Asset Purchase Programmes and Financial Markets: Lessons from the Euro Area*

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Abstract

We evaluate the effects of the ECB asset purchase programme (APP) on asset prices and its transmission channels. We identify these channels by exploiting predictions for cross-asset price movements, derived from a term structure model with bond supply effects that we extend to account for different types of risk premia. These predictions are empirically validated by means of an event-study methodology. We find that the impact of the APP on asset prices is economically significant, despite the low financial distress prevailing at announcement. Consistent with the model, we explain this puzzle by showing how low financial distress, while indeed weakening market segmentation channels ("local supply channel"), has reinforced "broad channels" because of its interplay with the asset composition of the APP, hence supporting "duration" and "credit" channels, and facilitating spill-overs to non-targeted assets.

JEL classification: E43, E44, E52, E58, E65, G14.

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1 Introduction

There is a large body of literature on the effects of asset purchase programmes carried out by the Federal Reserve in the US and by the Bank of England in the UK during the global financial crisis. Two main conclusions emerge. First, the impact on assets targeted by the programmes carried out in the aftermath of the Lehman's collapse is generally found to be stronger than the one exerted by subsequent programmes implemented when financial market distress receded.[1] Second, depending on the types of asset purchased, these programmes affect asset prices differently and via multiple channels, with "narrow channels" being relatively more important than "broad channels" – where channels are defined as "narrow" when the impact is concentrated on the assets targeted by the programme, with limited spill-overs to other market segments.[2]

In this paper, we study whether these conclusions continue to hold when assessed through the lens of the ECB asset purchase programme (APP) focusing on its effects on asset prices and its transmission channels. Our intuition is that the ECB programme might in principle provide relevant informational content in that, contrary to the LSAP1 in the US, as well as the first purchase programme carried out in the UK, it was announced at times in which financial conditions were stable, and various yields and spreads already compressed. Moreover, by comprising a variety of investment-grade public and private securities, the ECB programme has the potential of giving rise to a variety of transmission channels. Indeed, when announced in January 2015, asset purchases were intended to run until September 2016 amounting to €1.14 trillion and comprising public securities with different risk premia and residual maturity of more than 2 years and up to 30 years.[3]

[1]This finding is explicitly acknowledged for instance in Krishnamurthy and Vissing-Jorgensen (2011) when noting that effects as large as the ones generated by the first programme of Large Scale Asset Purchases (LSAP1) in the US are limited to "unusual times of financial crises". See also Krishnamurthy and Vissing-Jorgensen (2013), D'Amico and King (2013) and Meaning and Zhu (2011). Notably, this finding does not depend on asset purchases unlocking distressed market functioning. In fact, the bulk of the impact is found to arise at announcement ("stock effects"), whereas "flow effects" generated by the actual implementation of the purchases are overall limited; see for instance, D'Amico and King (2013) for the US, and Joyce and Tong (2012) and Breedon et al. (2012) for the UK.

[2]See, for instance, Krishnamurthy and Vissing-Jorgensen (2013) and D'Amico et al. (2012) for the US. In the UK, there is some evidence that scarcity effects on the targeted maturities of gilts have spilled over to other asset classes of similar maturity; see McLaren et al. (2014).

[3]Specifically, when announced in January 2015, the programme consisted of combined monthly purchases of €60 billion of investment-grade public and private securities, intended to be carried out until September

To account for assets with different types of risk premia, we extend a term structure model with bond supply effects, and derive model-based predictions for asset price movements. The first prediction implies that asset prices would respond to revisions in market expectations about future purchases prior to the actual purchases taking place and also in anticipation to the final announcement, thus giving rise to a "stock effect". The second type of predictions is on the cross-asset price responses to the purchase programme, which we exploit to identify the underlying transmission channels, as advocated by Krishnamurthy and Vissing-Jorgenson (2011). We validate empirically these predictions by means of an event-study methodology.

We find that once prior-to-announcement effects are accounted for, the APP has significantly lowered yields for a broad set of market segments, with effects that generally rise with maturity and riskiness of assets. Sizeable impact is estimated, for instance, for long-term sovereign bonds, with yields declining up to 50 basis points at the 10-year maturity for the "synthetic" euro area term structure[4], and by roughly twice as much in higher-yield member countries such as Italy and Spain. This economically important impact of the APP at a time of low financial distress appears puzzling in light of the existing literature documented above, that finds large effects of asset purchases primarily in periods of high financial distress. Consistent with the model, we explain this apparent puzzle by showing how low financial distress, while indeed weakening market segmentation channels, has reinforced "broad channels" because of its interplay with the asset composition of the APP. Specifically, targeting assets at long maturity and spanning the investment-grade space has supported the "duration" and "credit" channels, respectively. At the same time, the low financial distress prevailing at APP announcement, while weakening the "local supply channel", has facilitated spill-overs to non-targeted assets. Notably, our findings also imply that the reverse would hold in case of high financial distress and more segmented markets: purchase programmes would have large

2016, and in any case until the Governing Council of the ECB sees inflation stabilising at values consistent with its inflation aim; hence, asset purchases intended until September 2016 amounted to €1.14 trillion. On 3 December 2015, the ECB decided to extend the APP with monthly purchases intended to run until the end of March 2017, or beyond, if necessary. On 10 March 2016, the ECB decided to expand its monthly purchases under the APP to €80 billion starting in April 2016. As this paper focuses on policy decisions announced up until the start of the APP purchases in March 2015, the policy decisions taken thereafter are not considered here.

[4]The "synthetic" sovereign yield curve for the euro area is the yield curve estimated by the ECB using all euro area central government bonds and released on a daily basis. The daily releases are available at http://www.ecb.europa.eu/stats/money/yc/html/index.en.html.

effects on targeted assets, and precisely because of market segmentation the spill-overs to non-targeted assets would be limited, hence the relevance of "narrow channels" found in the literature. In essence, our findings provide a unifying interpretation to the main conclusions emerging from the literature, hence vindicating the intuition on the informational content of the euro area experience in shedding light on the efficacy of central banks' asset purchase programmes.

To derive the model predictions for the various transmission channels, we extend the discretised model version of Vayanos and Vila (2009) employed by Hamilton and Wu (2012) to allow for credit premium. This means formalising a "credit channel" into a set-up with bond supply effects, while continuing to entertain a "local supply /scarcity channel" and a "duration channel". Specifically, the model features two types of agents: i) the arbitrageurs who invest across market segments, subject to certain risk-bearing capacity; (ii) the preferred-habitat investors who display clienteles' demand over specific maturities (and asset classes). As noticed by Greenwood and Vayanos (2014), arbitrageurs' behaviour gives rise to portfolio-balance effects (Tobin 1958) whereby arbitrageurs diversify across maturities ("duration channel") and asset classes ("credit channel") any change in the compensation for risk associated to variations in the amount of assets held in their portfolios. Conversely, resting on the preferred-habitat theory (Modigliani and Sutch 1966), the presence of clienteles' demand over specific maturities gives rise to "local supply /scarcity channels", which manifest themselves more prominently in segmented markets.

To assess empirically the model's predictions, we employ an event-study methodology that improves on two dimensions on the standard approach followed in the literature. The latter approach typically focuses on changes in asset prices at the announcement dates, implicitly assuming that (i) the announcement dates include all news affecting expectations about the programme; (ii) the window over which changes in asset prices are measured is not distorted by other concomitant news. But these assumptions may not be valid. Therefore, first, because the January 2015 ECB's announcement was largely expected by financial markets, we identify a broad set of events comprising ECB's official announcements that, starting from September 2014, have affected market expectations about the programme; we then validate this "narrative" approach in dating the events with a more "agnostic" approach, based on an index of intensity of news coverage about a purchase programme in the euro area in the months prior to the official announcement. Second, we employ an event-study assessment based on a regression analysis that explicitly controls for macroeconomic releases (Altavilla and Giannone, 2014). Finally, to sharpen our identification of the channels of transmission, we also make use of high-frequency intraday data.

The remainder of the paper is organised as follows. Section 2 presents a theoretical model with bond supply effects on the term structure and derive predictions for the impact of central bank asset purchase programmes. In Sections 3, the model-based predictions are exploited to estimate and interpret the euro area APP. Section 4 extends the assessment to other asset classes, such as the exchange rate, the stock market and inflation expectations. Section 5 provides conclusions.

2 A reference model of bond supply effects

We present a theoretical model with bond supply effects on the term structure and derive predictions for the impact of central bank asset purchase programmes, which are interpreted in the model as a reduction in the bond supply in the hands of investors. This provides a unified model set-up for framing most of the transmission channels identified in the empirical literature on asset purchase programmes, channels typically encompassing a "local supply /scarcity channel", a "duration channel" and a "credit channel".[5] In essence, we extend the modelling framework by Vayanos and Vila (2009) to allow for credit premium, building on the discretised version of their model as in Hamilton and Wu (2012). This allows us to formalise a "credit channel" within a set-up with bond supply effects, while continuing to entertain a "local supply /scarcity channel" and a "duration channel". The inclusion of a "credit channel" is particularly relevant for interpreting asset purchases in the euro area, in light of the different degree of creditworthiness of sovereign bonds across euro area member countries.[6] Finally, we employ the model to draw two types of predictions that serve us as a guide through the empirical assessment of the ECB asset purchase programme (APP). The first type of predictions relates to the "stock effects", in the form of changes in asset prices resulting from the revision in the expectations about future withdraws of bond supply, and in anticipation to the actual purchases taking place. The second type of predictions relates to the identification of the transmission channels.

2.1 "Stock effects" of asset purchases

At the centre of the model economy is the interaction between two types of agents: the arbitrageurs and the preferred-habitat investors. The arbitrageurs have limited risk-bearing

[5]See, for instance, for the US Krishnamurthy and Vissing-Jorgensen (2013), Gagnon et al. (2011), Christensen and Rudebusch (2012), Cahill et al. (2013), Bauer and Rudebusch (2014); and for the UK Joyce and Tong (2012) and McLaren et al. (2014).

[6]When focusing on a previous ECB programme involving government bond purchases, the Securities Markets Programme (SMP), Krishnamurthy et al. (2014) identify a redenomination risk channel for some euro area countries. Notice that this channel is associated with a perceived breakup of the euro area that emerged at the time of the euro area sovereign debt crisis. Indeed, in launching this and other programmes, such as the Outright Monetary Transactions (OMT) and the Long-Term Refinancing Operations (LTROs), the ECB aimed at removing tail risk and addressing dysfunctional financial markets. As such, these types of programmes are different in nature from the APP, which has the objective to provide additional monetary policy stimulus in face of increasing deflation risks and to ease borrowing conditions of households and firms.

capacity and a mean-variance objective function defined as

$$E_t R^P_{(t,t+1)} - \frac{1}{2}\sigma Var_t R^P_{(t,t+1)} \tag{1}$$

where $R^P_{(t,t+1)}$ is the portfolio's return and σ is the risk-aversion coefficient. Because arbitrageurs can invest in all n-period zero-coupon bonds, the associated portfolio's return can be expressed as

$$R^P_{(t,t+1)} = \sum_{n=1}^{N} \omega_t^{(n)} R^{(n)}_{(t,t+1)} = \sum_{n=1}^{N} \omega_t^{(n)} [\exp(\overline{p}^{(n-1)}_{t+1} - \overline{p}^{(n)}_t) - 1] \tag{2}$$

where $\omega_t^{(n)}$ is the fraction of arbitrageurs' portfolio (relative to their net wealth W_t) held in n-period bonds, and $R^{(n)}_{(t,t+1)}$ is the one-period holding return of purchasing a $n-$period bond at time t at (log) price $\overline{p}^{(n)}_t$ and selling it at $t+1$ with residual maturity of $n-1$ at (log) price $\overline{p}^{(n-1)}_{t+1}$.

We extend Vayanos and Vila (2009) by considering that these zero-coupon bonds are subject to credit risk. Specifically, denoted by ψ_t, the time-t credit-risk intensity is assumed to be affine in a set of macroeconomic factors

$$\psi_{t+1} = \gamma' X_{t+1} \tag{3}$$

where these factors follow a VAR process

$$X_t = \mu + \Phi X_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \Sigma\Sigma') \tag{4}$$

To solve for the pricing equation, we conjecture that log bond prices are also affine functions in the set of macroeconomic factors

$$\overline{p}^{(n)}_t = -\overline{a}_n - \overline{b}'_n X_t \tag{5}$$

and the continuously compounded yield $y_t^{(n)}$ on $n-$period bond is given by $-p_t^{(n)}/n$.

