The Effects of the ECB's Expanded Asset Purchase Programme

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Abstract

This paper provides empirical evidence on the financial and macroeconomic impact of the news associated to the announcement launching the ECB's expanded asset purchase programme (APP). We proxy the APP announcement shock with an announcement variable derived from the institutional features of the APP and survey-based evidence. The variable is used in a time-varying coefficient VAR model with stochastic volatility to estimate the effects of the announcement shock. The evidence suggests that this shock had a significant upward effect on both real economic activity and HICP inflation in the euro area. The response of long-term interest rates gave rise to a flattening of the yield curve in the short term, followed by a steepening in the medium term. Several channels of transmission appear to have been activated, including the portfolio rebalancing channel, the exchange rate channel and the credit channel.

JEL classification: C32; E44; E52; E58.

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1 Introduction

In response to the financial crisis starting in the summer of 2007, the global economic recession of 2008/2009 and the European sovereign debt crisis starting in 2010, the European Central Bank (ECB) adopted a sequence of standard and non-standard monetary policy measures to support the euro area economy. Among these measures, a large-scale asset purchase programme, referred to as expanded asset purchase programme (APP), was launched in January 2015 by the Governing Council of the ECB to address the risks of euro area HICP inflation remaining too low for a prolonged period. Net asset purchases under the APP lasted until December 2018. Given the scope of the APP, it is very important to assess its impact on financial markets and the macroeconomy in the euro area.

There is by now a large empirical literature providing several estimates on the financial and macroeconomic impact of large-scale asset purchase programmes, or quantitative easing (QE) polices, in advanced economies, based on alternative approaches ranging from event studies to structural VARs to calibrated or estimated DSGE models.[1] For the euro area a number of studies on the financial and macroeconomic impact of the ECB's APP have been published in recent years.[2] However, there is a lack of studies on the effects of the APP based on empirical approaches which allow for changes in the financial and macroeconomic environment, both in terms of structural change and in terms of volatility, as well as non-linearities which can be particularly important in a monetary policy regime when unconventional monetary policy measures prevail.

Against this background, the purpose of this paper is to provide empirical estimates on the effects of the APP on euro area financial markets and the macroeconomy. The model used, a standard VAR with time-varying parameters and stochastic volatility, allows to take into account potentially important changes in the euro area macroeconomy as well as the transition of monetary policy towards a regime characterised by an effective lower bound of key ECB policy interest rates. From a methodological point of view, the main novelty of the paper is represented by the identification approach. Our identification scheme is based on a proxy variable capturing the unexpected component

[1] See for example the review of this literature provided by Borio and Zabai (2016).

[2] See for example Altavilla et al. (2015), Altavilla et al. (2020), Andrade et al. (2016), Blattner and Joyce (2016), De Santis (2020), Koijen et al. (2016), Wieladek and Garcia Pascual (2016), De Santis and Holm-Hadulla (2017), Eser et al. (2019) and Rostagno et al. (2019).

of the APP announcements. The proxy is derived by exploiting the specific institutional features of the APP concerning the announced time profile and monthly amounts of the securities to be purchased, combined with the results of a survey conducted by Bloomberg among private sector market participants. We focus on the initial APP announcement shock which took place in January 2015.

The main results of the empirical analysis are the following. First, the APP announcement shock had a significant positive impact on both HICP inflation and real economic activity growth. Second, we find also a significant effect of this shock on the yield curve, mainly driven by changes in the long-term interest rate, such that in response to the shock a flattening of the yield curve can be observed in the short term, followed by a steepening in the medium term. Third, also other financial variables appear to have been markedly affected, including stock prices and credit volumes, on the upside, and the exchange rate, on the downside (depreciation of the euro). Overall, in terms of channels of transmission, the evidence points to an activation of the portfolio rebalancing channel, the exchange rate channel and the credit channel, while the evidence on the relevance of the inflation re-anchoring channel and the signalling channel is more uncertain.

The remainder of the paper is structured as follows. Section 2 provides a discussion of the main features of the APP and the associated channels of transmission and illustrates the derivation of the APP announcement shock proxy. Section 3 explains the empirical approach, the main data used and the identification approach. Section 4 reports and discusses the results. Section 5 provides conclusions.

2 APP announcements

2.1 Main features of the APP

In order to mitigate the adverse effects of the financial, macroeconomic and sovereign debt crises experienced by the euro area since 2007, the ECB implemented multiple cuts in key interest rates and adopted a broad set of non-standard measures.[3] Among the latter, between 2015 and 2018 the ECB undertook large-scale net asset purchases, often characterised as quantitative easing. More precisely, on the 22nd of January 2015 the Governing Council of the ECB decided to initiate an expanded asset purchase programme (APP), against the background of low inflation, signs of decreasing longer-term inflation expectations and a gradual recovery in economic activity, which pointed to an increased

[3] See Gambetti and Musso (2017) for details on the standard and non-standard monetary policy measures adopted by the ECB since 2007.

likelihood that inflation would remain too low for a prolonged period. The APP encompassed the existing asset-backed securities purchase programme (ABSPP) and the third covered bond purchase programme (CBPP3), both of which were launched in September 2014, but also included a new public securities purchase programme (PSPP) aimed at purchasing bonds issued by euro area central governments, agencies and European institutions, to start in March 2015. Under this expanded programme the combined monthly purchases of public and private sector securities would amount to €60 billion, on average, starting in March 2015 and were to be carried out until at least September 2016 and in any case until the Governing Council would see a sustained adjustment in the path of inflation that was consistent with its aim of achieving inflation rates below, but close to, 2% over the medium term. Thus, the announced APP entailed combined purchases of public and private sector securities between March 2015 and September 2016 by €1.14 trillion, corresponding to 11.3% of 2014 euro area nominal GDP. Since progress towards a sustained adjustment in the path of inflation continued to be disappointing, the APP programme was subsequently re-calibrated on various occasions, with announcements in December 2015 (monthly purchases to run until March 2017, or beyond if necessary, and reinvestment of principal payments), March 2016 (monthly average purchases to increase to €80 billion, starting from April 2016, including a new corporate securities purchase programme, or CSPP, starting in June 2016), December 2016 (monthly purchases to run until December 2017, or beyond if necessary, and from April 2017 monthly average purchases reduced to €60 billion), and October 2017 (monthly purchases to run until September 2018, or beyond if necessary, and from January 2018 monthly average purchases decreased to €30 billion). In 2018 it was decided that the APP would be phased out, as announced in June (monthly purchases to run until December 2018 and from October 2018 monthly average purchases decreased to €15 billion) and December (end of net purchases and reinvestment of maturing securities).[4] Chart 1 shows the evolution of the purchases of securities for monetary policy purposes by the Eurosystem, including those under the APP, from 2009 to 2018.

2.2 Channels of transmission of the APP

The APP, similar to other large-scale asset purchases undertaken by the Fed and the Bank of England, operated via multiple transmission channels (ECB, 2015; Hammermann et al., 2019). First, according to the portfolio rebalancing channel, asset purchases by the central bank would lead sellers of these assets to rebalance their portfolios towards

[4] See Hammermann et al. (2019) for details on the various re-calibrations and transition phases.

other assets, thereby increasing the price of a broad range of financial assets, reducing their yields. Among other effects, the compression of yields will reduce the cost of external financing to both banks and non-financial corporations and increase the supply of bank lending which becomes a more attractive option for banks than investing in securities.[5] The exchange rate channel, according to which asset purchases might lead to a depreciation of the exchange rate, can be seen as a specific category within the more general class of the portfolio rebalancing channel, as portfolio rebalancing flows might include an increased demand for external assets by domestic residents and/or a repatriation of funds by non-residents. A second general category of channels is represented by the signalling channel, according to which asset purchases signal the commitment of the central bank to maintain an accommodative policy for a longer period of time to achieve its price stability objective, implying downward revisions in market expectations of future policy rates. This channel can be interpreted in a similar way as forward guidance, as the central bank signals its committment to maintain short-term interest rates at the effective lower bound for a longer period. The inflation expectations, or inflation re-anchoring, channel, according to which asset purchases increase longer-term inflation expectations, can be subsumed under the signalling channel category as it also operates via the central banks commitment to its mandate. Finally, the broad credit channel, which relates to the effects of asset purchases on the supply of bank lending and lending rates, is also likely to be relevant, although it operates at least in part via the increased asset prices and decreased yields induced by the asset purchases, as discussed above, thereby representing a subsequent step in the chain reaction activated by the portfolio rebalancing channel. At the same time, the related but more specific direct pass-through channel can be seen as a different channel compared to the portfolio rebalancing channel to the extent that specific asset purchases, such as asset-backed securities purchases, increase the price of the targeted assets, thereby encouraging banks to increase the supply of loans that can be securitised, which tends to lower bank lending rates.

Virtually all empirical studies on the financial and macroeconomic effects of large-scale asset purchases conclude that most of the impact of these policies takes place at the moment of the announcement of the policy, or even before their announcement in case central bank officials gave hints that such policy measures were seriouslsy being considered or would be implemented soon.[6] By contrast, the effects of the actual pur-

[5]Other specific channels highlighted in the literature, such as the duration channel (reduction of duration risk) or the scarcity channel (creation of scarcity in the assets purchased by the central bank), can be subsumed under the more general portfolio rebalancing channel category.

