The Reanchoring Channel of QE[*]
The ECB's Asset Purchase Programme and Long-Term Inflation Expectations

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Abstract

This paper analyses the impact of the European Central Bank's asset purchase programme on long-term inflation expectations. It documents that the announcements related to the launch of the programme have raised long-term inflation expectations towards the ECB's medium-term inflation objective. It argues that such a 'reanchoring channel' can enhance the effectiveness of the programme, especially when the policy rate is stuck at its lower bound. The channel can account for a third of the programme's inflation impact in a calibrated macroeconomic model with balance sheet constrained banks and uncertainty about the central bank's inflation target.

Keywords: Unconventional Monetary Policy, Reanchoring Inflation Expectations, Transmission of Large-Scale Asset Purchases

JEL codes: E44, E52, G12

1 Introduction

On 22 January 2015 the ECB joined several other central banks in implementing quantitative easing (henceforth QE) through a large-scale asset purchase programme, the APP. In spite of the popularity of QE as a tool of monetary policy accommodation at the effective lower bound (henceforth ELB) for nominal interest rates, its effectiveness remains debated (see e.g. Woodford, 2012). From an empirical perspective, the strength of the main transmission channel often emphasised by central banks, the portfolio rebalancing channel, is still discussed.

This paper shows that, in the case of the APP, an additional channel of transmission operated through long-term inflation expectations. Over the years from the launch of the European Monetary Union until the Great Recession, euro area long-term inflation expectations had remained anchored to the ECB's inflation objective. As of 2014, however, actual inflation declined persistently towards ultra-low levels and inflation expectations edged down at all horizons, including the long-term. The APP inverted this tendency and fostered a return of long-term inflation expectations towards price stability. We therefore dub this channel the reanchoring channel.

To start with, we present evidence on the reanchoring channel through an analysis of the impact of APP-related announcements on long-term inflation expectations. We measure the news content of these announcements by the interest rate changes that they induced within a 90-minute window. We then aggregate these market surprises over each quarter and analyse their impact on subsequent changes in survey-based and market-implied measures of long-term inflation expectations. Over the post-2013 sample, the analysis reveals a significant, negative relationship between APP-related announcements and changes in long-term inflation expectations within a quarter. A surprise easing associated with a 10 basis points decrease in the 5-year German Bund yield was typically accompanied by a 6 basis points increase in 5-year-ahead inflation expectations.

This evidence is not consistent with the standard monetary policy transmission mechanism embodied in DSGE models. In these models, after any shock inflation tends to return relatively quickly to the inflation target and long-term inflation expectations are always well anchored to the target. To relax this assumption, we adopt a formulation of expectations formation process in the spirit of Gürkaynak, Sack and Swanson (2005). We assume that the private sector cannot observe, or does not fully believe in, the central bank's long-term inflation objective. As a result, the private sector forms beliefs about the inflation objective based on the observable actions of the central bank, involving both the standard policy interest rate and asset purchases. Movements in all policy instruments can thus have an effect on the economy by guiding long-term expectations. For example, the beliefs updating rule implies that the private sector expects persistently low inflation to trigger a monetary policy response through lower interest rates or, at the ELB, asset purchases. This is rational, because in our framework QE is indeed a substitute for interest rate policy. Absent such response, the private sector would conclude that the central bank is content with low inflation and would thus lower its perceived long-term inflation target, compared to the central bank objective. By contrast, a policy response would validate prior beliefs and keep long-term inflation expectations well anchored.

The reanchoring channel operates over and above other transmission channels of large-scale asset purchases, which are also featured in the model. More specifically, we also allow for a form of the portfolio rebalancing channel, which generates by itself a role for QE. Financial intermediaries face funding constraints as in Gertler and Karadi (2013). As a result, asset purchases by the central bank raise inflation and stimulate economic activity also because they

ease aggregate credit conditions. Furthermore, higher inflation reduces real interest rates at the ELB, which amplifies the stimulative impact of the policy through standard transmission channels. While the main emphasis of this paper is on the reanchoring channel, the final section also presents additional, APP-related evidence which supports two versions of the portfolio rebalancing channel: the duration channel and the capital relief channel. First, we show that the fall in yields after the programme announcement was larger, the longer the maturity of the bonds. This evidence is consistent with the duration channel, which posits that central bank asset purchases should lead to a larger reduction of the yields on longer-term bonds, because they are more exposed to duration risk. Second, we show that the equity prices of banks holding a larger portfolio share of government bonds benefited more from the increase in sovereign bond prices produced by the APP. This is consistent with the view that one of the impacts of the APP was to release banks' capital constraints through the increased valuation of the assets on their balance sheets.

Our model simulations indicate that the APP as announced in January 2015 contributed to stabilize the euro area economy and to push up the inflation rate. Compared to a counterfactual scenario without the APP, the peak increase in inflation is around 40 basis points and in output around 1.1 percent. Inflation reanchoring proves to be an important channel, accounting for one third of the transmission of the APP to inflation. The programme announcement increases the perceived long-term inflation target by around 9 basis points. Relative to a calibration without the reanchoring channel, the peak impact of inflation increases by around 15 basis points.

We contribute to the literature by showing that APP-related announcements in the euro area increased survey-based measures of long-term inflation expectations. Previous studies have shown that expansionary QE announcements raised also market-based measures of inflation compensation all across the maturity spectrum (Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla, Carboni and Motto, 2015). Survey measures are free from risk compensation that APP announcements can modify, so their changes better reflect reactions of inflation expectations that is the focus of our analysis.

The reanchoring channel is related to the signalling channel of QE (Bhattarai, Eggertsson and Gafarov, 2015). Both channels emphasize the impact of QE on the path of nominal interest rates the central bank is expected to set, but they exert their influence through different mechanisms and have different impact on the yield curve. The reanchoring channel focuses on the information conveyed by the introduction of a quantitative easing program about the inflation objective of the central bank. Quantitative easing raises the perceived inflation objective. This lowers the perceived interest rate path in the short- and medium term because achieving higher objective requires easier interest rate policy. At the same time, it *raises* interest rate expectations in the long term in line with the higher perceived long-term inflation. In contrast, the signalling channel focuses on the policy's impact on bolstering the central bank's commitment to keep interest rates low to achieve its objective. It predicts lower interest rate

path in the short- and medium term similarly to the reanchoring channel, but predicts no impact on long-term inflation expectations. In practice, both channels can contribute to the effectiveness of quantitative easing policies, together and in interaction with standard portfolio balance channels (Gertler and Karadi, 2011; Curdia and Woodford, 2011; Chen, Cúrdia and Ferrero, 2012; Del Negro, Eggertsson, Ferrero and Kiyotaki, 2010; Bocola, 2016; Carlstrom, Fuerst and Paustian, forthcoming).

The rest of the paper is organised as follows. Section 2 presents the event study evidence on the reaction of long-term inflation expectations to the monetary policy announcements. The model is summarized in in Section 3. After describing the calibration in Section 4, we present the main model simulation results on the impact of the APP on the euro area economy in Section 5. Section 6 presents additional evidence on the portfolio balance channel and Section 7 offers some concluding remarks.

2   Event-study evidence

In this section, we present evidence on the impact of the ECB's monetary policy announcements on long-term inflation expectations. We measure the magnitude of policy news conveyed in these announcements by changes of interest rates within a narrow window around the announcements. We aggregate these market surprises over each quarter and analyse their impact on subsequent changes in survey-based and market measures of long-term inflation expectations.

We measure monetary policy surprises in a narrow window around regular ECB press conferences. The press conferences were conducted monthly up until 2014 and are taking place 8 times a year since. They are held by the President and the Vice President of the ECB between 14:30-15:30 CET, include a prepared Introductory Statement and a Questions and Answers session. They detail the economic outlook and the policy decisions of the Governing Council, including key parameters of the asset purchase programs and other non-standard measures. Decisions on the key policy rates, instead, are announced separately in a press release 45 minutes before the start of each press conference.[1] The separate announcements allow us to exclude the direct impact of contemporaneous interest rate surprises from our intra-day surprise measure. Three of these press conferences[2] included relevant forward guidance about the likely future behavior of policy interest rates. Because we have no robust way to separate the impact of the asset-purchase announcements from these forward guidance announcements, we show that our conclusions on the impact of asset purchase announcements are robust to excluding these days from our analysis.

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[1]Since March 10, 2016, key parameters of the asset purchase programs are also announced as part of the regular press release before the press conference. After this date, we increase our surprise measure by the asset price changes around the press release.

[2]June 5, 2014, October 22, 2015, and March 10, 2016

We use the five-year German Bund yield as our monetary policy indicator. It is a suitable benchmark rate, because the German sovereign debt is arguably one of the safest and most liquid assets within the euro area, and the five-year rate reflects the policy impact of non-standard policies. We construct intra-day market prices using quotes from Thomson Reuters Tick History database.[3] We measure the change of this indicator around the press conferences (Gürkaynak, Sack and Swanson, 2005). In particular, we use a 90-minute window starting 10 minutes before and ending 20 minutes after the hour-long event.[4] The window is long enough to incorporate market reactions to these high profile events, but is narrow enough so as it minimizes the chances that unrelated regular news announcements bias our measure. For example, the intra-day window would exclude monetary policy announcements of the Bank of England (BoE) regularly released at 12:00 CET the same day.

The red bars on Figure 1 show the quarterly sum of the surprises. The data reveals major easing surprises in 2014q2, when a set of new non-standard measures were introduced with an explicit aim to stimulate the euro area economy and drive the inflation towards the ECB's medium-term inflation objective; and in 2015q1, when the expanded asset purchase program was introduced. There were major tightening surprises over the course of 2013 and in 2015q4, when the recalibration of the asset purchase program did not fully meet market expectations.
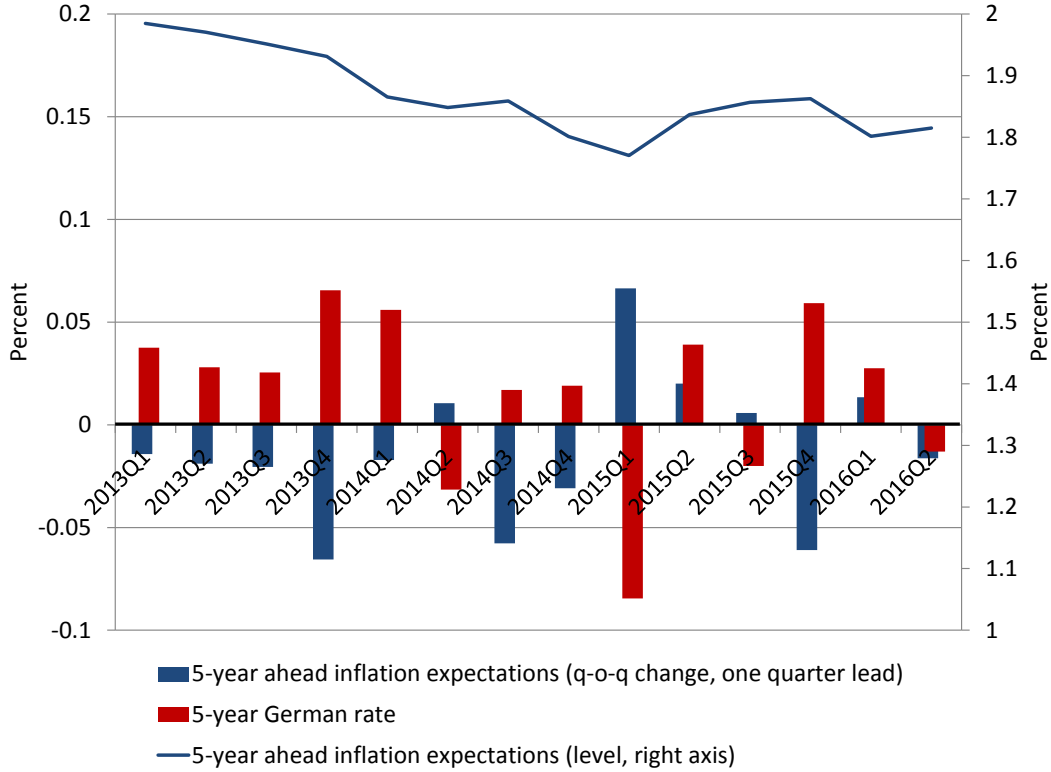
We measure long-term inflation expectations by the 5-year-ahead yearly inflation rate predicted by the Survey of Professional Forecasters. The survey is conducted quarterly usually in January, July, August and October, and it aggregates forecasts of over 50 forecasters from financial and research institutions. Figure 1 shows the development of the long-term inflation expectations since the first quarter of 2013, when the expectations started their gradual decline from slightly below the 2 percent rate[5]. The blue bars show the quarterly changes of these expectations. For the ease of visual comparison of policy surprises and the subsequent development of market expectations, we show the one quarter lead of the change of the inflation expectations on the figure. The figure shows that the gradual decline of the expectations were reversed in 2015q1, when the APP was introduced and the expectations persistently increased for 2 quarters, before their improvement were arrested in 2015q4 parallel with market disappointment with the December 2015 recalibration of the APP programme.

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[3]The database includes bid and ask quotes with time stamps (at the millisecond level) and with the identity of the posting institution. After cleaning the data from outliers, we measure the market price as the average of the highest bid and lowest ask prices out of the most recent five quotes made by distinct institutions. We disregard quotes posted more than 15 minutes ago, even if this reduces the number of available quotes below 5. Our choices are informed by our aim to obtain an accurate and timely proxy for market valuation. Choosing the five latest quotes balances timeliness with accuracy: if 5 institutions modified their quotes after a market news, we would like our measure to reflect the change, even if some still outstanding quotes (possibly posted before the news) still suggest different valuations. We disregard quotes older than 15 minutes altogether, because quotes can not be directly traded on. They are indicative of the valuation of the posting institution only when they were made, and can lose their actuality over time. The 15 minutes limit guarantees that our baseline surprise measure, which reads the asset price 20 minutes after the monetary policy news, does not include quotes made before the news. See Jarocinski and Karadi (2016)

[4]For the press releases since March 6, 2016, we use, analogously, a 30-minute window starting 10 minutes before the release.

[5]We present the development of the measure between 2001q1-2012q4 in the Appendix.

Figure 1: 5-year ahead inflation expectations and monetary policy surprises

The negative relationship between the policy surprises and the subsequent changes in long-term inflation expectations is apparent on the figure. To test the relationship more formally, we regress the quarterly changes in the 5-year-ahead SPF inflation expectations (Δy_t) on the lagged quarterly sum of the intra-day surprises of the 5-year German Bund yield ($\tilde{\Delta} x_{t-1}$).

$$\Delta y_t = \alpha + \beta \tilde{\Delta} x_{t-1} + \varepsilon_t,$$

The parameter β measures the causal impact of monetary policy surprises on the inflation expectations. The potential reverse causality is ruled out by the nature of the monetary policy surprise regressor we are using. Market rates arguably incorporate all available information, including market expectations on long-term inflation rates. Therefore, if the market foresees a policy response to the expected development of long-term inflation expectations, it already incorporates it in the market rate *prior* to the policy announcement. Our regressor measures *changes* in these rates in a narrow window around monetary policy announcements, so they are cleaned from the impact of any reverse impact. The parameter, instead, measures how an unexpected policy change influences the subsequent development of the expectations. Table 1 shows the estimated regression coefficients $\hat{\beta}$ for various samples and high-frequency instruments.