As derived in detail in Appendix A, the FOCs of the arbitrageurs' optimal portfolio allocation can be expressed in the following form

$$R^{(n)}_{(t,t+1)} - \overline{r}_t = \overline{b}'_{n-1}\Sigma\Sigma'\lambda_t \tag{6}$$

where

$$R^{(n)}_{(t,t+1)} \equiv -\overline{a}_{n-1} - \overline{b}'_{n-1}(\mu + \Phi X_t) + \frac{1}{2}(\overline{b}'_{n-1} + \gamma')\Sigma\Sigma'(\overline{b}_{n-1} + \gamma) - \frac{1}{2}\gamma'\Sigma\Sigma'\gamma + \overline{a}_n + \overline{b}'_n X_t \tag{7}$$

$$\overline{r}_t = \overline{a}_1 + \overline{b}'_1 X_t \tag{8}$$

$$\lambda_t \equiv \sigma \sum_{n=1}^{N} (\omega^{(n)}_t (\overline{b}_{n-1} + \gamma)) \tag{9}$$

Equation (6) implies that long bonds command a risk premium in the form of an expected holding period return in excess of the short rate $\overline{r}_t$, where both the short and the long bonds are here subject to credit risk. This premium can be decomposed into the standard components of the quantity of risk (the term $\overline{b}'_{n-1}\Sigma\Sigma'$), and the market price of risk (the term λ_t), where the latter captures the expected return per unit of risk, and is equal for all bonds. Contrary to most term structure specifications, however, in this model the price of risk is endogenously determined in equation (9), and is affected by the degree of risk aversion σ, and by arbitrageurs' bond holdings at various maturities $\omega^{(n)}_t$, weighted by the sensitivity of the bond price to macroeconomic factors $(\overline{b}_{n-1} + \gamma)$. To gain further intuition, and ensure that the model has an analytical solution, we consider one macroeconomic factor in the form of the short-term rate. This implies that $\overline{b}_n$ is the (negative of) of the elasticity of the price of bonds with respect to the short-term rate. Because the price of bonds declines when the short-term rate rises, $\overline{b}_n$ is positive; moreover, because this responsiveness is larger for long bonds, $\overline{b}_n$ tends to rise with the term to maturity. Therefore, holdings of bonds $\omega^{(n)}_t$ at long maturities receive relatively larger weights in equation (9) relative to those at short maturities; this means that a decline in holdings at long maturities leads to a lower price of risk demanded by arbitrageurs compared with the case in which the same decline in holdings would have been concentrated at shorter maturities. Finally, as described below, the fact that in equilibrium $\omega^{(n)}_t$ depends on the supply of bonds opens up the possibility for the latter to affect bond premia, via inducing a change in the market price of risk.

Turning to preferred-habitat investors, they have demand over specific maturities given by

$$\xi_t^{(n)} = \varphi(\overline{y}_t^{(n)} - \beta^{(n)}) \tag{10}$$

where the demand $\xi_t^{(n)}$ is normalised relative to the arbitrageurs' net wealth W_t, and $\beta^{(n)}$captures its intercept. Equilibrium conditions in the bond market require that the demand from arbitrageurs and preferred-habitat investors equates the supply of bonds $S_t^{(n)}$

$$\omega_t^{(n)} + \xi_t^{(n)} = S_t^{(n)} \tag{11}$$

Isolating $\omega_t^{(n)}$ in (11), and substituting it out in (9), we obtain the following expression for the market price of risk

$$\lambda_t \equiv \sigma \sum_{n=1}^{N} (S_t^{(n)} - \xi_t^{(n)})(\overline{b}_{n-1} + \gamma) \tag{12}$$

As anticipated above, by entering in the definition of the market price of risk, the supply of bonds does affect the whole term structure. The impact of the supply of bonds on the price of risks is evident from (12) once ignoring for a moment the demand by preferred-habitat investors, and keeping in mind that $\overline{b}_{n-1}$ is positive and increasing in the term to maturity, as noted above. Ceteris paribus, a reduction in the supply of bonds $S_t^{(n)}$ (akin to central bank asset purchases) leads to a decline in the price of risk, and hence a compression in risk premia; moreover, when removing bonds at longer maturities, the decline in the price of risk is more pronounced, as reflected by the higher weight attached to longer-term bond supply in (12). This reasoning continues to holds also once acknowledging that in equilibrium the demand from preferred-habitat investors $\xi_t^{(n)}$ does react simultaneously to changes in yields. More related to our extension, γ affects the price of risk directly in (12), as well as indirectly via $\overline{b}_{n-1}$, as illustrated below from the equilibrium equation for $\overline{b}_{n-1}$. In either ways, γ implies that assets with lower creditworthiness command a higher compensation per unit of risk. The intuition here is that γ makes the price of bonds more sensitive to macro factors because of the associated changes in credit-risk intensity ψ_{t+1}; therefore, with bonds subject to credit risk having a more uncertain payoff, arbitrageurs end up demanding larger compensation to hold them.

To derive an analytical solution for the pricing equation coefficients, we first assume constant supply of bonds $S^{(n)}$, meaning that changes in bond supply will be simulated by means of comparative statics. Then we verify the conjectured solution (5) by using equations (6), (7), (8), (12), and (10), where in the latter we substitute out for $\overline{y}_t^{(n)}$ using (5). This leads to a set of difference equations for the pricing coefficients that resemble the standard affine term structure pricing equations

$$\begin{aligned} \overline{a}_n &= a_1 + \overline{a}_{n-1} + (\overline{b}'_{n-1} + \gamma') \left(\mu + \Sigma\Sigma'\lambda_0 \left(\overleftrightarrow{a}_N, \overleftrightarrow{b}_N; \sigma, \gamma, \varphi, \overleftrightarrow{S}^{(N)}, \overleftrightarrow{\beta}^{(N)} \right) \right) + \\ &\quad -\frac{1}{2}(\overline{b}'_{n-1} + \gamma')\Sigma\Sigma'(\overline{b}_{n-1} + \gamma) \end{aligned} \tag{13}$$

$$\overline{b}'_n = b'_1 + (\overline{b}'_{n-1} + \gamma') \left(\Phi + \Sigma\Sigma'\lambda_1 \left(\overleftrightarrow{b}_N; \sigma, \gamma, \varphi \right) \right) \tag{14}$$

where a_1 and b_1 are the pricing equation coefficients of the short-term risk-free rate r_t, the expression for λ_t is rearranged as $\lambda_t \equiv \lambda_0 + \lambda_1 X_t$, and $\overleftrightarrow{a}_N$, $\overleftrightarrow{b}_N$, $\overleftrightarrow{S}^{(N)}$ and $\overleftrightarrow{\beta}^{(N)}$ collect respectively $\overline{a}_i$, $\overline{b}_i$, $S^{(i)}$, $\beta^{(i)}$ for all i from 1 to N.[7]

In particular, our recursive formulas are prima facie identical to those underpinning the model by Borgy et al. (2011) who similarly develop an arbitrage-free affine term structure model of potentially defaultable sovereign bonds. However, their model specification assumes that the market price of risk is a linear function of macroeconomic factors with exogenous loading coefficients, as formalised in (most) affine term structure literature. Instead, in our model the price of risk is endogenously determined, turns out to be affected by the supply of bonds, and has loading coefficients on the macroeconomic factors that are function of the model's parameters, including γ. This novelty is also reflected by the fact that, contrary to standard affine term structure models, the equilibrium recursive formulas (14) and (15) are characterised by a fixed point mapping in which the vectors $\overline{a}_n$ and $\overline{b}_n$ are a function of λ_t, which itself is a function of the coefficients $\overline{a}_n$ and $\overline{b}_n$, and so on.

To gain further intuition on what follows, it is convenient to rearrange the FOCs in term

[7] See Appendix A for the expression of λ_t and further details on the derivation of the model.

of bond yields rather than excess holding period returns[8]

$$\overline{y}_t^{(n)} = \frac{1}{n}E_t\left(r_t + r_{t+1} + ...\right) + \frac{1}{n}E_t\left(\gamma'\left(\mu + \Phi X_t\right) + \gamma'\left(\mu + \Phi X_{t+1}\right) + ...\right) \quad (15)$$
$$\frac{1}{n}E_t\left((\overline{b}'_{n-1} + \gamma')\Sigma\Sigma'\lambda_t + (\overline{b}'_{n-2} + \gamma')\Sigma\Sigma'\lambda_{t+1} + ...\right)$$

The first component represents the average level of the expected future short-term risk-free rates. The second component relates to the credit premium, as evident from its being parameterised by γ; specifically, it is the premium that also a risk-neutral investor would demand as a compensation for the smaller payoff expected at maturity from bonds with lower degree of creditworthiness. The third component is the premium that risk-averse investors require for holding bonds; notice that this type of compensation has to do with the fact that bonds are inherently risky assets because of their uncertain payoffs prior to maturity. In other words, this risk premium is related to the fact that the price of a bond fluctuates during its life because of stochastic changes in the macro factors. As noticed above, it is via this channel, and specifically through the price of risk, that asset purchases affect bond yields. While this risk premium arises also when γ is equal to zero, once we allow for bonds with lower creditworthiness (e.g. positive values for γ) this brings about an additional source of uncertainty for bond prices. The implications is that lower-rated bonds command an higher risk premium than zero-credit-risk bonds. Specifically, γ enters the risk premium component in (15), both directly and indirectly; as noticed above, the indirect channel works both via $\overline{b}'_{n-1}$ as well as via affecting the price of risk λ_t. For the purpose of further exposition, it is important to notice here that a reduction in the supply of lower-rated bonds,by affecting λ_t, leads to a compression in the risk premium above and beyond the default-free component. Finally, notice that for $\gamma = 0$ the credit premium channel is shut down, and our model reduces to a specification à la Vayanos and Vila (2009). Having derived the solution for the bond pricing equation and yields, we now turn to the first set of predictions, related to the "stock effects" of asset purchases.

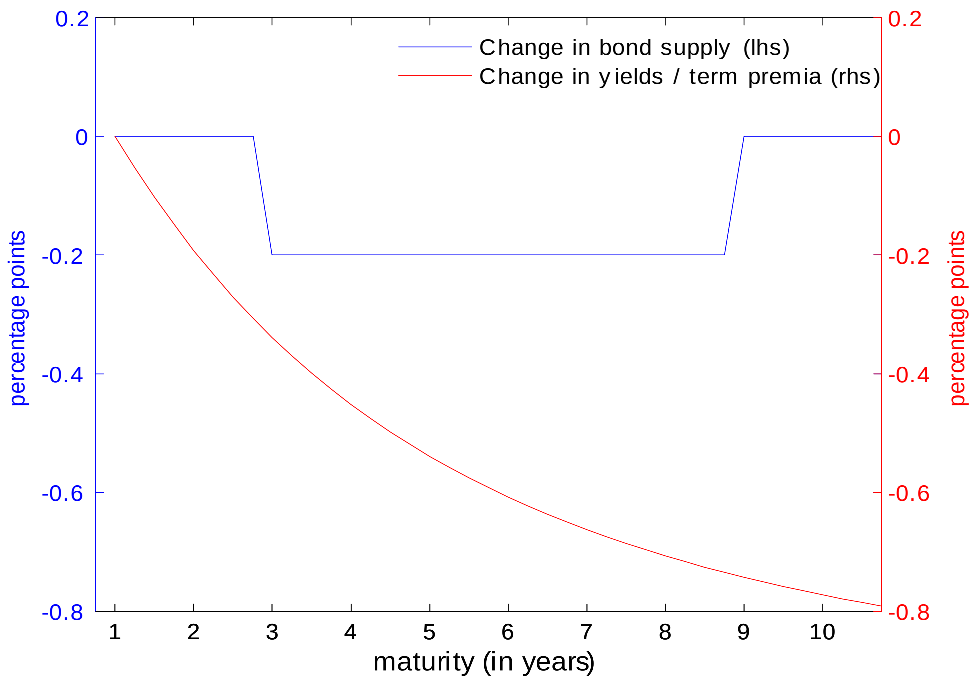
Prediction 1: "Stock effects of asset purchases". *Asset purchases affect bond yields via financial markets' reactions to current and expected future withdraws of bond supply, in*

[8] Notice that for ease of exposition, a standard convexity term is disregarded here.

anticipation to the actual purchases taking place ("stock effects").

One implication of the forward-looking nature of the yield equation (15) is that prevailing yields are affected by market expectations about future withdraws of bond supply (purchases by the central bank), in addition to changes in the current supply of bonds. To illustrate this point, we consider an anticipated future decline in the supply of bonds for maturities between three and nine years (blue line in Figure 1). According to equation (15), this leads to a decline in yields today resulting from a reduction in risk premia (red line in Figure 1). As arbitrageurs integrate maturity segments, the compression in risk premia (i) affects the whole term structure because stemming from a decline in the price of risk, (ii) is increasing in the term to maturity because of the higher sensitivity of long bonds to the pricing factors.