[6]See for example, the evidence reported by D'Amico et al. (2012), Gagnon et al. (2011) and Krish-

chases which follow the announcements appear to be more limited, as economic agents and financial markets have already adjusted their expectations, decision-making and portfolios. As a result, it is essential to take into account the effects of the unexpected component of the announcement of the APP, for which purpose we derive a proxy in the next sub-section.

2.3 Proxy for the APP announcement shock

As discussed above, the APP was shaped by several announcements: the initial launch in January 2015, four re-calibrations in December 2015, March 2016, December 2016 and October 2017 and two transitions in June 2018 and December 2018. When assessing the impact of the APP a key challenge is to disentangle the expected from the unexpected components of the amounts of security purchases announced. Indeed, it has to be recognised that the announcement of the APP in January 2015 was to some extent expected, following various references by ECB Executive Board members in speeches in previous months.[7] However, the core question is not whether an announcement launching or re-calibrating a large-scale asset purchase programme was expected. The key question is the extent to which the amounts of purchases announced in each phase of the APP was anticipated, in a similar way as standard monetary policy shocks can be seen as deviations of actual from expected interest rate changes. For this purpose, it can be useful to use as reference a survey of private sector market analysts conducted by Bloomberg, available from 2015 to 2018 ahead of each APP announcement. Although the number of experts surveyed and the questions asked varied over time, on average 40 to 50 market analysists posted a reply to surveys conducted by Bloomberg few days ahead of each of the above-mentioned announcements and some questions were repeated every time, allowing to quantify the total and the monthly amounts of asset purchases expected. Two questions, in particular, from the Bloomberg survey on the APP are useful for our purposes. The first, available for all surveys conducted few days before each of the above-mentioned announcements, refers to the total amounts of asset purchases expected. As can be seen from the left-hand panel in Chart 2, the total amount of purchases announced in January 2015 (€1.14 trillion) far exceeded expectations, the

namurthy and Vissing-Jorgensen (2011) for the US; Altavilla et al. (2015), Andrade et al. (2016), De Santis (2016) and Blattner and Joyce (2016) for the euro area; and Joyce et al. (2011) for the UK.

[7] For example, President Draghi mentioned during the ECB Press Conference of December 2014 that in early 2015 the ECB would, among other things, reassess "the expansion of the balance sheet".

median of which was €550 billion.[8] By contrast, the revised total amounts of purchases announced subsequently were less of a surprise, being very close to the median (March 2016, October 2017 and June 2018) or to the lower bound of the range of expectations (December 2015, at the 10th percentile; and December 2016, at the 25th percentlile). The second question of interest refers to the expected monthly average net purchases, unfortunately not available for the surveys conducted few days ahead of the December 2015 and December 2016 announcements. In this respect, the amount of monthly average purchases announced in January 2015 (€60 billion) was also higher than what was expected by the strong majority of experts (median: €40 billion; 75th percentile: €56 billion) (see the right-hand panel in Chart 2). To a large extent, also the increase in the amount of monthly average purchases announced in March 2016 (to €80 billion) was unexpected (median: €75 billion; 75th percentile: €80 billion), while the reductions announced in October 2017 and June 2018 appear to have been fully anticipated.

As a result of these survey results, we argue that there is clear survey-based evidence suggesting that the quantitative elements of the APP announcements in January 2015 and in March 2016 entailed a positive surprise to private sector agents, while the revisions in the amounts of asset purchases associated to the other announcements were to a large extent anticipated. At the same time, we recognise that the evidence pointing to a marked quantitative upward surprise is stronger for the January 2015 announcement, while the quantitative surprise element of the March 2016 re-calibration announcement was more limited. Therefore, while we will consider both episodes when deriving our proxy for the unexpected component of the APP measures announced, in assessing the effects of the APP we will concentrate on the impact of the initial announcement launching the APP.

Following the above discussion, we construct the APP announcement variable with reference to the amounts of average monthly net purchases and then derive a proxy for the unexpected part of the announcement. Let a_t be the flow of asset purchases announced in month t and let

$$a_t = a_{t-1} + b_t.$$

The variable a_t is equal to zero before January 2015, equal to €60 billion between

[8] This positive surprise was widely reported by the financial presss. For example, on the day after the APP announcement in January 2015, the Financial Times published an article entitled "Central bank bond-buying proposal beats all expectations" reporting that "Market analysts polled by Bloomberg earlier this week had expected some €550bn-worth of government bond purchases. The ECB now intends to buy double that amount, launching a €1.1tn bond-buying spree, the vast majority of which will involve purchases of sovereign debt." (Financial Times, 23 January 2015, p. 3).

January 2015 and February 2016, equal to €80 billion between March 2016 and November 2016, back to €60 billion between December 2016 and September 2017, equal to €30 billion between October 2017 and May 2018, equal to €15 billion between June 2018 and November 2018 and equal to €0 billion from December 2018 onwards (see Chart 1). Thus, the change, $b_t = \Delta a_t$, is non-zero in six episodes, although we assume that the change is not known with certainty only in two episodes (January 2015 and March 2016). Accordingly, we model the change in announced net asset purchases as

$$b_t = \begin{cases} E_{t-1}b_t = 0 \ \text{ if } t \neq \{2015{:}1,\ 2016{:}3,\ 2016{:}12,\ 2017{:}10,\ 2018{:}6,\ 2018{:}12\}\ , \\ E_{t-1}b_t \ + \tilde{b}_t \ = 40 + 20 \text{ if } t = \{2015{:}1\}\ , \\ E_{t-1}b_t + \tilde{b}_t \ = 15 + 5 \ \text{ if } t = \{2016{:}3\}\ , \\ E_{t-1}b_t = -20 \ \text{ if } t = \{2016{:}12\}\ , \\ E_{t-1}b_t = -30 \ \text{ if } t = \{2017{:}10\}\ , \\ E_{t-1}b_t = -15 \text{ if } t = \{2018{:}6,\ 2018{:}12\}\ . \end{cases}$$

where $\tilde{b}_t$ is a stochastic component reflecting the unexpected part of the announced change and $E_{t-1}b_t$ represents the the expectations of the agents on the basis the results of the above-mentioned Bloomberg survey. Based on the evidence discussed above, as baseline scenario we assume that the expected component of the announcement, $E_{t-1}b_t$, in January 2015 and in March 2016 corresponds to a fraction of the change Δa_t equal to the median expectation for the amounts of monthly average purchases, i.e. $E_{t-1}b_t =$ €$40bn$ (thus, $\tilde{b}_t =$€$20bn$) for January 2015 and $E_{t-1}b_t =$ €$15bn$ (thus, $\tilde{b}_t =$€$5bn$) for March 2016. We use $\tilde{b}_t$ as external instrument for the estimation of the unexpected component of the change in the announced asset purchases, modelled as

$$\tilde{b}_t = \begin{cases} 0 \ \text{ if } t \neq \{2015{:}1,\ 2016{:}3\}\ , \\ 20 \text{ if } t = \{2015{:}1\}\ , \\ 5 \ \text{ if } t = \{2016{:}3\}\ . \end{cases}$$

3 Empirical approach

In this section we discuss how to include the above proxy into a statistical model to derive the effects of announcement shocks. After an example to illustrate the main intuition behind our empirical approach, we will discuss more in detail the empirical model adopted.

3.1 Intuition

Recall that the announcement shock is a shock which occurs only rarely, as it does not take place most of the time. In other words, its variance is zero most of the time and positive in a very few episodes. Formally, we can write, $\tilde{b}_t = \sigma_t e_t$, $e_t \sim WN(0,1)$, where $\sigma_{e,t}$ can be either positive, in which case it corresponds to the standard deviation of $\tilde{b}_t$, or zero, in the absence of the shock. Now, consider a second variable z_t that depends on $\tilde{b}_t$, and, for simplicity, let us assume it has an autoregressive structure. The structural representation of $\tilde{b}_t$ and z_t is given by

$$\begin{pmatrix} \tilde{b}_t \\ z_t \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} \tilde{b}_{t-1} \\ z_{t-1} \end{pmatrix} + \begin{pmatrix} \sigma_{e,t} & 0 \\ c_{21}\sigma_{e,t} & \sigma_u \end{pmatrix} \begin{pmatrix} e_t \\ u_t \end{pmatrix}$$

where $u_t \sim WN(0,1)$ is a second structural shock. Notice that for simplicity we have assumed that the variance of this second shock is constant and that z_t does not predict $\tilde{b}_t$. Both of these assumptions can be relaxed and nothing, in the analysis, would change. In this model the impulse response functions of e_t on z_t are either $[c_{21} + (a_{21} + a_{22}c_{21})L + a_{22}(a_{21} + a_{22}c_{21})L^2 + ...]\sigma_{e,t}$ or zero. Indeed depending on $\sigma_{e,t}$, the process switches from a VAR(1) (when $\sigma_{e,t} > 0$) to a simple univariate AR(1) (when $\sigma_{e,t} = 0$). The reduced form representation of the model above is

$$\begin{pmatrix} \tilde{b}_t \\ z_t \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} \tilde{b}_{t-1} \\ z_{t-1} \end{pmatrix} + \begin{pmatrix} \eta_{1,t} \\ \eta_{2,t} \end{pmatrix}$$

with

$$\begin{pmatrix} \eta_{1,t} \\ \eta_{2,t} \end{pmatrix} \sim WN\left(0, \begin{pmatrix} \sigma^2_{e,t} & c_{21}\sigma^2_{e,t} \\ c_{21}\sigma^2_{e,t} & c^2_{21}\sigma^2_{e,t} + \sigma^2_u \end{pmatrix}\right),$$

that is a VAR with time-varying residuals covariance matrix. Suppose that an estimate of the VAR parameters and the time-varying variances of the reduced form model are available. Then, to recover the impulse response functions of the structural shock e_t, two steps are required. The first step consists in the identification of the period t in which the shock occurs, when the variance is not zero. The second step is represented by the application of the Cholesky decomposition using the estimates of the residuals variance at time t. This is the strategy we pursue in the next section.