Table 1: Impact of high-frequency surprises in the 5-year German sovereign bond yield on 5-year ahead inflation expectations

	(1) Post 2013	(2) Pre 2013	(3) APP	(4) APP, No FG
	Change in 5-year-ahead inflation expectations			
5-year German yield surprise	-0.599*** (-4.392)	0.0932 (1.551)	-0.583** (-3.151)	-0.508*** (-3.960)
Sample	2013q1-2016q2	2001q1-2012q4	2014q2-2016q2	2014q2-2016q2
Observations	15	47	10	10
R-squared	0.523	0.051	0.457	0.539

Robust t-statistics in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The first regression was run over the sample of 2013q1-2016q2. The Results show a significant negative relationship. The coefficient suggests that 10 basis points decrease in the 5-year German Bund yield caused by a policy easing is accompanied by an around 6 basis points subsequent increase of the 5-year-ahead inflation expectations. The goodness of fit of the regression is high, though the sample is quite short. The second column tests the relationship over the 2001q1-2012q4 sample. The coefficients are insignificant in line with the view that over this period long-term inflation expectations were well anchored and unresponsive to policy surprises. Columns 3 and 4 show the robustness of the results over the 2014q2-2016q2 sample, when the asset purchase announcements were a dominant driving force of policy surprises. Column 3 includes all surprises over the sample, and column 4 shows the impact if meetings are excluded with key modifications of the forward guidance. The results stay significant with similar estimated parameters. In the Appendix, we show evidence that the results stay robust if we use the 5 years inflation expectations 5 years ahead of the market as reflected in inflation-linked swap rates. In the subsequent sections, we analyse in a stylized model how the effectiveness of policy easing is enhanced if we explicitly take into account the impact of policy on long-term inflation expectations as shown in this section.

3 The model

We assess the macroeconomic impact of the APP in the euro area through the lens of a stylized macroeconomic model. The model is based on Gertler and Karadi (2013) that extends standard monetary macroeconomic models (see e.g. Christiano, Eichenbaum and Evans, 2005; Smets and Wouters, 2007) with financial intermediaries that face funding constraints. We incorporate uncertainty and learning about the central bank's long-term inflation target. As

a result, asset purchases by the central bank raise inflation and stimulate economic activity not only because they ease aggregate credit conditions, but also because they help to reanchor inflation expectations, in line with evidence shown in the previous section. We calibrate the model to capture relevant observations of the euro area economy, and use it to simulate a stylized economic environment that forms the backdrop to recent asset purchase policies. We then assess the macroeconomic impact of the APP policy as announced in January 2015, and show how modifying some of its key characteristics might further enhance its effectiveness.

3.1 Households

There is a continuum of identical households of measure unity. Households consume, save, supply differentiated labor services and set wages in a staggered fashion.

Each household is comprised of a fraction $1 - f$ of workers and a fraction f of bankers. Workers supply differentiated labor and return the wages they earn to the household. Each banker manages a financial intermediary and transfers any earnings similarly back to the household. The households save by holding long-term private assets and government debt (see below) and by depositing funds to intermediaries they do not own. Within the family there is perfect consumption insurance.

The banker has a finite expected lifetime. Each banker stays a banker with probability σ or becomes a worker with probability $1 - \sigma$, independently of history. The exiting bankers transfer their net worth to their families. We introduce finite horizon for bankers to insure that over time they do not save themselves out of their financing constraints. The exiting bankers are replaced by a similar number of workers randomly becoming bankers, keeping the relative proportion of each type fixed. The household provides its new bankers with a small amount of start-up funds. These funds sum to ω across households.

Let C_t be consumption and L_t family labor supply. The discounted utility of the household is

$$\tilde{E}_t \sum_{i=0}^{\infty} \beta_{t,t+i} \left[\ln(C_{t+i} - hC_{t+i-1}) - \frac{\chi}{1+\varphi} L_{t+i}^{1+\varphi} \right] \tag{1}$$

with $0 < \beta_{t,t+i} < 1$, $0 < h < 1$ and $\chi, \varphi > 0$. The discount factor $\beta_t = \rho_\beta \beta_{t-1} + \varepsilon_{\beta t}$ is time-varying and follows a first-order autoregressive process and $\beta_{t,t+i} \equiv \Pi_{s=0}^{i} \beta_{t+s}$. The discount factor shock offers a parsimonious way to account for unmodelled changes in the households' 'savings preference'. The expectations of the households are formed over their information set that excludes the central bank's long-term inflation target.[6] We denote their expectations by $\tilde{E}_t$ to differentiate them from rational expectations. Labor supply L_t is a composite of heterogeneous labor services

$$L_t = \left[\int_0^1 L_{ft}^{\frac{\varepsilon^W - 1}{\varepsilon^W}} df \right]^{\frac{\varepsilon^W}{\varepsilon^W - 1}} \tag{2}$$

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[6] We describe the households' information set and learning process in Section 3.4.

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where L_{ft} is the supply of labor service f. The corresponding wage index is

$$W_t = \left[W_{ft}^{1-\varepsilon^W} \right]^{\frac{1}{1-\varepsilon^W}}. \tag{3}$$

As in Woodford (2003), we consider the limit of the economy as it become cashless, and thus ignore the convenience yield to the household from real money balances.

The household saves by holding deposits, short- and long-term government bonds and long-term private assets. Both intermediary deposits and government debt are one period real bonds that pay the gross real return R_t from $t-1$ to t. In the equilibrium we consider, the instruments are both riskless and are thus perfect substitutes. Thus, we impose this equilibrium condition from the outset. We denote the total quantity of short-term debt the household acquires by D_{ht}.

We assume long-term government bonds are perpetuities that pay one dollar per period indefinitely. We denote the bond holdings of the household by B_{ht}. Let q_t be the price of the bond and P_t the price level. Then the real rate of return on the bond R_{bt+1} is given by

$$R_{bt+1} = \frac{1/P_t + q_{t+1}}{q_t} \tag{4}$$

The variables q_t and P_t are determined in the general equilibrium of the model, as we show later.

While holding short-term assets is costless, we assume that households can hold long-term government bonds subject to transaction costs.[7] In particular, we suppose that for government bonds a household faces a holding cost equal to the percentage $\frac{1}{2}\kappa(B_{ht} - \overline{B}_h)^2/B_{ht}$ of the total value of government bonds held for $B_{ht} \geq \overline{B}_h$. Accordingly, there is a certain amount of bonds that the household can hold costlessly. Going above this level involves transactions costs which are increasing at the margin. We motivate this cost structure as capturing in a simple way limited participation in asset markets by households that leads to incomplete arbitrage.

The household budget constraint is

$$C_t + D_{ht} + q_t[B_{ht} + \frac{1}{2}\kappa(B_{ht} - \overline{B}_h)^2] = \frac{W_t}{P_t}L_t + \Pi_t + T_t + R_t D_{ht-1} + R_{bt}B_{ht-1}, \tag{5}$$

where Π_t denotes the payouts to the household from ownership of both non-financial and financial firms and, T_t denotes lump sum taxes.

Nominal wages are set in a staggered fashion following Calvo (Erceg, Henderson and Levin, 2000). We assume that wages for each particular labor service W_{ft} can be adjusted with probability $1 - \gamma_W$. With probability γ_W wages follow an indexation scheme. In particular, $W_{ft} = \Pi_t^\dagger W_{ft-1}$, where $\Pi_t^\dagger = \Pi_{t-1}^{\gamma_{Wi}}\Pi_t^{*1-\gamma_{Wi}}$ with $\Pi_t = P_t/P_{t-1}$ is the gross inflation rate,

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[7]For simplicity, we exclude households from holding long-term private assets. In the euro area, only around 10 percent of outstanding liabilities of non-financial corporations are held directly by non-leveraged institutions according to the sectoral accounts. Incorporating direct capital holdings into our model would only marginally change our quantitative conclusions.

$\Pi_t^* = P_t^*/P_{t-1}$ is the optimal price change of the adjusting retail firms (as we explain below) and γ_{Wi} is an indexation parameter. The households satisfy any demand for labor services at the preset wages.

The household's objective is to choose $C_t, W_{ft}, D_{ht}, B_{ht}$ and S_{ht} to maximize (1) subject to (5) and the wage-setting constraints. Let $u_{C_t t}$ denote the marginal utility of consumption. Then the first order conditions for consumption/saving are standard:

$$\tilde{E}_t \Lambda_{t,t+1} R_{t+1} = 1 \tag{6}$$

with

$$\Lambda_{t,t+1} \equiv \beta_{t+1} \frac{u_{C_{t+1}}}{u_{C_t}}$$

The optimal wage W_t^* for all adjusting firm satisfies

$$\tilde{E}_t \sum_{i=0}^{\infty} \gamma_W^i \Lambda_{t+i} \left[\frac{W_t^* \Pi_{t,t+i}^\dagger}{P_{t+i}} - \mu_W L_{ft+i}^\varphi \right] L_{ft+i} = 0 \tag{7}$$

with $\mu_W = \frac{1}{1 - 1/\varepsilon_W}$ and $L_{ft} = \left(\frac{W_{ft}}{W_t} \right)^{-\varepsilon^W} L_t$.

The law of large numbers implies that the evolution of the nominal wage index follows

$$W_t = \left[(1 - \gamma_W)(W_t^*)^{1-\varepsilon_W} + \gamma_W (\Pi_t^\dagger W_{t-1})^{1-\varepsilon_W} \right]^{\frac{1}{1-\varepsilon_W}} . \tag{8}$$

The household's long-term asset demands are given by:

$$B_{ht} = \overline{B}_h + \frac{\tilde{E}_t \Lambda_{t,t+1}(R_{bt+1} - R_{t+1})}{\kappa} \tag{9}$$

Demand for long-term bonds above its frictionless capacity level is increasing in the excess return relative to the curvature parameter κ that governs the marginal transaction cost.

3.2 Banks

Banks collect short-term liabilities from households and use them, together with their own equity capital, to provide long-term loans to non-financial firms and to purchase long-term government bonds.

Long-term private assets provide funding for non-financial firms to finance capital. Let Z_t be the coupon payment from a security that is financing a unit of capital, Q_t, the market value of the security, and δ the depreciation rate of a unit of capital. Then the rate of return on the security, R_{kt+1}, is given by:

$$R_{kt+1} = \frac{Z_{t+1} + (1-\delta)Q_{t+1}}{Q_t} \tag{10}$$

The general equilibrium determines Z_t and Q_t.

3.2.1   The Bank's Problem

Let n_t be the amount of equity capital - or net worth - that a banker j has at the end of period t; d_t the deposits the intermediary obtains from households, s_t the quantity of financial claims on non-financial firms that the intermediary holds and b_t the quantity of long term government bonds. The intermediary balance sheet is then given by

$$Q_t s_t + q_t b_t = n_t + d_t \tag{11}$$

Net worth is accumulated through retained earnings. It is thus the difference between the gross return on assets and the cost of liabilities:

$$n_t = R_{kt} Q_{t-1} s_{t-1} + R_{bt} q_{t-1} b_{t-1} - R_t d_{t-1} \tag{12}$$

The banker's objective is to maximize the discounted stream of payouts back to the household, where the relevant discount rate is the household's intertemporal marginal rate of substitution, $\Lambda_{t,t+i}$. To the extent the intermediary faces financial market frictions, it is optimal for the banker to retain earnings until exiting the industry. Accordingly, the banker's objective is to maximize expected terminal wealth, given by

$$V_t = \tilde{E}_t \sum_{i=1}^{\infty} (1-\sigma)\sigma^{i-1} \Lambda_{t,t+i} n_{t+i} \tag{13}$$

To motivate a limit on the bank's ability to obtain deposits, we introduce the following moral hazard problem: At the beginning of the period the banker can choose to divert funds from the assets it holds and transfer the proceeds to the household of which he or she is a member. The cost to the banker is that the depositors can force the intermediary into bankruptcy and recover the remaining fraction of assets.

We assume that it is easier for the bank to divert funds from its holdings of private loans than from its holding of government bonds: In particular, it can divert the fraction θ of its private loan portfolio and the fraction $\Delta\theta$ with $0 \leq \Delta < 1$, from its government bond portfolio. Here we are attempting to capture in a simple way that the bank's private loan portfolio is likely an easier target for bank malfeasance than its government bond portfolio given that it is more difficult for depositors to monitor the performance of latter than the former.

Accordingly for depositors to be willing to supply funds to the banker, the following incentive constraint must be satisfied

$$V_t \geq \theta Q_t s_t + \Delta\theta q_t b_t. \tag{14}$$

The left side is what the banker would lose by diverting a fraction of assets. The right side is the gain from doing so.

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The bankers maximization problem is to choose s_t, b_t and d_t to maximize (13) subject to (11), (12) (14).

As we show in the Appendix, in the resulting equilibrium banks face an endogenous 'risk-adjusted' leverage constraint:

$$Q_t s_t + \Delta q_t b_t \leq \phi_t n_t \tag{15}$$

where ϕ_t is the leverage ratio:

$$\phi_t = \frac{\tilde{E}_t \Omega_{t,t+1} R_{t+1}}{\theta - \tilde{E}_t \Omega_{t,t+1}(R_{kt+1} - R_{t+1})} \tag{16}$$

with $\Omega_t = \Lambda_{t,t+1}[1 - \sigma + \sigma\theta\phi_t]$ being the banks' discount factor. The equilibrium leverage ratio ϕ_t ensures that the bank abstains from absconding with a fraction of their assets. Furthermore, the two assets do not enter the same way into the balance sheet constraint. Government bonds burden the banks' balance sheet capacity less than private assets. This is a direct consequence of the difference in the assets' absconding rates: households are willing to extend more funds to banks that hold more government bonds, because they could abscond with less of these. The relative absconding rate Δ determines the 'risk-weight' of the government bonds relative to private assets.

The equilibrium also requires that the banks are indifferent between investing into private assets and into government bonds. Their arbitrage condition is

$$\Delta \tilde{E}_t \Omega_{t+1}(R_{kt+1} - R_{t+1}) = \tilde{E}_t \Omega_{t+1}(R_{bt+1} - R_{t+1}). \tag{17}$$

The condition accounts for the lower relative absconding rate of government bonds, which allows banks to raise more outside funding (face lower margin requirements) for their government bond holdings.