Figure 1: Impact of a reduction in the supply of bonds on the term structure ("*stock effects*" of an illustrative asset purchase programme).



2.2 Transmission channels of asset purchases

Albeit in a stylised form, the yield equation (15) conveniently captures relevant dimensions emerging from the empirical literature, as well as within the policy debate, in relation to the transmission channels of asset purchase programmes and their effectiveness: first, the degree of risk-bearing capacity by marginal investors, here captured by the risk aversion parameter σ which affects the compensation of risk for a given amount of bonds removed from the market via central bank asset purchases; second, the role of specialised investors, here captured by preferred-habitat investors whose clienteles' demand over specific maturities opens up the possibility for market segmentation; third, the size and composition of asset purchase programmes, where the composition here is across maturities (captured by $S_t^{(n)}$) as well as creditworthiness (parameterised by the coefficient γ). The interaction between these dimensions affects the relative importance of the transmission channels; just how exactly, it is illustrated below by simulating changes in the supply of bonds by means of comparative statics. Specifically, to derive model predictions that can be used in the our empirical analysis for identifying the different channels, it is convenient to consider a shortening in the average maturity of the supply of bonds, while leaving unchanged the overall stock of bonds detained by the private sector. In essence, this is achieved via a reduction in the supply of long-term bonds and an equal-size increase in the supply of short-term bonds.[9] Clearly, the compression in yields and premia would simply be reinforced if one were to consider a decline in the overall supply of bonds available to the private sector.

We start out deriving the model's predictions for default-free bonds, by shutting down the "credit premium channel"; this is achieved by setting to zero the coefficient γ.

Prediction 2: "local supply (/asset scarcity) and duration channels". *An asset purchase programme that shortens the maturity structure of the supply of default-free bonds held by the private sector:*

- *lowers bond yields only in the targeted maturity segments in case arbitrageurs become extremely risk averse and unwilling to trade bonds, and hence preferred-habitat investors remain the sole market participant ("local supply or asset scarcity channel")*

- *lowers bond yields across all maturities via a compression of premia in case arbitrageurs are active market participants; moreover, with a more pronounced magnitude at long maturities ("duration channel") .*

[9]Incidentally, this simulation is akin to the Maturity Extension Program (MEP) carried out by the FED between 2011 and 2012.

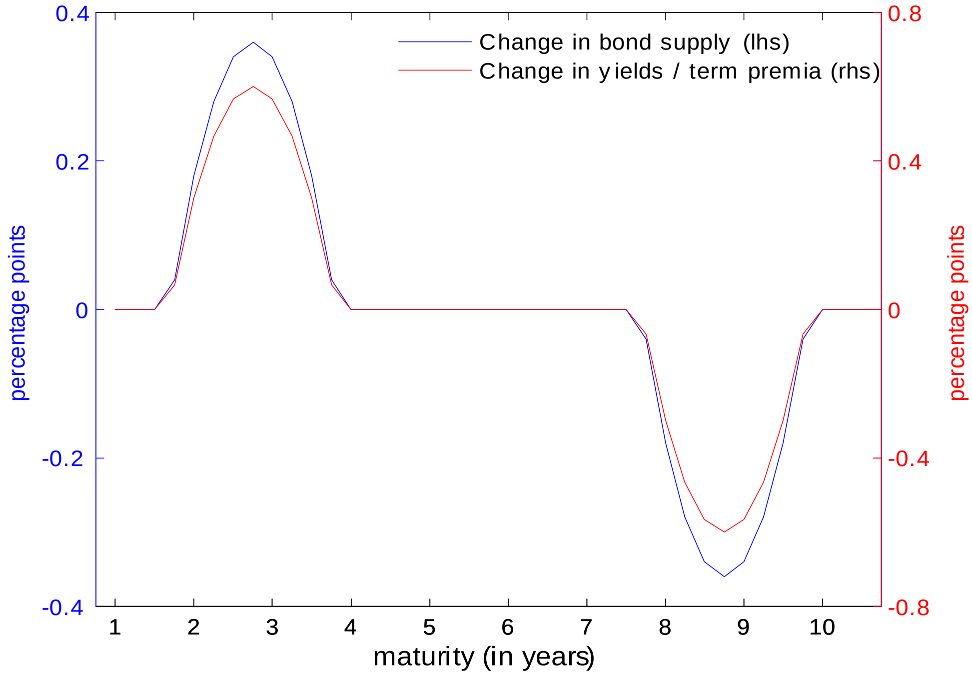
Considering some polar cases for the degree of risk aversion parameter σ conveniently sheds light on the interaction between preferred-habitat investors and arbitrageurs, allowing to identify two distinct transmission channels on default-free bonds, and namely the "local supply (/asset scarcity) channel" and the "duration channels".

Under arbitrary high risk aversion σ, the arbitrageurs' optimisation problem translates de facto into minimising bond portfolios' variance; eventually, arbitrageurs optimally choose to stop trading long bonds, and invest only in the short-term rate. When that's the case, long bond prices are disconnected from the short-term rate as preferred-habitat investors, the sole type of bond market participant, do not integrate maturity segments. Akin to a situation of extreme segmentation, the $n-$period bond yields are pinned down by equilibrium conditions between the demand of preferred-habitat investors (10) and the supply of bonds at that specific maturity. Building from the insights and analysis in Cochrane (2008), Figure 2 depicts a change in the supply $S_t^{(n)}$ that captures the decline in the average maturity of bond supply (blue line). It shows that changes in the supply of bonds affect yields in the targeted maturity segments, with no spill-overs to the non-targeted segments ("local supply channel"). The strength of the impact on targeted segments is larger when the demand by preferred-habitat investors is inelastic; intuitively, with a demand less sensitive to yields, investors are willing to sell their bonds to the central bank only for a larger drop in the expected returns of these securities, and namely for larger decline in yields (increase in prices) today.

On the contrary, under low risk aversion σ, the same path of bond supply leads to an attenuated impact on the targeted segments, and compresses risk premia across all maturities, with a more pronounced magnitude at long maturities ("duration channel") (Figure 3).

Intuitively, this finding captures the type of tension that emerges when considering a decline in risk aversion. From one side, we have that changes in bond supply ceteris paribus have lower impact on premia, up to point of no effects when σ is zero. From the other side, we have larger spill-overs to the non-targeted segments compared to the high risk aversion case, because the higher risk-bearing capacity by arbitrageurs makes them more effective in integrating market segments. To gain further intuition as to why a decline in the average maturity of bond supply leads to a compression in term premia across all maturities, we set

Figure 2: Impact of a shortening in the average maturity of the supply of default-free bonds on the term structure under extreme risk aversion and market segmentation ("*local supply channel*").



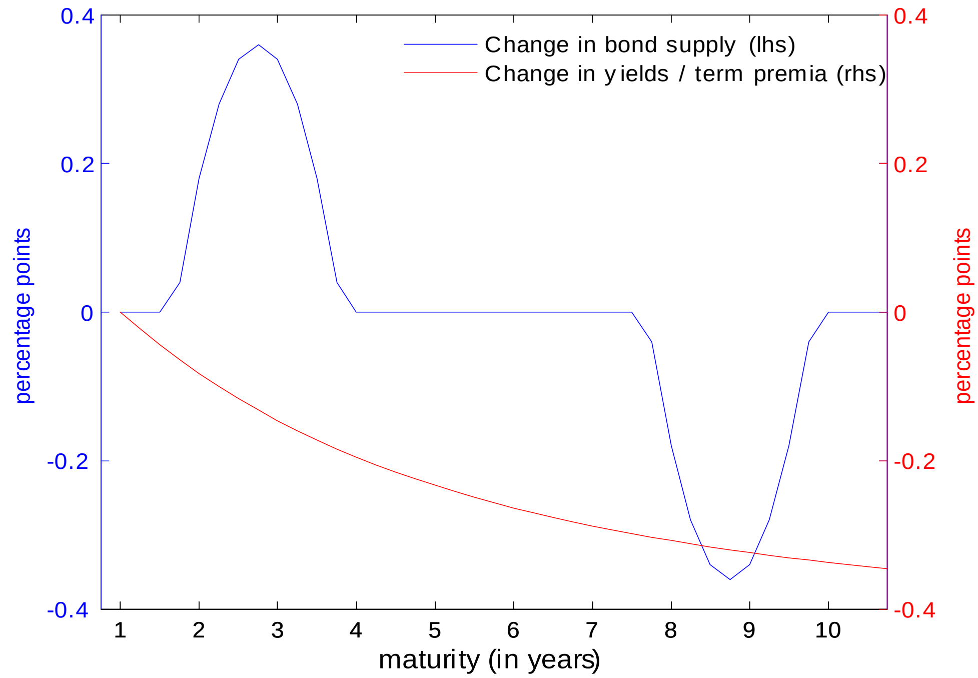
to zero the coefficient for the preferred-habitat demand equation φ, meaning that risk-averse arbitrageurs are de facto the sole market participant. This implies that the market price of risk (12) takes the simplified form

$$\lambda_t \equiv \sigma \sum_{n=2}^{N} S_t^{(n)} b_{n-1} \tag{16}$$

Because the sensitivity of bond prices to the pricing factors b_n raises with the term to maturity, a decline in the maturity structure of bond supply, even at unchanged stock, lowers the market price of risk, as evident in equation (16) by the larger weights attached to long-term bonds relative to short-term bonds. Moreover, the higher sensitivity of bond prices to the pricing factors also implies that, for a given reduction in the market price of risk, term premia decline more at longer maturities - see equation (15).

Overall, the prediction here is that, by absorbing duration risk from the market, shortening the maturity structure of the supply of bonds leads to lower risk premia which are

Figure 3: Impact of a shortening in the average maturity of the supply of default-free bonds on the term structure in a situation of active risk-adverse arbitrageurs ("*duration channel*").



diversified by arbitrageurs across all maturity segments, and are more pronounced at long maturities ("duration channel"), as illustrated in Figure 3.

In what follows, we derive the model's predictions for the "credit premium channel" by activating the credit-risk intensity coefficient γ, while continuing to consider relatively low levels of risk aversion so as to allow arbitrageurs to be active market participants.

Prediction 3: "credit premium channel". *An asset purchase programme has both direct and indirect effects on credit premia.*

- *Directly, an asset purchase programme that shortens the maturity structure of the supply of a given class of defaultable bonds held by the private sector compresses credit premia (vis-à-vis the default-free bonds) across the whole term structure of the targeted class; moreover, with a more pronounced magnitude at long maturities ("quantity of risky asset mechanism")*

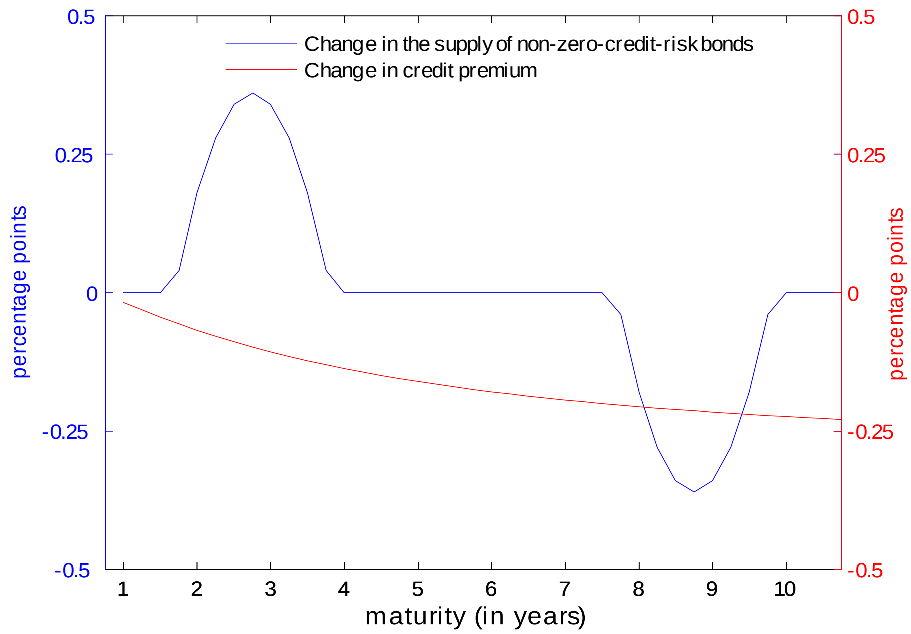
- *Indirectly, asset purchases compress credit premia via two, possibly self-reinforcing mechanisms. First, the impact of purchases on the price of targeted assets spills over* *to the price of other non-targeted assets, as long as arbitrageurs are effective in integrating market segments ("portfolio rebalancing"). Second, general equilibrium effects triggered by the programme compresses credit premia via the (risk-neutral) pricing of default, affecting both targeted and non-targeted assets ("general equilibrium effects").*

We start out by considering the direct effects of asset purchases on the targeted class of defaultable bonds. As captured by equations (12), (14) and (15), the credit-intensity parameter γ interacts with the bond supply along two dimensions: first, via the market price of risk; second, via the sensitivity of long bonds to the pricing factors. Consequently, an asset purchase programme that shortens the maturity structure of the supply of a given rating class of bonds held by the private sector compresses credit risk premia in the targeted class vis-à-vis the default-free bonds across the whole term structure, as depicted in Figure 4; moreover, the magnitude is more pronounced at longer maturities. In essence, this prediction pertains to a situation in which the central bank directly removes assets from investors' portfolios and this compresses credit premia required by arbitrageurs with limited risk-bearing capacity ("quantity of risky assets" mechanism). Notably, this type of mechanism has been found by Kryshnamurti and Vissing-Jorgensen (2013) as the key driver of the impact of FED interventions in the mortgage-backed securities (MBS) market, namely a market which requires active sophisticated investors to mobilise their possibly scarce capital. It is precisely the tightness of the capital constraint for these investors to determine MBS return premium, together with the MBS exposures in investors' portfolios. They argue that, by reducing these exposures, FED purchases had the effect of freeing up capital for investors, and hence compressing premia in the MBS market.

