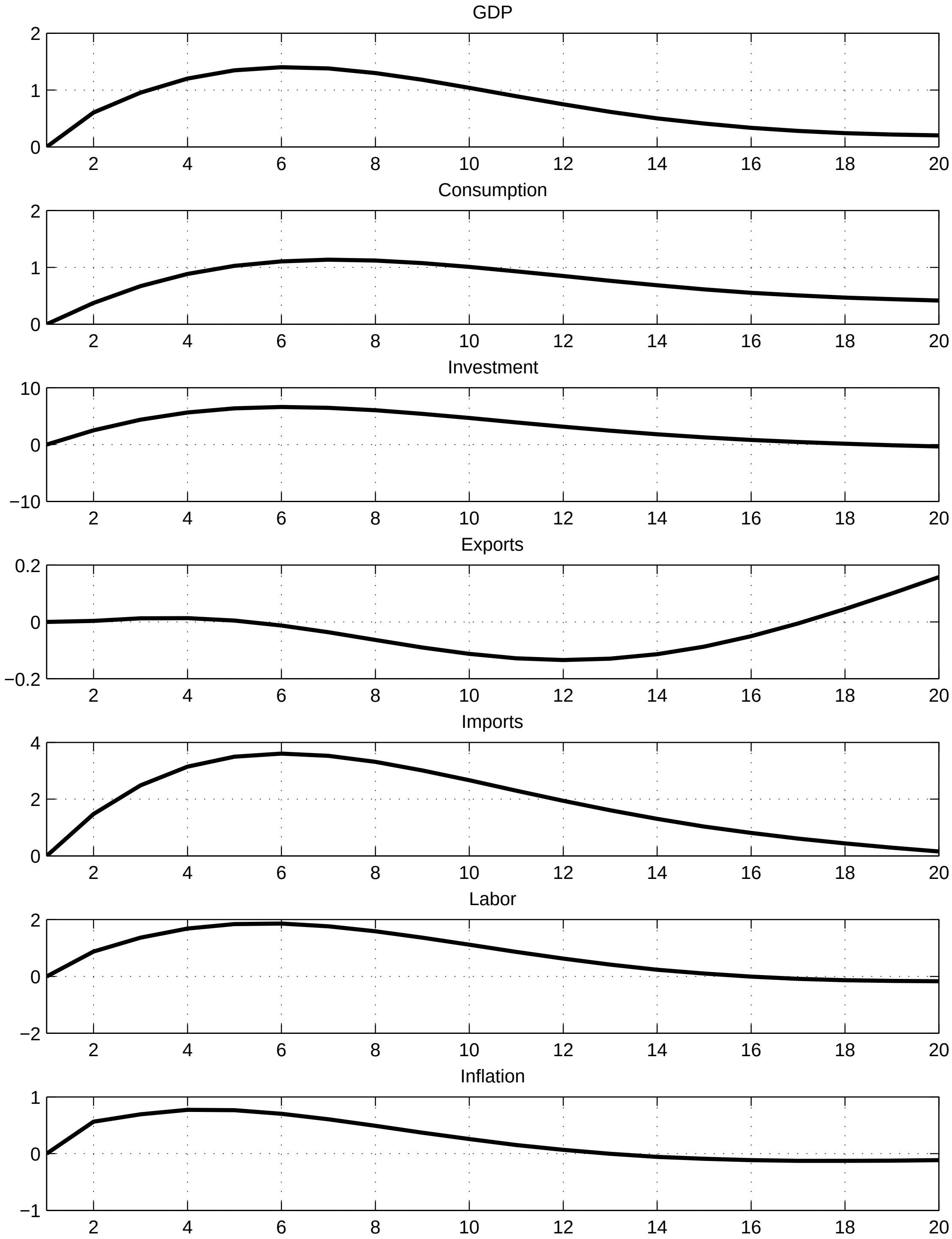
Note: EA=euro area; US=United States; CHN=China; JAP=Japan; RW=Rest of the world.