The above simple example also clarifies why estimating a standard fixed-coefficients VAR (i.e., a VAR with fixed parameters and constant volatility) cannot be the empirical optimal strategy. Imagine estimating a standard fixed-coefficients VAR for the two variables above. First, the estimated σ^2_e would be a weighted average of the true value 0 and $\sigma^2_{e,t}$. It is true that OLS would still be consistent and the appropriate rescaling of the impulse response functions could yield the correct responses. However, inference could be problematic and, in addition, the estimates could suffer from small sample problems. Second, if also the covariace structure is changing over time, specifically c_{12}, then the response would be distorted. Third, allowing for time-variation might matter a lot in practice. Indeed, a number of papers have shown that the forecasting performance of VARs improve when the standard VAR is augmented with stochastic volatility (Clark, 2011; Chiu et al., 2017).

3.2 The model

To deal with the issues raised above, we use a VAR model with stochastic volatility and time-varying parameters. The time-varying variance is the key feature of the model, needed to correctly analyze the effects of the APP shock. Variations in the VAR parameters, altough not essential, are allowed for the sake of generality and to capture potential changes in model dynamics. The model nests the fixed-coefficients VAR. Let $y_t = [cb_t\ \tilde{b}_t\ x_t\ z_t]'$, where cb_t are actual Eurosystem security purchases, $\tilde{b}_t$ is the proxy for the announcement shock, x_t is the the long-term interest rate and z_t is the variables of interest, which in turn will include a macroeconomic or financial variable, as specified below. We assume

$$y_t = A_{0,t} + A_{1,t}y_{t-1} + ... + A_{p,t}y_{t-p} + \varepsilon_t \tag{1}$$

where ε_t is a $n \times 1$ Gaussian white noise vector of innovations with time-varying covariance matrix Σ_t, $A_{0,t}$ is a $n \times 1$ vector of time-varying coefficients and $A_{i,t}$ are $n \times n$ matrices of time-varying coefficients, $i = 1, ..., p$. The residuals and the structural shocks, $e_t \sim N(0, I)$, are related by the following equation: $\varepsilon_t = B_{0,t}e_t$. Annex I provides details on the specification and estimation of the model, which are standard.

The baseline model includes four monthly variables spanning the period July 2009 to December 2018: two of these variables are needed for the identification (Eurosystem security purchases for monetary policy purposes in EUR billions, cb_t, and the proxy for the announcement shock, or the unexpected component of the announcements, $\tilde{b}_t$, also in EUR billions), while the third variable (x_t, the long-term interest rate) enhances the identification of the shocks as it captures key channels of transmission. Thus, these three variables are present in all specifications of the models we consider. The fourth variable included (z_t) refers to the alternative variables of interest, which will vary and include alternative financial and macroeconomic variables.

The choice of the policy variable deserves some discussion. The focus on the series for Eurosystem security purchases for monetary policy purposes, i.e. the sum of purchases that started in mid-2009 with the first covered bond purchase programme (CBPP1), instead of the total Eurosystem balance sheet (i.e. total assets), is justified by the fact that the latter reflects several changes that affected the total balance sheet but have hardly anything to do with monetary policy (such as gold revaluations) or are related to policies other than those of interest in the present study and taking place around the same periods, complicating the identification.[9] We take as reference the series for total Eurosystem security purchases rather than that only for the APP security purchases as the latter starts only in March 2015, making the estimation period statistically too short.[10]

The macroeconomic effects are studied using the harmonised index of consumer prices (HICP) and a monthly index associated to real economic activity (Eurocoin). To investigate the effects on financial markets we use, in turn, long-term and short-term interest rates (to capture the effects on the yield curve), non-financial corporation credit volumes and bank lending rates (effect on credit markers) and, finally, stock prices and the Euro nominal effective exchange rate (other financial market effects). For the assessment of the role of various channels of transmission of the APP we also consider other variables, such as measures of inflation expectations (re-anchoring channel) and short-term forward interest rates (policy signaling channel).

Since the series need to be stationary, the flow of purchases and interest rates are included in first differences while consumer prices, credit volumes, stock prices and the exchange rate are included as monthly growth rates. Annex II provides details on the definition, treatment and sources of the data.

3.3 Reduced form estimates and identification

We begin our analysis by discussing a few interesting findings obtained from the estimation of the reduced form model. First, virtually all of the VAR coefficients $A_{i,t}$ $(i = 1, ..., p)$ display only marginal variation over time. This was to some extent expected given that the sample period is relatively short, although the adoption of unprecedented

[9]It is interesting to note that such choice is also supported by the conclusion of Haldane et al. (2016) that "it is only when central bank balance sheet expansions are used as a monetary policy tool that they have a significant macro-economic impact" (p.1).

[10]Thus, this series also includes the covered bond purchase programmes starting in 2009 (CBPP1) and in 2011 (CBPP2) and the securities markets programme (SMP) starting in 2010, in addition to the purchase programmes associated to the APP (ABSPP, CBPP3, PSPP and CSPP).

monetary policy measues and the transition to the effective lower bound period dictated, ex ante, to adopt a model allowing for possible changes in parameters. Second, all of the VAR coefficients in the equation for $\tilde{b}_t$ are zero, which reflects the fact that none of the variables of the model can predict the proxy for the announcement shock. Third, the variance of the residual of the equation for $\tilde{b}_t$, reported in Chart 3, is zero most of the time and displays only two peaks, in correspondence to the January 2015 and the March 2016 announcements. Thus, while the VAR parameters appear to be broadly constant, the variance of the shock displays major fluctuations. Fourth, the shock ε_{2t} is uncorrelated with any of the other residuals of the model, the largest correlation being smaller than 0.004.

These results have important implications. The first and second findings imply that the estimated specification broadly corresponds to a fixed-parameters VAR with stochastic volatility. Most importantly, the second and third findings imply that the residual ε_{2t} in the $\tilde{b}_t$ equation *corresponds* to the announcement shock, e_{2t}, in the non-zero variance periods. The estimated announcement process is

$$\tilde{b}_t = \begin{cases} 0 & \text{if } t \neq \{2015{:}1,\ 2016{:}3\}\ , \\ \varepsilon_{2t} = e_{2t} & \text{if } t = \{2015{:}1,\ 2016{:}3\}\ . \end{cases}$$

In what follows we focus on the effects of the APP shock on macroeconomic and financial variables. To impose exact orthogonality between the residual ε_{2t} and the remaining shocks we derive the Cholesky decomposition of the model, i.e. we impose $B_{0,t} = S_t$, where S_t is the Cholesky factor of Σ_t and study the effects of e_{2t}. However, let us stress again that this yields responses which are identical to those of the residual ε_{2t}. It should be noted that the key implication of using the Cholesky decomposition in the model with the variables ordered as discussed above (the flow of asset purchases first, proxy for APP announcement shock second and then the remaining variables of interest) and assessing the effects of the APP with reference to the impulse response functions of the variables to the second shock (our identified APP announcement shock) is that the latter shock has no effect on impact on the flow of actual security purchases. This assumption reflects the institutional features of the APP as it was formulated both in January 2015 (with the announced purchases starting only two months later, in March 2015) and in March 2016 (with the announced increase in monthly average purchases starting only one month later, in April 2016). The relative ordering of the third and fourth variables is irrelevant for our purposes.