Indirectly, asset purchases compress credit premia via two additional, and possibly self-reinforcing, mechanisms.

First, the impact of purchasing assets held by the private sector spill over to other non-targeted assets as arbitrageurs integrate market segments ("portfolio rebalancing"); as noticed above, their effectiveness in doing so depends on their risk-bearing capacity. For instance, this prediction can be seen in our model specification by augmenting arbitrageurs' portfolio so as to include two types of defaultable bonds, namely targeted and non-targeted bonds. In this case, the optimal asset allocation problem by arbitrageurs implies that the targeted and non-targeted assets are priced equally, irrespective of the relative withdraws of these two types of assets induced by central bank purchases. In other words, conditional on a given maturity and probability to default, targeted and untargeted bonds are simply perfect substitutes from the perspective of arbitrageurs, and their relative supply does not affect their relative pricing.

Figure 4: Impact of a shortening in the average maturity of the supply of non-zero-credit-risk bonds on credit premium.



Second, a compression in credit spreads can arise from broader general equilibrium effects, irrespective as to whether these assets are targeted or non-targeted, and in fact it can result endogenously also in cases where asset purchases do not target defaultable assets ("general equilibrium effects").[10] To gain some intuition on this mechanism, let us consider an expression for the credit risk premium c_p generalising equation (15):

$$c_p = f\left(\psi(X), \Sigma\Sigma', \sigma(X), \omega(S)\right) \tag{17}$$

[10]Albeit building on different set-ups, models à la Gertler and Karadi (2013) provide a formalisation of some of the mechanisms described here. In particular, under certain circumstances, the central bank purchasing assets may free up intermediary capital and thus expand the overall demand for private assets, a mechanism that resembles the "quantity of risky assets". Moreover, by boosting the economy, central bank purchases indirectly lead to a rise in the price of capital, a contraction in the external finance premium for the corporate sector, and thus a narrowing in the corporate bond spreads ("general equilibrium effects").

The latter equations captures the idea that the credit risk on a given security depends on the amount of risk borne by that security (as function of $\Sigma\Sigma'$ and ψ) and the compensation that risk-averse agents require to bear it (function of σ), where we generalise by assuming that the latter may be ultimately affected by macroeconomic conditions, X. Therefore, to the extent to which a purchase programme is effective in lowering expected credit losses (lower probability of default and loss-given-default) and reducing investors' risk-aversion, in anticipation to better macroeconomic conditions credit premia for both targeted and non-targeted assets would decline irrespective as to whether the programme does or does not comprise defaultable assets. Finally, both the "portfolio rebalancing" and the "general equilibrium effects" mechanisms share the prediction of spill-overs towards the credit risk premia of non-targeted defaultable bonds.

3 Empirical Framework

The model-based predictions of Section 2 provide guidance in estimating and interpreting the euro area APP. Mirroring the modelling part, the empirical validation here is structured around the twofold perspective of estimating the "stock effects" of the APP, and disentangling the associated channels of transmission.

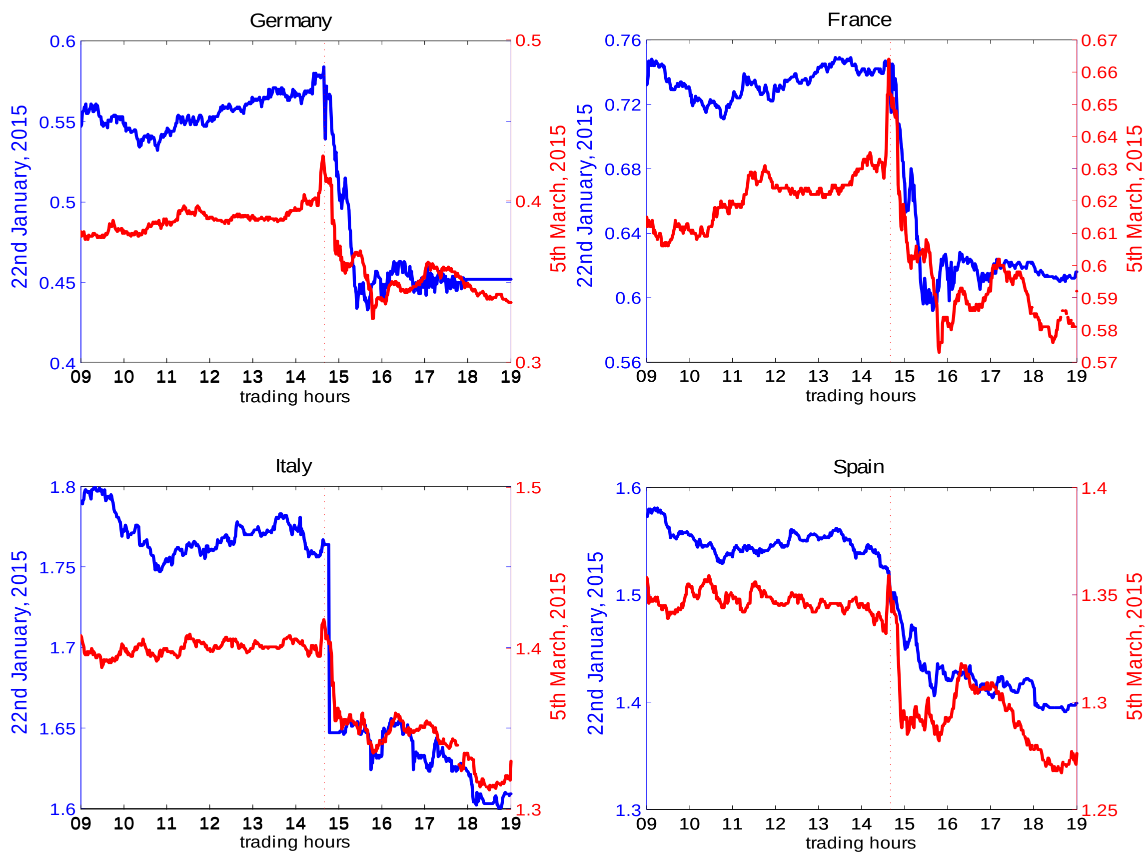
3.1 Estimating the "stock effects" of the APP

This section presents estimates of the "stock effects" of APP on selected asset prices, focusing primarily on public sector targeted securities. It does so by illustrating first the market reactions on the announcements dates of January 22 and March 5, 2015, namely the two dates in which the Governing Council announced, respectively, the launch and the timing of the purchase programme of public securities (PSPP). Indeed, as illustrated above, our model predicts that markets would price in the impact of the January announcement of the programme in anticipation to the actual purchases taking place. By the same reasoning, asset prices would react to APP-related news prior to the January announcement itself, as over the preceding months market participants had revised likelihood and size of the programme. Motivated by these considerations, we then extends the event study by comprising asset prices' reaction around a broader set of event dates, identified on the basis of official communications about, and hinting to, the programme. As a robustness check, to ensure that the identified events capture all the relevant information, we assess the consistency of this narrative approach vis-à-vis a more "agnostic" approach based on news coverage on the euro area purchase programme.

Intraday reaction at the official communication dates on the APP. At the heart of the event-study assessments on large-scale purchase programmes is the market reaction following the announcement dates. Provided that markets are highly liquid, the narrower is the window length around these announcements the sharper tends to be the identification of their effects on asset prices, primarily because the less likely is the arrival of concomitant economic releases. Figure 5 displays high-frequency intraday movements of sovereign yields for the largest euro area economies on the two Governing Council event dates in which the launch and the timing of the PSPP were announced (January 22 and March 5, 2015). Because euro area sovereign bonds are relatively highly liquid, to isolate the effects we identify a narrow communication window of 60 minutes around (20 before and 40 after) the Governing Council press conference, where the latter is indicated in the charts by the vertical dashed lines. It is striking how these vertical lines mark a significant step decline in sovereign yields for both event dates and across main euro area countries. That's particularly evident for the 10-year Italian and Spanish bonds, whose yields have plummeted immediately after the two press conference announcements and have continued to recede further in the course of the day. Interestingly, a specific feature of the ECB policy communication process that wanted the decisions on the key policy rates to be announced at 13:45, namely in advance to the press conference of 14:30, allows us to attribute these market reactions around the press conference to APP-related news, rather than to interest rate decisions.

Event study based on a broader set of official communication announcements. Because prior-to-the-announcement news led financial markets to revise likelihood and size of the purchase programme, and hence to price in the programme accordingly, confining the assessment to the formal announcement date would mean underestimating the overall impact of the programme.

Figure 5: Intraday movements in 10-year sovereign yields of selected euro area sovereign bonds at the two official communication dates on the APP (ECB Press Conference identified with vertical lines).



Source: Thomson Reuters. Note: The solid (blue) line represents movements on 22 January 2015 (LHS axis) and dashed (red) line represents movements on 5 March 2015 (RHS axis).

That's particularly relevant for the euro area, whereby, as the narrative goes, a series of public interventions by ECB officials, together with deteriorating prospects for euro area inflation, led financial markets to believe that the purchase programme was increasingly likely. To see the ground for this, notice that sovereign yields in euro area economies fell for most of the period from end of August 2014 to March 2015, with visible declines around the policy meetings.[11] Sure, these effects are not only due to increasing expectations on a

[11] Specifically, over this period, the 10-year bond yields in Germany, France, Italy and Spain have decreased by as much as 50, 60, 110, 90 basis points, respectively.

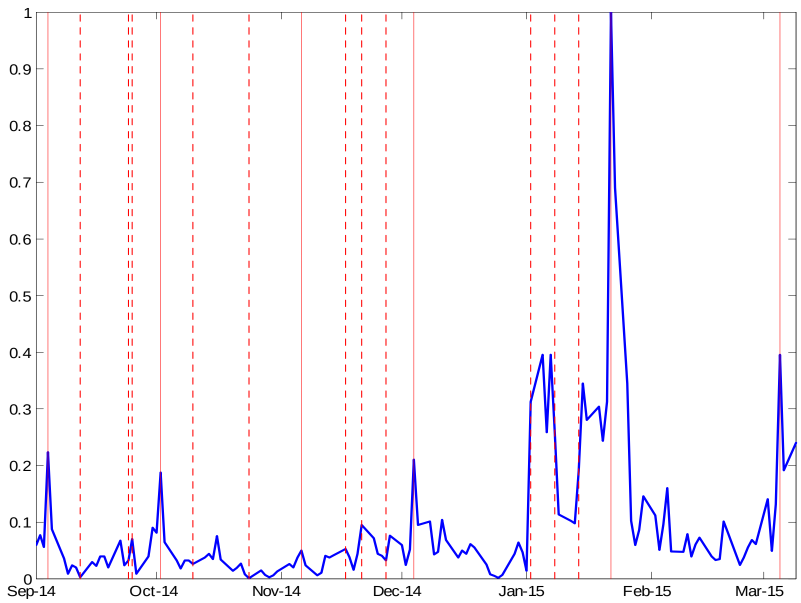
large-scale asset purchase programme. In fact, the ECB had pursued a variety of policy interventions since mid-2014 which might have contributed to the decline in yields, together with negative macroeconomic news. Yet, as we are going to argue, starting from September 2014, policy-related effects on yields can more confidently be ascribed to the anticipation of the programme. This is strongly supported by a series of articles published in international newspapers starting from September 2014 explicitly alluding to a likely QE-type programme by the ECB.[12] To address these issues systematically, we employ an event-study methodology that improves on two dimensions on the standard approach employed in the literature to assess the impact of large-scale asset purchases in the US and the UK. The standard event-study approach, followed for instance by Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011), is based on measuring the change in interest rates at the announcement dates of the programme, implicitly assuming that: (i) the selected set of events includes all news that have affected expectations about the programme, (ii) the window over which the change in yields is measured is sufficiently wide to capture all the effects but not too wide to be distorted by other news that may have affected yields (e.g. macroeconomic surprises). While convenient, these working assumptions are somehow arbitrary and possibly conducive to biased estimates of the effects of the programme. In what follows we describe how we have addressed these concerns.