The bank's net worth develops as

$$n_t = (R_{kt} - R_t)Q_{t-1}s_{t-1} + (R_{bt} - R_t)q_{t-1}b_{t-1} + R_t n_{t-1} \tag{18}$$

3.2.2 Aggregation

Let S_{pt} be the total quantity of loans that banks intermediate, B_{pt} the total number of government bonds they hold, and N_t their total net worth. Since neither component of the maximum adjusted leverage ratio ϕ_t depends on bank specific factors, we can simply sum across the portfolio restriction on each individual bank (15) to obtain

$$Q_t S_{pt} + \Delta q_t B_{pt} \leq \phi_t N_t \tag{19}$$

Equation (19) restricts the aggregate value of (adjusted) assets that the banking system can hold to be less than or equal to the multiple ϕ_t of total bank capital. When the constraint is binding, variation in N_t will induce fluctuations in overall asset demand by intermediaries.

Total net worth evolves as the sum of the retained earnings by the fraction σ of surviving bankers and the transfers that new bankers receive, ω, as follows.

$$N_t = \sigma[(R_{kt} - R_t)\frac{Q_{t-1}S_{pt-1}}{N_{t-1}} + (R_{bt} - R_t)\frac{q_{t-1}B_{pt-1}}{N_{t-1}} + R_t]N_{t-1} + \omega \tag{20}$$

The main sources of variation in N_t are fluctuations in the ex post return on loans R_{kt} and the ex post return on bonds R_{bt}. Further, the percentage impact of this return variation on N_t in each case, is increasing in the bank's degree of leverage, reflected by the respective ratios of assets to net worth, $Q_{t-1}S_{pt-1}/N_{t-1}$ and $q_{t-1}B_{pt-1}/N_{t-1}$.

3.3 Central Bank Asset Purchases

If private intermediation is balance sheet constrained, excess returns on assets arise with negative consequences for the cost of capital and real activity. Within our model, large-scale asset purchases provide a way for the central bank to reduce excess returns and thus mitigate the consequences of a disruption of private intermediation.

In particular, we now allow the central bank to purchase quantities private loans S_{gt} and long-term government bonds B_{gt}. For each type of security it pays the respective market prices Q_t and q_t. When limits to arbitrage in the private market are operative, the central bank's acquisition of securities will have the effect of bidding up the prices on each of these instruments and down the excess returns. To finance these purchases, it issues riskless short term debt D_{gt} that pays the safe market interest rate R_{t+1}. In particular, the central bank's balance sheet is given by

$$Q_t S_{gt} + q_t B_{gt} = D_{gt} \tag{21}$$

where we assume that the central bank turns over any profits to the Treasury and receives transfers to cover any losses. We suppose that the central bank issues the short term debt to households.[8]

As we discussed earlier, these kinds of asset purchases essentially involve substituting central bank intermediation for private intermediation. What gives the central bank an advantage in this situation is that, unlike private intermediaries it is able to obtain funds elastically by issuing short-term liabilities. It is able to do so because within our framework the government can always commit credibly to honoring its debt. Accordingly, there is no agency conflict than inhibits the central bank from obtaining funds from the private sector. Put differently, in

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[8]Alternatively, we could interpret D_{gt} as interest bearing reserves (essentially overnight government debt) held by banks on account at the central bank. It is equivalent to our baseline case with short-term debt to households, if we assume that banks cannot abscond with reserves.

contrast to private financial intermediation, central bank intermediation is not balance sheet constrained.

At the same time, we allow for the central bank being less efficient than the private sector at making loans. In particular, we assume the central bank pays an efficiency cost of τ per unit of private loans or government bonds intermediated. Accordingly, for asset purchases to produce welfare gains, the central bank's advantage in obtaining funds cannot be offset by its disadvantage in making loans. Its advantage in obtaining funds is greatest when excess returns are large (i.e when limits to private arbitrage are tight).

The way asset purchases affect the real economy is ultimately by affecting the price Q_t and (hence the) excess return on capital $\tilde{E}_t\Omega_{t,t+1}(R_{kt+1} - R_{t+1})$. Accordingly, let S_t and B_t be the total supplies of private loans and long term government bonds, respectively. Then by definition:

$$
\begin{aligned}
S_t &= S_{pt} + S_{gt} \\
B_t &= B_{pt} + B_{ht} + B_{gt}
\end{aligned}
$$

(22)

where as before S_{pt} and B_{pt} are the total amounts that are privately intermediated, and B_{ht} is the direct government bond holding of the households determined by equation (9). We combine these identities with the balance constraint on the banks to obtain the following relation for the total value of private securities:

$$
Q_t S_t = \phi_t N_t + Q_t S_{gt} + \Delta(q_t B_{gt} - q_t(B_t - B_{ht}))
$$

(23)

For central bank asset purchase to affect asset prices and returns, limits to arbitrage must be present for both banks and households.

Consider first limits to arbitrage of banks. If their balance sheet constraint is binding, given the total quantity of bank equity, an increase in the central bank's holding of either private securities or long-term government bonds raises the total demand for private securities. Intuitively, with limits to arbitrage present on private credit flows, central bank intermediation expands overall asset demand. Further, given that asset supplies are relatively inelastic in the short run, the enhanced asset demand pushes up Q_t and down the excess return on capital.

Equation (23) also reveals that it matters which asset the central bank acquires. In particular, purchases of government bonds will have a weaker effect on the demand for private assets than would the direct purchase of this asset by the factor $\Delta < 1$. Intuitively, the central bank acquiring government bonds frees up less bank capital than does the acquisition of a similar amount of private loans. It is effectively by freeing up intermediary capital that asset purchases are able to expand the overall demand for private assets. In the limiting case of frictionless arbitrage in the government bond market (i.e., $\Delta = 0$), bond purchases have no effect.

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The responsiveness of household portfolios to arbitrage opportunities also influences the effects of asset purchases on prices and excess returns. Consider first the case where the marginal transaction costs facing the household are infinity (i.e. $\kappa = \infty$). In this instance, a household holds the frictionless capacity value of the government bond $\overline{B}_h$ and is completely unresponsive to arbitrage opportunities. The presence of inelastic household security demand, further strengthens the effects of a given size purchase of either security. It does so by reducing the participation of the active traders in the market (in this case the banks). Because everything else equal the purchases are larger relative to bank holdings of the respective asset, they will have a larger impact on prices and returns. These results are consistent with the fact that asset prices depend on asset supplies if household demand is relatively inelastic (e.g for "preferred habitat" reasons.) We stress, however, that it is also key that arbitrage by the active traders in the market is limited. Absent the balance sheet constraint on banks, asset purchases would be neutral despite inelastic asset demands by households.

As household government bond demand becomes increasingly elastic (κ moves toward zero), the effects of central bank asset purchases weaken. As before, assuming total supplies of each asset are inelastic in the short run, central bank purchases of either security will place downward pressure on excess returns. A decline in excess returns, however, reduces households' security holdings, dampening the overall effect of the purchases on asset demands. Put differently, household asset demands move in a way that offsets the effect of central bank asset purchases. This offsetting effect becomes stronger as transactions cost become smaller. In the limiting case of zero transactions cost, of course, households are able to perfectly arbitrage and central bank asset purchases are neutral.

3.4 Monetary policy and learning

In this section, we describe the conduct of monetary policy and private sector expectation formation.

We suppose monetary policy is characterized by an interest rate rule with a time-varying inflation target. The effective lower bound censors the rule at 0. Let i_t be the net nominal interest rate, i the steady state nominal rate, i_t^* a shadow rate that would be set without the lower bound. Then $i_t = \max(0, i_t^*)$. The rule is

$$i_t^* = i + \rho_i(i_{t-1} - i) + (1 - \rho_i)\left[\pi_t^* + \kappa_\pi(\pi_t - \pi_t^*) + \kappa_y y_t\right] + \kappa_{\Delta\pi}(\pi_t - \pi_{t-1}) + \kappa_{\Delta y}(y_t - y_{t-1}) + \varepsilon_t \quad (24)$$

where π_t^* is the central banks' long-term inflation target and ε_t is an exogenous shock to monetary policy. The rule responds (i) to the inflation target, (ii) to the deviation of the inflation rate from the target, and to the quarterly change in the (iii) inflation rate and (iv) output. The rule captures the past conduct of euro area monetary policy better than a conventional Taylor rule (see Christoffel, Coenen and Warne, 2008).

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We suppose that the interest rate rule is sufficient to characterize monetary policy in normal times. When the effective lower bound in binding, however, we allow for large scale asset purchases. In particular, we suppose that the central bank purchases the fraction φ_{st} of the outstanding stock of private securities and the fraction φ_{bt} of the outstanding stock of long term government bonds:

$$
\begin{aligned}
S_{gt} &= \varphi_{st} S_t \\
B_{gt} &= \varphi_{bt} B_t
\end{aligned}
\tag{25}
$$

where both φ_{st} and φ_{bt} obey second-order stationary stochastic processes. We denote the risk-adjusted sum of the asset holdings of the government relative to steady state annual output as $\Psi_t = (Q_t S_{gt} + \Delta q_t B_{gt})/4\bar{Y}$.

3.4.1 Learning the long-term inflation target

We assume that the private sector cannot observe neither the central bank's long-term inflation objective π^* (Gürkaynak, Sack and Swanson, 2005). Furthermore, it does not know the magnitude of the monetary policy shock ε_t either, so it needs to solve a signal extraction problem to form expectations about them. For this, they use all available information, including the observable actions of the central bank. Both the policy rate and the magnitude of asset purchases are informative, so the central bank can guide expectations through an asset purchase programme even when the interest rate is stuck at its lower bound. In particular, we assume that the perceived interest rate target (π^{*e}) is updated through a constant gain learning process

$$
\begin{aligned}
\pi_{t+1}^{*e} &= \rho_{\pi^{*e}} \pi_t^{e*} - \xi \left\{ s_t - s_t^e \right\} \\
s_t &= i_t - \varsigma \Psi_t - \left[(1-\rho_i)\kappa_\pi + \kappa_{\Delta\pi} \right] \pi_t - \left[(1-\rho_i)\kappa_y + \kappa_{\Delta y} \right] y_t \\
s_t^e &= \tilde{E}_{t-1} \left[s_t \right]
\end{aligned}
\tag{26}
$$

where $\rho_{\tilde{\pi}^*}$ is the (close to unity) persistence of shocks to the perceived inflation target, s_t is a signal to the private sector about the tightness of the policy, and superscript e reflects private sector expectations of a variable in time t formed in $t-1$. The tightness of the policy s_t is measured as the difference of its two main components. First, it is influenced by the current monetary stance, which is a linear combination of the interest rate i_t and the central bank's risk-adjusted asset holdings Ψ_t. The parameter ς measures the relative importance of the two policy tools. We will calibrate this parameter consistently with the relative impact of the two tools in our model. Second, the signal is influenced by the current observable components of the monetary policy rule (24), disregarding constants and lagged variables that do not contribute to contemporaneous surprises. In case the signal implies tighter policy than expected (($s_t > s_t^e$)) market participants attribute the surprise partly to a potential change

in the inflation target and reduce their perceived inflation target. The gain parameter ξ is governed by the relative perceived volatility of the inflation target and the monetary policy shocks. They will attribute the remaining discrepancy between the stance and the rule to a monetary policy shock.

The learning process implies different behavior at and away from the lower bound. Consider first the case when interest rate is away from the effective lower bound ($i_t = i_t^* > 0$) and there are no asset purchases ($\Psi_t = \Psi_t^e = 0$). The signal measures the deviation of the current interest rate from that implied by the interest rate rule. If the signal exceeds private sector expectations ($s_t > s_t^e$) then either the actual inflation target must be lower than expected, or a temporary monetary policy shock must have driven the policy rate away from the rule. Our updating rule posits that the private sector attributes the surprise partly to each of these factors and reduces their perceived target proportionally to the surprise. In an environment when the inflation target happens to be constant (as we will assume in our simulations) and the interest rate lower bound is not binding, temporary deviations from the systematic rule would cause only small and short-lived deviations of private sector expectations from the actual inflation target. The reason is that regular interest rate responses to inflation and activity are informative about the true target, and will keep the private sector's long-term inflation expectations well anchored around it. This environment is not unlike in the euro area before 2013, where the long-term inflation expectations were well anchored as we documented in Section 2.

In contrast, if the interest rate is stuck at its lower bound then conventional interest rate policy cannot be used to stimulate the economy and bring inflation closer to the inflation objective. As a consequence, interest rate observations cease to be informative about the long-term inflation target. If financial intermediaries face balance sheet constraints, however, the central bank can use asset purchase policy as a substitute to interest rate policy. Correspondingly, we assume that in this case the private sector turns its attention towards the asset holdings of the central bank (Ψ_t) to learn about its inflation target. The updating rule implies that if low inflation rates are unaccompanied by asset purchases at the effective lower bound then the private sector would conclude that the central bank is content with the lower inflation rate. They would lower their perceived long-term target, which would deanchor their long-term inflation expectations from the true inflation objective. New purchases, in contrast, would convey information about the actual inflation target of the central bank, and it helps to reanchor long-term inflation expectations. This would be consistent with our observations in the euro area after 2013 as reported in Section 2.

3.5   The Production Sector, Fiscal Policy and Equilibrium

We now close the model by describing the non-financial production sector, and the general equilibrium.

There are three types of non-financial firms in the model: intermediate goods producers, capital producers, and monopolistically competitive retailers. The latter are in the model only to introduce nominal price rigidities. We describe each in turn.

3.5.1 Intermediate Goods Producers

Intermediate goods producers make output that they sell to retailers. They are competitive and earn zero profits in equilibrium. Each operates a constant returns to scale technology with capital and labor inputs. Let Y_t be output, A_t total factor productivity, L_t labor, K_t capital, Then:

$$Y_t = A_t K_t^\alpha L_t^{1-\alpha} \tag{27}$$

Let P_{mt} be the relative price of intermediate goods. Then the firm's demand for labor is given by

$$W_t = P_{mt}(1-\alpha)\frac{Y_t}{L_t} \tag{28}$$

It follows that we may express gross profits per unit of capital Z_t as follows:

$$Z_t = P_{mt}\alpha\frac{Y_t}{K_t}. \tag{29}$$

The acquisition of capital works as follows. At the end of any period t, the intermediate goods producer is left with a capital stock of $(1-\delta)K_t$. It then buys I_t units of new capital from capital producers. Its capital stock for $t+1$ is then given by

$$K_{t+1} = I_t + (1-\delta)K_t \tag{30}$$

To finance the new capital, the firm must obtain funding from a bank. For each new unit of capital it acquires it issues a state-contingent claim to the future stream of earnings from the unit. Banks are able to perfectly monitor firms and enforce contracts. As a result, through competition, the security the firm issues is perfectly state-contingent with producers earning zero profits state-by-state. In addition, the value of the security Q_t is equal to the market price of the capital underlying security. Finally, the period $t+1$ payoff is $Z_{t+1} + (1-\delta)Q_{t+1}$: the sum of gross profits and the value of the leftover capital, which corresponds to the definition of the rate of return in equation (10).