3.4 Simulation

A potential drawback of our empirical procedure is that there are very few observations of the APP shock. Accordingly, our identifiction could be flawed because such small number of realisations of the shock might not be enough to correctly estimate its effects. To check the practical relvance of such issue in the context of our empirical procedure we perform a simulation. We consider the following simple model

$$\begin{pmatrix} \Delta m_t \\ \Delta a_t \\ z_t \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0.3 & 0.5 \end{pmatrix} \begin{pmatrix} \Delta m_{t-1} \\ \Delta a_{t-1} \\ z_{t-1} \end{pmatrix} + \begin{pmatrix} 1 & L^2 & 0.3L \\ 0 & 1 & 0 \\ 1 & 2 & 3 \end{pmatrix} \begin{pmatrix} e_{1t} \\ \sigma_t e_{2t} \\ e_{3t} \end{pmatrix} \tag{2}$$

where Δa_t s the announcement, Δm_t is asset purchases and z_t is a third variable, and the vector $e_t \sim WN(0, I)$. The shock e_{2t} is the announcement shock. Notice that the announcement shock has random walk type of effects on the announcement and asset purchases, with the difference that the effects on the latter are delayed by two months while the effects on former are instantaneous. The numbers assigned to the coefficient matrices are chosen in order to ensure that we have an invertible VARMA. However, such choice, although arbitrary, is not essential, as indeed other invertible parameterisations would lead to the same conclusion. We consider a sample of $T = 112$ observations, as in our empirical analysis. The parameter σ_t is calibrated as follows: $\sigma_{65} = 2$, $\sigma_{79} = 1$ and $\sigma_t = 0$ for all of the remaining time periods. Hence, the APP shock has only two nonzero realizations in $t = 65$ and $t = 79$. We generate N datasets of T observations from this model. For each dataset we estimate a fixed coefficients VAR (VAR) and a time-varying coefficients VAR (TV-VAR), both specified with two lags. We impose a Cholesky identification; the second shock is the estimated APP shock.

Chart K in Annex III plot the results. The black solid lines are the mean of the point estimates obtained for the N samples. The gray area delimits the 16% and 84% percentiles of the distribution of the point estimates (across samples). The red lines are the theoretical impulse response functions in the above model. Both the VAR (Chart K, LHS) and the TV-VAR (Chart K, RHS) correctly capture the true impulse response functions, as the black and red lines overlap almost perfectly. Moreover, the TV-VAR produces bands with are slightly narrower than the VAR. As discussed above, the reason could be the increased efficiency when allowing for the variance to be varying over time.

All in all, the results point out that the potential too-few observations problem is not empirically relevant in our case. Our approach is successful in estimating the true responses even when there are only two non-zero observations of the shock.

4 The effects of APP shocks

4.1 Macroeconomic effects

The impact of the APP announcement shock taking place in January 2015 on the variables of interest is assessed on the basis of impulse response functions. Specifically, we report the posterior median of the impulse response functions of the variables to the APP announcement shock, along with the area delimited by the 16th and the 84th percentiles, with both median responses and percentiles multiplied by the estimated size of the shock in that month. While the model is estimated with the variables in first difference or growth rates, we report the impulse responses to the variables in levels.

Looking first at the effects of the January 2015 shock on the Eurosystem security purchases, after being nil in the first month (as imposed by restriction) and very close to zero in the second month, the impact jumps up from the third month onwards and remains at levels just above €40 billion, thus suggesting that indeeed about two thirds of the monthly average purchases announced can be considered as unexpected (Chart 4). This interpretation is also supported by the impact of the shock on the APP announcement news proxy, which immediately jumps and remains at levels close to €20 billion. Note that these results are not an implication of the assumed size of the APP announcement news proxy, as with other sizes in the latter that we experimented with, the impact of both variables (actual purchases after the second month and APP announcement news proxy) do not necessarily converge and remain at the level of the APP announcement proxy.

The impact of the January 2015 shock on the HICP, while very close to zero on impact, increases over time stabilising around 1 percent after six months, and remains markedly significant for at least three years. By contrast, the impact on Eurocoin, a monthly index tracking quarterly growth of euro area real GDP, appears to be mainly concentrated in the short run. More precisely, it is close to zero on impact but increases and becomes significant after six months, peaking at around eight months when the impact is about 0.24 percentage points, suggesting that in the absence of the initial APP announcement shock quarterly real GDP growth may have been about one quarter of a percentage point lower three quarters after the shock. The impact of the shock on Eurocoin then decreases and becomes insignificant after 12 months. Of course, while the impact of the shock on real economic activity growth is estimated to be temporary, the effects on the level of real output are persistent.

Available studies on the impact of the APP, and more generally on the impact of QE policies introduced in recent years in advanced economies, unambiguously point to a positive effect on real economic activity and inflation, although with estimates varying quantitatively. Indeed, alternative estimates of the effects of such QE measures based on alternative approaches vary significantly, as exemplified in the systematic comparisons of the peak effects on real GDP and inflation reported in Table 7 of Borio and Zabai (2016) (p.23). Of course, the different magnitude of all of these estimates reflects the different modelling approaches adopted, the different identification schemes applied as well as the different features of the QE measures implemented by various central banks in different periods. Overall, our estimates on the impact of the APP announcement shocks on real economic activity growth and the HICP do not differ much from other estimates, falling within the range of estimates reported by Borio and Zabai (2016), and not far from those reported by Andrade et al. (2016), Wieladek and Garcia Pascual (2016) and Rostagno et al. (2019) for the euro area.

4.2 Financial market effects

In order to shed light on the financial market effects of the APP announcement shocks, which allow to assess the role of various channels of transmission of these shocks, we consider the impact on the yield curve, stock prices, the exchange rate, credit markets, inflation expectations and short-term forward rates.

4.2.1 The yield curve

As regards the impact on the yield curve, the January 2015 shock is estimated to have affected significantly the 10-year composite euro area government bond yield, which responds negatively in the short term (by about -15 basis points on impact, and a maximum of about -30 basis points after four months), while in the medium to longer term the shock has an opposite effect, pushing the yield upwards persistently (stabilising at about +30 basis points after six months) (Chart 5). By contrast, the effect on the shorter-term yield is more contained, as the 1-year composite euro area government bond yield displays a limited short-run declining impact (-5 basis points on impact and a maximum of about -15 basis points after seven months) and then converges to about -5 basis points from the 12th month onwards. As a result, the slope of the yield curve first declines, for about four months, and sub-sequently increases, mainly driven by the dynamics of the longer-term interest rate. Very similar responses of the yield curve to these two shocks are found also for the largest euro area countries, i.e. when we use

10-year and 1-year yield for, in turn, Germany, France, Italy or Spain, instead of those for the euro area, in the same model with euro area purchases and APP announcement news proxy (see Chart M in Annex IV).[11] Moreover, these responses turns out to be robust to alternative variables, as illustrated in detail in the robustness analysis section.

These estimates, specifically for the short term, are broadly in line with those from the empirical literature. For example, a number of event studies have shown that the announcement of the APP in January 2015 had a significant downward effect on long-term interest rates in the euro area (Altavilla et al., 2015, De Santis, 2016, Andrade et al., 2016). Indeed, according to these studies, the short-term effect of the APP on the euro area composite 10-year sovereign bond yield was between about 30 basis points and about 70 basis points, with a median of about 40 basis points (see the range of estimates from various studies summarised in Table 1 in Andrade et al., 2016, p.13).[12] The estimated impact of QE policies adopted in recent years in other jurisdictions, namely in the US, UK or Japan, on the respective 10-year government bond yield, according to the available empirical studies, varies but is always negative and significant (see Table 4 in Borio and Zabai, 2016, pp. 11-12). These estimates differ somewhat from ours, in part due to the different time frame and frequency of the data, as for example event studies often use daily or even intra-daily data and focus on the effect of QE announcements over one day or one week, during which presumably the impact is strongest. Beyond the short term, results are still debated. For example, Wright (2012) finds that the effect of US monetary policy news shocks from 2008 onwards have a short-term significant downward effect on 10-year yields but these effects die out after few months. By contrast, Joyce and Tong (2012) provide some evidence that the depressing effects of the UK's large-scale purchases on long-term yields are quite persistent.

Our finding of a short-term flattening, followed by a steepening, of the yield curve in response to a shock associated to the APP announcement is, to the best of our knowledge, a novel finding, warranting therefore a more detailed discussion. There are at least two possible interpretations to this finding. A first, more optimistic, interpretation is that the APP announcement shock had a significant short-term expansionary effect on the economy through various channels, improving the financial and macroeconomic outlook,

[11] Note that for Spain we use the 2-year government bond yield instead of the 1-year yield as the latter is not available for the whole sample period considered.

[12] Eser et al. (2019) find a larger impact on long-term interest rates, but they include the effects also of the various re-calibrations. They find a compression effect of the overall APP on 10-year sovereign term premia by about 95 basis points, of which 50 basis points can be associated to the January 2015 announcement. Thus, these estimates are broadly in line with our results and the other studies mentioned.

which is then eventually reflected in higher long-term interest rates. Such interpretation, also discussed by Wright (2012) with reference to his finding of a short-run negative reponse of the long-term interest rate to US monetary policy news shocks which quickly is reversed and converges towards zero after few months, would not be very different from the effects of any expansionary shock to real economic activity on the long-term interest rate, except for the lagged effect in the case of the APP shock reflecting the fact that in the short run the portfolio rebalancing channel prevails and leads to a temporary compression of interest rates. An alternative interpretation, not necessarily incompatible with the first possible explanation discussed, relates to the excess sensitivity of long-term interest rates to monetary policy news, as documented for example by Gürkaynak et al. (2005) and Hanson and Stein (2015). For instance, Gürkaynak et al. (2005) find evidence of a high sensitivity of long-term interest rates to both macroeconomic news and monetary policy surprises which are hard to explain on the basis of standard macroeconomic models. Interestingly, they also find that monetary policy surprise tightenings cause short-term forward rates to increase but long-term forward rates to fall. While different explanations have been offered for such excess sensitivity of long-term interest rates to monetary policy news, ranging from changing long-run inflation expectations (Gürkaynak et al., 2005) to changes in term premia associated to shifts in the demand for long-term bonds from yield-oriented investors (Hanson and Stein, 2015), our analysis does not allow for an assessment of their respective potential role in driving the changes in the yield curve. Overall, we cannot exclude that both interpretations may have some explanatory power for the changing slope of the yield curve over time in response to the APP shock.