Selecting the set of events. Starting from September 2014, we identify a broad set of event dates based on ECB's official communication interventions which could have conveyed information on the programme. Specifically, we select a) the ECB Press Conference of the Governing Council meetings, and b) the speeches given by President Draghi where he hinted to the possible implementation of a large-scale asset purchase programme thereby reinforcing the probability of an asset purchase program to happen. Overall, this leads us to consider seventeen event dates, identified between September 2014 and March 2015, and reported

[12] Just to name few examples, on the 20 September 2014 the Financial Times published the article entitled "Weak ECB loans take-up paves the way for QE", where "weak loans take-up" refers to the lower than expected volumes in the second TLTRO. On the 27 November 2014, again the Financial Times published the article entitled "US data disappoint as possibility of European QE comes into focus", and a couple of days later it qualifies the message with the article "Draghi needs support on QE in the eurozone". About one month later, on the 3 January 2015, the Economist published the article "Euro-zone quantitative easing. Coming soon?".

in Table B.1, Appendix B. As a robustness check, we compare this “narrative” approach in dating events with a more “agnostic” approach based on an index of intensity of news coverage on possible purchase programmes in the euro area.[13]

Figure 6: Index of news coverage on the APP.



Note: The blue line is the Index of news computed from Factiva. The vertical (red) solid lines represent the date of the ECB's Governing Council meetings, i.e. September, 04 2014; October, 02 2014; November, 06 2014; December, 04 2014; January, 22 2015; and March, 05 2015. The vertical (red) dashed lines represent the non-Governing Council events.

Indeed, a possible concern about the “narrative” approach is that the event dates might fall short of capturing all relevant information, as market participants, having learnt how ECB's decisions depend on the outlook for inflation, may have revised market expectations about the likelihood of the APP on the back of economic data releases, beyond and above official ECB communication. Taking into account news coverage might appease these concerns by capturing APP-related news that stem either from economic releases or from official communication. With this in mind, we construct an index of news coverage on APP using an extensive range of different news sources from the Dow Jones' news database, Factiva.[14]

[13] This approach based on an index of intensity news coverage is similar to the one followed by Middeldorp (2015) and Middeldorp and Wood (2016) who also find how the ECB asset purchase programme was largely anticipated by financial markets.

[14] Specifically, for each calendar day starting from 1 September 2014, we search for a number of keyword variables connected to the announcement and the implementation of the APP. The query is set so that for

Figure 6 displays the index (blue line), normalised to have a maximum value of one, which is reached at the APP announcement, together with the event dates (vertical red lines) identified on the basis of the "narrative" approach, and distinguishing between Governing Council and non-Governing Council meeting dates.[15] Overall, it is striking how the news index spikes up around the identified event dates and that's particularly the case for the six Governing Council meetings, which represent "local maxima" of the news index. While there are minor mismatches at times between the news index and the identified event dates, there is overall support for our identification of the event dates, which will be used in the rest of the analysis. Similarly to the standard event-study methodology, we consider daily change in yields around these event dates and assume that the overall effect of the programme can be obtained by cumulating the change in yields occurred over each event.[16]

Controlling for macroeconomic releases. Simply attributing to policy announcements the changes in asset prices around the identified event dates clearly fall short to acknowledging the impact of other concomitant news, and prominently the macroeconomic news. To see the ground for this concern, Figure 7 depicts for instance the high-frequency intraday movements of French and German sovereign bonds at 10-year maturity during September 5, 2014, and December 5, 2014, namely the day after the ECB's Governing Council meeting in those months. In essence, that means that a standard event study based on two-day window changes would mechanically attribute the drop on September 5 and the increase on December 5 to policy-related announcements. By contrast, the sharp reduction in yields just around the time of the release of different-than-expected US employment report is suggestive

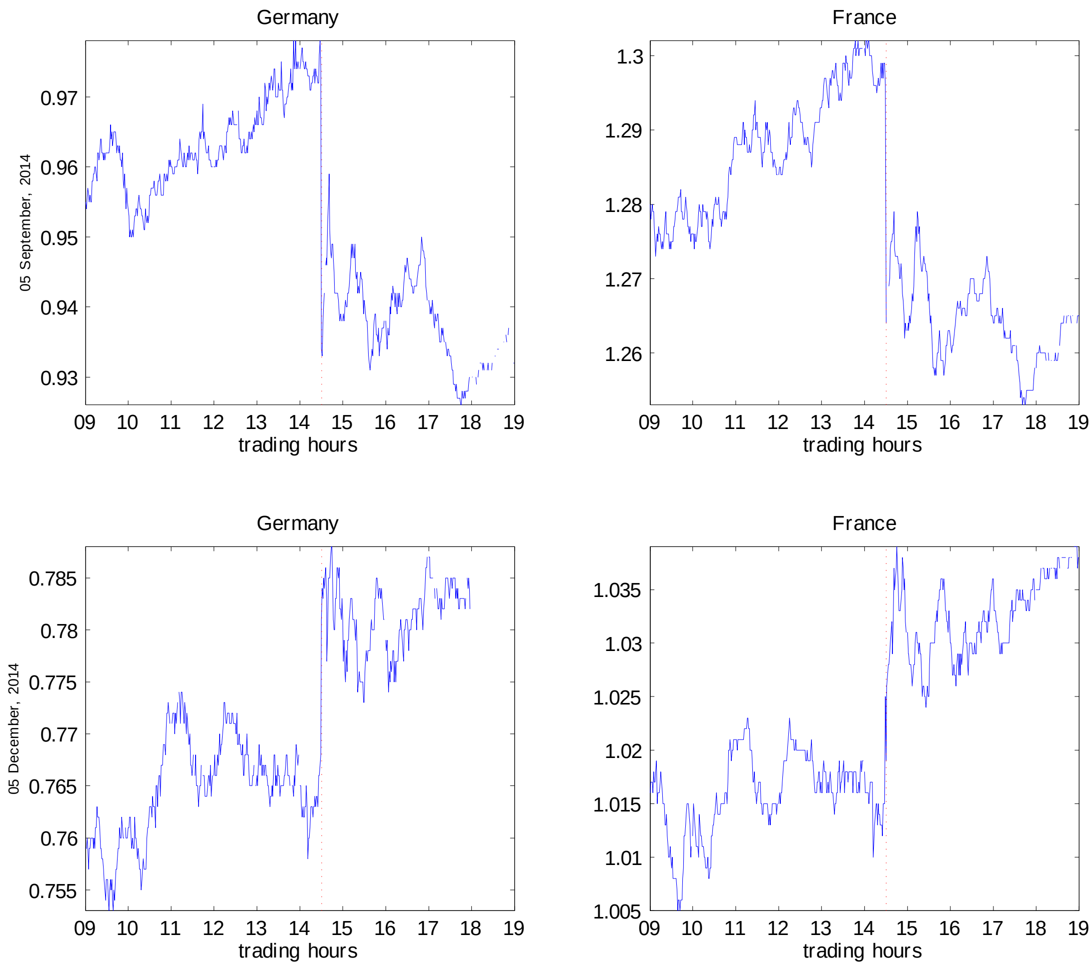
an article to be included in our sample it should simultaneously contains at least one word coming from two different sets. The first set is "ECB", "European Central Bank", and "Draghi". The second set is "QE", "quantitative easing", "asset purchase", and "APP". To avoid possible contamination of the results from the quantitative easing programs of other central banks we exclude the article if it does contain one of the following words: "Federal Reserve", "Bank of Japan", "Bank of England", "BoJ", "BoE", "Fed", "Japan", "US", "U.S.", and "England". We limited the search to English-language news sources. The total volume of news articles connected to our query over the period spanned from September 2014 to March 2015 is about 20,000, mostly coming from "publication" and "web news". Blogs, boards, pictures and multimedia only have a very limited coverage in the selected sample.

[15] The number of news identified at the APP announcement amounts to about 7% of the total news.

[16] In principle, this approach means that the estimated effect we obtain is in all likelihood an underestimation of the 'true' effects of the programme because we do not consider flow effects on yields that may occur when the actual purchases take place.

of non-policy factors at play.[17]

Figure 7: Impact of a surprise in the US employment report on selected 10-year euro area sovereign yields.



Note: The figure displays the impact on the German and French 10-year sovereign yields of the release of the US employment report on the 5^{th} of September and 5^{th} of December 2014, namely the day after the ECB's Governing Council meetings in those months. The vertical gridline denotes the exact time of releases (i.e. 14:30 p.m.).

This is not an exception: all variables contained in the US employment report such as change in non-farm payroll, employment rate and unemployment rate are usually released

[17] The two examples demonstrate how positive and negative news in US might influence the sovereign yields in the euro area. In September 5, for example, the negative news in the change in non-farm payroll (it was expected 230E+3 while the actual was 142E+3) translated into a decrease in the yields in Germany and France. In December 5, instead, positive news in the change in non-farm payroll (expected 230E+3 while the actual was 321E+3) is associated with an increase in the euro area yields.

the first Friday of the month. Because on the first Thursday of the month the ECB Governing Council announces its policy deliberations,[18] a two-day event study on market reaction following those announcements will most likely be contaminated by movements in yields possibly due to US macroeconomic developments.[19]

Regression analysis and results. On the basis of the above considerations, following the approach in Altavilla and Giannone (2014), we have carried out an event-study assessment on the basis of a regression analysis that explicitly controls for macroeconomic releases. Specifically, our estimates are obtained by regressing the daily changes in yields on the event dummies (see Table B.1 in Appendix B) as well as on the surprise component of a wide set of macroeconomic releases:

$$\Delta y_t = \sum_{j=1}^{k} \alpha_j D_{j,t} + \sum_{j=1}^{k} \beta_j D_{j,t-1} + \sum_{s=1}^{m} \gamma_s News_{s,t} + \varepsilon_t \tag{18}$$

where Δy_t is the daily change in yields of a given asset; $D_{j,t}$ is dummy variable that takes value one at time of the policy event j and zero otherwise, k is the total number of events; $News$ is the surprise component of macro releases. Specifically, we consider macroeconomic news for the euro area, its largest economies and the US, collected from Bloomberg over the sample period ranging from the beginning of January 2014 to the end of March 2015 (see Table B.2 in Appendix B). Statistical significance is assessed by using heteroskedasticity robust standard errors. The event dummy coefficients are jointly tested with an F-test under the zero-null hypothesis.

Table 1 reports the estimated effects of the APP for the sovereign yields of the four largest member countries, as well as for the synthetic euro area sovereign term structure, at selected contract maturities of 5, 10 and 20 years.[20]

[18] Note that since January 2015 the frequency of ECB Governing Council meetings has changed from monthly to every six weeks.

[19] Controlling for macroeconomic releases becomes even more relevant when using wider windows, on account of possibly slow yield reactions due to the novelty of, and the diversity of beliefs about, the purchase programme's mechanisms.

[20] The synthetic sovereign yield curve for the euro area is the yield curve estimated by the ECB using all euro area central government bonds and released on a daily basis. The daily releases, including charts and tables, are available at http://www.ecb.europa.eu/stats/money/yc/html/index.en.html. For further details, see the article "The New Euro Area Yield Curves" in the February 2008 issue of the ECB's Monthly Bulletin.

Table 1: Changes in sovereign bond yields of selected euro area economies around the APP event dates (*basis points*)

	5-year maturity					10-year maturity					20-year maturity				
	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain	Euro Area	Germany	France	Italy	Spain
Controlled event study															
1-day change	-30*	2	-21	-60***	-67***	-29*	-17	-30*	-75***	-80***	-22	-13	-28*	-72***	-78***
2-day change	-33**	2	-21*	-27***	-44***	-47*	-18*	-27*	-60***	-65***	-54**	-30*	-38**	-71***	-79***
Standard event study															
1-day change	-27*	1	-21	-63***	-65***	-24*	-16*	-30*	-79***	-78***	-17**	-14*	-29*	-70***	-68***
2-day change	-36**	-3	-26*	-42***	-49***	-48*	-23*	-36**	-72***	-69***	-56***	-37*	-50**	-78***	-77***

Source: ECB and Thomson Reuters.