3.5.2 Capital Goods Producers

Capital producers make new capital using input of final output and subject to adjustment costs. They sell the new capital to firms at the price Q_t. Given that households own capital producers, the objective of a capital producer is to choose I_t to solve:

$$\max \tilde{E}_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left\{ Q_\tau^i I_\tau - \left[1 + f \left(\frac{I_\tau}{I_{\tau-1}} \right) \right] I_\tau \right\} \tag{31}$$

From profit maximization, the price of capital goods is equal to the marginal cost of investment goods production as follows,

$$Q_t = 1 + f \left(\frac{I_t}{I_{t-1}} \right) + \frac{I_t}{I_{t-1}} f'(\frac{I_t}{I_{t-1}}) - \tilde{E}_t \Lambda_{t,t+1} (\frac{I_{t+1}}{I_t})^2 f'(\frac{I_{t+1}}{I_t}) \tag{32}$$

Profits (which arise only outside of steady state), are redistributed lump sum to households.

3.5.3   Retail Firms

Final output Y_t is a CES composite of a continuum of mass unity of differentiated retail firms, that use intermediate output as the sole input. The final output composite is given by

$$Y_t = \left[\int_0^1 Y_{ft}^{\frac{\varepsilon-1}{\varepsilon}} df \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{33}$$

where Y_{ft} is output by retailer f.

Retailers simply re-package intermediate output. It takes one unit of intermediate output to make a unit of retail output. The marginal cost is thus the relative intermediate output price P_{mt}. We introduce nominal rigidities following Calvo. In particular, each period a firm is able to freely adjust its price with probability $1 - \gamma$. Accordingly, each firms chooses the reset price P_t^* to maximize expected discounted profits subject to the restriction on the adjustment frequency. Following standard arguments, the first order necessary condition for this problem is given by:

$$\tilde{E}_t \sum_{i=0}^{\infty} \gamma^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} - \mu P_{mt+i} \right] Y_{ft+i} = 0 \tag{34}$$

with $\mu = \frac{1}{1-1/\varepsilon}$. From the law of large numbers, the following relation for the evolution of the price level emerges:

$$P_t = \left[(1-\gamma)(P_t^*)^{1-\varepsilon} + \gamma(P_{t-1})^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{35}$$

3.5.4   Fiscal Policy

Government expenditures are composed of: government consumption, which we hold fixed as a share of output at g and the net interest payments from an exogenously fixed stock of long-term government debt, which we set at $\overline{B}$. Revenues consist of of lump sum taxes and the earnings from central bank intermediation net transaction costs. Central bank asset purchases are financed by short-term government debt. Given the central bank balance sheet (21), we can express the consolidated government budget constraint as:

$$gY_t + (R_{bt} - 1)\overline{B} = T_t + (R_{kt} - R_t - \tau)Q_{t-1}S_{gt-1} + (R_{bt} - R_t - \tau)q_{t-1}B_{gt-1} \tag{36}$$

3.5.5 Resource Constraint and Equilibrium

Output is divided between consumption, investment, government consumption, and expenditures on central bank intermediation Φ_t. The economy-wide resource constraint is thus given by

$$Y_t = C_t + [1 + f\left(\frac{I_t}{I_{t-1}}\right)]I_t + G + \Phi_t \tag{37}$$

with $\Phi_t = \tau(Q_{t-1}S_{gt-1} + q_{t-1}B_{gt-1})$.

The link between nominal and real interest rates is given by the Fisher relation

$$1 + i_t = R_{t+1}\tilde{E}_t\frac{P_{t+1}}{P_t} \tag{38}$$

Finally, to close the model, we require market clearing in markets for private securities, long term government bonds and labor. The supply of private securities at the end of period t is given by the sum of newly acquired capital I_t and leftover capital $(1 - \delta)K_t$:

$$S_t = I_t + (1 - \delta)K_t \tag{39}$$

The supply of long term government bonds is fixed by the government

$$B_t = \overline{B} \tag{40}$$

and labor market clears.

We note that because of Walras' Law, once the market for goods, labor, and long-term securities cleared, the market for riskless short-term debt will be cleared automatically. This completes the description of the model.

4 Calibration

We calibrate the parameters of our model to capture key euro area stylized facts.

Standard model parameters are taken from the New Area-Wide Model (NAWM), which is an open-economy macroeconomic model estimated on euro area data and used regularly within the European Central Bank for forecasting and policy analysis (Christoffel, Coenen and Warne, 2008). The NAWM is estimated over the sample of 1985Q1-2011Q4 and explains the behavior of 18 different macroeconomic variables.

We calibrate financial variables to match key long-term moments in the euro area. The tightness of the aggregate credit conditions implicitly determines the potential credit-easing effect of the asset-purchase programme. We use observations on the average long-term level of interest rate premia of private and public assets over the short-term riskless policy rate to calibrate the extent of overall and asset-specific funding constraints. In particular, we calibrate

Table 2: Calibrated parameter values

		Households
β	0.994	Discount rate
h	0.567	Habit parameter
χ	20.758	Relative utility weight of labor
B/Y	0.700	Steady state Treasury supply
$\bar{B}^h/B$	0.750	Proportion of long term Treasury holdings of the HHs
κ	1.000	Portfolio adjustment cost
φ	2.000	Inverse Frisch elasticity of labor supply
ϵ_W	4.333	Elasticity of labor substitution
γ_W	0.765	Probability of keeping the wage constant
$\gamma_{W,-1}$	0.635	Wage indexation parameter
$\rho_{\pi^{*P}}$	0.990	Persistence of a shock to the perceived inflation objective
ξ	0.0622	Kalman-gain
ς	0.0683	Relative weight of APP surprise
		Financial Intermediaries
θ	0.315	Fraction of capital that can be diverted
Δ	0.840	Proportional advantage in seizure rate of government debt
ω	0.0047	Proportional transfer to the entering bankers
σ	0.925	Survival rate of the bankers
		Intermediate good firms
α	0.360	Capital share
δ	0.025	Depreciation rate
		Capital Producing Firms
η_i	5.169	Inverse elasticity of net investment to the price of capital
		Retail Firms
ϵ	3.857	Elasticity of substitution
γ_P	0.920	Probability of keeping the price constant
$\gamma_{P,-1}$	0.417	Price indexation parameter
		Government
$\frac{G}{Y}$	0.200	Steady state proportion of government expenditures
ρ_i	0.865	Interest rate smoothing parameter
κ_π	1.904	Inflation coefficient in the policy rule
$\kappa_{d\pi}$	0.185	Inflation growth coefficient in the policy rule
κ_{dy}	0.147	Output growth coefficient in the policy rule
$\rho_{i,elb}$	0.500	Interest rate smoothing leaving the lower bound
γ_ψ	0.290	Share of private assets in the purchase program
		Shocks
ψ	0.018	Initial asset purchase shock
$\rho_{1,\psi}$	1.700	First AR coefficient of the purchase shock
$\rho_{2,\psi}$	-0.710	Second AR coefficient of the purchase shock
ε_β	0.044	Initial savings preference shock (β)
ρ_β	0.815	Persistence of the savings preference shock (β)

the private credit spread to match the average spread (2.45 percent) between the euro area long-term composite cost of borrowing indicator and the overnight Eonia rate between January 2003 and September 2015. The spread of the public assets are measured by the difference between the euro area 10-year yield and the Eonia rate between January 2003 and September 2015 (2.1 percent).

The leverage of banks influences how much changes in their asset valuations impact their market capitalization, thereby it determines the strength of the financial feedback loop. We calibrate the leverage of our financially constrained agents to 6, which is the average leverage of

financial institutions and non-financial corporations in the euro area. The data uses monetary and other financial institution and NFC assets over equity weighted by their relative assets between 1999Q1 and 2014Q2 based on euro area sectoral accounts. We include the leverage of non-financial corporations because in practice both banks and firms hold leveraged positions. In our model, we do not allow firms to lever up, so we assign the average composite leverage to the financial intermediaries.

We calibrate the learning rule about the ECB's inflation objective to roughly capture the behavior of long-term inflation expectations around the introduction of the extended APP. We set the persistence of the shocks to the perceived inflation objective to $\rho_{\pi^{*p}} = 0.99$. This implies that the surprises have very persistent impact on the perceived target, but the impact is not permanent, so the system converges back to its original steady state.

In the months prior to the introduction of the policy, long-term inflation expectations declined by approximately 15 basis points.[9] This deanchoring of inflation expectations helps us to pin down the impact of inflation surprises on the perceived target. A learning gain parameter $\xi = 0.062$ is in line with these observations. The same parameter determines the influence of the interest rate surprise on long-term inflation expectations. This is lower than a similar coefficient calibrated on US data (Gürkaynak, Sack and Swanson, 2005, 0.1) in line with the fact that the European Central Bank follows a transparent, and inflation-oriented policy. Such policy has been shown to anchor long-term inflation objectives tightly before the interest rate lower bound was reached (Gürkaynak, Levin and Swanson, 2010).

We assume that an interest rate surprise has the same quantitative impact on the perceived inflation objective as an equivalent asset purchase policy. We find that the APP is comparable to a monetary policy shock of -1.1 percentage point,[10] so we set the learning parameters in a way that such interest rate surprise has the same impact as the APP. This implies a relative gain coefficient of $\varsigma = 0.068$.

With these calibrations, the impact of the APP programme on the perceived inflation objective turns out to be around 9 basis points on impact. This is the magnitude of the response of market-based long-term inflation expectations reflected in market prices (in particular, 5- and 10-year-ahead inflation swaps) on the day of the announcement of the program, and it is also in line with the change in the long-term inflation expectations of professional forecasters.[11] It is interesting to note that this requires a minor (less than 0.8 basis points) direct impact of the baseline asset purchase program on the perceived inflation objective. This direct impact gets amplified by more than an order of magnitude through two main channels. First, the policy raises inflation by easing lending conditions, which raises the perceived inflation objective indirectly through generating inflation surprises. Second, the higher perceived objective postpones the expected date of lift-off of the interest rate from its lower bound and also lowers

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[9]The survey of professional forecasters found that the average forecast for the five year ahead inflation rate decreased from 1.93 in 2013Q4 to 1.77 in 2015Q1 before the announcement of the APP programme.

[10]See Figure 9 in the Appendix

[11]The SPF 5-year-ahead inflation forecasts increased from 1.77 percent in 2015Q1 to 1.86 percent by 2015Q3.

the expected path of the policy rate after lift-off. The more accommodative expected policy raises actual inflation further through forward looking price-setting decisions.

4.1 Numerical solution algorithm

We solve the model with first-order perturbation around a non-stochastic steady state. Our focus is the equilibrium response of market participants to unexpected innovations that hit in period 1. In line with standard impulse response analysis, we assume that no further shock hits the economy after period 1. Furthermore, we analyse particular realizations when the inflation target of the central bank stays constant. In our learning equilibrium, market participants are unaware of this particular outcome, and they also expect potential future variation both in the inflation target and in monetary shocks. They use policy decisions to learn about the target, and form their expectations about future policy and economic outcomes based on their beliefs. We assume that banks' balance sheet constraints stay binding in the narrow neighborhood of the steady state we analyse. In contrast, the effective lower bound only binds temporarily while the policy rule would require a interest rate below zero.

Our algorithm obtains a solution over the impulse response space. The algorithm starts from a non-stochastic steady state with perceived inflation target equal to the actual one. In period 1, shocks realize. The algorithm solves the equilibrium outcomes for each period $t = 1, 2, \ldots$ until convergence to the steady state. Let's assume we are in period t with a predetermined perceived inflation target of π_t^{*e} inherited from the previous period.

1. Market participants form their expectations about the current policy rate based on their perceived inflation target. In contrast, the central bank sets the rate following its actual, constant inflation target. We assume that the market participants consider the difference between their policy rate expectation and the actual market rate as an unobserved monetary policy shock. This perceived monetary policy shock will be an endogenous variable in each period t that our algorithm solves for through a fixed point iteration. At this stage, assume we have guessed a perceived monetary policy shock ε_{it}^e.

2. The endogenous variables in period t are influenced by the perceived future development of prices and quantities. To obtain these, we use a standard perfect foresight algorithm. The idea behind this is that given the perceived inflation target and the perceived monetary policy shock $(\pi_t^{*e}, \varepsilon_{it}^e)$ market participants do not expect future innovations, so they solve the system with perfect foresight. In other words, they do not expect to be surprised again in the future (even though we know that they will be unless their perceived target and the actual target coincide). The core of our algorithm is a deterministic Newton-type solver implemented in the `Dynare` package that obtains equilibrium impulse responses for all endogenous variables of the loglinearized system assuming that the effective lower bound is binding in the first s periods. We insert this perfect foresight solver into an iterative loop that searches for the lowest T such that the perceived rule implies a solution

with interest rate below zero for $s \leq T$ and an interest rate above zero afterwards. The loop determines the perceived liftoff date T_t^e, which, in turn, influences the perceived development of forward looking variables and determines the current outcome.

3. The algorithm then checks whether the perceived interest rate and the actual policy rate equal in period t for the guessed perceived monetary shock ε_{it}^e. If they are not, the algorithm updates the monetary policy shock in a fixed point iteration until convergence. When they are equal, the period t outcomes are determined by the current equilibrium values of the system.

4. Finally, market participants update their perceived inflation target π_{t+1}^{*e} according to equation 26 based on any difference between actual outcomes in period t and their expectations formed in period $t - 1$.

5. We repeat the algorithm for period $t + 1$, unless the steady state is reached.

5   Results

5.1   Macroeconomic impact of asset purchases

The introduction of the APP was preceded by a deteriorating economic outlook, persistently low inflation rates, deanchoring inflation expectations, low long-term yields, and the policy rate stuck at its lower bound. We capture key features of this environment by a persistent fall in demand caused by an unexpected increase in the households' 'preference for savings' (ε_β). The shock captures unmodelled factors that induce households to postpone their consumption (like debt overhang or elevated precautionary savings caused by higher uncertainty). The red dashed line on Figure 2 shows the dynamic response of key macroeconomic variables to the shock. The shock mitigates consumption demand, which worsens economic outlook, reduces inflation and lowers asset prices. Without an asset purchase programme (red dotted line), the shock would have reduced the inflation rate by more than 2 percent, the output by around 7 percent. This brings the policy rate to its lower bound, so monetary policy cannot stabilize the economy using conventional instruments. In particular, the interest rate would have stayed stuck at its lower bound for more than 2 years. Excess savings generate a downward pressure on long-term sovereign yields, the ten-year government bond rate would have dropped by more than 100 basis points. If financial markets were frictionless, high savings would generate a investment boom, which would mitigate the negative impact on aggregate demand. Here, in contrast, lower asset prices reduce the market capitalization of financial intermediaries. This hampers their ability to raise external funds and channel savings towards investment. Therefore, aggregate lending declines and expected loan spreads increase, which keep investment from increasing at the outset of the demand shock.