Figure 1: EAPP. EA financial variables



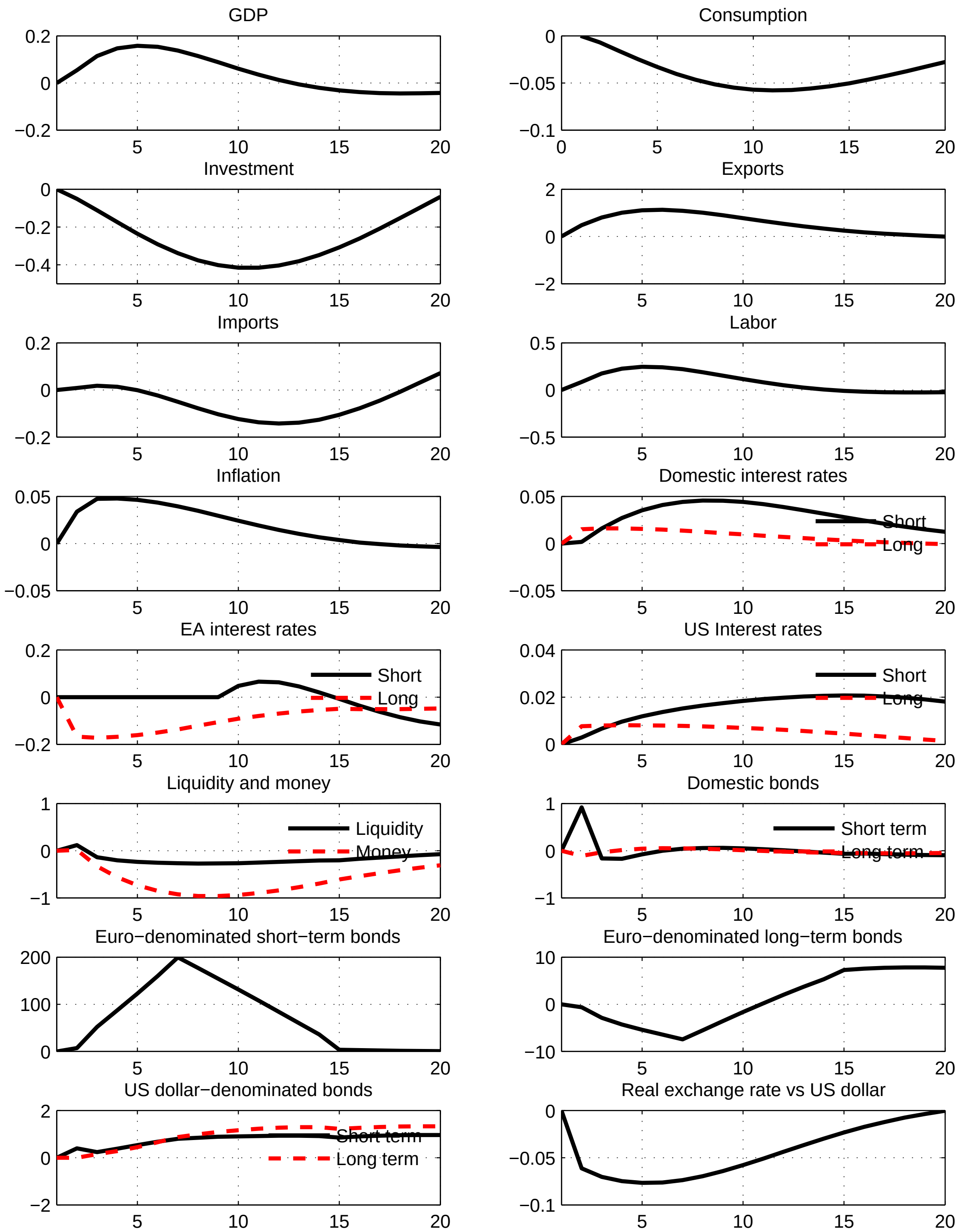
Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for interest rates, annualized percentage point deviation.

