A framework for analysing quantitative easing in the open economy[1]

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Abstract:

The paper investigates the effects of quantitative easing (QE) in an open-economy dynamic general-equilibrium model which includes assets of different types and maturity. We introduce central bank asset purchases of long-term bonds held by domestic and foreign residents and explicitly model the impact on the central bank's balance sheet. Bond purchases are financed through enhanced liquidity provision to the private sector. Under imperfect substitutability between asset classes, QE affects the term premium, stock prices, the exchange rate and the private sector's saving decisions. We use the model to simulate the impact of the ECB's QE programme; for 13 basis points term-premium reduction the model generates 1.3% effective euro depreciation and raises real GDP in the Euro area by 0.3% and prices by 0.5% until the end of 2016. Frontloading QE strengthens its expansionary effect in the short and medium term, unless it is associated with an earlier exit, whereas its effectiveness is inversely related to the openness of the economy. By allowing the zero lower bound constraint to become endogenously binding, we also study the potential for QE to accelerate the exit from a liquidity trap.

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1. Introduction

In March 2015 the ECB has joined the group of Western central banks that have implemented large-scale asset purchase programmes as unconventional policy measures. These asset purchases, also called Quantitative Easing (QE), have led to a strong extension of the central banks' balance sheet. By end-July 2015 the amount of outright purchases on the balance sheet had reached 24% of GDP in the case of the US Federal Reserve, 64% of GDP in the case of the Bank of Japan, 21% of GDP in the case of the Bank of England, and 5% of GDP in the case of the ECB (Constâncio 2015). The ECB's QE programme announced in January 2015 has a volume of €1000 billion, corresponding to circa 10% of annualised euro area (EA) GDP. The amount is to be purchased in monthly tranches of €50 billion up to September 2016. In early December 2015 the ECB announced the extension of the programme up to, at least, until March 2017.

Operating close to the zero bound, the ECB considered its "conventional" monetary accommodation to be insufficient to address weak inflation dynamics, declines in inflation expectations and sizeable economic slack in the Eurozone. As a result, the balance sheet interventions were proposed to "achieve the price stability objective, given that interest rates have reached their lower bound" (Draghi 2015). In practice, the ECB purchases financial assets of longer maturity and extends liquidity (base money) to the private sector (Claeys et al. 2015, Valiante 2015).

This paper investigates the impact of QE programmes on financial variables and real economic activity in the context of an open-economy dynamic general-equilibrium model calibrated to the Euro area. In particular, we use and extend the European Commission's QUEST model by explicitly specifying the central bank's balance sheet and by introducing government bonds of different maturity. The model includes different asset types (short-term and long-term government bonds, productive capital, and foreign assets) that are imperfect substitutes. The purchase by the central bank of long-term government bonds leads to a portfolio reallocation that affects the term premium, corporate financing costs, the exchange rate, and savings behaviour. The financial market implications, in turn, affect domestic demand, net exports, output, and inflation. The model is calibrated to reproduce term-premium effects of the order of magnitude observed after the start of ECB QE for the announced path of asset purchases.

We extend previous theoretical contributions on QE operating through the portfolio rebalancing channel by allowing for an international dimension to our analysis. Unlike the papers that have situated their analysis in closed-economy models, we assume that the EA is linked to a rest-of-the-world aggregate (ROW) by goods trade and international capital markets. As a result, we can study the transmission of QE to the real sector through the exchange rate channel, and assess the importance of international spillovers.

Starting from an attempt to quantify the impact of the ECB programme, which was announced and subsequently launched in the first months of 2015, we can address several aspects of QE design through the lens of a dynamic general equilibrium framework, namely the preferability of back- or frontloading of balance sheet operations, the importance of the duration of QE programmes, the impact of QE exit, and the effectiveness of QE in recession versus "normal" times (i.e. when short-term policy rates are not stuck at the zero bound). The latter question relates to the discussion of whether QE should become part of the standard toolkit of monetary policy.

Moreover, using solution techniques for an occasionally and endogenously binding zero lower bound constraint in recessions lends itself to a model-based assessment of whether QE succeeds in steering the economy away from the liquidity trap.

In recent years, there have been a number of papers evaluating the effects of QE using DSGE models which transmit the effects of central bank balance sheet measures.[2] Our paper is mostly related to the subset of the literature examining the effects of QE through the so-called portfolio rebalancing channel. The DSGE literature that introduces assets of different maturity is divided in two broad modelling environments for the analysis of QE. A first strand, including Vayanos and Vila (2009) and Harrison (2012), evaluates the effects of large-scale asset purchases (LSAPs) using the preferred-habitat setup. In such models the Euler equation for households is adjusted to allow for a linear combination of short- and long-term interest rates. The long-term interest rate may then deviate from its long-run expectation by a preference term that increases in the relative supply of assets with long and short maturity. We follow a second strand, adopted e.g. by Chen et al. (2011) and Falagiarda (2013), and introduce QE explicitly as central bank balance sheet operation, assuming that assets of different type and maturity are imperfectly substitutable as captured by transaction costs on portfolio adjustment. The introduction of portfolio adjustment

[2] For a review of complementary theoretical frameworks studying QE see Caglar et al. (2012).

costs implies that agents face quadratic costs whenever the relative composition of their asset portfolio deviates from the target (steady-state) level.

The remainder of this paper is organized as follows: Section 2 describes the modelling of QE and the transmission channels to financial and real variables. In Section 3 we present simulation results that gauge the impact of the ECB's QE programme on interest spreads, exchange rates and economic activity, notably real GDP and inflation, for different specifications of the QE programme. In Section 4 we investigate the effect the international dimension by experimenting with the degree of openness of the economy. In Section 5, we attempt to assess how QE can lift the economy from a zero lower bound environment endogenously. In Section 6 we finally conclude.

2. Modelling framework

QE denotes a monetary policy strategy to increase the size of the central bank's balance sheet. In particular, the central bank purchases long-term government bonds, with the aim of reducing the interest spread between short and long maturities (i.e. flattening the yield curve), and finances this transaction by providing additional liquidity to the private sector. QE intends to affect private-sector portfolio and saving decisions especially when short-term policy rates are already at or close to the zero lower bound (ZLB).