Notes: Based on the 17 event dates reported in Table B.1, Appendix B. Asterisks denote statistical significance at the *** 1 percent level, ** 5 percent level, * 10 percent level.

To place these estimates in perspective, we also report the effects based on a standard event-study methodology derived by considering the changes in yields around the event dates without controlling for macroeconomic news. All results are shown in terms of both one- and two-day window changes.[21] Overall, the estimates suggest that APP has substantially lowered sovereign bond yields, with a magnitude that rises with the maturity of the bonds and is more pronounced for high-yield countries. For the 10-year maturity, the decline in the synthetic euro area sovereign yields amounts to about 30-50 basis points depending on the window's size considered. As for the countries, the one-day drop in yields for Germany, France, Italy and Spain amount to 17, 30, 75, 80 basis points, respectively. When considering two-day changes, our findings are broadly unchanged for Germany and France, while somewhat lower for Italy and Spain. Compared to the 5-year maturity bucket, the declines in 10-year maturity bucket are more pronounced, and are broadly in line with those in the 20-year maturity bucket when looking at one-day changes; however the declines in the 20-year maturity yields tend to be more persistent as evident from the two-day window changes. Consistent with intuition, controlling for macroeconomic release can be particularly relevant when considering the 2-day window changes; just how relevant is illustrated by comparing our estimates with those from a standard event-study approach, also reported in the table: for Italian 10-year bonds, the difference between the two approaches is above 10 basis points.[22]

3.2 Estimating the transmission channels of the APP

In the literature, the direct effects of purchases on asset prices are typically recast under the general umbrella of a risk premium channel. And while somewhat differing, the various taxonomies generally include under this risk-premium umbrella the channels identified in Section 2, and namely a local supply (scarcity) channel, a duration channel, and a credit risk channel. In term of indirect effects of asset purchases, the literature typically identifies a

[21] A one-day window change is measured as the change in yields from the closing level the day prior to the event to the closing level the day of the event; a two-day window changes is measured as the change in yields from the closing level the day prior to the event to the closing level the day after the event.

[22] Note that Georgiadis and Gräb (2015) also evaluate the impact of the APP on financial markets relying on an event study. The empirical strategy used in their paper, however, is different from ours. The major difference is that they only rely on the single announcement of the 22nd of January. As also acknowledged by the authors, this choice leads to underestimation of the overall effect of the APP. As indirectly suggested by Figure 6, expectations about a large scale asset purchase by the ECB started building up in early September 2014. This explains the smaller impact of the APP on financial markets that they find.

signaling channel. Specifically, the signalling channel refers to the fact that asset purchases may provide a signal on the path of risk-free short-term rates to be expected going forward, even if per se the purchases would not have direct effects on asset prices; in this sense, the signaling channel is compatible with frictionless financial market assumptions.

3.2.1 Signaling Channel

As in most of the literature, the signaling channel is not explicitly formalised in Section 2. Nevertheless, our model equation (15) captures the predictions associated to this channel, which works via the expectation component, and namely via expected future risk-free rates, and it does not directly affect risk premia. Specifically, the predictions can be broadly summarised as follows. APP lowers future expected short-term risk-free rates, thereby affecting symmetrically all yields. Moreover, it has to be expected that the signaling channel has a stronger downward impact on short and intermediate maturity than on long-maturity rates, as the central bank's willingness to commit to low rates in the distant future is probably more limited.[23] To validate these predictions, as a proxy for expected risk free rates, we rely on the overnight index swap (OIS) rates for the euro area.[24] Indeed, being based on contracts that involve the exchange of a predefined fixed interest rate (the OIS rate) with one linked to a compounded overnight interbank interest rate, OIS rates should incorporate minimal credit risk.

Table 2 displays the one- and two-day window changes in the OIS forward rates at short and medium maturities, namely maturities at which most transaction activity in the euro area OIS swap market takes place. Drawing on the prediction that the signaling channel would most prominently manifest itself at intermediate maturities, the signaling effect is estimated to contribute at most 10 basis points at two-year horizon.[25] The focus on those short- medium-term maturities largely appeases the concerns that OIS rates might embody a term premium component, given that at such maturities the compensation for term risk

[23] It is conceivable that long-term nominal interest rates should actually increase at the announcement of a purchase programme, as the positive impact of purchases on financial conditions (and with a lag on the economy) generated by the signaling channel should lead to an upward revision of inflation expectations and economic growth prospects, with the latter putting upward pressure on future real interest rates.

[24] The EONIA is the overnight interbank interest rate in the euro area.

[25] This estimated effect also accounts for most of the actual changes in OIS rates at those maturities observed over the relevant sample period.

Table 2: Changes in OIS forward rates around the APP event dates (*basis points*)

	3-month OIS forward rates, term to maturity			
	1y	2y	3y	4y
Controlled event study				
1-day change	-9	-3	2	2
2-day change	-1	-11	-5	1
Standard event study				
1-day change	-11	-4	1	0
2-day change	-3	-12	-9	-4

Source: Bloomberg.

is likely to be rather contained. Overall, as it is unlikely that the signaling effect becomes stronger at higher maturities,[26] we conclude that the signaling channel explains only part of the decline in long-term yields of the type documented in the previous section. This means that additional channels have been at play.

3.2.2 Risk Premium Channel

In what follows, to separate out the different transmission channels underpinning the risk premium channel of the APP, we exploit the predictions for cross-asset reactions derived in Section 2.[27]

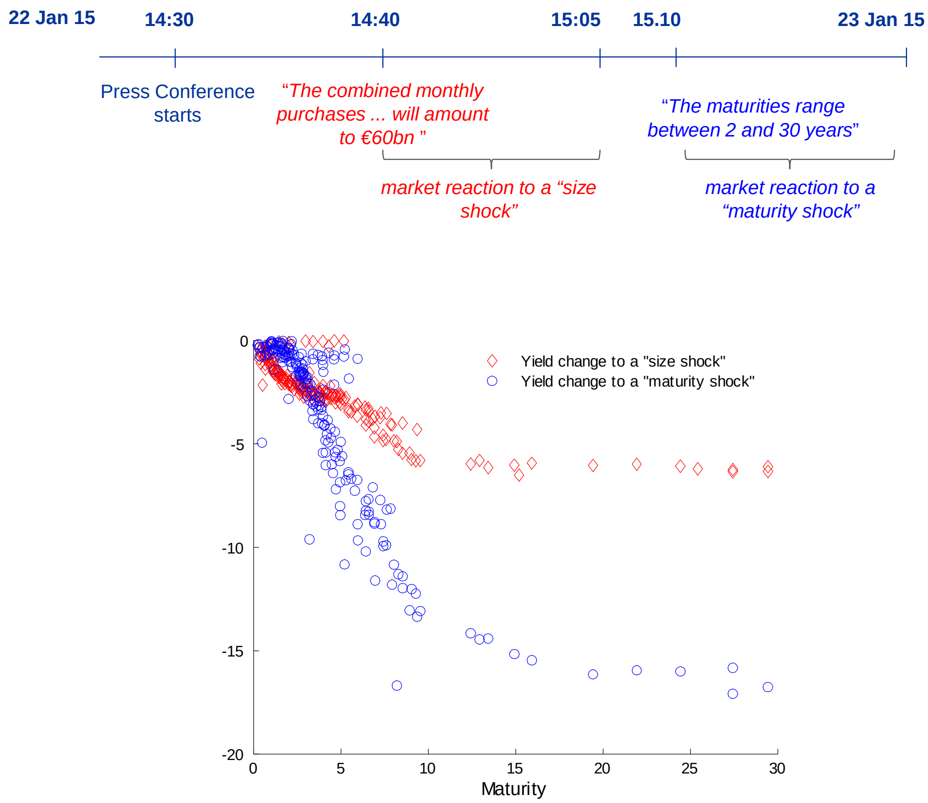
Local supply (asset scarcity) and duration channels. To recall from Section 2, in the presence of clienteles for certain bonds and/or specific maturities, the model prediction is that a decline in the supply of these preferred assets ("preferred habitat" theory) bids up their price and reduces their yields. In practice, this scarcity channel can manifest itself in different versions, depending on the types of assets investors have special preference for. A specific version occurs when investors have special preferences for liquid safe assets, as documented for instance in Krishnamurthy and Vissing-Jorgensen (2013) for the US Treasuries. Hence, asset purchases by the central bank compress the yields of these safe-haven assets, relative

[26] See for instance Bauer and Rudebusch (2014) for the US.

[27] Krishnamurthy and Vissing-Jorgenson (2011) advocate the use of cross-asset price movements to assess purchase programmes.

to the risk-free policy rates, by inducing a scarcity effect on the asset supply in the hands of private investors.[28]

Figure 8: High frequency reaction of Bund yields around the announcements of (i) the size of the APP and (ii) the maturities' range of the purchases during the 22 January Press Conference.



Note: Each diamond/circle represents the change in an individual bond at the ISIN level.

Similarly, we start out with a narrow definition of local supply channel by restricting the focus on the liquid and safe assets represented in the euro area by the Bunds.[29] In isolation, this scarcity channel would predict a limited impact on Bund yields for maturities above the ten years prior to January 22 announcement, as markets expected no purchases above the 10-year maturity.[30] Instead, Bund yields at 20-year maturities have declined pretty much in line with the 10-year yields also before the January 22 announcement, something at odd with the prediction of the local supply channel. Similarly inconsistent with the prediction

[28] Moreover, this safety premium channel is expected to spill over only to other assets that are similarly safe and liquid.

[29] Indeed every time there are fiscal concerns in the euro area there is a flight to safety into Bunds.

[30] For instance, on the basis of a survey conducted in December 2014, the maturity buckets of the APP expected by market participants were the following: 2-10 years for J.P. Morgan; 5-10 years for Goldman Sachs, 3-10 years for Nomura.

from the local supply channel is the market response to the January 22 announcement. To see this point, Figure 8 depicts the high-frequency response of Bund yields to two distinct announcements during the January 22 Press Conference: (i) the announcement on the total stock of the programme (red diamonds), communicated at 14.40; (ii) the announcement on the maturity's range for the bond purchases (blue circles), communicated at 15.10. First, the local supply channel predicts no response to the stock surprise for maturity buckets above ten years (black vertical line), as market continued to expect no purchases in those segments; instead, what we observe is that yields above the ten-year maturity did react pretty much in line to those at the 10-year maturity. Second, the announcement about the purchases' maturities ranging between 2 and 30 years, by constituting a maturity distribution surprise, would lead to an increase in yields below the 10-year maturity and a decline for longer maturities, according to the local supply channel; in fact, what we observe is a fall in yields across the whole term structure, with effects that raise with the term to maturity. Crucially, these market reactions are precisely the types of predictions implied by the duration channel, as documented in Section 2. Table 3 provides further support to the duration channel by displaying how the finding of Bund yields declining by more at longer maturities continue to hold when considering all events, alternative window length and it is robust across the two event-study methodologies.

Table 3: Changes in Bund yields around the APP event dates (*basis points*)

	term to maturity				
	1y	3y	5y	10y	20y
Controlled event study					
1-day change	-8	-5	2	-17	-13
2-day change	-10	-3	2	-18	-30
Standard event study					
1-day change	-8	-6	1	-16	-14
2-day change	-13	-5	3	-23	-37

Source: Thomson Reuters.

Admittedly, the theory is not explicit as to whether the duration channel applies to a specific asset class or to the whole financial market segment broadly defined as fixed-income securities. When considering a broader interpretation of the duration channel, the associated prediction is that APP lowers yields by similar magnitude across all long-term duration bonds.[31] The extent to which this is the case is illustrated in Table 4 which depicts, alongside the Bund yields, the CDS-adjusted sovereign bond yields of selected euro area economies at 10-year maturities.[32] The adjustment in sovereign yields using CDS is meant to remove the credit risk components, thus making the assets comparable when validating the duration risk effects. Overall, these results provide support for a broadly defined duration risk channel with effects spanning across various securities. Once accounting for almost 10 basis points of signaling effects, the broad duration risk effects are estimated at about 10 basis points for the 10-year maturity bucket.

Table 4: Changes in sovereign (CDS-adjusted) yields around the APP event dates (*basis points*)

	10-year maturity			
	Germany	France (CDS adjusted)	Italy (CDS adjusted)	Spain (CDS adjusted)
Controlled event study				
1-day change	-17	-25	-33	-44
2-day change	-18	-17	19	-8
Standard event study				
1-day change	-16	-23	-33	-43
2-day change	-23	-20	9	-12

Source: Bloomberg, Thomson Reuters.