Figure 2: EAPP. EA variables



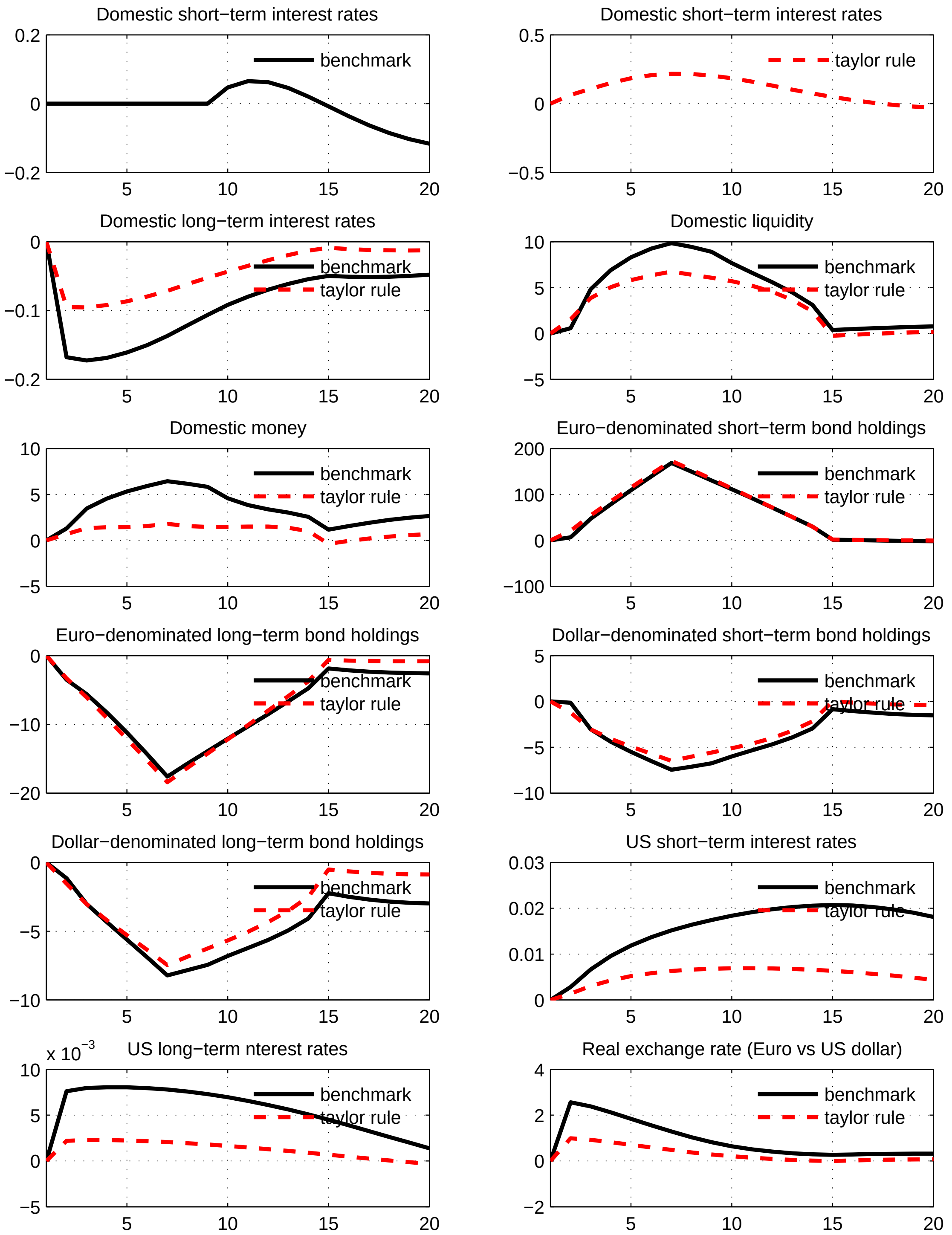
Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation annualized percentage point deviation.