We introduce these elements of QE in the European Commission's QUEST macroeconomic model with one production sector (tradables) and two regions, namely the euro area (EA) and the rest of the world (RoW). A detailed description of the QUEST model can be found, e.g., in Ratto et al. (2009) and Vogel (2014).

The specific model extension that we are interested in introduces long-term government bonds (superscript L) alongside short-term government debt (superscript S) and an explicit central bank balance sheet. Following Woodford (2001), Chen et al. (2012), and Liu et al. (2015), long-term government debt is modelled through bonds for which the nominal coupon c, which is a fraction of the principal, depreciates over time at rate δ_b. The price in period t of a long-term bond issued in t (P_t^N) equals the discounted value of future payments:

(1) $$P_t^N = \sum_{n=0}^{T} \frac{\delta_b^n}{(1+i)^{1+n}} c$$

where T is the maturity period of the bond. Analogously, the price in period *t* of a long-term bond issued in *t-1* (P_t^O) equals the discounted sum of outstanding payments:

(2) $$P_t^O = \sum_{n=0}^{T-1} \frac{\delta_b^{1+n}}{(1+i)^{1+n}} c$$

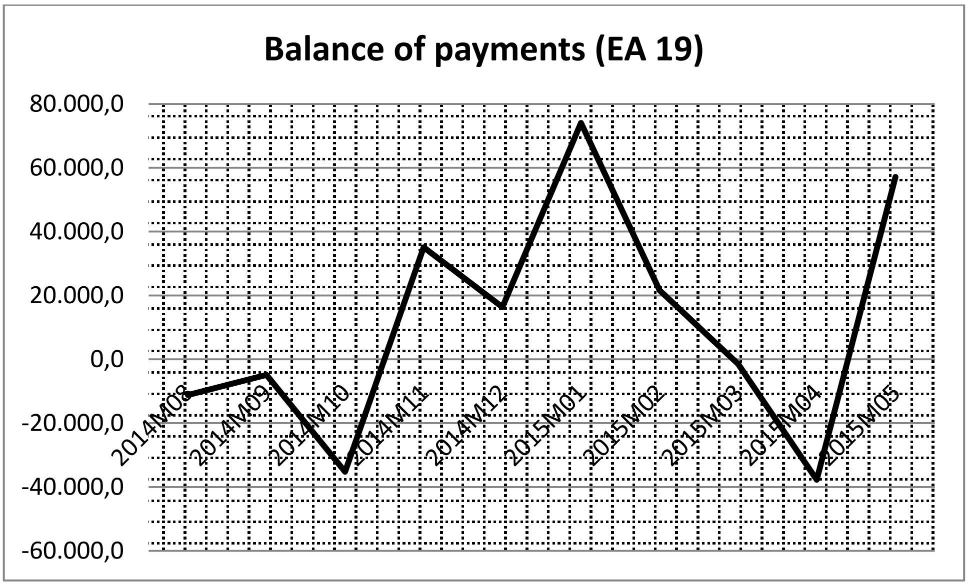
If $\delta_b/(1+i) < 1$ and *T* is large, the price in *t* of long-term bonds issues in *t-1* corresponds (approximately) to the price of newly issue long-term bonds times the depreciation rate:

(3) $$P_t^O = \delta_b P_t^N$$

Equation (3) shows that the price of the long-term bond that pays a declining coupon declines over time at the rate δ_b. We assume the long-term bonds in the model to have 10-year maturity, so that, on average, one 1/40th of the long-term bonds mature in each quarter. The depreciation rate on the coupon is set in line with this to $\delta_b = 0.975$. This is consistent with the ECB's announcement in specifying that Eurozone government bonds considered for the QE programme will mature anywhere from two years to 31 years (Valiante, 2015).

There is considerable evidence that Eurozone residents increased their portfolio of government bonds significantly in March and April of 2015, the initiation phase of the ECB's QE programme. This observation points to the possibility that these bonds have been purchased by the ECB from non-EA residents as part of the QE programme. Figure 2 shows that during the second quarter of 2015 non-Eurozone residents reduced their euro-denominated long-term debt portfolio by an amount of 61 billion euro. This approximately corresponds to 50% of the total amount of government bonds purchased by the ECB in the same time horizon. Moreover, prior to the launching of QE, Hartwig Lojsch et al. (2011) report that within a given country of the EA, non-residents hold on average 52% of government debt, whilst residents held the smaller share of 48%. 38% of resident government debt in turn was held by monetary and financial institutions and less than 2% by the central bank.

Figure 2: Eurozone balance of payments bond flows (EUR mln)



Note: Total economy liabilities (million Euro). Source: AMECO

In line with this evidence we allow for the EA-wide central bank to purchase EA bonds that are held by EA residents and non-residents. Total government debt consists of long-term bonds B_t^L held by domestic ($B_t^{L,H}$) and foreign agents ($B_t^{L,F}$) and of short-term bonds B_t^S :

(4) $$B_t = B_t^{L,H} + B_t^{L,F} + B_t^{L,CB} + B_t^S$$

We assume that long-term bonds account for a constant share of government debt:

(5) $$B_t^L = s^L B_t$$

The share of long-term bonds is set to $s_L = 0.5$ in the simulations, implying that the average maturity matches the value reported by Hartwig Lojsch et al. (2011) for EA government debt.