Figure 2: A stylized demand shock and the asset purchase program
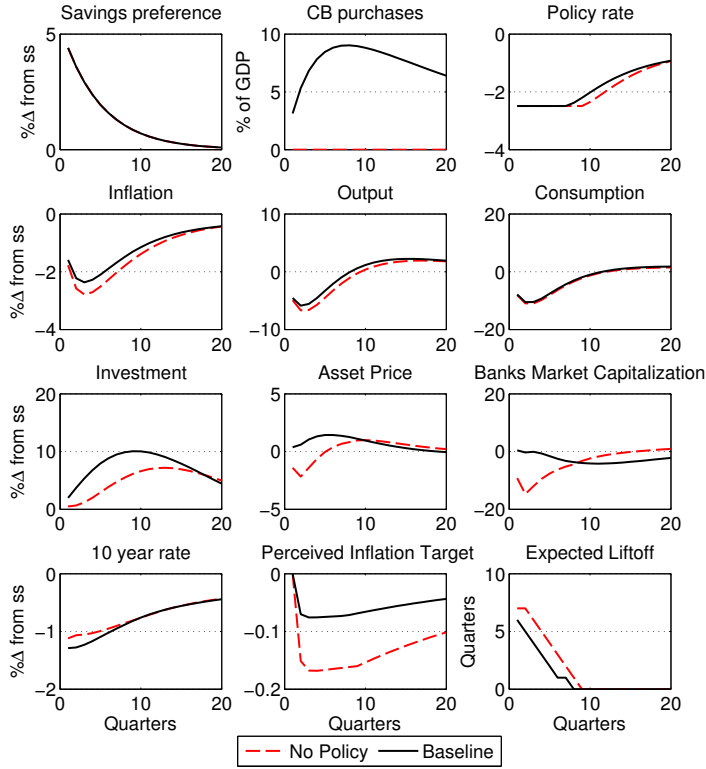
The figure shows the response of key economic variables to a stylized savings shock, partly counteracted by an asset purchase program (baseline) and compares it to the counterfactual behavior of the economy in case of no policy response.

Deanchoring inflation expectations contribute to the deteriorating outlook. The shock gradually lowers the perceived inflation target by around 15 basis points. As a result, inflation rates stay persistently below the central bank's medium-term inflation objective, because forward-looking price setters expect a tighter policy after the interest rate lifts off from its lower bound. Low inflation rates, furthermore, raise current real interest rates and further mitigate aggregate demand. The deteriorating outlook endogenously postpones the date the agents expects the policy rate to lift-off from the lower bound. Initially, agents expect the lower bound to bind for 7 quarters. As the persistent shock leads them to lower their perceived inflation target and even more their inflation expectations, 7 quarters later they still expect the lower bound to bind for a further 2 quarters. Eventually the interest rate stays at its lower bound for 9 quarters.

The introduction of the APP helps the European Central Bank to guide inflation towards its medium-term inflation objective. We capture the programme in a stylized fashion. The central bank purchases both private and public assets in a fixed 29-71 percent proportions. To account for both the quantity and the average maturity of the purchases, we measure the

stock of purchased assets in 'ten-year equivalents.' We obtain this measure by multiplying the purchases with the maturity and divide them by 10. The measure assumes that the 'riskiness' of assets increases linearly with maturity, i.e. an asset with 10-year maturity is twice as risky as an asset with 5-year maturity. At its peak, the purchased assets reach 11.3 percent of 2014 euro area GDP. The average maturity of sovereign bonds is 9 years, and the maturity of covered bonds is 5.3 years, so the weighted maturity of the programme is 8 years. Consequently, the programme reaches around 9 percent of GDP in ten-year equivalents. The central bank's holdings of purchased assets follow a hump-shaped pattern increasing dynamically in the first two years, stay fairly constant in the following two years and then they gradually approach zero as the assets mature. In particular, the programme is modelled as a second-order autoregressive shock with the AR(1) coefficient of 1.7 and an AR(2) coefficient of -0.71.

The solid black line on Figure 2 shows the baseline outcome of our demand shock with an active asset purchase policy response, and Figure 4 plots the impact of the programme relative to the no policy outcome. Overall, the APP increases inflation gradually by around 40 basis points and output by around 1.1 percent reaching their peak in around 2 years. These effects are higher, but of a comparable magnitude to improvements in 2 year ahead inflation and output expectations measured by the Survey of Professional Forecasters.[12]. The policy would also reduce the 10-year sovereign yields and private corporate bond rates by around 20 basis points. The impact of the policy on inflation and output would be comparable to a standard monetary policy shock of -1.1 percentage point (see Figure 9 in the Appendix).

As Figure 3 shows, around one third of the inflation impact compared to the baseline is due to the inflation reanchoring channel. The policy raises the perceived long-term inflation target by around 9 basis points. The target increase has an amplified impact on near-term inflation: the peak impact of inflation increases by around 15 basis points relative to a calibration without the channel. The impact on inflation gets amplified because of the binding interest rate lower bound and the balance sheet constraints. First, higher inflation expectations at the lower bound reduce real interest rate rates and stimulate demand and inflation in a self-reinforcing positive spiral. Second, the feedback gets further amplified by the positive impact on asset prices that eases the balance sheet constraints of the financial intermediaries, eases credit conditions and further stimulates demand. These interactions make the inflation reanchoring channel an important factor in the macroeconomic transmission of the asset purchase programme.

5.2 Extending the maturity

The model can be employed to assess the macroeconomic impact of counterfactual asset purchase policy scenarios. Figure 4 shows the impact of a policy in which the central bank raises the average maturity of purchased assets from 8 to 11 years. This would increase the peak

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[12]The average forecast for HICP 2 years ahead increased by 31 basis points in 2 quarters between 2015Q1 and 2015Q2 (by 21 basis points within the first quarter) The cumulative GDP forecast 2 years ahead increased by 75 basis points within the same 2 quarters (by 70 basis points within the first).

Figure 3: Amplification effect of the reanchoring channel
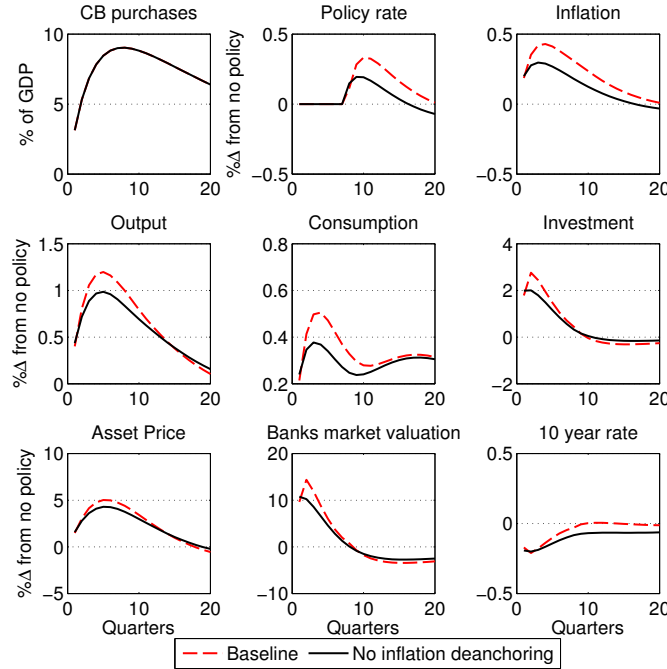
The figure compares the impact of the baseline to a scenario where the perceived inflation target is assumed to stay unchanged. The figure shows that, indeed, the impact of the reanchoring channel amplifies the impact of the policy shock.

public holdings of assets to 12 percent of GDP in ten-year equivalents. As the figure shows this would make the policy more efficient. Purchasing assets with higher duration would eliminate more interest rate risk from the portfolios of financial intermediaries, which would allow them to extend lending. The policy would increase inflation at its peak by around 50 basis points and GDP by around 1.4 percent.

5.3 Interaction with forward guidance

The asset purchase programme improves inflation and output expectations. The policy rule, as a result, would at some future date prescribe higher interest rates, thus shortening the length the period in which the interest rate is expected to stay at its lower bound. The expected interest rate path, therefore, would automatically mitigate the effectiveness of the asset purchase programme. The effectiveness of the asset purchase programme could be improved if the ECB could credibly commit to keep the interest rate at its lower bound longer, despite the improving outlook. Figure 5 illustrates this idea showing the impact of the APP when forward guidance ensures that the expected lift-off date remains unchanged after the announcement of the asset purchase programme.

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Figure 4: Baseline policy vs. a purchases of assets with 11 years to maturity
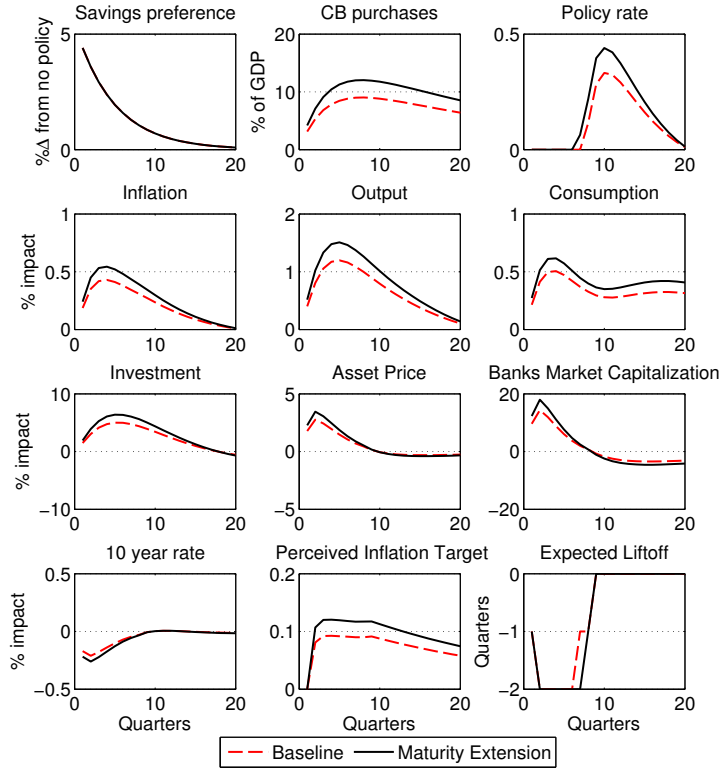
The figure shows the impact of responses to a baseline policy and an alternative asset purchase policy with extended average maturity (11 years from 8 years).

6 Other channels

In this section, we provide additional evidence on the portfolio balance channel in the euro area relying again on event studies. We focus on the most sizable fraction of the APP: Eurosystem purchases of sovereign bonds under the Public Sector Purchase Programme, or PSPP. The section is divided in two parts, each analyzing a particular component of the portfolio balance channel. The two components are the reduction of duration risk and the bank capital relief.

Duration risk denotes the exposure of long-term bonds to unexpected changes in policy interest rates. Such risk induces a premium on bond yields. The asset valuation channel posits that the premium is a function of the stock of long-term bonds held by the private sector. By reducing the premium, central bank purchases should lead to a reduction in yields on all bonds, but especially longer-term bonds that are more exposed to duration risk. We present prima facie evidence consistent with this hypothesis: the fall in yields after the programme announcement is larger, the longer the maturity of bonds.

The capital relief channel suggests that the higher prices of sovereign bonds induced by the APP should have benefited banks through the ensuing increased valuation of the assets on their

Figure 5: Baseline vs. asset purchases with forward guidance
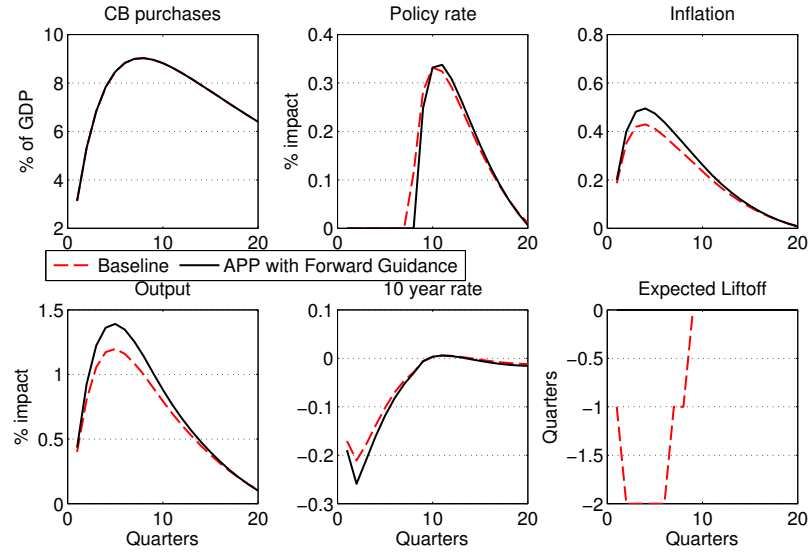
The figure compares the impact of the baseline to an asset purchase programme combined with forward guidance that ensures that the liftoff expectations remain unchanged.

balance sheets, which was akin to a capital injection. However, lower bond yields also have adverse effects on banks through the reduced profitability deriving from a flatter yield curve. We study the relative importance of these two competing forces by looking at the reaction of banks' asset prices after the APP announcement. Since the capital relief channel should be stronger for banks holding a larger amount of sovereign bonds, we specifically test whether the equity prices of banks holding a larger portfolio share of government bonds benefited more from the increase in bond prices. Our results provide support for the capital relief channel.

6.1 Evidence of the duration channel

In this section, we analyze effects on bond yields of the announcement of the PSPP on 22 January 2015 and of the beginning of its implementation on 9 March 2015 on bond yields. We focus on these dates because of the associated sizable changes in euro area sovereign bond yields. Figure 6 gives an overview of the main results. The vertical lines in the graph mark the announcement and initial implementation dates, 22 January 2015 and 9 March 2015. We show that average yields (in basis points) plotted relative to the day prior to the PSPP announcement, dropped on average by about 13 basis points after the announcement and an additional 14 basis points after the implementation.[13] This effect is more pronounced for medium duration (between 5 and 10) and long duration (more or equal to 10). While medium duration bond yields appear to decline by about 12 basis points on announcement and another

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[13]Note that we are correcting for non-time-varying bond-specific characteristics. This, however, does not change the averages significantly.

14 basis point at implementation, long duration bond yields drop by about 22 basis points and about 25 basis points, respectively.

The finding of yields effects on the implementation day is striking, since all market-relevant information on the programme had been released previously, on 5 March. It is however unlikely that the yields effects on 9 March are evidence of the scarcity channel, because no yields effects are recorded further to purchases in subsequent days. We conjecture that the effects recorded after 9 March are due to the diffusion of new information such as the exact maturity distribution of the purchases, which had not previously been announced.