Figure 3: EAPP. RW variables



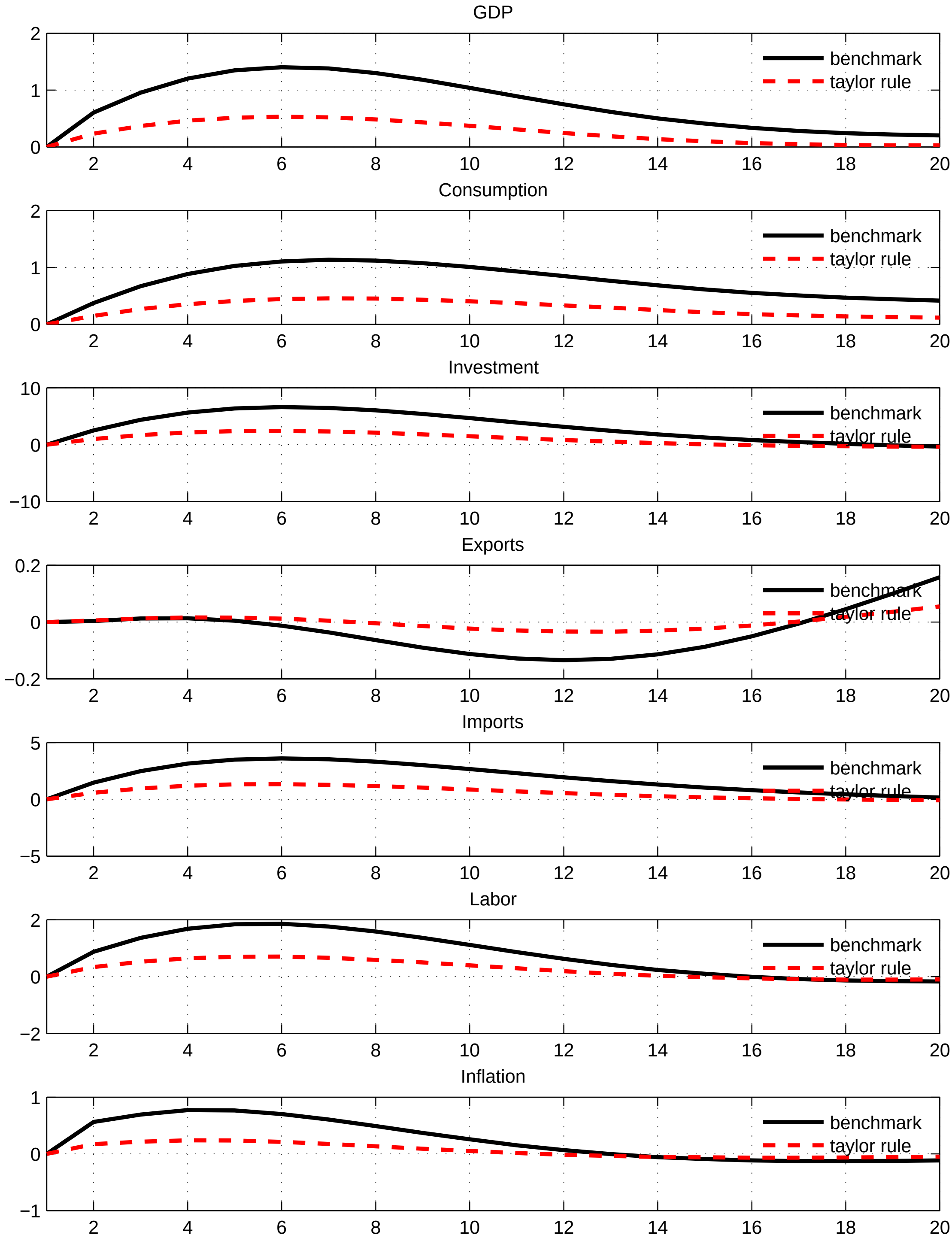
Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation and interest rates, annualized percentage point deviation.