4.2.2 Stock prices and the exchange rate

Other financial variables, such as stock prices and the exchange rate, have also been affected markedly by the APP announcement shock. For example, the January 2015 shock caused stock prices to increase in the short and medium run (with maximum effect on the median impulse response by almost 15% after three months, stabilising at around 13% after eight months). A strong significant effect is also estimated for the euro nominal effective exchange rate, the impulse response function of which declines markedly in the short run and remains persistently negative in the medium run as a result of the shock (with a peak effect after four months, at around -8%, then converging to about -6% after ten months) (Chart 6).

The estimated impact on stock prices is somewhat stronger than the estimates reported by Altavilla et al. (2015) based on an event study (while they find a 1% increase in their controlled event study with 2-day window, they report a 5% increase in their standard event study with 2-day window). By contrast, the impact of the shock to the exchange rate is somewhat smaller than that reported by Altavilla et al. (2015), although the comparability is imperfect as they focus on the Euro-US dollar exchange rate (a 12% depreciation of the Euro in both the controlled and standard event studies with 2-day window). At the same time, as shown by Borio and Zabai (2016), while most studies find that large scale-asset purchases have a marked negative impact on the exchange rate, estimates vary significantly (see Table 4 in Borio and Zabai, 2016, pp. 11-12). Of course, the differences can be explained by the different approaches used, as for example event studies focus on the very short-term impact of monetary policy surprises on these financial variables, without inference on the persistence of these effects over periods of time spanning at least few months, thus not being necessarily in contrast to the estimates we report. These impulse responses can shed some light on various channels of transmission of the APP shocks, notably the portfolio rebalancing channel and the exchange rate channel. In this respect, these results suggest that both the portfolio rebalancing channel and the exchange rate channel were clearly activated.

4.2.3 Credit markets

Evidence can also be found that the credit channel was operational following the APP announcement shock. Indeed, looking at credit markets, specifically for credit to non-financial corporations, we find that the response of total credit to firms increased significantly in the short term following the January 2015 APP announcement shock (with peak effect, at almost 8%, after three months, stabilising around 7% after eight months) (Chart 7). In parallel, the impact on bank lending rates for loans to enterprises appears to be more muted and very uncertain (with signs of marginal and persistent negative impact from the fifth month onwards, but the 68th percentiles clearly suggest that the effect on lending rates is very uncertain).

4.2.4 Other variables

In order to assess to which extent other channels of transmission of the APP announcement shock might have been activated, we also estimated models with alternative variables, specifically long-term inflation expectations (SPF inflation expectations, 5 years ahead) to quantify the role of the inflation re-anchoring channel and short-term forward rates (three-month overnight index swap, OIS, forward rates two-years ahead) to analyse the signalling channel. The estimates for the model with long-term inflation expectations suggest that the re-anchoring of inflation expectations was marginal as a result of APP announcement shock, with long-term inflation expectations increasing by 3 basis points at the peak after eight months following the January 2015 shock (see left-hand side panel in Chart N in Annex IV). At the same time, these estimates seem very uncertain, as signalled by the wide range of the 68th percentiles. The activation of the signalling channel is also very uncertain, as for example the impulse responses of the short-term forward rates are negative in the short term but of very small magnitude (-10 basis points after four months following the January 2015 shock) and surrounded by a wide range delimited by the 16th and 84th percentiles (see right-hand side panel in Chart N in Annex IV).[13]

4.3 Comparison to effects based on a VAR without stochastic volatility

In order to assess empirically to which extent it is important to consider a model with stochastic volatility, it can be useful to compare the estimated impulse responses to the APP announcement shock as reported above to the corresponding ones derived from a standard VAR model with fixed coefficients and constant volatility (VAR), with the same variables, ordered in the same way, and with the same recursive identification (with standardised impulse responses to be able to compare them). As shown in Chart 8, the impulse responses of the macroeconomic and financial variables to the January 2015 APP announcement shock are very similar qualitatively, but in the context of the VAR they tend to be of smaller magnitude and/or significantly more uncertain. For example, the effect of the shock on the HICP estimated within the VAR is about half that in derived from the time-varying VAR with stochastic volatility (TV-VAR) and is significant only for about six months as opposed to the whole time horizon considered (three years). Moreover, while the median impulse response of Eurocoin across the two models is very similar, within the VAR it is never significant, in contrast to the case of the TV-VAR, when it is significant in the short term (although not on impact).

[13] Similar results, including the wide range of the 68th percentiles, is found for the three-month OIS forward rates six-months, one-year and three-years ahead.

5 Sensitivity analysis

In order to assess whether the estimated macroeconomic impact of the identified APP shock is robust, we perform various sensitivity exercises. More precisely, we compare the estimated impact of the APP shock on financial and macroeconomic variables resulting from the baseline model with different specifications, first by using alternative financial and macroeconomic variables and second by considering an alternative identification scheme with sign restrictions. Finally, we discuss to which extent the shocks that we identify and estimate might be distorted by so-called central bank information shocks, i.e. shocks associated to the central bank's assessment of the economic outlook rather than genuine monetary policy shocks.

5.1 Alternative variables

It can be interesting to examine whether the impact of the APP announcement shock changes if alternative financial and macroeconomic variables are included in the model. As regards other macroeconomic variables, we consider the HICP excluding energy and food prices (HICPex, often used as a proxy for underlying inflation) instead of the headline HICP and consider total employment instead of Eurocoin. The impulse response of HICPex is somewhat smaller to the baseline one, as for example the response peaks at almost 1 percent following the January 2015 shock after four months, but later on converges to around 0.50 percent from twelve months ahead on (see left-hand side panel in Chart O in Annex V). Employment increases gradually and stabilises at around +0.3 percent shortly after 12 months following the January 2015 shock, confirming that the impact of shocks on the real economy is persistent (see right-hand side panel in Chart O in Annex V). As regards financial variables, we consider the composite (GDP-weighted) euro area 10-year and 2-year government bond yields instead of the composite euro area 10-year and 1-year spot government bond yields of the baseline models. Also in this case the impulse response of the yield curve is very similar to the baseline one, with dynamics driven by the long-term interest rate and a short-term flattening followed by a subsequent steepening of the curve (see Chart P in Annex V). Finally, in order to assess whether the evidence regarding the activation of the inflation re-anchoring channel and the signalling channel is robust, we also consider models with an alternative inflation expectation measure (capital market based 5-year forward rate 5 years ahead) and an alternative short-term forward rate (three-month overnight index swap, OIS, forward rates six-months ahead). The impule responses of these variables does not change much compared to the baseline ones, as in both cases it appears that the effect of the APP shock remains limited and very uncertain (Chart Q in Annex V). Overall, alternative macroeconomic and financial variables do not point to a significantly different impact of the January 2015 APP announcement shock on the euro area economy compared to the baseline results shown in the previous section.