To compare our estimate of the impact of the PSPP to that of other QE programmes, we first compute the observed change on 10-years yields of the bonds purchased under the PSPP. This amounts to 14 basis points at announcement, and 16 basis points at implementation. Our analysis does not account for the fact that the January 22 announcement did not come as a full surprise. Bond prices most likely moved already before the January announcement in reaction to expectations of future purchases.

Table 3 gives a precise overview of the estimates of our event study. In column 1, we show the average effect on all bonds that are eligible and show market prices on Bloomberg. Even in this baseline model without additional controls, we can explain a significant portion of the variation with two dummies capturing the announcement and implementation effect.[14] Controlling for bond-specific non-time-varying heterogeneity between bonds, estimates of the announcement and implementation are not affected (column 2) significantly. Note that this econometric setup does not allow to control for common time effects. However, investigating cross-sectional differences allow us to include strong controls such as non-time-varying heterogeneity across bonds, daily common time effects, and common time trends within country. With these most stringent controls, we capture nearly 80% of total variation, but do not affect significantly our cross-sectional difference estimates. Column 3 (5) and 4 (6) show the regression results with and without these controls for different maturity (duration) buckets. This study is based on a panel dataset dated 22 December 2014 to 12 April 2015. The results are not sensitive towards a shorter or longer sample periods.

6.2 Evidence of the capital relief channel

In this section we look for direct evidence of the capital relief channel using individual banks' data on stock prices and balance sheet information. Our main testable hypothesis is that equity prices should increase more, the larger the share of sovereign bonds in the bank's balance sheet. We focus on two dates: 22 January 2015, when the PSPP decision was publicly communicated; 5 March 2015, when further details of the programme were announced. Given our focus on

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[14]Note that the econometric approach for this event study does not influence the estimates significantly. In the reported table, the announcement dummy captures the yield changes at announcement and the day after, and the implementation dummy yield changes at the implementation and two days after. The reported results are robust against regressions with two-day and four-day steps as well as regression of the yield on the yield lagged and dummies for each implementation/announcement date (and other controls).

Figure 6: Bond yields around the PSPP announcement and implementation

This figure shows average yield (in basis points) of purchased bonds with maturities 2 - 30 years for different duration buckets relative to the day prior the PSPP announcement on 22 January 2015 correcting for non-time varying bond specific characteristics, against calendar date. Bond yields are shown separately for short duration (below 5 years), medium duration (between 5 and 10) and long duration (more or equal to 10). Each duration bucket is split further into bonds that were purchased immediately after the start of the program (within the first three days) and those we purchased thereafter. The vertical lines in the graph mark the announcement and implementation, 22 January 2015 and 9 March 2015. The sample period spans from 1 January 2015 to 17 April 2015. The graph depicts daily market yields for all bonds eligible for purchase under the PSPP.
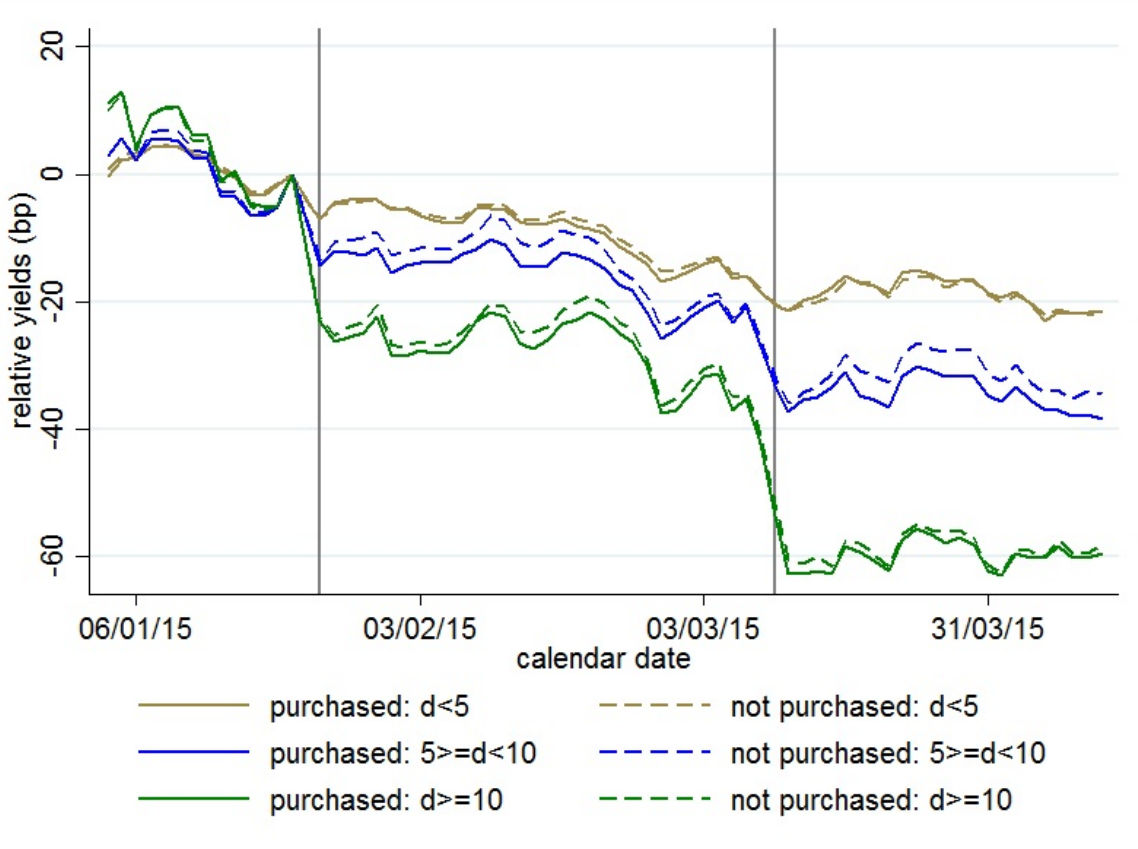
individual banks' stock prices, some of which may be less actively traded, our results are based on 2-day stock price changes.

As control variables, we use: (1) proxies for general economic conditions in each country, which should capture the expected impact on banks of the improved economic outlook; (2) the change in national bond yields following the PSPP announcement, which represents a measure of the change in the slope of the yield curve; (3) proxies for banks' capitalization levels.

Concerning banks' holdings of sovereign bonds, we rely on two different sources: SNL, which covers more banks and has up-to-date information based on end-2014 balance sheets, but includes less detail on the country and maturity composition of sovereign bond holdings; the EBA stress test of 2014, which covers fewer and larger banks, is based on end-2013 information,

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Table 3: The PSPP announcement and implementation effect

This table reports the results from regressing the changes PSPP eligible bond yields on the announcement period, the implementation phase and the interaction terms between announcement and medium duration, announcement and long duration, implementation and medium duration, and implementation and long duration. Short duration is defined as below 5, medium duration between 5 and 10 and long duration as more or equal to 10. The announcement period is 22 January 2015 and 23 January 2015 and the implementation phase is from 9 March 2015 to 11 March 2015. The first two columns include only the announcement and implementation phase, whereas columns 3 to 6 show also differential impacts. Column 3 and 4 show differential impacts by maturity bucket, while column 5 and 6 by duration bucket. The sample period goes from 22 December 2014 to 12 April 2015. Standard errors are clustered by bond. Each column indicates whether the regression contains time (Time FE) and bond fixed effects (Firm FE) or time times country fixed effects (Time FE x Country FE). Source of data: Bloomberg.

VARIABLES	(1) average effect	(2) average effect	(3) maturity	(4) maturity	(5) duration	(6) duration
annoucement	-12.61***	-12.60***	-3.43***		-3.87***	
	(0.44)	(0.44)	(0.36)		(0.43)	
implmentation	-14.44***	-14.43***	-3.30***		-3.51***	
	(0.38)	(0.38)	(0.26)		(0.26)	
MT bond x announcement			-6.25***	-6.29***	-6.77***	-7.44***
			(0.54)	(0.48)	(0.58)	(0.44)
MT bond x implementation			-8.73***	-8.77***	-10.01***	-10.13***
			(0.42)	(0.41)	(0.43)	(0.43)
LT bond x announcement			-19.64***	-20.24***	-17.82***	-18.24***
			(0.86)	(0.63)	(0.93)	(0.68)
LT bond x implementation			-22.82***	-22.97***	-21.07***	-21.82***
			(0.42)	(0.40)	(0.55)	(0.49)
Observations	26,976	26,976	26,976	26,976	26,976	26,976
R-squared	0.249	0.268	0.374	0.797	0.357	0.777
-	-	-	-	-	-	-
Bond FE	NO	YES	YES	YES	YES	YES
daily Time FE	NO	NO	NO	YES	NO	YES
Time x Country FE	NO	NO	NO	YES	NO	YES
-	-	-	-	-	-	-
Cluster Bond	YES	YES	YES	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

but has more precise coverage in terms of key characteristics of the sovereign bonds held by banks.

Table 10 in the appendix presents summary statistics for our data on stock price changes for the SNL and EBA samples, respectively.

Tables 4 and 5 present the results of our regression equation, which in the most general form includes the following variables

$$\Delta P_{it} = \alpha + \beta_1 \cdot \Delta yld_{kt} + \beta_2 \cdot \Delta SM_{kt} + \beta_3 \cdot \text{EA bank} + \beta_4 \cdot \text{exposure}_{it_0} + \beta_5 \cdot \text{Shortfall}_{it_0} + \varepsilon_i \quad (41)$$

The dependent variable is represented by the change in the logarithm of the closing-price of individual banks' stocks. More precisely, for an announcement date t and bank i, the dependent variable is $\Delta P_{jt} \equiv \left[\ln \left(P_{t-1}^{close} \right) - \ln \left(P_{t-1}^{close} \right) \right] \cdot 100$.

The following explanatory variables are included in the regressions. (1) The change in 10-year sovereign bond yields: $\Delta yld_{kt} = yld_{k,t-1} - yld_{k,t-1}$, where k denotes the country where the bank is located. (2) The change in the national stock market index SM_{kt} of the country where the bank is located: $\Delta SM_{kt} = \left[\ln \left(SM_{t-1}^{close} \right) - \ln \left(SM_{t-1}^{close} \right) \right] \cdot 100$. (3) The share of

sovereign bonds on each bank's balance sheet, denoted as exposure, measured at a point in time t_0 prior to the PSPP announcements. The point t_0 corresponds to end-2014 for the SNL database and to end-2013 for the EBA database. We adopt two different definitions of exposure. In the SNLdatabase, we have exposure$_{it_0}$ = total sovereign bond holdings$_{it_0}$/ total assets$_{it_0}$ · 100, where the total sovereign bond holdings$_{it_0}$ variable includes all bond holdings irrespective of the issuing sovereign. In the EBA database we have more refined information about the maturity and the issuer. We therefore work with exposure$_{it_0}$ = EA sovereign bond holdings (5-10y)$_{it_0}$/total assets$_{it_0}$ · 100, where EA sovereign bond holdings (5-10y)$_{it_0}$ denotes exposure to sovereign bonds with remaining maturity between 5 and 10 years and issued by a euro area sovereign. (4) We also use a EA bank dummy, which is 1 if the bank is located in a euro area country. (5) Finally, when using EBA data, we can also construct a Shortfall $_{it_0}$ dummy, which is equal to 0 if the bank was considered undercapitalised in the comprehensive assessment and thus indicates whether the bank is well capitalised.

Our results based on the SNL and EBA databases are reported in Table 4 to 7, respectively. Tables 4 and 6 focus on bank equity price changes between 21 and 23 January 2015; Tables 5 and 7 concentrate on changes between 4 and 6 March 2015. The significance of all coefficients is computed using White robust t-statistics with degrees of freedom correction.

The first column in Table 4 includes only the constant and the country-specific regressors Δyld_{kt} and ΔSM_{kt}. All three regressors are statistically significant and positive. The regression explains 9% of the cross-sectional variation in banks' stock prices. Banks' stock prices increased on average when the PSPP programme was announced; the increase was larger for banks based in countries where the national equity price index increased more; however, a larger fall in the country's 10-year government bond yields was accompanied by a lower increase in banks' stock prices.

The finding of a lower increase in bank equity prices, the larger the fall in long-term sovereign yields, is suggestive of an adverse effect on bank profitability. A flattening of the yield curve should, ceteris paribus, reduce bank profitability, because banks engage in maturity transformation.

The second column in Table 4 adds the euro area bank dummy to the regression. The dummy is strongly significant and negative. The other regressors also remain significant and the R^2 increases to 19%. We interpret also the euro area dummy as a reflection of the negative impact of the flattening of the yield curve on banks' profitability. This effect is presumably stronger for euro area banks, because their profits should be more closely affected by the slope of the euro area yield curve than profits of non-euro area banks.

Regression results including individual banks' exposure to sovereign bond yields are reported in the third column of Table 4. The point estimate is equal to 0.06, implying that, ceteris paribus, a bank holding 10% more sovereign bonds as a ratio of its total assets experienced a larger stock prices increases by 0.6%. Since 10% is one standard deviation in the cross-sectional distribution of sovereign bond holdings, this effect is non-negligible, as well as

Table 4: Equity price reactions between January 21 and 23, 2015
SNL sample

	(1)	(2)	(3)
constant	2.5521***	2.086***	1.7368***
	(4.3814)	(3.8071)	(3.2107)
Δyield	15.6672***	9.124***	8.7575***
	(4.6094)	(2.8323)	(2.7549)
ΔSM	0.3914***	0.7964***	0.7673***
	(2.8819)	(3.9617)	(4.5419)
EA bank (d)		-2.233***	-2.5587***
		(-3.6466)	(-4.6897)
exposure			0.0563***
			(2.7259)
Adj. R^2	0.09	0.1861	0.2585
No. Obs.	150	150	120
	(White robust t-statistics)		

Table 5: Equity price reactions between 4 and 6 March 2015
SNL sample

	(1)	(2)	(3)
constant	0.5074	0.217	-0.4215
	(1.3946)	(0.3136)	(-0.3866)
Δyield	-4.9054	-2.255	4.2711
	(-1.0385)	(-0.2835)	(0.4258)
ΔSM	0.3752*	0.3	0.5937***
	(1.963)	(1.5511)	(3.0655)
EA bank (d)		0.6483	0.9845
		(0.6738)	(0.8073)
exposure			0.0289
			(1.0161)
Adj. R^2	0.0071	0.007	0.0152
No. Obs.	150	150	120
	(White robust t-statistics)		

strongly significant. All other regressors also remain significant and the R^2 goes up further to 26%.

This result is consistent with the view that, by pushing up bond prices, the PSPP produced a "stealth recapitalisation" of leverage-constrained institutions, including banks (see Brunnermeier and Sannikov, 2013). The increased valuation of bond prices can thus be expected to foster an improvement in credit conditions and to boost economic activity. Brunnermeier and Sannikov (2013) also argue that stealth recapitalisation can be expected to help more those institutions that hold a larger share of long-term bonds. Our results are consistent with this view, since stock prices increase more for banks with larger sovereign bonds exposure.