Figure 4: EAPP and standard Taylor rule. EA financial variables



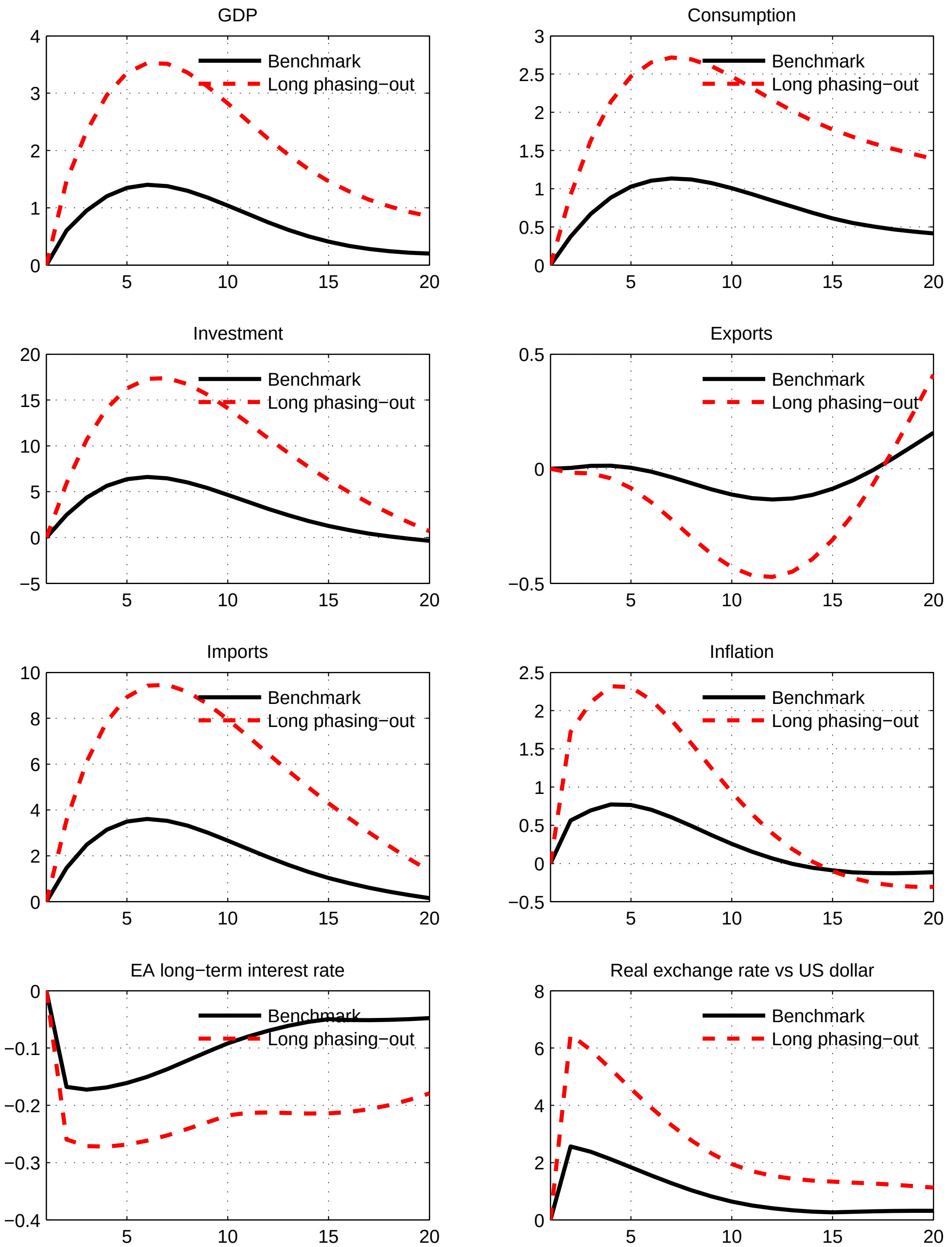
Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation and interest rates, annualized percentage point deviation.