The model introduces imperfect substitutability between short-term and long-term bonds, which takes the form of quadratic portfolio adjustment costs. In particular, households have a preference for holding a mix of short-term and long-term bonds, and deviations from the target value κ for the ratio of long-term over short-term debt generate quadratic adjustment costs, which are scaled by the parameter γ_b. The same formulation of portfolio preferences/adjustment costs has been used previously by, e.g., Andrés et al. (2004), Falagiarda (2013), Harrison (2012), and Liu et al. (2015). As shown by Schmitt-Grohé and Uribe (2003), an analogous formulation for (net) foreign assets relative to the target $\bar{B}^*$ closes the external part of the model. Private households with access to financial markets (superscript r for Ricardian) face the following optimisation problem:[3]

(6)
$$\max L^r = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t^r, N_t^r)$$
$$-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t \beta^t \left(\begin{array}{l} \frac{(1+t_t^c)P_t^C}{P_t} C_t^r + \frac{P_t^C (K_t - (1-\delta_k)K_{t-1})}{P_t} + \frac{B_t^S}{(1+i_t)P_t} \\ + \frac{P_t^N B_t^{L,H}}{P_t} \left(1 + \frac{\gamma_b}{2} (\kappa \frac{B_t^S}{B_t^{L,H}} - 1)^2 \right) + \frac{e_t B_t^*}{(1+i_t^*)P_t} + \frac{\gamma_f}{2} \left(\frac{e_t (B_t^* - \bar{B}^*)}{P_t} \right)^2 \\ + \frac{e_t P_t^{N*} B_t^{L,H*}}{P_t} \left(1 + \frac{\gamma_b^*}{2} (\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}} - 1)^2 \right) - \frac{TR_t}{P_t} - \frac{c B_{t-1}^{L,H}}{P_t} - \frac{c^* e_t B_{t-1}^{L,H*}}{P_t} \\ - \frac{\delta_b P_t^N B_{t-1}^{L,H}}{P_t} - \frac{\delta_b^* e_t P_t^{N*} B_{t-1}^{L,H*}}{P_t} - \frac{B_{t-1}^S}{P_t} - \frac{e_t B_{t-1}^*}{P_t} - \frac{(1-t_t^w) W_t N_t^r}{P_t} \\ -(i_{t-1}^k - (i_{t-1}^k - \delta_k) t_{t-1}^k - \varphi_{t-1}) \frac{P_t^C}{P_t} K_{t-1} - \frac{D_t}{P_t} \end{array} \right)$$

Ricardian households receive labour income, returns on financial assets, income i_t^k from lending capital to firms net of an (exogenous) risk/insurance premium given revenue uncertainty φ_t, and dividends D_t from firm ownership. $K_t = I_t + (1-\delta_k)K_{t-1}$ is the capital stock as the sum of new investment I_t and the previous-period capital stock depreciated at rate δ_k. The government levies taxes t_t^w on income from labour, t_t^k on corporate income and t_t^c on consumption. The price in period *t* of a short-term (1-period) bond of nominal value B_t^S is $B_t^S / (1+i_t)$, with i_t being the short-term nominal interest rate. Analogously, $e_t B_t^* / (1+i_t^*)$ is the price in domestic currency of a foreign bond B_t^*, where e_t is the nominal exchange rate defined as the value in domestic currency of one unit of foreign currency.

[3] The description here omits adjustment costs in the real sector of the economy (price, wage, capital, and labour adjustment costs) that do not affect the first-order conditions for portfolio holdings and savings. These adjustment costs are present in the full version of the model used for the simulations. Details on the specification of the real-sector adjustment frictions can be found in, e.g., Vogel (2014).

The maximisation problem (6) provides us with the following first-order conditions (FOC):

(7) $$\frac{\partial L^r}{\partial B_t^S} \Rightarrow \beta E_t(\frac{\lambda_{t+1}}{\lambda_t}) = E_t(\frac{P_{t+1}}{P_t})\left(\frac{1}{1+i_t} + \gamma_b \kappa P_t^N (\kappa \frac{B_t^S}{B_t^{L,H}} - 1)\right)$$

(8) $$\frac{\partial L^r}{\partial B_t^{L,H}} \Rightarrow \beta E_t(\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t}{P_{t+1}}) = E_t(\frac{P_t^N}{\delta_b P_{t+1}^N + c})\begin{pmatrix} 1 + \frac{\gamma_b}{2}(\kappa \frac{B_t^S}{B_t^{L,H}} - 1)^2 \\ -\gamma_b \kappa(\kappa \frac{B_t^S}{B_t^{L,H}} - 1)\frac{B_t^S}{B_t^{L,H}} \\ +\gamma_b^* \kappa^* (\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}} - 1)\frac{e_t P_t^{N*}}{P_t^N} \end{pmatrix}$$

(9) $$\frac{\partial L^r}{\partial B_t^{L,H*}} \Rightarrow \beta E_t(\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t}{P_{t+1}}\frac{e_{t+1}}{e_t}) = E_t(\frac{P_t^{N*}}{\delta_b^* P_{t+1}^{N*} + c^*})\begin{pmatrix} 1 + \frac{\gamma_b^*}{2}(\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}} - 1)^2 \\ -\gamma_b^* \kappa^* (\kappa^* \frac{B_t^{L.H}}{B_t^{L,H*}} - 1)\frac{B_t^{L,H}}{B_t^{L,H*}} \end{pmatrix}$$

(10) $$\frac{\partial L^r}{\partial B_t^*} \Rightarrow \beta E_t(\frac{\lambda_{t+1}}{\lambda_t}) = E_t(\frac{e_t}{e_{t+1}}\frac{P_{t+1}}{P_t})\left(\frac{1}{1+i_t^*} + \gamma_f \frac{e_t(B_t^* - \bar{B}^*)}{P_t}\right)$$

(11) $$\frac{\partial L^r}{\partial K_t} \Rightarrow \beta E_t(\frac{\lambda_{t+1}}{\lambda_t}) = E_t(\frac{P_{t+1}}{P_t}\frac{P_t^C}{P_{t+1}^C})\frac{1}{(1+i_t^k - \varphi_t - \delta_k) - t_t^k(i_t^k - \delta_k)}$$

(12) $$\frac{\partial L^r}{\partial C_t^r} \Rightarrow U_t^C = \frac{(1+t_t^c)P_t^c}{P_t}\lambda_t$$

(13) $$\frac{\partial L^r}{\partial N_t^r} \Rightarrow U_t^N = \frac{(1-t_t^w)W_t}{P_t}\lambda_t$$

Combining (7) with (8), (9) and (10) and (11) illustrates the transmission channels of QE to the real economy:

(14) $$\frac{1}{1+i_t} + \gamma_b \kappa P_t^N (\kappa \frac{B_t^S}{B_t^{L,H}} - 1) = E_t(\frac{P_t^N}{\delta_b P_{t+1}^N + c})\begin{pmatrix} 1 + \frac{\gamma_b}{2}(\kappa \frac{B_t^S}{B_t^{L,H}} - 1)^2 \\ -\gamma_b \kappa(\kappa \frac{B_t^S}{B_t^{L,H}} - 1)\frac{B_t^S}{B_t^{L,H}} \\ +\gamma_b^* \kappa^* (\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}} - 1)\frac{e_t P_t^{N*}}{P_t^N} \end{pmatrix}$$

(15) $$\frac{1}{1+i_t}+\gamma_b\kappa P_t^N(\kappa\frac{B_t^S}{B_t^{L,H}}-1)=E_t(\frac{e_t}{e_{t+1}}\frac{P_t^{N*}}{\delta_b^* P_{t+1}^{N*}+c^*})\begin{pmatrix}1+\frac{\gamma_b^*}{2}(\kappa^*\frac{B_t^{L,H}}{B_t^{L,H*}}-1)^2\\ -\gamma_b^*\kappa^*(\kappa^*\frac{B_t^{L.H}}{B_t^{L,H*}}-1)\frac{B_t^{L,H}}{B_t^{L,H*}}\end{pmatrix}$$

(16) $$\frac{1}{1+i_t}+\gamma_b\kappa P_t^N(\kappa\frac{B_t^S}{B_t^{L,H}}-1)=E_t(\frac{e_t}{e_{t+1}})\left(\frac{1}{1+i_t^*}+\gamma_f\frac{e_t(B_t^*-\overline{B}^*)}{P_t}\right)$$

(17) $$\frac{1}{1+i_t}+\gamma_b\kappa P_t^N(\kappa\frac{B_t^S}{B_t^{L,H}}-1)=E_t(\frac{P_t^C}{P_{t+1}^C})\frac{1}{(1+i_t^k-\varphi_t-\delta_k)-t_t^k(i_t^k-\delta_k)}$$

(18) $$\frac{1}{1+i_t}+\gamma_b\kappa P_t^N(\kappa\frac{B_t^S}{B_t^{L,H}}-1)=\beta\frac{(1+t_t^c)P_t^c U_{t+1}^C}{(1+t_{t+1}^c)P_{t+1}^c U_t^C}$$

The impact on asset prices of central bank purchase of long-term bonds derives from private investor portfolio adjustment costs, i.e. imperfect substitutability between different financial assets. For $\gamma_b > 0$, i.e. bonds of different duration are imperfect substitutes, the effects of reducing $B_t^{L,H}$ relative to B_t^S in the household portfolio are similar to the impact of a reduction of the short-term interest rate i_t in the FOC. Unconventional monetary policy can, hence, mimic the effects of short-term interest rate reductions.

In particular, when the central bank intervenes by purchasing long-term bonds, private investors that aim at re-establishing the portfolio mix of short-term and long-term assets can respond by holding more corporate equity and foreign bonds, and by reductions in savings. The first response means a portfolio reallocation towards equity and foreign-currency assets that increases the price of corporate equity (rising stock market) and the price of foreign currency (exchange rate devaluation). Equations (15)-(16) show that QE leads to higher demand for foreign assets and depreciation of the domestic currency (increase in e_t) for given levels of i_t (restricted, e.g., at the ZLB) and i_t^*. Equation (17) illustrates the portfolio reallocation from government bonds towards corporate equity. Equation (18) shows that QE reduces private saving in the short term similar to a reduction in the short-term interest rate.

Concerning the transmission to the real economy, rising stock markets reduce the financing costs of corporations and, dampening the required return to capital, translate (under decreasing returns to capital) into stronger investment and capital accumulation. Exchange rate depreciation strengthens net exports provided that export and import demand are sufficiently price elastic. The second response of reduced savings to restore the preferred portfolio mix strengthens contemporaneous consumption demand.

The stock of government debt which is composed of short-term and long-term bonds follows:

$$\text{(19)} \qquad \frac{B_t^S}{(1+i_t)P_t} + \frac{P_t^N}{P_t} B_t^L = \frac{B_{t-1}^S}{P_t} + \frac{(\delta_b P_t^N + c)B_{t-1}^L}{P_t} + \frac{PGE_t}{P_t} - \frac{TAX_t}{P_t} - \frac{PR_t^{CB}}{P_t}$$

where PGE_t, TAX_t and PR_t^{CB} are, respectively, primary government expenditure (public consumption, public investment, transfers), total tax revenue (labour, consumption, and corporate taxes), and the operating profit of the central bank as an additional source of government revenue.

The evolution of the net foreign asset (NFA) position of the domestic economy follows:

$$\text{(20)} \qquad \begin{aligned} & e_t(B_t^* + P_t^{N*} B_t^{L,H*}) - P_t^N B_t^{L,F} \\ & = (1+i_{t-1}^*)e_t B_{t-1}^* + (c^* + \delta_b^* P_t^{N*})e_t B_{t-1}^{L,H*} - (c + \delta_b P_t^N)e_t B_{t-1}^{L,F} + P_t^X X_t - P_t^M M_t \end{aligned}$$

The operating profit of the central bank equals the sum of base money issuance and interest income minus the current expenditure on buying long-term bonds, where the latter equals the change of the value of long-term bonds on the central bank's balance sheet:

$$\text{(21)} \qquad PR_t^{CB} = \Delta M_t + cB_{t-1}^{L,CB} - (P_t^N B_t^{L,CB} - \delta_b P_t^N B_{t-1}^{L,CB})$$

Under the central bank's budget constraint (21), purchases of long-term government bonds can be financed either by increasing liquidity (money issuance), or by reducing the central bank's operating profit.[4] In line with the standard definition of QE and the ECB announcement, the first option of enhanced liquidity provision is chosen.