As a caveat, notice however that the broad duration channel here is validated in relation to the sovereign market segments only. And it should be also acknowledged that there might be some kind of specialness in all targeted sovereign bonds: by buying those assets, the central bank creates a shortage of assets in specific demand by investors, such as for instance banks and institutional investors who may have also some home bias and therefore

[31] For instance, in their assessment on the financial market effects of the FED's asset purchase programmes, Gagnon et al. (2011) propose a broad interpretation of the duration risk channel which applied to all fixed-income market.

[32] We cannot extend the analysis to the 20-year maturity due to the lack of data availability on CDS rates for that maturity.

do not easily switch to similar assets issued by other jurisdictions. Our finding would then be also consistent with a more general notion of scarcity channel than the one highlighted by Krishnamurthy and Vissing-Jorgensen (2013) for the US Treasuries, a notion that would apply not only to the safe asset represented in the euro area by the Bund, but to all sovereign bonds. Finally, even if adjusted for their CDS, sovereign bond yields in France, Italy and Spain tend to decline more strongly than the Bund, suggesting that additional channels might be at play.

Credit premium channel. To assess the credit channel, as empirical proxy for targeted bonds embedding a credit premium we consider here the sovereign bond of France, Italy and Spain,[33] whereas we treat German bonds as default-free assets. Regarding non-targeted bonds, we focus on euro area corporate bonds for financial and non-financial corporations.[34]

Table 5 reports the estimated changes in the sovereign spreads for France, Italy and Spain for selected maturities around APP event dates, alongside the impact on the implied euro area sovereign spreads. Overall, the estimates suggest a sizeable impact of the programme. For instance, one-day changes in 10-year sovereign bond spreads range from -13 basis points in France to -58 basis points in Italy. In general, results are robust to considering alternative approaches and window lengths around the announcement dates, with some exception for the 5-year maturity.[35] Alongside the impact on sovereign spreads, Table 5 also reports the change in the spreads for BBB-rated bonds issued by euro area financial and non-financial corporations.[36] One-day changes in corporate spreads amount to around 20 basis points for both financial and non-financial corporations. When considering two-day changes, so as to account for possible delayed reactions of corporate bonds compared with the more

[33] Notice that the sovereign bonds of these three economies have different risks, with France persistently enjoying a better rating than Italy and Spain.

[34] When announced in January 2015, the APP did not include corporate sector bonds. In March 2016, the Governing Council of the ECB decided to "include investment-grade euro-denominated bonds issued by non-bank corporations established in the euro area in the list of assets that are eligible for regular purchases under a new corporate sector purchase programme". As noticed above, policy decisions taken after the start of the APP in March 2015 are not considered here.

[35] As a further robustness check, to isolate the insurance premium against default risk we also consider the impact of APP on credit default swap rates for sovereign bonds of France, Italy and Spain. The same conclusion holds, in that APP has significant credit risk effects, with a magnitude that increases with the riskiness of the underlying assets. Specifically, the one-day changes in 5-year sovereign CDS rates are estimated at -15, -51, -44 basis points for France, Italy and Spain, respectively.

[36] The spreads are vis-à-vis the swap rate of corresponding maturity.

liquid sovereign bonds, the effects tend to be substantially larger for financial corporations, reaching about 30 basis points. The narrowing in the spreads for euro area financial and non-financial corporations bonds is overall more contained than for sovereign bonds, at least for high-yield sovereign securities. Specifically, comparing the corporate bonds with the sovereign bonds of comparable 5-year maturity, we find that the one-day declines in BBB-rated euro area corporate bond spreads are in line with those of the higher-rated French sovereign bonds, and more contained than in the euro area sovereign bond spreads. In isolation however those numbers do not allow to draw a conclusion of the APP-related spill-overs from sovereign to corporate spreads, in that this incomplete pass-through can be simply an historical regularity. To derive an historical benchmark, we employ the following regression specification that expresses bond spreads for euro area financial and non-financial entities as function of sovereign bond spreads, as well as of additional control variables, over the sample period from January 1999 to December 2014.

$$CS_{ijt} = \alpha_i + \gamma_t + \beta SS_{jt} + \delta X_{ijt-1} + \lambda Z_{jt} + \varepsilon_{ijt}$$

Specifically, the dependent variable CS_{ijt} denote the time$-t$ corporate spreads for financial and non-financial entities i, operating in country j, where j denotes one among the five largest euro area countries considered in the analysis (i.e. Germany, France, Italy, Spain, and The Netherlands).[37] SS_{jt} is the time$-t$ sovereign spreads of country j, while α_i and γ_t are firm and time (month) fixed effects, respectively. X_{ijt-1} denotes firm specific controls that may affect corporate bond spreads, and namely bond-specific maturity and rating.[38] Finally, Z_{jt} comprises additional controls at country and euro area level such as the expected default frequency (EDF)[39] and the bond market volatility, respectively. The coefficient β captures the spillover from sovereign to corporate bond spreads. Table 6 displays the regression results for financial and non-financial corporations, considering the whole sample of companies (columns (1) and (3)), as well as the subsample of triple-B-rated companies (columns (2) and (4)), where the latter case is comparable to the one displaued for the APP.

[37]Overall, we consider 1604 non-financial companies, and 2028 financial companies.

[38]The rating is a variable that goes from 1 to 10 and assigns the lowest value to the higher credit rating (i.e. it assumes value 1 for AAA bonds and 10 for BBB-).

[39]Expected default frequency are from Moody's.

Table 5: Changes in the spreads of sovereign and corporate bonds around the APP event dates (*basis points*)

	Sovereign bonds								Corporate bonds	
	5-year maturity				10-year maturity				Intermediate maturity	
	Euro Area	France	Italy	Spain	Euro Area	France	Italy	Spain	BBB financial	BBB non-financial
Controlled event study										
1-day change	-32	-17	-62	-40	-12	-13	-58	-56	-20	-16
2-day change	-35	-17	-29	-44	-30	-9	-42	-53	-27	-22
Standard event study										
1-day change	-28	-22	-64	-36	-7	-13	-63	-54	-19	-9
2-day change	-34	-23	-40	-48	-26	-13	-50	-56	-28	-15

Source: Bloomberg, Markit, Thomson Reuters.

Note: The sovereign bond spreads are vis-à-vis the German Bunds of corresponding maturity.
The corporate bond spreads are vis-à-vis the mid-swap rate of corresponding maturity.

The estimate for β suggests that a decrease in sovereign bond spreads by 100 basis points is associated, on average, with a statistically significant decrease in triple-B-rated corporate spreads by 42 and 55 basis points for financial and non-financial corporations, respectively.[40]

Table 6: Historical spill-overs sovereign spreads to corporate spreads

	Financial		Non-financial	
	(1)	(2)	(3)	(4)
Sov. Spread	0.66***	0.42***	0.50***	0.55***
	(0.04)	(0.07)	(0.02)	(0.03)
Corp. Rating	0.13***	0.22***	0.12***	0.16***
	(0.02)	(0.06)	(0.01)	(0.04)
Corp. Maturity	-0.11***	0.04	-0.15***	-0.23***
	(0.01)	(0.03)	(0.01)	(0.03)
Bond Vol	0.33***	0.81***	0.29***	0.40***
	(0.01)	(0.3)	(0.01)	(0.03)
EDF	0.21***	-0.24	0.40***	0.33***
	(0.02)	(0.25)	(0.03)	(0.06)
Controls	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
S&P Rating	AAA to BBB-	BBB+ to BBB-	AAA to BBB-	BBB+ to BBB-
R^2	0.56	0.53	0.22	0.20
Firms	1942	316	1604	884
Observation	73843	5866	67763	29759

Note: Standard errors in parentheses are clustered at the firm level.
Sample: 1999m8-2014m12. * p<0.1, ** p<0.05, *** p<0.01

The estimates underpinning the APP event study imply a larger spillover intensity for financial corporations and a broadly similar one for non-financial corporations compared to the historical regularities; specifically, a 100 basis points decline in sovereign spreads would be associated to a decline in the triple-B-rated corporate spreads by 63 and 50 basis points for financial and non-financial corporations, respectively. Therefore, the overall conclusion for the APP's credit channel is that credit premia have declined substantially for the targeted

[40] Recently, Bedendo and Colla (2015) find a lower lower pass-through for non-financial corporation then the one we estimate; indeed, when investigating how the sovereign creditworthiness affects the credit risk of the non-financial corporate sector in the euro area, they find that a 100 basis points increase in sovereign spreads translates into 15-23 basis points increase in corporate spreads, on the basis of credit default swap data, considering eight countries and 118 non-financial companies.

assets, with a sizeable spill-over intensity to non-targeted assets when viewed through the lens of historical regularities.

4 Effects of the APP on other asset classes

A further implication of the decline in yields documented above being APP-driven is that the resulting easing pressures should be evident also on other assets such as the exchange rate, the stock market and inflation expectations.

Table 7: Changes in the exchange rate Euro-USD, euro stock market, and inflation swap rates around the APP event dates (*percent and basis points*)

	Euro-USD exchange rate (in %)	Dow Jones Euro Stoxx (in %)	Inflation swap rates (in basis points)			
			1-year	2-year	5-year	10-year
Controlled event study						
1-day change	-5	2	14	8	15	6
2-day change	-12	1	33	25	24	4
Standard event study						
1-day change	-5	3	9	7	15	6
2-day change	-12	5	5	7	14	-3

Source: ECB, Thomson Reuters.

As reported in Table 7, we find that the euro has depreciated by 5% vis-à-vis the US dollar on the basis of one-day changes, and by 12% when considering two-day changes. Moreover, the euro stock market index was up at the announcement dates. Finally, we consider the impact on inflation swap rates. For purchase programmes providing a stimulus to the real economy, the response of inflation expectations is crucial whereby, for instance, a decline in inflation expectations matching the one in nominal yields would leave the real interest rates unchanged. More generally, the response of inflation expectations is a metric for gauging the credibility of these purchase programmes vis-à-vis financial markets in addressing deflation risks. As a measure of private sector's inflation expectation, we consider inflation swap rates for maturities between one and ten years. Inflation expectations rates have increased across all maturities, considering both the one-day and the two-day changes; the effects are more pronounced at short- medium term maturities. Specifically, the one-day change in inflation swap rates is around 15 basis points for the 1-year and the 5-year maturity, and around 6 basis points of the 10-year maturity.

5 Conclusions

Existing literature suggests that large-scale asset purchase programmes tend to be more effective on asset prices in periods of high financial distress. We find that, despite announced at a time of low financial distress, the ECB asset purchase programme has significantly lowered yields in a broad set of market segments, with effects that generally rise with maturity and riskiness of assets, and with significant spill-overs to non-targeted assets. We rationalise this apparent puzzle by showing how low financial distress, while indeed weakening market segmentation channels, has reinforced "broad channels" because of its interplay with the asset composition of the APP. Specifically, targeting assets at long maturity and spanning the investment-grade space has supported the "duration" and "credit" channels, respectively. At the same time, the low financial distress prevailing at APP announcement, while weakening the "local supply channel", has facilitated spill-overs to non-targeted assets. Therefore, our findings support the view that the effectiveness of asset purchases is not limited to times of financial market distress, albeit the strength of the transmission channels might differ across risk and liquidity regimes. In particular, the relatively strength of "narrow" versus "broad" transmission channels rests on the efficacy of marginal investors to integrate across market segments, primarily related to their risk-bearing capacity. While in our model this capacity is simply parameterised by the risk aversion coefficient, an interesting question for future research is the formalisation of a more refined portfolio allocation problem in relation to arbitrageurs' attitude towards risk, and specifically allowing the possibility of an endogenous response of risk aversion to changes in underlying economic conditions. A related extension would be to frame this decision problem into a general equilibrium framework that would account for the feedback loops between the macroeconomy and asset prices.