Figure 5: EAPP and standard Taylor rule. EA real variables



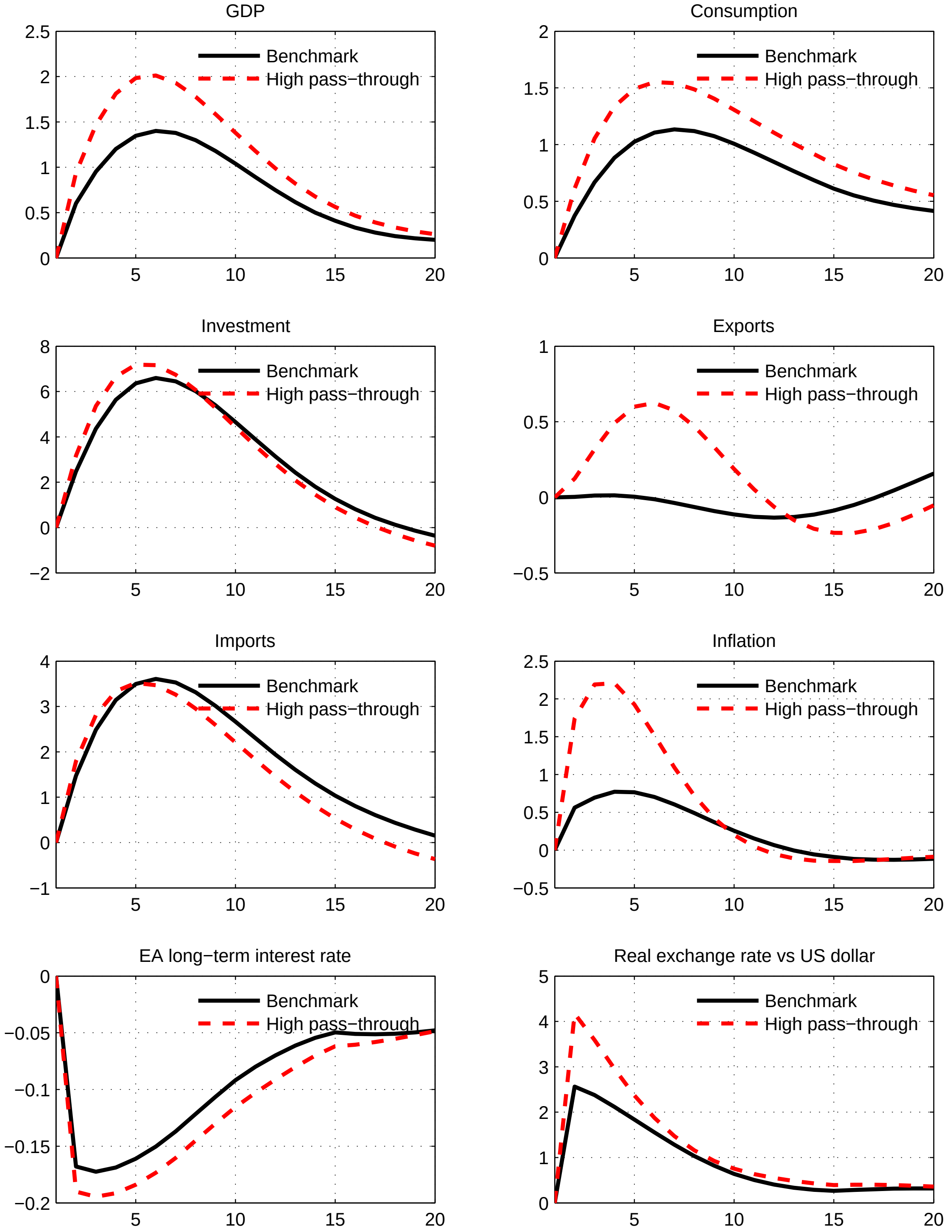
Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation and interest rates, annualized percentage point deviation.

Figure 6: EAPP long phasing-out. EA variables



Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation and interest rates, annualized percentage point deviation.

Figure 7: EAPP and high pass-through. EA variables



Notes: horizontal axis, quarters; vertical axis, percent deviations from the baseline, for inflation and interest rates, annualized percentage point deviation.