Purchases of long-term bonds by the central bank can be modelled as endogenous response to the economic environment (e.g., the economy's position in the business cycle or the slope of the yield curve) similar to a Taylor rule, or as exogenous path ε_t^{CB} :

(22) $$B_t^{L,CB} = (1-\rho_L)\bar{B}^{L,CB} + \rho_L B_{t-1}^{L,CB} + (1-\rho_L)F(.) + \varepsilon_t^{CB}$$

The simulations do not assume an endogenous response, i.e. F(.)=0, and calibrate the exogenous path to the ECB programme instead. Affecting government revenues directly (interest rate on government debt, central bank profit) or indirectly (tax revenues), QE also affects the evolution of government debt to some extent. The budget-closure rule in the model ensures the stabilisation of government debt around its target level. In the simulations we assume that debt stabilisation operates through the adjustment of the labour tax rate.

Although the modelling of portfolio decisions focuses on private households as financial investors, it can also be understood as including pension and investment funds that act on behalf of households. Banks as financial intermediaries are not included in the model, but they can be thought of as facing a similar decision problem based on a preferred portfolio mix. When the central bank buys long-term government bonds from banks, the latter can respond by buying more bonds from households (secondary market), buying more equity and foreign assets, and providing more loans to equilibrate their portfolio structure.

The empirical literature on unconventional monetary policy has listed a number of channels through which QE can affect macroeconomic variables (see Krishnamurthy and Vissing-Jorgensen, 2011). The relevance of the individual channels is an empirical matter and likely to vary across countries and time. Empirical evidence on the interest rate, GDP and inflation effects and the relevance of different transmission channels is provided, e.g., in Bauer and Neely (2014), Bowman et al. (2015), Darracq-Paries and De Santis (2015), Lo Duca et al. (2016), and Schenkelberg and Watzka (2013). Our modelling approach incorporates the following transmission channels:

[4] A third option, in general, is for the central bank to sell other assets from its portfolio to sterilise the impact of its intervention on the central bank balance sheet.

- The purchase by the central bank of long-term bonds reduces the return on these bonds for given expectations about future short-term interest rates, i.e. it lowers the term premium, which is the difference between the return on the long-term bond and the expected sequence of future short-term rates ("term premium channel").

- Portfolio rebalancing in the private sector in response to central bank purchases of (safe) long-term government bonds lead to higher demand for (riskier) assets. In particular, demand for corporate equity and real estate may increase and strengthen corporate and construction investment ("safety channel").

- QE strengthens the demand for foreign-currency assets and leads to a depreciation of the domestic currency. The devaluation improves the price competitiveness of domestic output and the trade balance, if trade is sufficiently price elastic and openness towards non-EA countries significant ("exchange rate channel").

- QE in its original definition means an expansion of the central bank balance sheet that implies growth in base money ("liquidity channel"); our model does not incorporate implications for the credit supply by banks, however.

- If QE depreciates the exchange rate and stimulates demand and output, it also increases inflation expectations. A rise in inflation expectations reduces the real interest rate and should strengthen interest-sensitive demand in the economy, particular when the zero bound on nominal short-term rates is binding ("inflation channel").

- Balance-sheet operations that change the market value of long-term government bonds affect the financing conditions of the government. Using the financing-cost reduction to lower taxes or increase primary expenditure would add demand stimulus in the short term. Using the budgetary saving due to lower financing costs to pay down government debt reduces the future tax burden on the private sector ("fiscal channel").

Although it plays a prominent role in the general discussion of QE effects, the "signalling channel", according to which QE communicates a commitment by the central bank to leave interest rates low for an extended period of time, is absent in our set-up. In the model, the path of future risk-free interest rates depends on the monetary policy rule. To the extent that QE succeeds in stimulating aggregate demand and stabilising inflation expectations, future policy rates are likely to rise. Also absent are the "prepayment risk channel" and the "default risk channel" (Krishnamurthy and Vissing-Jorgensen, 2011), which according to Demary and Huether (2015) are of minor relevance in the EA context.

The central focus of the empirical literature is on central bank announcements, rather than actual implementation of QE. As Fratzscher et al. (2013) state "an important caveat is that [...] announcements do not imply any change in supply of e.g. US Treasury securities at the time the announcements are made, but they merely indicate that such a change will occur at some point in the future, to some degree, and with certain probability" (p.10). As a result, this methodology essentially captures a change in expectations about future asset prices rather than current asset prices.

Bauer and Rudebusch (2013) contribute to this issue by quantifying the statistical uncertainty surrounding estimates derived from the workhorse models in empirical income finance and, using a suitable methodology, find that the primary effect of the Fed's QE operated under announcements, leading to lower market expectations of the future policy path. As a result, their analysis suggests a more prominent role for QE to operate through the signalling channel.

In an attempt to disentangle announcement and implementation effects of QE, Christensen and Rudebusch (2012) use a structural model to decompose the declines in government bond yields following announcements by the Fed and the Bank of England. They are able to distinctly capture effects related to changes in expectations about future monetary policy (signalling channel) and changes in term premiums (term premium channel). The results suggest that for the US the main effect of QE operated by affecting policy expectations, whereas for the UK yield declines were driven solely by term-premium reductions.

Abstracting from an explicit bank-lending channel in our analysis can lead to our results being considered as an upper bound in magnitudes. In our model, corporates borrow from the capital market instead of banks, and their financing costs fall as a result of QE. In a more bank-centric system, as in Europe, firms refinance more strongly through credit, suggesting that the equity price channel could be overstated in our methodology. However, recent empirical evidence by Huelsewig et al. (2015) suggests little dampening impact of QE on borrowing rates in the EA.

3. Quantitative Analysis

This section presents the simulation results for implementing the ECB's QE in our model. The simulated QE path corresponds to the announcement of purchasing €1000 billion long-term bonds in monthly steps of € 50 billion from March 2015 until September 2016. A gradual exit from QE is assumed thereafter. The long-term bond purchase is financed by an increase in liquidity supply and the zero lower bound is taken to be binding for the horizon of the simulation. Subsequently, we perform a number of policy experiments by contrasting the result to counterfactuals in order to investigate several aspects of QE design such as the duration of the programme, its timing, and exit paths. We also consider the ECB announcements from December 3rd, 2015, to extend the programme at least until March 2017.

Calibration

The value of portfolio adjustment costs γ_b determines the impact of QE on the term premium. This impact on the term premium is very difficult to identify from data, because it requires knowledge of the relevant time horizon, i.e. when did agents start anticipating which volume and time path of QE, and additional domestic and international factors such as the time path of (other) risk premia and the path of expected future short-term interest rates.