Brunnermeier and Sannikov (2013) also suggests that, ceteris paribus, more severely lever-aged banks should benefit less from the PSPP. We explore this conjecture in more detail in Tables 6 and 7 with the EBA database, which includes information on banks' capital levels before the programme.

Table 5 shows that most regression coefficients are not significant explanatory variables of equity price changes between 4 and 6 March. In many cases, however, the sign of point the estimates is consistent with that observed between 21 and 23 January.

Columns 1-3 in Table 6 display the regression results for the EBA database. In this case, we can focus on sovereign bond holdings of a specific maturity. This is arguably important, since large holdings of short-term sovereign bonds should not be affected much by the PSPP. The reason is that shorter term yields were already close to zero before the PSPP was announced. We therefore select the 5/10-year maturity bracket, which is also more consistent with the 10-year yield change that we include as control in the regression.

The results for the EBA sample are largely consistent with those based on the SNL sample. All coefficients have similar sign and magnitude. They are also statistically significant with the exception of the bond exposure coefficient, which is positive, but insignificant. The discrepancy between the two databases could be due to a number of reasons. First and foremost, the smaller statistical significance could be due to the fact that the EBA sample is much smaller–it includes about 1/3 of the banks in the SNL sample. A second possibility is that the SNL information is more up-do-date, thus closer to markets' information set when pricing the effects of the PSPP announcement on equity prices.

Finally, column 4 in Table 6 includes the capital shortfall dummy in the regression. The dummy is positive, but statistically insignificant.

7   Concluding remarks

This paper provides evidence suggesting that an important channel of transmission of the ECB's QE programme was the reanchoring of long-term inflation expectations.

We have presented evidence showing that expansionary policy announcements related to the APP have triggered a shift in long-term inflation expectations towards levels consistent with the ECB's definition of price stability. A surprise easing associated with a 10 basis points decrease in the 5-year German Bund yield was typically accompanied by a 6 basis points increase in 5-year-ahead inflation expectations.

Our model simulations indicate that the reanchoring channel accounted for one third of the transmission of the APP to inflation. In the absence of the reanchoring channel, the peak impact of the programme would have been to increase inflation by only 25 basis points, instead of 40 basis points as in our baseline. The standard portfolio balance channel accounts for the impact of the APP on the euro area economy when the reanchoring channel is not active.

Table 6: Equity price reactions between 21 and 23 January 2015
EBA sample

	(1)	(2)	(3)	(4)
constant	4.0805**	1.512	1.2512	-0.0481
	(2.6233)	(1.1449)	(0.8388)	(-0.0281)
Δyield	18.0779***	8.2205*	9.0655**	6.6658*
	(2.9935)	(1.8491)	(2.1523)	(1.7438)
ΔSM	0.0147	1.773**	1.9578**	1.6934**
	(0.0196)	(2.553)	(2.2477)	(2.6812)
EA bank (d)		-4.6503***	-5.365***	-4.249***
		(-5.7227)	(-3.7109)	(-5.5096)
exposure			0.265	
			(0.6694)	
Shortfall (d)				1.5243
				(1.6029)
Adj. R^2	0.0693	0.3241	0.3243	0.3436
No. Obs.	51	51	51	51
	(White robust t-statistics)			

Table 7: Equity price reactions between 4 and 6 March 2015
EBA sample

	(1)	(2)	(3)	(4)
constant	1.0425*	0.7179	0.7263	2.857
	(2.0046)	(1.2908)	(1.3148)	(1.2956)
Δyield	-4.6478	-0.8825	-0.7829	4.925
	(-0.9524)	(-0.0756)	(-0.0652)	(0.3071)
ΔSM	0.9683***	0.8518**	0.8487**	0.7121
	(3.8375)	(2.4341)	(2.3283)	(1.5227)
EA bank (d)		0.7706	0.9242	0.7211
		(0.4661)	(0.4488)	(0.4966)
exposure			-0.0656	
			(-0.272)	
Shortfall (d)				-2.2799
				(-0.9201)
Adj. R^2	0.0524	0.0407	0.0209	0.0966
No. Obs.	51	51	51	51
	(White robust t-statistics)			

Our analysis offers further lessons for the implementation of asset purchase programmes. First, for given amount of assets purchased, macroeconomic benefits are larger, the higher the duration of the targeted assets. This lesson is a direct implication of the duration risk channel. Equivalently, effectiveness can be enhanced through purchase of corporate bonds, to the extent that the spread on such bonds is related to investors' leverage constraints.

A second lesson is that asset purchases can be usefully combined with a reinforced form of forward guidance. The more asset purchases are successful in leading to an upward increase in expectations of future inflation and output growth, the higher the risk that they trigger unwarranted beliefs of an earlier lift-off of the nominal interest rate from its effective lower bound. Under such circumstances, explicit forward guidance as to the likely future date of "lift-off" would be useful when implementing QE-type programmes. These lessons are broadly in line with the evolution of the APP in 2016.

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A   Solution to the bank's maximization problem

To solve the bank's maximization problem, it is instructive to define two value functions. The end-of-period value function V_{t-1} measures the franchise value of a bank j that ends period $t-1$ with private assets s_{t-1}, government bonds b_{t-1} and net worth n_{t-1}:

$$V_{t-1}(s_{t-1}, b_{t-1}, n_{t-1}) = \tilde{E}_{t-1}\Lambda_{t-1,t}\{(1-\sigma)n_t + \sigma W_t(n_t)\} \tag{42}$$

With probability $1 - \sigma$ the banker exits and transfers next period net worth n_t back to the household. Next period net worth develops as in equation 18. With probability σ the banker survives and its continuation value is determined by its beginning-of-next-period value function W_t, which we define below. We conjecture that this value function is a linear function of its state variables:

$$V_t = \mu_{st}Q_t s_t + \mu_{bt}q_t b_t + \nu_t n_t, \tag{43}$$

and its coefficients $(\mu_{st}, \mu_{bt}, \nu_t)$ are common across banks.

The beginning-of-period value function of the bank W_t with net worth n_t is determined by the following constrained maximization problem:

$$W_t(n_t) = \max_{s_t, b_t} V_t(s_t, b_t, n_t) \tag{44}$$

subject to

$$V_t(s_t, b_t, n_t) \geq \theta Q_t s_t + \Delta\theta q_t b_t. \tag{45}$$

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The bank chooses its private loan and government bond holdings to maximize its end-of-period-value subject to its incentive constraint. Let λ_t be the Lagrange multiplier associated with the incentive constraint (45). After substituting equation 43, its Lagrangean is

$$(1 + \lambda_t)(\mu_{st}Q_t s_t + \mu_b q_t b_t + \nu_t n_t) - \lambda_t(\theta Q_t s_t + \Delta\theta q_t b_t). \tag{46}$$

The first-order necessary conditions require that

$$\mu_{st} = \frac{\lambda_t}{1 + \lambda_t}\theta, \tag{47}$$

$$\mu_{bt} = \Delta\frac{\lambda_t}{1 + \lambda_t}\theta = \Delta\mu_{st}, \tag{48}$$

and

$$\lambda_t\left[(\mu_{st}Q_t s_t + \mu_{bt}q_t b_t + \nu_t n_t) - (\theta Q_t s_t + \Delta\theta q_t b_t)\right] = 0. \tag{49}$$

When the incentive constraint is not binding ($\lambda_t = 0$, $\forall$ t),financial markets are frictionless: Banks acquire assets to the point where the marginal value of obtaining assets are zero $\mu_{st} = \mu_{bt} = \nu_t = 0$. The end-of-period value function in this case is obviously linear. When the incentive constraint is binding ($\lambda_t > 0$), the optimality conditions give rise to an endogenous 'risk-adjusted' leverage constraint:

$$Q_t s_t + \Delta q_t b_t = \phi_t n_t$$

where ϕ_t is the leverage ratio:

$$\phi_t = \frac{\nu_t}{\theta - \mu_{st}}$$

The measure of assets that enters the bank's balance sheet constraint applies a weight of Δ to government bonds, reflecting the weaker constraint on arbitrage for this asset than for private loans. As the bank expands this adjusted measure of assets by issuing deposits, its' incentive to divert funds increases. The constraint (45) limits the portfolio size to the point where the bank's incentive to cheat is exactly balanced by the cost of losing the franchise value. In this respect the agency problem leads to an endogenous capital constraint.

Observe that ϕ_t is the maximum ratio of the adjusted measure of assets to net worth that the bank may hold without violating the incentive constraint. It depends inversely on θ; An increase in the bank's incentive to divert funds reduces the amount depositors are willing to lend. Conversely, an increase in the discounted excess return on assets, μ_{st} or the discounted safe rate, ν_t increases the franchise value of the bank, V_t reducing the bank's incentive to divert funds. Depositors thus become willing to lend more, raising ϕ_t.

The beginning-of-period value function is also linear, as it can be seen from the following straightforward derivation:

$$
\begin{aligned}
W_t(n_t) =& \mu_{st}\left(Q_t s_t^* + \Delta q_t b_t^*\right) + \nu_t n_t \\
=&(\mu_{st}\phi_t + \nu_t)n_t \\
=&\theta\phi_t n_t
\end{aligned}
\tag{50}
$$

The beginning-of-period value function can be used to obtain solution to the end-of-period value function. The latter is given by

$$
\mu_{st-1}Q_{t-1}s_{t-1} + \mu_{bt-1}q_{t-1}b_{t-1} + \nu_{t-1}n_{t-1} = \tilde{E}_{t-1}\Lambda_{t-1,t}\{(1-\sigma)n_t + \sigma W_t(n_t)\},
\tag{51}
$$

where the net worth develops as

$$
n_t = (R_{kt} - R_t)Q_{t-1}s_{t-1} + (R_{bt} - R_t)q_{t-1}b_{t-1} + R_t n_{t-1}.
$$

Substitution leads to an identity that needs to be satisfied for all possible steady state values:

$$
\mu_{st-1}Q_{t-1}s_{t-1} + \mu_{bt-1}q_{t-1}b_{t-1} + \nu_{t-1}n_{t-1} =
$$
$$
\tilde{E}_{t-1}\Lambda_{t-1,t}\{[(1-\sigma) + \sigma\theta\phi_t]\,(R_{kt} - R_t)Q_{t-1}s_{t-1} + (R_{bt} - R_t)q_{t-1}b_{t-1} + R_t n_{t-1}\}.
$$

This implies that

$$
\begin{aligned}
\mu_{st} =& \tilde{E}_t\Omega_{t,t+1}(R_{kt+1} - R_{t+1}) \\
\mu_{bt} =& \tilde{E}_t\Omega_{t,t+1}(R_{bt+1} - R_{t+1}) = \Delta\mu_{st} \\
\nu_t =& \tilde{E}_t\Omega_{t,t+1}R_{t+1} \\
\Omega_{t-1,t} =& \Lambda_{t-1,t}\left[1 - \sigma + \sigma\theta\phi_t\right]
\end{aligned}
\tag{52}
$$

where $\Omega_{t-1,t}$ is the bank's 'augmented' discount factor, reflecting the shadow value of a unit of its net worth. The derivation proves that our conjecture is satisfied and the end-of-period value function is indeed linear and its coefficients are independent of bank specific characteristics.

B Long-Term Bond Yields

We have argued that the effects of APP are transmitted to the real economy via their impact on excess returns (relative to a frictionless benchmark.) Popular discussions of LSAPs, however, emphasize the impact on long term bonds rates and various credit spreads. The empirical literature has followed this direction by studying the effects of LSAPs on these variables. Of course another relevant consideration in focusing on the behavior of these yields is that excess returns are not directly observable.

Within our model the government bond is a consol that pays a dollar in perpetuity. Let $R^n_{bt+1+i} \equiv R_{bt+1+i} \cdot \frac{P_{t+1+i}}{P_{t+i}}$ be the ex post gross nominal return on this security from $t+1+i$; Then we can express the nominal price $P_t q_t$ as the following discounted sum:

$$P_t q_t = \sum_{i=1}^{\infty} \frac{1}{E_t \Pi^i_{j=1} R^n_{bt+j}} \tag{53}$$

To understand the impact of APP on long term bond yields it is useful to define R^{n*}_{bt+j} as the ratio of nominal return in the absence of credit market frictions, everything else equal; and define $\Psi_{t+j} = R^n_{bt+j}/R^{n*}_{bt+j}$ as the ratio of nominal return to is "frictionless value". We can express the discounted return as

$$P_t q_t = \sum_{i=1}^{\infty} \frac{1}{E_t \Pi^i_{j=1} \Psi_{t+j} R^{n*}_{bt+j}} \tag{54}$$

where discount factors depend on the expected sequence of excess returns measure by Ψ_{t+j}. Finally, we compute the nominal (net) yield to maturity, as the constant per period nominal discount rate i^n_{bt} that yields the same nominal value as the consol, given the same sequence of coupon payments:

$$\sum_{s=1}^{\infty} \frac{1}{(1+i^n_{bt})^s} = \sum_{i=1}^{\infty} \frac{1}{E_t \Pi^i_{j=1} \Psi_{t+j} R^{n*}_{bt+j}} \tag{55}$$

To a first order, we can decompose the movement in i^n_{bt} into terms reflecting the expected path the frictionless nominal rate R^{n*}_{bt+j} and terms reflecting the excess return Ψ_{t+j}. As we saw in the previous section, APP work by pushing down the component of i^n_{bt} due to expected excess returns that stem from limits to arbitrage. Absent these excess returns, APP would have no effect on i^n_{bt}.

On the other hand, to the extent that long term bond purchases are successful in pushing down excess returns the overall impact on i^n_{bt} may be muted by an expected increase in the frictionless nominal rate. In particular, by pushing down excess returns the APP stimulate both real activity and inflation, leading to an expected future increase in short term interest rates. It is the expected response of future short rates than dampens the overall responds of APP on long term yields.

We can similarly construct a yield to maturity for the private security. The main difference is that now the per period payoff is the nominal dividend payment net depreciation, $[Z_{t+1} - \delta] P_{t+1}$. Finally, much of the evidence of APP on returns is reported for securities of a given finite maturity, as opposed to consols or other kinds of infinitely-lived assets. In the quantitative section we describe how we approximate the returns on shorter maturity securities.