5.2 Alternative identification

We assess how estimates change when we impose an alternative set of identification restrictions in models with five variables. The idea is to examine the impact of the January 2015 APP announcement shock with slightly bigger models and also with sign restrictions based on the institutional features of the APP programme, the results of previous studies and other economic considerations. The alternative identification scheme, applied to models with Eurosystem security purchases, the APP announcement shock proxy, the long-term interest rate, Eurocoin and a fifth variable of interest, includes the above-mentioned baseline restrictions (zero, magnitude and timing) and adds a number of sign restrictions, as summarised in Table A in Annex IV: 1) a positive lagged effect (by two months) of the shock on Eurosystem purchases (on top of the zero impact restriction), as implied by the institutional features of the January 2015 APP announcement; 2) a positive effect on impact on the APP announcement news proxy, to ensure we capture the effect of the shock under consideration in that specific month; 3) a negative effect on the long-term interest rate on impact and with one month lag, which is an effect estimated by all studies on the impact of QE measures (see for example, Borio and Zabai, 2016, Table 4 in pp.11-12) and is in line with the results reported in the main section that the negative effect is not only on impact but persists for some time; 4) a positive lagged effect (by three months, i.e. at the beginning of the sub-sequent quarter after the shock) on Eurocoin, to ensure we do not capture other shocks which might have the above-mentioned effects, such as adverse shocks to aggregate demand or aggregate supply which would also have a negative effect on long-term interest rates (given the worsened macroeconomic outlook caused by the shock) and if large enough might endogenously trigger an expansionary APP announcement measure; 5) a sign on the response of the fifth variable as would be expected by theoretical or conceptual considerations, such as a positive lagged effect on HICP inflation, a positive lagged effect on stock prices, a negative lagged effect on both the exchange rate and the 1-year yield, a positive lagged effect on credit to firms and a negative lagged effect on lending rates applied to firms, in all cases imposed with a lag of three months, i.e. at the beginning of the quarter following the shock, in line with the expected macroeconomic lagged response and the results reported in the main section and previous studies that the maximum effects are estimated with a lag.[14] Overall, in the context of these models and sign restrictions, most often the response of the Eurosystem purchases, after being nil in the first month (as imposed by restriction) and almost zero in the second month, jumps up from the third month onwards and remains at levels close to €20 billion, while the APP announcement news proxy immediately jumps and remains at levels close to or just above €10 billion, only slightly less than estimated in the baseline model (Chart R in Annex V). Moreover, the estimated effects of the APP announcement shock considered on financial and macroeconomic variables are very similar qualitatively and often also quantitatively to those estimated in the context of the baseline four-variables models and identification scheme. In particular, Eurocoin increases significantly only in the short term, although in most cases to a smaller extent than in the baseline model (for all cases except for the model with the short-term interest rate, for which the response is very similar), and the HICP response gradually increases and stabilises at significant levels, around 0.6 percent, i.e. somewhat lower than in the baseline estimation. Stock prices also in this case respond by rising especially in the short term, reaching a slighlty lower but, at 10%, still strong maximum response, although it moderates somewhat in the medium run compared to the baseline model. Similarly, the exchange rate displays a similar response as in the baseline case, but with a somewhat smaller magnitude compared to the baseline model. As regards the yield curve, the responses are also similar in several respects, although compared to the baseline case the short-term decline of the long-term interest rate is somewhat stronger and less uncertain (and, looking at all models with five variable, its reversal to positive levels in the medium run appears only in four out of the six models) and the 1-year yield declines more persistenlty. Hence, the short-term flattening of the yield curve, followed by a steepening later on, is also found in most of these alternative models. Finally, credit to firms increases significantly and persistently, although somewhat less compared to the baseline model, while the lending rate declines more significantly.

[14] In the absence of this fifth set of sign restrictions, impulse responses for the fifth variables are very similar but in some cases of somewhat smaller magnitude and characterised by higher uncertainty. Moreover, results are very similar if restrictions on the fifth variables are imposed only with one or two, instead of three, months delay, but in some cases results are characterised by higher uncertainty.

5.3 Central bank information shocks

Recent studies have suggested that the announcements by central banks may reflect information both about policy changes as well as about the central bank's assessment of the economic outlook (see for example Nakamura and Seteinsson, 2018, and Jarocinski and Karadi, 2020). Accordingly, central bank announcements can be seen as having two components: a genuine monetary policy component and a non-policy new information component. Thus, if the central bank information shock component is disregarded, the identification of monetary policy shocks might be distorted. Capturing both components of the central bank announcement shocks requires high-frequency data, and therefore is not feasible within our approach. However, recently Jarocinski and Karadi (2020) have undertaken an empirical analysis of the ECB announcements from 1999 to 2016 and estimated the associated central bank information shocks. The time series of such shock is reported in Chart S in Annex V. As can be observed from the chart, the size of the ECB information shock in January 2015 is rather small, in contrast to those coinciding with the re-calibrations in December 2015 and March 2016. Hence, it can be argued that the identification and estimation of the APP announcement shock of January 2015, which is the main focus of this paper, is unlikely to have been distorted to a significant extent by the contemporaneous central bank information shock.

6 Conclusions

This paper provides some evidence on the financial and macroeconomic impact of the ECB's expanded asset purchase programme (APP), concentrating on the announcement news effects of the January 2015 announcement, based on a structural VAR featuring time-varying parameters and stochastic volatility and a novel identification scheme combining zero, timing and magnitude restrictions derived from the specific institutional features of the APP programme and survey-based evidence quantifying the expectations on asset purchases. Overall, the analysis points to a significant positive macroeconomic impact of the APP announcement shock, with significant short-term responses of both real economic activity growth and HICP inflation and more persistent responses on the level of real output and the HICP. Several financial variables appear to have also been affected by these shocks, including the yield curve, mainly driven by changes in the long-term interest rate, giving rise to a flattening of the yield curve in the short term, followed by a steepening in the medium term. The significant impact of the APP announcement shock on stock prices points to an activation of the portfolio rebalancing channel, while the persistent depreciation of the exchange rate suggests that also the exchange rate channel was operational. Credit market variables also appear to have responded significantly, indicating that the credit channel played a role in the transmission of APP shock, while the evidence on the relevance of the inflation re-anchoring channel and the signalling channel is more uncertain.

Some caveats to be borne in mind when assessing more in general the impact of the APP in the euro area is that the analysis reported in our study only provides a quantification of the impact of the APP announcement shock of January 2015, thus not including also the effects of the re-calibrations of the APP announced in December 2015, March 2016, December 2016 and October 2017, and it does not provide an assessment of the impact of the actual purchases.

As a follow-up to this work, it would be interesting to undertake a similar analysis to other jurisdictions which applied similar policies, such as QE implemented in the US, UK and Japan in recent years, with an appropriate adaptation of the identification scheme such as to reflect the common features of all of these measures, to compare their macroeconomic impact and try to understand what factors might explain possible differences, including the presence of negative interest rates or the interaction of QE with different non-standard monetary policy measures.

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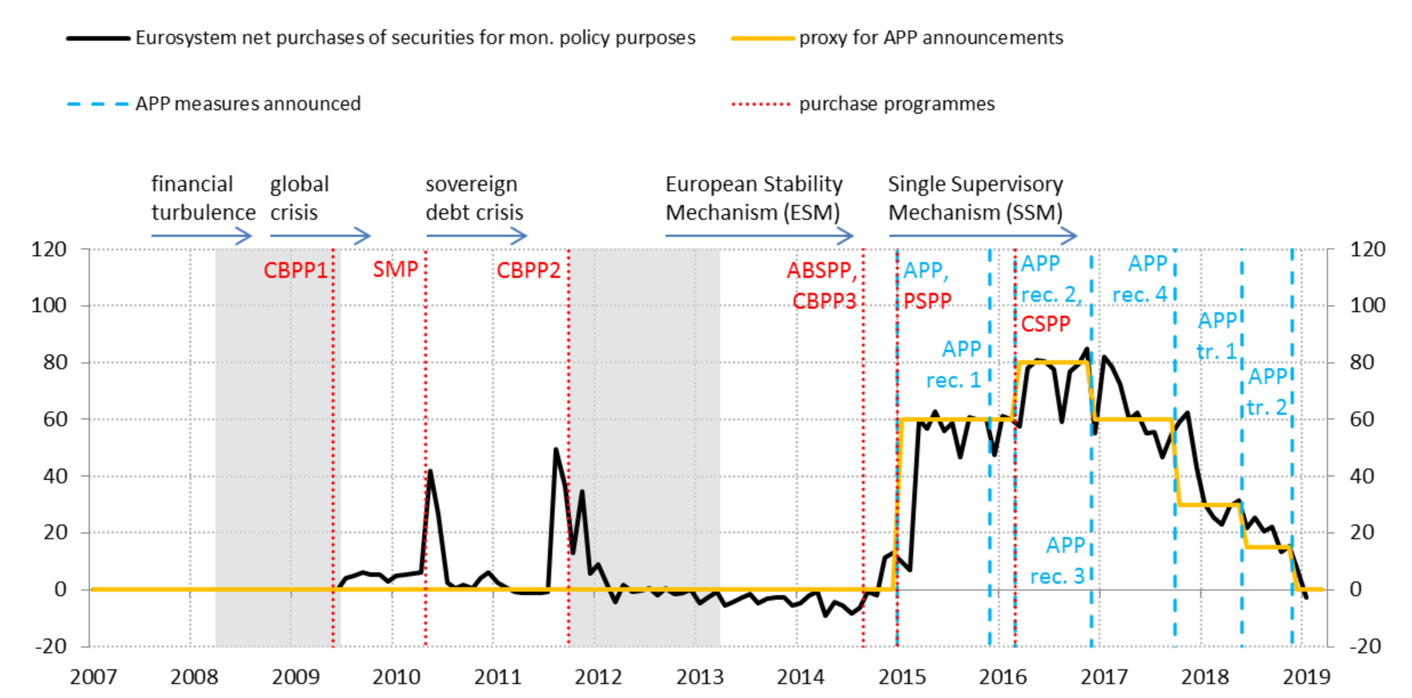
Chart 1 – Eurosystem security purchases for monetary policy purposes and proxy for APP announcements, January 2007 to December 2018

(monthly flows, EUR billions)