As an assessment of the ECB's January 2015 QE programme is still outstanding, Table 1 and Figure 1 provide some crude evidence. They show the change in the yield of inflation-indexed 10-year bonds for Germany, France and Italy over three different time intervals. The bond yields have fallen by 30-80 basis points between May 2014, when there was already some expectation of EA QE, and January 2015, when the ECB finally announced the programme. Yield changes are smaller if shorter time horizons are considered. The fall in yields between end-December 2014 and end-January 2015, e.g., amounts to only 10-20 basis points.

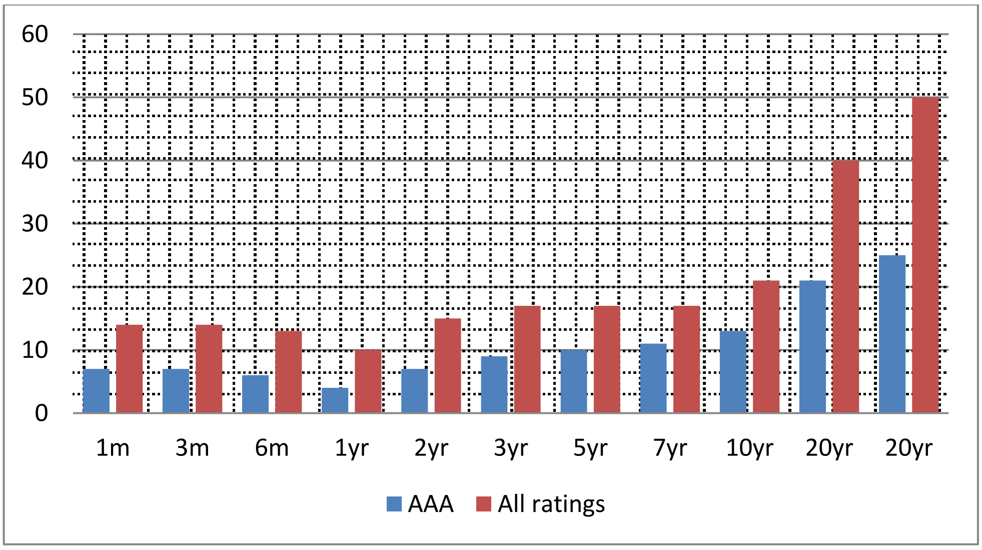
Table 1: Changes in bond yields for selected EA countries

Change in yield of 10-year inflation-indexed government bonds (% points)[1]			
	Germany	France	Italy
30/05/14-31/01/15	-0.39	-0.61	-0.80
31/10/14-31/01/15	-0.06	-0.22	-0.41
31/12/14-31/01/15	-0.10	-0.11	-0.20

[1] Indexation to French CPI for France and to EA HICP for others.
Source: Bloomberg

Figure 1 presents the announcement effect (or the ability of the QE programme to surprise the market). As can be seen, between the date of announcement and the beginning of the programme interest rates of EA public bonds fell significantly. Depending on the maturity structures these declines range from -7 basis points (20-year maturity bonds) to -50 basis points (10-year maturity bonds).

Figure 1: Announcement effect (basis points)



In line with this information and given the ECB programme we set the value of γ_b to generate an approximately -13 bps term premium decline. The remaining model parameters follow the standard QUEST calibration to match long-term ratios from national accounts and average adjustment frequencies reported in empirical research. The zero bound on short-term policy rates is assumed to bind during 2015-16.

Further evidence that we employ to verify our calibration of the adjustment cost parameter can be found in Gagnon et al. (2011). The paper estimates whether long-term yields are related to the 10-year Treasury term premium and find that the US Fed QE1 should have reduced the term premium by approximately 52 bps and the 10-year Treasury yield by approximately 82 bps.

If QE has contributed to the decline in long-term bond yields, it has not reversed the fall in inflation expectations over the same horizon. Instead, inflation expectations based on 10-year swap rates have declined until end-January 2015 (Table 2). This does not exclude that QE has mitigated the fall in expected inflation, which has been associated primarily with falling commodity prices, i.e. that inflation expectations would have fallen by more without the QE perspective. However, by end-January 2015, the trend of falling expected inflation had not reversed.

Table 2: Changes in swap rates and expected inflation

Change in overnight rate for 10-year interest swaps (% points)			
	Nominal	Real	Inflation[1]
30/05/14-31/01/15	-0.86	-0.29	-0.56
31/10/14-31/01/15	-0.35	-0.03	-0.32
31/12/14-31/01/15	-0.14	-0.03	-0.12

[1] Inflation is the break-even value given nominal and real swaps.
Source: Bloomberg

After the announcement of QE, inflation expectations have stabilised in February and risen somewhat during the first half of March 2015. A contribution of QE to this pattern is plausibly, but other factors, such as the partial recovery of oil prices during February 2015, may also have played a role.

Results

Table 3 reports simulation results for the ECB's initial QE path (March 2015–September 2016) for the years 2015 and 2016. Higher private consumption and investment demand, which is associated with lower savings and portfolio rebalancing, raise real GDP growth by 0.2 pp in the first year and 0.1 pp in the second year. The contribution of net exports (exchange rate depreciation) is modest given adjustment frictions that reduce the short-term elasticity of export and import demand with respect to the nominal exchange rate. Inflation rises by 0.3 pp in both years in response to stronger output growth and exchange rate depreciation.

Table 3: EA results for ECB QE path March 2015-September 2016

	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.22	0.30
CONSUMPTION_PCER	0.37	0.48
INVESTMENT_PCER	0.31	0.43
EXPORTS_PCER	0.10	0.19
IMPORTS_PCER	0.26	0.46
PRICE.LEVEL.GDP_PCER	0.29	0.62
CPI.LEVEL_PCER	0.28	0.59
NEER_PCER	1.02	1.00
in percentage terms:		
GDP.GROWTH_ER	0.22	0.08
INFL.PGDP_ER	0.29	0.33
INFL.CPI	0.28	0.31

Note: Results are deviations from a no-QE baseline

Our results are qualitatively in line with a number of empirical studies that have estimated the impact of QE in other samples. In particular, Baumeister and Benati (2010) find that the Fed's QE1 programme on the US economy led to a 4% positive impact on real GDP in 2009Q1 and a 0.4 percentage point impact on inflation in 2009Q2. Chung et al. (2011) find that a 50 bps decline in the term premium in the U.S. (QE2) has led to an increase of real GDP by approximately 2% in 2012 and an increase of inflation by 0.7 percentage points in 2011.