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A A term structure model of bond supply effects with a credit premium channel

Let $R^P_{(t,t+1)}$ denote the one-period holding return of arbitrageurs' porfolio

$$R^P_{(t,t+1)} \equiv \sum_{n=1}^{N} \omega_t^{(n)} R_{t,t+1}^{(n)} = \sum_{n=1}^{N} \omega_t^{(n)} \left[\frac{\overline{P}_{t+1}^{(n-1)}}{\overline{P}_t^{(n)}} - 1 \right]$$

where $\omega_t^{(n)}$ is the fraction of arbitrageurs' wealth hold in bonds with matuirty n. The zero-coupon bonds are subject to credit risk meaning that

$$\overline{P}_{t+1}^{(0)} = \begin{cases} 1 & \textit{with probability } exp(-\psi_{t+1}) \\ 0 & \textit{with probability } 1 - exp(-\psi_{t+1}) \end{cases}$$

where the time-t credit-risk intensity ψ_t is assumed to be affine in a set of macroeconomic factors

$$\psi_{t+1} = \gamma' X_{t+1}$$

In turn, the macroeconomic factors follow the VAR process

$$X_t = \mu + \Phi X_{t-1} + v_t \qquad\qquad v_t \sim N(0, \Sigma\Sigma').$$

We conjecture that (log) prices $p_t^{(n)}$ of long bonds are affine to these macroeconomic factors

$$\ln(\overline{P}_t^{(n)}) \equiv \overline{p}_t^{(n)} = -\overline{a}_n - \overline{b}_n' X_t \tag{B.1}$$

so that

$$R^P_{(t,t+1)} \equiv \sum_{n=1}^{N} \omega_t^{(n)} [\exp(p_{t+1}^{(n-1)} - p_t^{(n)}) - 1] = \sum_{n=1}^{N} \omega_t^{(n)} [\exp(-\overline{a}_{n-1} - \overline{b}_{n-1}' X_{t+1} + \overline{a}_n + \overline{b}_n' X_t) - 1].$$

The arbitarbeurs' optimasation problem is about choosing $\omega_t^{(n)}$ to maxime their objective function defined over the mean and the variance of their portfolio:

$$\max_{\omega_t^{(n)}} E_t[R^P_{(t,t+1)}] - \frac{1}{2}\sigma Var_t[R^P_{(t,t+1)}] \tag{B.2}$$

$$s.t. \quad : \quad \sum_{n=1}^{N} \omega_t^{(n)} = 1 \tag{B.3}$$

where

$$E_t[R^P_{(t,t+1)}] \approx \sum_{n=1}^{N} \omega_t^{(n)}[(-\bar{a}_{n-1} - (\bar{b}'_{n-1} + \gamma')(\mu + \Phi X_t) + \frac{1}{2}(\bar{b}'_{n-1} + \gamma')\Sigma\Sigma'(\bar{b}_{n-1} + \gamma) + \bar{a}_n + \bar{b}'_n X_t])$$

$$Var_t[R^P_{(t,t+1)}] \approx \left[\sum_{n=1}^{N}(\omega_t^{(n)}(\bar{b}'_{n-1} + \gamma')\Sigma\Sigma'\sum_{n=1}^{N}(\omega_t^{(n)}(\bar{b}_{n-1} + \gamma))\right]$$

where the derivation of the latter equations follows Hamilton and Wu (2012). The FOCs of the Lagrangian (L_t) corresponding to the maximisation problem presented in equations (B.2)-(B.3) are given by

$$\frac{\partial L_t}{\partial \omega_t^{(n)}} \quad : \quad (-\bar{a}_{n-1} - (\bar{b}'_{n-1} + \gamma')(\mu + \Phi X_t) + \frac{1}{2}(\bar{b}'_{n-1} + \gamma')\Sigma\Sigma'(\bar{b}_{n-1} + \gamma) + \bar{a}_n + \bar{b}'_n X_t$$

$$-(\bar{b}'_{n-1} + \gamma')\Sigma\Sigma'\sigma\sum_{n=1}^{N}(\omega_t^{(n)}(\bar{b}_{n-1} + \gamma)) - \varkappa_t = 0$$

$$\frac{\partial L_t}{\partial \omega_t^{(1)}} \quad : \quad -\gamma'(\mu + \Phi X_t) + \frac{1}{2}\gamma'\Sigma\Sigma'\gamma + (\bar{a}_1 + \bar{b}'_1 X_t) - \gamma'\Sigma\Sigma'\sigma\sum_{n=1}^{N}(\omega_t^{(n)}(\bar{b}_{n-1} + \gamma)) - \varkappa_t = 0$$

where

$$\lambda_t \equiv \sigma\sum_{n=1}^{N}(\omega_t^{(n)}(\bar{b}_{n-1} + \gamma))$$

and $\varkappa_t$ is the Lagrange multiplier associated to the constraint.

The FOCs can then be expressed in the form of excess holding period returns

$$R^{(n)}_{(t,t+1)} - \bar{r}_t = \bar{b}'_{n-1}\Sigma\Sigma'\lambda_t \tag{B.4}$$

where

$$R_{(t,t+1)}^{(n)} \equiv -\overline{a}_{n-1} - \overline{b}_{n-1}'(\mu + \Phi X_t) + \frac{1}{2}(\overline{b}_{n-1}' + \gamma')\Sigma\Sigma'(\overline{b}_{n-1} + \gamma) - \frac{1}{2}\gamma'\Sigma\Sigma'\gamma + \overline{a}_n + \overline{b}_n' X_t \quad \text{(B.5)}$$

and

$$\overline{r}_t = \overline{a}_1 + \overline{b}_1' X_t$$

The preferred-habitat investors have demand over specific maturities which can be written as

$$\xi_t^{(n)} = \varphi(y_t^{(n)} - \overline{\beta}^{(n)}) = \frac{\varphi}{n}\overline{a}_n + \frac{\varphi}{n}\overline{b}_n' X_t - \varphi\overline{\beta}^{(n)}$$

Assuming constant supply of bonds $S^{(n)}$, the equilibrium conditions in the bond market imply

$$\xi_t^{(n)} + \omega_t^{(n)} = S^{(n)}$$

and isolating $\omega_t^{(n)}$, we obtain

$$\omega_t^{(n)} = (S^{(n)} - \frac{\varphi}{n}\overline{a}_n + \varphi\overline{\beta}^{(n)}) - \frac{\varphi}{n}\overline{b}_n' X_t$$

After substituting it out the expression for $\omega_t^{(n)}$, we obtain the following expression for the market price of risk λ_t

$$\begin{aligned}
\lambda_t &= \sigma\sum_{n=1}^{N}(\omega_t^{(n)}(\overline{b}_{n-1} + \gamma)) = \sigma\sum_{n=1}^{N}((\overline{b}_{n-1} + \gamma)[(S^{(n)} - \frac{\varphi}{n}\overline{a}_n + \varphi\overline{\beta}^{(n)}) - \frac{\varphi}{n}\overline{b}_n' X_t]) \\
&= \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(S^{(n)} - \frac{\varphi}{n}\overline{a}_n + \varphi\overline{\beta}^{(n)}) + \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(-)\frac{\varphi}{n}\overline{b}_n' X_t
\end{aligned}$$

which can be recast in the standard generalised form

$$\begin{aligned}
\lambda_t &= \lambda_0\left(\overleftrightarrow{a}_N, \overleftrightarrow{b}_N; \sigma, \varphi, \overleftrightarrow{S}^{(N)}, \overleftrightarrow{\beta}^{(N)}\right) + \lambda_1\left(\overleftrightarrow{b}_N; \sigma, \gamma, \varphi\right) X_t \quad \text{(B.6)} \\
\lambda_0 &\equiv \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(S^{(n)} - \frac{\varphi}{n}\overline{a}_n + \varphi\overline{\beta}^{(n)}) \\
\lambda_1 &\equiv \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(-)\frac{\varphi}{n}\overline{b}_n'
\end{aligned}$$

where $\overleftrightarrow{a}_N$, $\overleftrightarrow{b}_N$, $\overleftrightarrow{S}^{(N)}$ and $\overleftrightarrow{\beta}^{(N)}$ collect respectively $\overline{a}_i$, $\overline{b}_i$, $S^{(i)}$, $\beta^{(i)}$ for all i from 1 to N.

To derive an analytical solution for the pricing equation coefficients, we verify the conjectured solution (B.1) by using equations (B.4), (B.5), (B.6), and expressing the short-term risk free rate r_t as

$$r_t \equiv a_1 + b_1' X_t = (\overline{a}_1 + \overline{b}_1' X_t) - \gamma'(\mu + \Phi X_t) - \gamma'\Sigma\Sigma'\lambda_t + \frac{1}{2}\gamma'\Sigma\Sigma'\gamma$$

In practice, we derive the following set of difference equations for the pricing coefficients which resemble for instance Borgy et al. (2011) who similarly develop an arbitrage-free affine term structure model with credit risk:

$$\overline{a}_n = \left(a_1 + \overline{a}_{n-1} + (\overline{b}_{n-1}' + \gamma')(\mu + \Sigma\Sigma'\lambda_0) - \frac{1}{2}(\overline{b}_{n-1}' + \gamma')\Sigma\Sigma'(\overline{b}_{n-1} + \gamma)\right) \quad \text{(B.7)}$$

$$\overline{b}_n' = (b_1' + (\overline{b}_{n-1}' + \gamma')(\Phi + \Sigma\Sigma'\lambda_1)) \quad \text{(B.8)}$$

$$\overline{a}_1 = \left(a_1 + \gamma'(\mu + \Sigma\Sigma'\lambda_0) - \frac{1}{2}\gamma'\Sigma\Sigma'\gamma\right)$$

$$\overline{b}_1 = (b_1' + \gamma'(\Phi + \Sigma\Sigma'\lambda_1)$$

$$\lambda_0 \equiv \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(\overline{S}^{(n)} - \frac{\varphi}{n}\overline{a}_n + \varphi\overline{\beta}^{(n)})$$

$$\lambda_1 \equiv \sigma\sum_{n=1}^{N}(\overline{b}_{n-1} + \gamma)(-)\frac{\varphi}{n}\overline{b}_n'$$

The main difference is that in our model the price of risk is endogenously determined, turns out to be affected by the supply of bonds, and has loading coefficients on the macroeconomic factors that are function of structural parameters. One implication is reflected by the fact that, contrary to standard affine term structure models, the equilibrium recursive formulas B.7 and B.8 are characterised by a fixed point mapping in which the vectors $\overline{a}_n$ and $\overline{b}_n$ are a function of λ_t, which itself is a function of the coefficients $\overline{a}_n$ and $\overline{b}_n$, and so on.

B Additional tables

Table B.1: Identified event dates

Date	First newswire	Event
September 04, 2014	14:34	ECB press conference
September 12, 2014	14:12	News conference following a meeting of euro area finance ministers in Milan
September 24, 2014	08:20	Interview with Europe 1, conducted on 23 September 2014 and aired on 24 September 2014
September 25, 2014	05:00	Interview with Lithuanian business daily Verslo Zinios
October 02, 2014	14:40	ECB press conference
October 10, 2014	16:00	Statement at the Thirtieth meeting of the IMFC, Washington
October 24, 2014	16:41	An ECB spokesman reading from Mario Draghi's speaking points at a euro area summit, Brussels
November 06, 2014	14:35	ECB press conference
November 17, 2014	15:17	Introductory remarks at the EP's Economic and Monetary Affairs Committee
November 21, 2014	09:33	Speech at the Frankfurt European Banking Congress, Frankfurt am Main
November 27, 2014	09:45	Introductory remarks at the Finnish parliament and speech at the University of Helsinki
December 04, 2014	14:37	ECB press conference
January 02, 2015	08:00	Interview with Handelsblatt, published on 2 January 2015
January 08, 2015	16:05	Letter to Mr Luke Ming Flanagan (member of the European Parliament), published on 8 January 2015
January 14, 2015	09:00	Interview with Die Zeit, published on 15 January 2015
January 22, 2015	14:40	ECB press conference
March 05, 2015	14:30	ECB press conference

Table B.2: Data Releases of macroeconomic variable used in the event study

Country	Variable	Country	Variable
Euro area	Consumer Confidence	Italy	GDP WDA QoQ
Euro area	CPI MoM	Italy	Industrial Production MoM
Euro area	Economic Confidence	Italy	Markit/ADACI Manufacturing PMI
Euro area	GDP SA QoQ	Spain	GDP QoQ
Euro area	Industrial Production SA MoM	Spain	Markit Manufacturing PMI
Euro area	Markit Eurozone Manufacturing PMI	Spain	Retail Sales YoY
France	Consumer Confidence	Spain	Unemployment rate
France	CPI YoY	Spain	CPI EU Harmonised YoY
France	GDP QoQ	United States	Chicago Purchasing Manager
France	Industrial Production MoM	United States	Consumer Confidence Index
France	Markit Manufacturing PMI	United States	CPI MoM
Germany	CPI MoM	United States	FOMC Rate Decision (Upper Bound)
Germany	GDP SA QoQ	United States	GDP Annualized QoQ
Germany	IFO Business Climate	United States	GDP Price Index
Germany	Industrial Production SA MoM	United States	Housing starts
Germany	Markit/BME Manufacturing PMI	United States	Initial Jobless Claims
Germany	Unemployment rate	United States	ISM Manufacturing
Germany	ZEW Survey Expectations	United States	U. of Mich. Sentiment
Italy	Business Confidence	United States	Unemployment rate
Italy	CPI EU Harmonized YoY	United States	Change in Nonfarm Payrolls