C   Additional tables and figures

Figure 7: 5-year ahead inflation expectations and monetary policy surprises
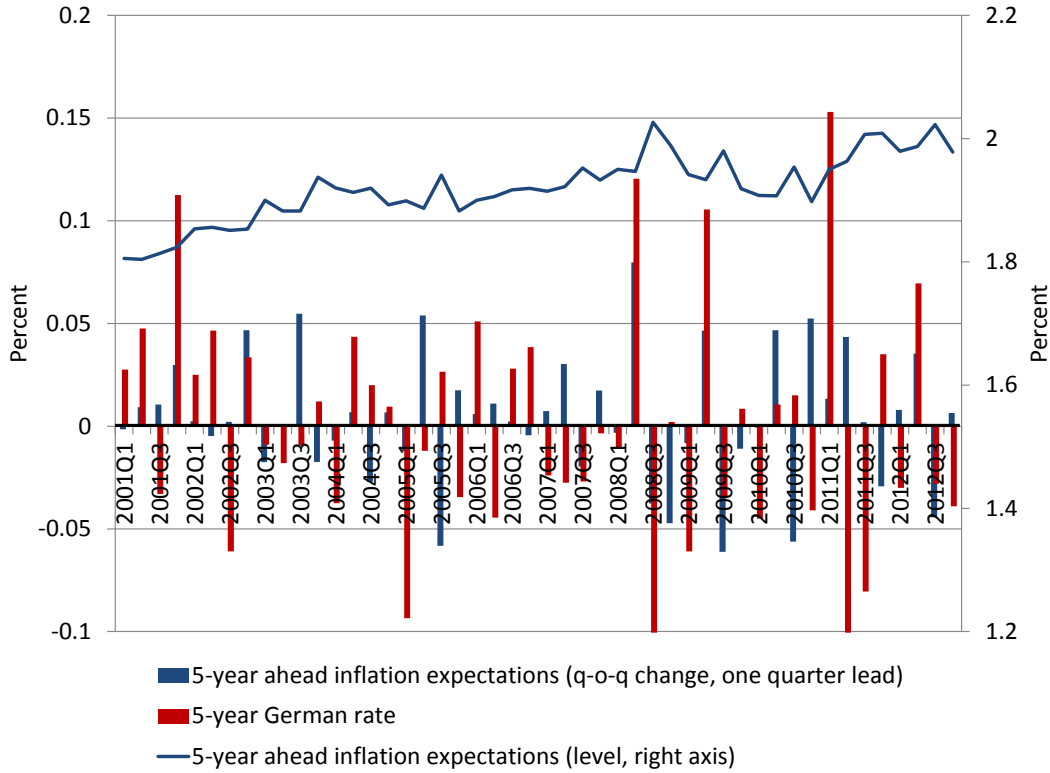

- **5-year ahead inflation expectations (q-o-q change, one quarter lead)**
- **5-year German rate**
- **5-year ahead inflation expectations (level, right axis)**

Table 8: Impact of high-frequency surprises in the 5-year German sovereign bond yield on 5-by-5 inflation-linked swap yields

|	(1) Post 2013	(2) Pre 2013	(3) APP	(4) APP, No FG
	Change in 5x5 inflation-linked swap yields			
5-year German yield surprise	-1.222** (-2.754)	0.571*** (4.303)	-1.533** (-2.592)	-1.189** (-2.571)
Sample	2013q1-2016q2	2004q1-2012q4	2014q2-2016q2	2014q2-2016q2
Observations	15	34	10	10
R-squared	0.315	0.176	0.426	0.399

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 8: Macroeconomic impact of an interest rate innovation
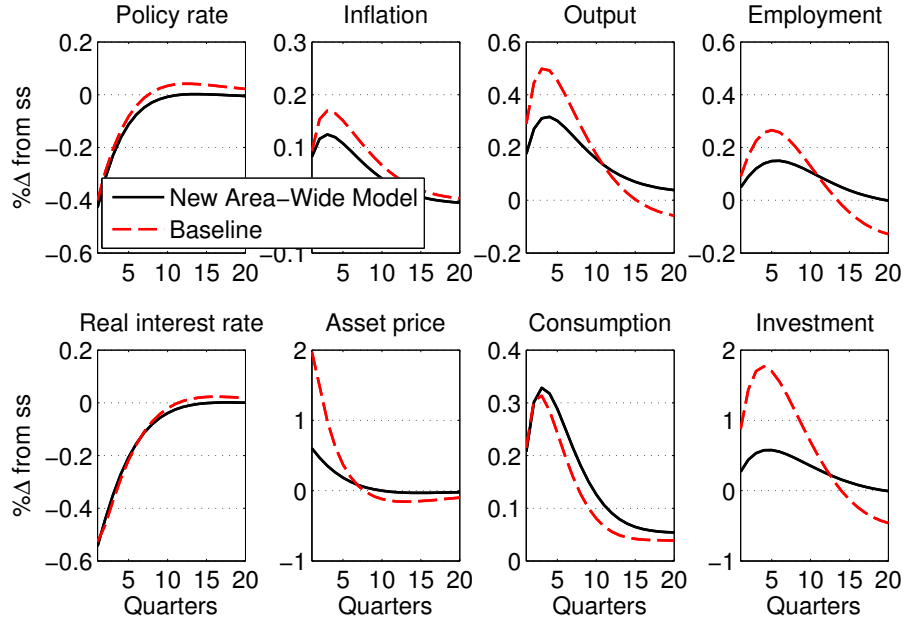
The figure shows the macroeconomic impact of a persistent interest rate innovation as estimated by the New Area-Wide Model and according to the baseline calibration of our model.

Figure 9: Baseline policy impact and a comparable monetary policy shock
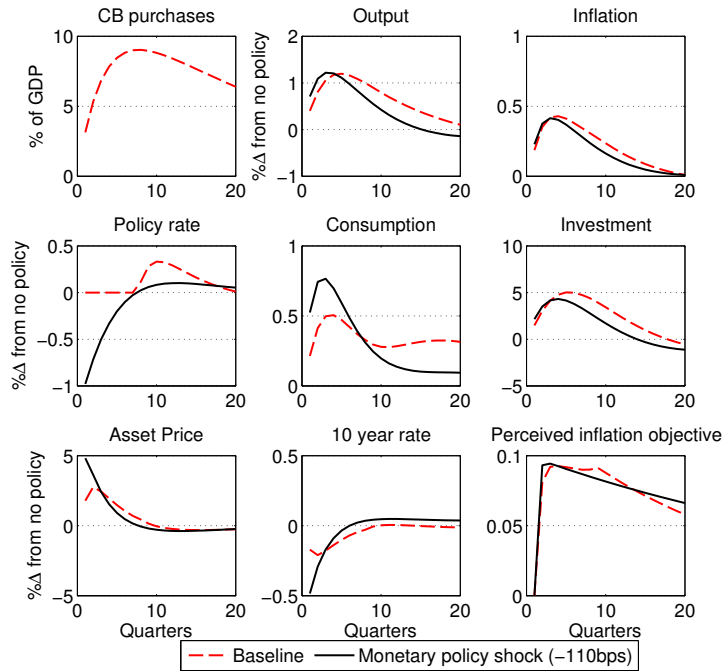
The figure compares the impact of the baseline policy to that of a -1.1 percentage point monetary policy shock. The two policies have comparable inflation and output responses.

D   Data

In Section 2, we use Reuters' Tick History database to measure unconventional monetary policy surprises around Governing Council press conferences. Table 9 list the dates and times of the press conferences since June 2014. Its third column shows the nature of the unconventional policy announcements: were they related to asset purchase programme (APP) or they also included key new forward guidance announcements (FG). The fourth column describes the relevant details of the announcements.

The micro-database used in Section 6.1 combines three data sources. First, we use the purchases of euro area bonds conducted by the Eurosystem under the PSPP at the individual bond level. Our sample covers the period from 9 March 2015 to 30 December 2015.[15] Second, we approximate the dataset of all assets eligible for purchase under the PSPP for the period both before and after the announcement using data from the ECB's collateral database.[16] [17] Third, we gather information on individual bonds from Bloomberg for all eligible bonds.

The database used in Section 6.2 includes all listed banks for which publicly available balance sheet information is available on their holdings of sovereign bonds. We however exclude Greek and Cypriot banks from the sample, because their stock market prices were extremely volatile over the PSPP announcement period. The total number of banks is 120 for the SNL dataset and 51 for the EBA dataset.

Two notable features emerge from the table. First, individual banks' stock prices have increased, on average, both on 22 January and on 5 March. On 22 January the increase is equal to 1.4% for the EBA sample and 1.2% for the SNL sample. These averages, which are not value weighted, compare to a 2.8% increase in the STOXX Europe 600 Banks index. The second notable feature emerging from table 10 is that the banks' equity prices increased less than the overall stock market index. The STOXX Europe 600 went up by 3.4%. The difference is particularly large for euro area-based banks. The EURO STOXX Banks index increased by 1.3%, compared to a 3.2% increase in the total EURO STOXX. This suggests that concerns with the effect of the PSPP on banks' profitability might have been in the mind of stock market investors.

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[15]We thank DG-M/BMI for sharing the data with us.

[16]Eligibility criteria for marketable debt securities are: (i) The securities must be denominated in Euro and issued by a central government of a member state whose currency is the euro, or by recognized agencies, development banks and international organizations located in the euro area. (ii) The issuer of the debt securities must have at least one public rating provided by an external credit assessment institution of at least Credit Quality Step 3 in the Eurosystem's harmonized rating scale (that is from BBB- onwards). (iii) If the credit assessment does not comply with at least Credit Quality Step 3, the securities are eligible only if they are issued by a member state under a financial assistance program. (iv) The securities must have a minimum remaining maturity of 2 years and a maximum remaining maturity of 30 years and 364 days. (v) Securities must have a yield to maturity above the deposit facility rate.

[17]We thank the DG-M/MOA Division at the ECB for advice on how to approximate the historical list of PSPP eligible assets.

Table 9: Governing Council (GC) announcements related to the asset purchase programs

Date	Time	UMP	Description
05/06/2014	14:30-15:30	APP, FG	GC decided to intensify preparatory work related to outright purchases in the ABS market. It also launched a series of 4-year TLTRO at fixed rate that could have been perceived by markets as commitment to longer low interest rates.
03/07/2014	14:30-15:30	APP	GC confirmed the preparatory work related to outright purchases in the ABS market.
07/08/2014	14:30-15:30	APP	GC confirmed the preparatory work related to outright purchases in the ABS market.
04/09/2014	14:30-15:30	APP	GC decided to start purchasing broad portfolios of simple and transparent asset-backed securities (ABSPP programme) and of euro-denominated covered bonds (CBPP3 programme).
02/10/2014	14:30-15:30	APP	GC stated that it will start purchasing covered bonds and asset-backed securities in the fourth quarter of 2014 until June 2016.
06/11/2014	14:30-15:30	APP	GC stated it has started purchasing covered bonds under the new programme. It confirmed that it will soon start to purchase asset-backed securities.
04/12/2014	14:30-15:30	APP	GC stated that it has started purchasing covered bonds and asset-backed securities.
22/01/2015	14:30-15:30	APP	GC decided to launch an expanded asset purchase programme, encompassing the existing purchase programmes for asset-backed securities and covered bonds, for an amount of €60 billion. The purchases are intended to be carried out until the end of September 2016.
05/03/2015	14:30-15:30	APP	GC stated that, on 9 March 2015, it will start purchasing euro-denominated public sector securities in the secondary market and that it will also continue purchasing asset-backed securities and covered bonds. It reaffirmed that purchases are intended to run until the end of September 2016.
15/04/2015	14:30-15:30	APP	GC reaffirmed that purchases are intended to run until the end of September 2016.
03/06/2015	14:30-15:30	APP	GC reaffirmed that purchases are intended to run until the end of September 2016.
16/07/2015	14:30-15:30	APP	GC reaffirmed that purchases are intended to run until the end of September 2016.
03/09/2015	14:30-15:30	APP	GC increased the PSPP issue share limit from 25% to 33%. The purchases are intended to run until the end of September 2016, or beyond, if necessary.
22/10/2015	14:30-15:30	APP, FG	GC stated to fully implement the monthly asset purchases of €60 billion until the end of September 2016, or beyond, if necessary. It also stated that the degree of monetary policy accommodation will need to be re-examined at next December monetary policy meeting and that it is willing and able to act by using all the instruments available within its mandate if warranted. Further lowering of the deposit facility rate was discussed.
03/12/2015	14:30-15:30	APP	GC extended the asset purchase programme until the end of March 2017, or beyond, if necessary and it included euro-denominated marketable debt instruments issued by regional and local governments located in the euro area. It also decided to reinvest the principal payments on the securities purchased under the APP as they mature, for as long as necessary.
21/01/2016	14:30-15:30	APP	GC stated that it will be necessary to review and possibly reconsider its monetary policy stance at its next meeting in early March.
10/03/2016	13:45, 14:30-15:30	APP, FG	GC decided to extend the monthly purchases under the asset purchase programme to €80 billion starting in April, and to increase the issue share limits from 33% to 50%. It affirmed that with today's comprehensive package of monetary policy decisions it is providing substantial monetary stimulus. GC expected the key ECB interest rates to remain at present or lower levels for an extended period of time, and well past the horizon of its net asset purchases. It also did not anticipate that it will be necessary to reduce rates further.
21/04/2016	13:45, 14:30-15:30	APP	GC reaffirmed that the purchases are intended to run until the end of March 2017, or beyond, if necessary.
02/06/2016	13:45, 14:30-15:30	APP	GC reaffirmed that the monthly asset purchases of €80 billion are intended to run until the end of March 2017, or beyond, if necessary.

Table 10: Summary table for 2-day price changes

	21-23 January			4-6 March		
	mean	median	std. dev.	mean	median	std. dev.
Full SNL sample:						
equity return	1.19	0.99	2.79	0.96	0.64	3.68
exposure[1]	12.00	10.11	11.77	12.00	10.11	11.77
Δ yield $(10y)$[2]	-0.19	-0.16	0.18	-0.01	0.00	0.08
Δ SM [2]	1.56	1.54	1.99	0.90	0.91	1.46
STOXX Europe 600 return	3.36			0.91		
STOXX Europe 600 Banks return	2.85			0.83		
Full EBA sample:						
equity return	1.43	1.61	3.08	2.06	1.71	2.93
exposure[3]	1.57	0.85	1.76	1.57	0.85	1.76
SNL subsample of EA countries:						
equity return	0.60	0.54	2.81	1.45	0.82	2.71
exposure[1]	12.96	10.79	12.89	12.96	10.79	12.89
Δ yield $(10y)$[2]	-0.23	-0.16	0.21	-0.04	-0.01	0.07
Δ SM [2]	1.81	2.39	2.26	1.05	0.95	1.51
EURO STOXX return	3.21			1.21		
EURO STOXX Banks return	1.28			1.54		
EBA subsample of EA countries:						
equity return	0.24	0.36	2.83	2.58	2.05	3.31
exposure[3]	2.34	1.87	1.75	2.34	1.87	1.75

[1] Exposure is defined as total sovereign exposure as % of total assets.

[2] Average over 28 EU countries/ 19 euro area countries. Bond yields excluding EE, CY, LV.

[3] Exposure is defined as exposure to EA sovereign bonds with 5- to 10-year maturity as % of total assets.