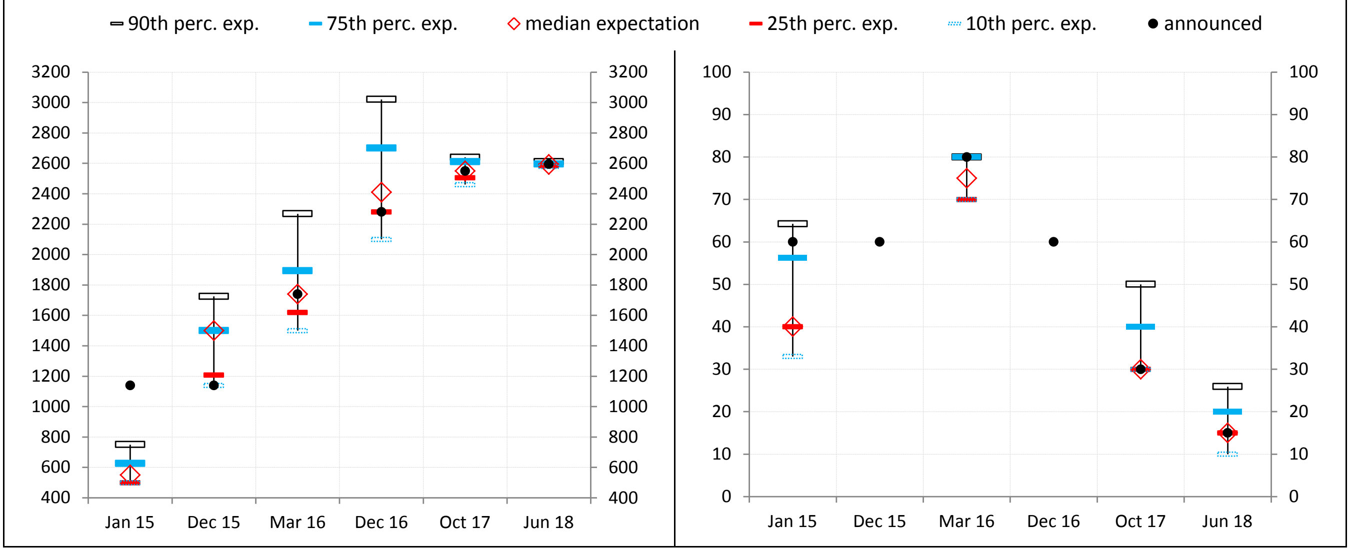
Source: CEPR and European Central Bank.

Note: The arrows and associated text refer to major events or phases. Vertical red dotted lines and associated acronyms refer to major non-standard monetary policy measures adopted by the ECB. Vertical dashed blue lines and associated text delimit the dates of the introduction and subsequent re-calibrations of the expanded asset purchase programme (APP). Shaded areas delimit Euro Area recessions as dated by the CEPR Euro Area Business Cycle Dating Committee.

	Measure	Announcement	Start of programme	End of programme
CBPP1	First Covered Bond Purchase Programme	2 July 2009	July 2009	June 2010
SMP	Securities Markets Programme	10 May 2010	May 2010	September 2012
CBPP2	Second Covered Bond Purchase Programme	3 November 2011	November 2011	October 2012
CBPP3	Third Covered Bond Purchase Programme	4 September 2014	October 2014	December 2018
ABSPP	Asset-backed Securities Purchase Programme	4 September 2014	November 2014	December 2018
APP	Expanded Asset Purchase Programme	22 January 2015	March 2015	December 2018
PSPP	Public Sector Purchase Programme	22 January 2015	March 2015	December 2018
APP rec. 1	APP first re-calibration	3 December 2015		
APP rec. 2	APP second re-calibration	10 March 2016		
CSPP	Corporate Sector Purchase Programme	10 March 2016	June 2016	December 2018
APP rec. 3	APP third re-calibration	8 December 2016		
APP rec. 4	APP fourth re-calibration	26 October 2017		
APP tr. 1	APP first transition	14 June 2018		
APP tr. 2	APP second transition	13 December 2018		

Chart 2 – Results of Bloomberg survey on expectations of APP security purchases ahead of ECB's Governing Council meetings with major APP announcements

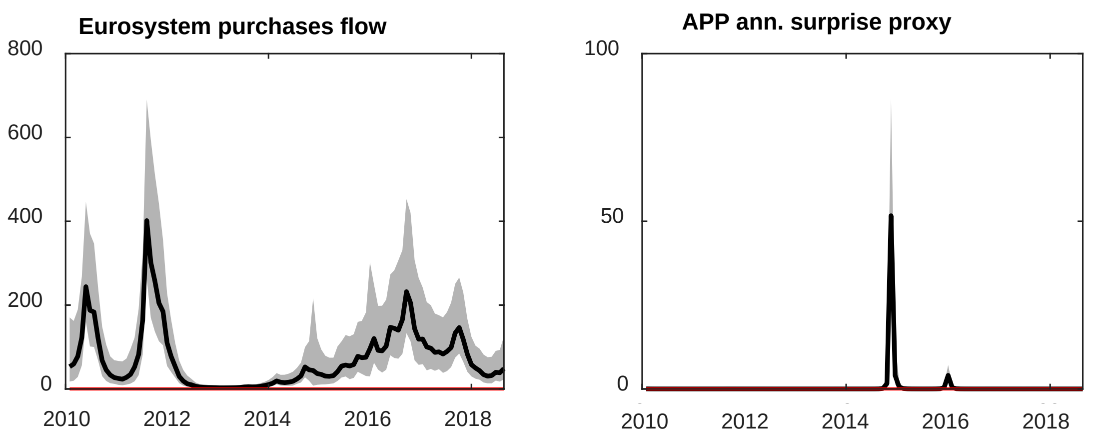
Expected total amount of APP purchases	Expected monthly amount of APP purchases



Source: Bloomberg and ECB.
Note: Median, 10th, 25th, 75th and 90th percentiles of total and monthly amounts of security purchases related to the APP programme expected by experts consulted by Bloomberg few days before meetings of the ECB Governing Council when major APP decisions were announced. Vertical axes refer to billions of euros. For surveys ahead of the Dec. 2015 and Dec. 2016 meetings no information is available on quantitative monthly purchases expectations.

Date	Announcement	Governing Council meeting	Bloomberg survey
Jan. 2015	APP initial announcement	22 January 2015	19 January 2015
Dec. 2015	APP first re-calibration	3 December 2015	25 November 2015
Mar. 2016	APP second re-calibration	10 March 2016	7 March 2017
Dec. 2016	APP third re-calibration	8 December 2016	2 December 2016
Oct. 2017	APP fourth re-calibration	26 October 2017	22 October 2017
Jun. 2018	APP first transition	14 June 2018	8 June 2018
Dec. 2018	APP second transition	13 December 2018	Not available

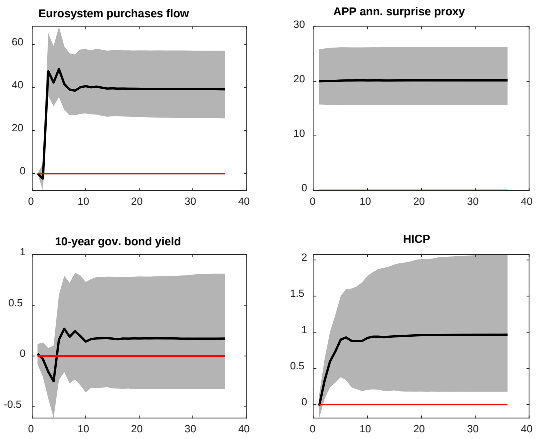
Chart 3 - Stochastic volatility



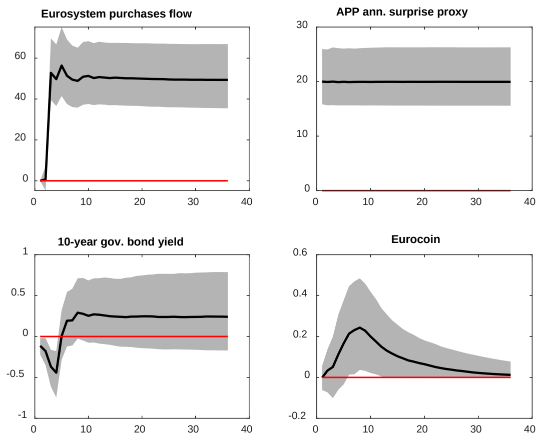
Note: Residual time-varying variances. Black full lines: posterior medians. Grey areas: areas delimited by the 16th and 84th percentiles.