The simulation reported in Table 3 assumes that tax payers benefit from the positive impact of QE on the government debt-to-GDP ratio (tax base growth, denominator effect) through a moderate reduction in the labour income tax that stabilises government finances at the pre-QE level. The alternative that positive fiscal effects are used to reduce the stock of government debt leads to very similar results, because the implied tax reduction in the scenario of Table 3 remains temporary and below 0.3 pp.

Table 4 looks at the question of whether there is quantitatively important non-linearity in the QE effects with regard to the *starting conditions*. Compared to Table 3, Table 4 places QE in a more adverse macroeconomic context whereby a recession is triggered through adverse demand shocks. In particular, real GDP growth is lower by 1 pp in 2015 and 1 pp in 2016. As can be seen, the effects here are somewhat higher, suggesting a 0.3 pp increase in real GDP in 2015 and 0.1 pp in the 2016. The increase in inflation is somewhat lower at 0.2 pp in 2015 and 0.3 pp in 2016. The more positive GDP effect is associated with stronger euro depreciation (improving export demand) and a more prolonged period of low interest rates (strengthening consumption and investment demand). The results in Table 4 provide evidence for nonlinearities in the transmission mechanisms of the QE programme.

Table 4: EA results in more adverse environment

	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.28	0.41
CONSUMPTION_PCER	0.46	0.62
INVESTMENT_PCER	0.19	0.25
EXPORTS_PCER	0.14	0.30
IMPORTS_PCER	0.19	0.33
PGDP_PCER	0.22	0.51
CPI_PCER	0.23	0.53
NEER_PCER	1.29	1.21
in percentage points:		
GDP.GROWTH_ER	0.28	0.13
INFL.PGDP_ER	0.22	0.29
INFL.CPI	0.23	0.30

Note: Results are deviations from a no-QE baseline

Extensions and counterfactuals

We perform a number of policy experiments by contrasting the benchmark results in Table 3 with counterfactual simulations to investigate several aspects of QE design such as the duration of the programme, its timing, and exit paths.

Table 5 addresses the question of whether the *time path* of QE implementation affects its macroeconomic effects. It reports results for a scenario of accelerated QE in which the volume of €1000 billion long-term bonds is bought by 2015q4 rather than 2016q3. As in the case of 2-year QE in Table 3, exit in the sense of balance sheet reduction starts in 2017q1. Table 5 indicates a more pronounced impact of frontloaded QE, notably on inflation, which derives from the frontloading of private-sector portfolio rebalancing and its implications for the exchange rates and private sector demand.

Table 5: EA results for frontloading of QE

	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.24	0.30
CONSUMPTION_PCER	0.40	0.47
INVESTMENT_PCER	0.21	0.26
EXPORTS_PCER	0.12	0.25
IMPORTS_PCER	0.23	0.35
PGDP_PCER	0.29	0.60
CPI_PCER	0.29	0.59
NEER_PCER	1.20	1.11
in percentage points:		
GDP.GROWTH_ER	0.24	0.06
INFL.PGDP_ER	0.29	0.31
INFL.CPI	0.29	0.30

Note: Results are deviations from a no-QE baseline

Second, we address the issue of extending the duration of the QE programme by assuming the purchase of long-term bonds to continue until March 2017 as announced by the ECB in December 2015. As can be seen in Table 6, some of the effects from increasing the duration of the programme already become visible in 2015 and 2016.

Table 6: EA results for ECB QE path March 2015-March 2017

Impact of QE on EA economy in QUEST		
	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.37	0.49
CONSUMPTION_PCER	0.62	0.79
INVESTMENT_PCER	0.52	0.71
EXPORTS_PCER	0.16	0.31
IMPORTS_PCER	0.45	0.78
PGDP_PCER	0.51	1.07
CPI_PCER	0.48	1.01
NEER_PCER	1.71	1.70
in percentage points:		
GDP.GROWTH_ER	0.37	0.12
INFL.PGDP_ER	0.51	0.55
INFL.CPI	0.48	0.53

Note: Results are deviations from a no-QE baseline

The results in Table 6 should be interpreted cautiously. They illustrate the QE effect when agents in the economy are fully aware of the extended duration of the programme already from the start. If this were the case, then real GDP growth in 2015 would have been stronger by 0.4 pp, followed by an additional increase of 0.1 pp. in 2016. Effects are different if the announcement of QE extension from December 2015 is treated as surprise. A proper re-evaluation of the extension of the programme during implementation, i.e. the December 2015 announcement, would require assumptions on the expectations of the private sector in this respect, i.e. the nature of the extension as surprise or not. We leave this to future work.

Table 7 investigates the design of QE along two dimensions, namely the duration of the programme and the assumed speed of exit. In particular it looks at the limiting case where exit does not occur, implying that long term government bonds purchased by the ECB remain on the central bank balance sheet permanently. Clearly, this scenario suggests substantially larger real effects from QE leading to a rise in real GDP growth by 1.2 pp in 2015 and an additional 0.3 pp in 2016.

Table 7: EA results for QE without exit

Impact of QE on EA economy in QUEST		
	2015A	2016A
in per cent:		
GDP.REAL_PCER	1.16	1.48
CONSUMPTION_PCER	2.22	2.75
INVESTMENT_PCER	1.56	2.06
EXPORTS_PCER	0.44	0.82
IMPORTS_PCER	1.87	3.08
PGDP_PCER	2.14	4.04
CPI_PCER	1.93	3.72
NEER_PCER	5.45	5.50
in percentage points:		
GDP.GROWTH_ER	1.16	0.32
INFL.PGDP_ER	2.11	1.84
INFL.CPI	1.91	1.75

Note: Results are deviations from a no-QE baseline

4. Heterogeneity of transmission

An important characteristic of our model is that we extend previous work by including an international dimension in our analysis. Unlike other studies, which have situated their analysis in closed-economy models, we link the EA to a rest-of-the-world aggregate (ROW) through trade and financial market ties. This allows us to include QE transmission through the exchange rate channel in the picture. We have focused the analysis on aggregate EA effects. Differences across EA Member States in pre-QE government bond yields and economic conditions raise the question of whether QE effects differ across countries and, notably, between the "core" and the "periphery" of the EA. Empirical work, e.g., by Falagiarda and Reitz (2015) finds evidence for heterogeneity across EA economies.