Chart 4 - Impulse response functions of macroeconomic variables to the January 2015 APP announcement shock

Model with the HICP



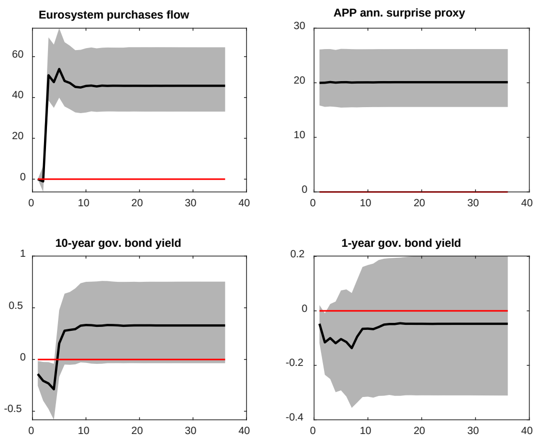
Model with Eurocoin



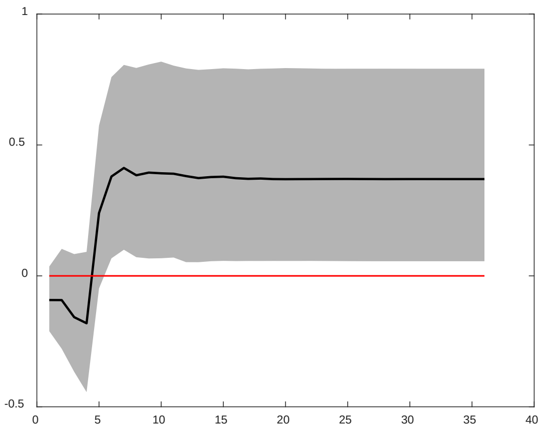
Note: Full black lines are the median impulse response functions, grey areas delimit the space between the 16th and 84th percentiles of impulse response functions. Median responses and percentiles multiplied by the estimated size of the shock in the respective month. Horizontal axes refer to number of months, while vertical axes refer to billions of euros (for Eurosystem purchase flow and APP announcement proxy), percentages (for the HICP) or percentage points (for long-term interest rates and Eurocoin).

Chart 5 - Impulse response functions of the yield curve to the January 2015 APP announcement shock

Model with the 10-year and 1-year yields

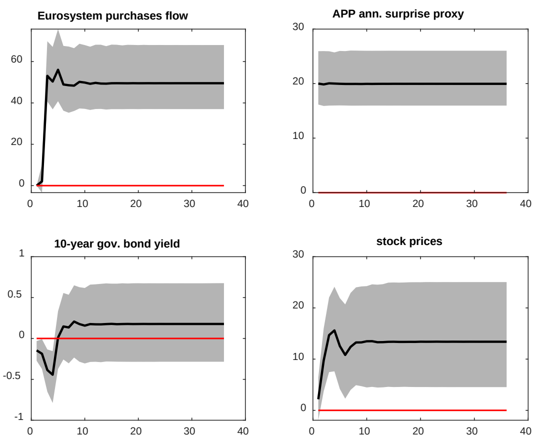
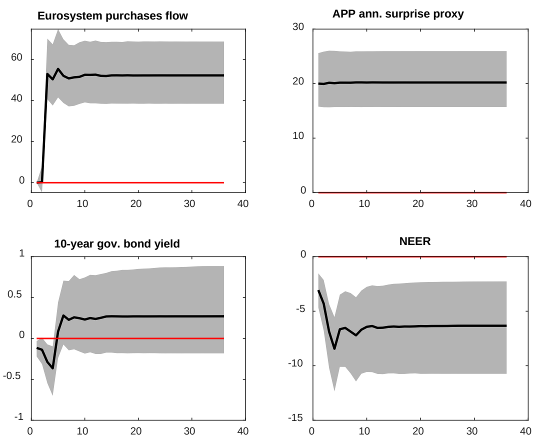


Slope of the yield curve (10Y yield – 1Y yield)



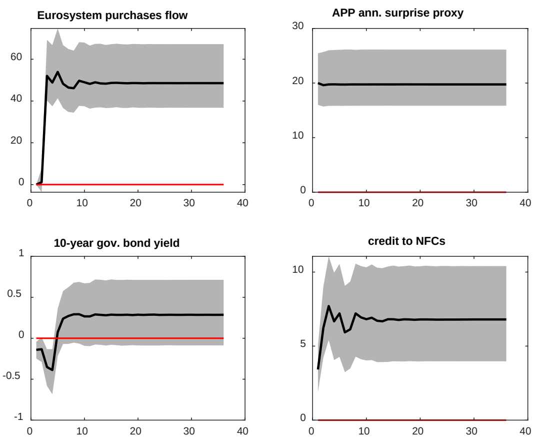
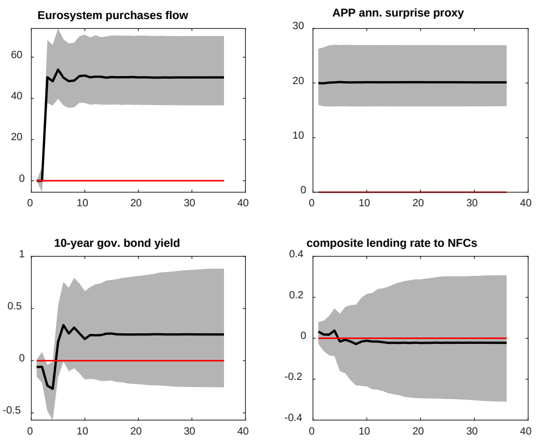
Note: Full black lines are the median impulse response functions, grey areas delimit the space between the 16th and 84th percentiles of impulse response functions. Median responses and percentiles multiplied by the estimated size of the shock in the respective month. Horizontal axes refer to number of months, while vertical axes refer to billions of euros (for Eurosystem purchase flow and APP announcement proxy) or to percentage points (for interest rates).

Chart 6 - Impulse response functions of financial variables to the January 2015 APP announcement shock

Model with stock prices	Model with the nominal effective exchange rate (NEER)
	

Note: Full black lines are the median impulse response functions, grey areas delimit the space between the 16th and 84th percentiles of impulse response functions. Median responses and percentiles multiplied by the estimated size of the shock in the respective month. Horizontal axes refer to number of months, while vertical axes refer to billions of euros (for Eurosystem purchase flow and APP announcement proxy) or percentages (for stock prices and exchange rates).

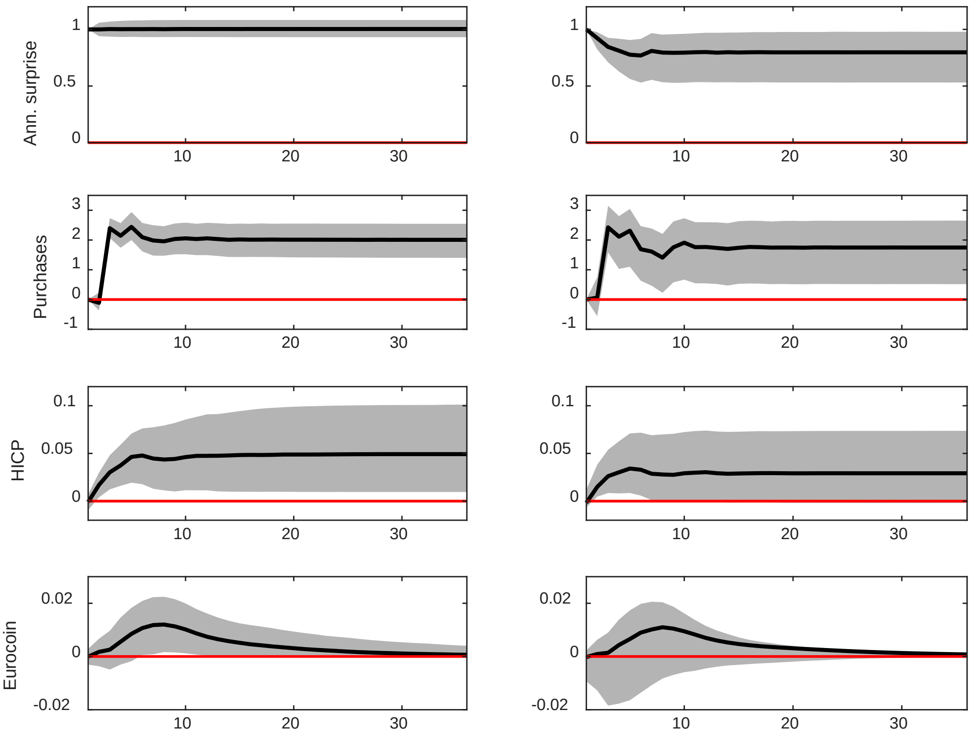
Chart 7 - Impulse response functions of credit market variables to the January 2015 APP announcement shock

Model with credit to non-financial corporations (NFCs)	Model with the bank composite lending rate to non-financial corporations (NFCs)
	

Note: Full black lines are the median impulse response functions, grey areas delimit the space between the 16th and 84th percentiles of impulse response functions. Median responses and percentiles multiplied by the estimated size of the shock in the respective month. Horizontal axes refer to number of months, while vertical axes refer to billions of euros (for Eurosystem purchase flow and APP announcement proxy), percentage points (for lending rates) or percentages (for credit). NFC stands for non-financial corporations.

Chart 8 – Comparison of IRFs of VAR models with time-varying coefficients (TV-VAR) and VAR models with constant parameters (VAR)

TV-VAR models	VAR models



Note: Full black lines are the median impulse response functions, grey areas delimit the space between the 16th and 84th percentiles of impulse response functions. Median responses and percentiles standardised, with size of the shock normalised to one billion. Horizontal axes refer to number of months, while vertical axes refer to billions of euros (for Eurosystem purchase flow and APP announcement proxy), percentages (for the HICP) or percentage points (for long-term interest rates and Eurocoin).