From the portfolio rebalancing perspective, cross-country differences can result from asymmetries in the programme or country-specific supply elasticities for long-term bonds that the central bank is going to buy. If, e.g., private holders are more willing to sell "periphery" bonds to the central bank, but hold on to their "core" bonds, the ECB purchase would imply less term-premium reduction in "periphery" compared to "core" countries. Hence, QE would be less effective in the EA periphery in particular in the case of significant home bias in financial markets.

Regionally differentiated effects may also derive from uneven financial constraints across countries. The direction is, however, ambiguous and depends on the precise nature of the constraints. Where larger parts of the household sector have no access to capital markets (no portfolio reallocation or savings response), immediate QE effects will be weak. If weak private demand is due to binding credit constraints, however, QE effects may become more effective. In particular, QE-related growth in the value of pledgeable collateral (housing wealth, firm value, and financial wealth) could ease credit constraints for households and firms.

Extra liquidity from QE and the rebound of asset values may also increase credit supply by banks, in particular where the latter are operating at the leverage constraint. To the extent that banks remain fragile and undercapitalised in "periphery" countries, however, additional liquidity through QE may not be converted into more credit supply to the private sector.

Finally, real effects through the exchange rate channel differ obviously due to heterogeneity in trade elasticities and openness to non-EA trade, although not necessarily across the core-periphery dimension. The trade effects may feed back into financial conditions, i.e. via higher stock market gains of more export-oriented firms and countries. To explore the role of openness, Tables 8 and 9 present simulation results for two contrasting cases of high home bias (10% export share in GDP in the steady state) and low home bias (90%

export share in GDP in the steady state) respectively. Trade openness in the benchmark model is relatively low, with exports accounting for 23% of GDP in the steady state.

As can be seen, openness is inversely related to the effectiveness of QE. A more closed economy (high home bias) implies a QE impact on real GDP growth of 0.3 pp in 2015; a more open economy (low home bias) implies a real GDP growth effect of only 0.1 pp in 2015.

Table 8: Results with higher home bias

Impact of QE on EA economy in QUEST		
	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.32	0.40
CONSUMPTION_PCER	0.47	0.58
INVESTMENT_PCER	0.38	0.50
EXPORTS_PCER	0.13	0.25
IMPORTS_PCER	0.35	0.61
PGDP_PCER	0.41	0.84
CPI_PCER	0.40	0.83
NEER_PCER	1.34	1.32
in percentage points:		
GDP.GROWTH_ER	0.32	0.08
INFL.PGDP_ER	0.41	0.43
INFL.CPI	0.40	0.43

Note: Results are deviations from a no-QE baseline

Table 9: Results with lower home bias

Impact of QE on EA economy in QUEST		
	2015A	2016A
in per cent:		
GDP.REAL_PCER	0.07	0.13
CONSUMPTION_PCER	0.22	0.31
INVESTMENT_PCER	0.24	0.35
EXPORTS_PCER	0.06	0.12
IMPORTS_PCER	0.14	0.25
PGDP_PCER	0.13	0.31
CPI_PCER	0.13	0.29
NEER_PCER	0.60	0.60
in percentage points:		
GDP.GROWTH_ER	0.07	0.06
INFL.PGDP_ER	0.13	0.18
INFL.CPI	0.13	0.16

Note: Results are deviations from a no-QE baseline

5. Can QE alleviate the liquidity trap?

Given the objective of QE of extending credit to the private sector through purchases of long-term governments in times of a binding zero lower bound, any analysis on the effectiveness of QE would be incomplete without mention to the consequences for the nominal interest rate. Using solution techniques for an temporarily and endogenously binding zero lower bound constraint we perform assess whether QE is successful in steering the economy away from a liquidity trap in periods of severe recessions.

[Work in progress: results to be added and to be discussed.]

6. Conclusions

The paper analyses quantitative easing (QE) in an open-economy dynamic general-equilibrium model which includes assets of different types and maturity. We model QE explicitly as asset purchase by the central bank that expands the central bank's balance sheet. In particular, QE is modelled as central bank purchases of long-term government bonds financed by enhanced liquidity provision to the private sector. With imperfect substitutability between short-term and long-term assets, QE affects private-sector portfolio allocation and saving decisions and, by consequence, term premia, stock prices, the exchange rate and private demand.

The model has been used to assess the impact of the ECB's QE programme as announced in January 2015, i.e. the announced purchase of € 1000 billion long-term bonds in monthly steps of € 50 billion up to September 2016, under the assumption of a term premium reduction by 13 basis points, which is in the order of magnitude of experience with QE in other countries and with early evidence from EA financial markets. With 13 basis points term-premium reduction, the model generates 1 per cent effective euro depreciation and raises real GDP in the euro area by 0.3% and prices by 0.4% until the end of 2016. The impact on long-run inflation expectations remains modest in our setting.

We have used our model for counterfactual simulations to assess the importance of back-loading versus frontloading of balance sheet operations, the duration of QE programmes, and the speed of exit. Frontloading QE strengthens its expansionary effect in the short and medium term, unless it is associated with an earlier exit. Increasing long-term inflation (expectations) significantly requires the balance sheet expansion to be very long lasting.

The paper also discussed state-dependent effects of QE, finding a stronger impact on GDP in heavier recessions, and the role of trade openness (exchange rate channel) for the effectiveness of QE.

Finally, solution techniques for an endogenously and temporarily binding zero lower bound constraint shall be employed to investigate the success of QE in steering the economy away from the liquidity trap.

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