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The impact of size, composition and duration of the central bank balance sheet on inflation expectations and market prices

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ABSTRACT

We analyse the effects of announcements of changes in the Eurosystem's balance sheet size, duration and composition on inflation expectations, the exchange rate, the 10-year euro area government bond yield and stock returns, using local projections. We explicitly take into account interaction effects between the three balance sheet dimensions. We provide evidence for the duration extraction channel of monetary policy transmission as we find that the bond yield is sensitive to the combined impact of shocks to balance sheet size and duration. The exchange rate is also affected by a joint size-duration shock. Moreover, the bond yield and exchange rate are sensitive to the joint effect of changes in size and composition. The results indicate that interactions between balance sheet dimensions matter.

Central banks' balance sheets have become an important topic in monetary policy discussions, in particular since central banks have increasingly made recourse to non-standard monetary policy measures over the past decade. By engaging in unconventional monetary policy the central bank actively uses its balance sheet to influence financial market outcomes, the real economy, inflation expectations, and ultimately inflation. On the asset purchase side, transmission channels include the signalling channel, the portfolio rebalancing and in particular the duration extraction channel. For refinancing operations, in particular liquidity effects play a role. In this paper, we assess the impact of different dimensions of the Eurosystem's balance sheet – size, duration and composition – on inflation expectations in the euro area[1], the 10-year benchmark euro area bond yield, the euro nominal effective exchange rate and stock returns between April 2008 and June 2017, including to shed light on those transmission channels. Also given that the exchange rate and stock prices are no targets for monetary policy, the effect on these variables is likely of indirect nature, driven by changes in market expectations and spill-overs from changes in other variables. By focussing on announcements of balance sheet policies, not their implementation, we analyse the importance of stock effects, i.e. effects of changes in market expectations on the future central bank portfolio (e.g. regarding size, duration or composition) induced by new information, in the transmission of monetary policy.

The ECB has embarked on non-standard policies expanding the Eurosystem balance sheet since the global financial crisis, mindful of euro area-specific institutional factors. While the Federal Reserve already announced large-scale asset purchases of mortgage-backed securities in 2008, the ECB's measures centred around liquidity provision in 2007–2009. In addition to rate cuts, the ECB expanded the range of eligible collateral for its refinancing operations and introduced measures to ensure the elastic supply of liquidity to banks, including through long-term refinancing operations. During the sovereign debt crisis of 2011–2012 and amid financial fragmentation along national lines and banks in vulnerable countries losing access to wholesale funding, which led to a serious disruption of the monetary policy transmission mechanism, the ECB carried out further long-term refinancing operations. It also announced the Outright Monetary Transactions (OMT) Programme and

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the Securities Markets Programme (SMP). The prolonged slump of the euro area economy and bank deleveraging through reduced lending by mid-2014 constituted growing risks that low inflation could de-anchor inflation expectations and cause a deflationary spiral. With short-term rates already close to zero, the ECB embarked on a negative interest policy and introduced targeted long-term refinancing operations to support bank lending to the private sector. Furthermore, the ECB announced the expanded asset purchase programme (APP), encompassing the asset-backed securities programme, the third covered bond purchase programme and the secondary market purchase of bonds issued by euro area central governments, agencies and European institutions in January 2015.[2] In March 2016, a second round of TLTROs was introduced to reinforce the ECB's accommodative monetary policy stance and to strengthen the transmission of monetary policy by further incentivising bank lending to the real economy, together with a new corporate sector purchase programme. The ECB interest rates were further cut, bringing the rate for the main refinancing operations to zero. Institutionally, euro area specific safeguards were introduced for the non-standard policy measures, to take into account the particular circumstances in the monetary union, in particular with regard to asset purchases. Specifically, the amounts of securities purchased under the public sector purchase programme (PSPP) were guided by the Eurosystem's national central banks' capital key, implemented in a decentralised manner across the Eurosystem, subject to issue share and issuer limits, not conducted around dates of new issuance and risk sharing was limited to 20% of the PSPP portfolio. These measures aimed to preserve market functioning and price formation and to ensure the purchases would not be perceived as circumventing the euro area's monetary financing prohibition (Article 123 of the Treaty on Monetary Union; see also Hartmann and Smets 2018).

Our study of non-standard monetary policy in the euro area relates to both the literature on transmission channels of unconventional policies, in particular to signalling and duration extraction, and to the existing, but much scarcer literature on the composition of the central bank balance sheet. In the euro area, the size and composition of the balance sheet has traditionally been determined by the liquidity demand of banks. With the start of the APP, however, there has been a shift to more active management of size, duration and composition for monetary policy purposes (ECB 2015). Our study sheds light on the effects of this more active management of the balance sheet. We construct measures of unexpected balance sheet shocks across the three dimensions (size, duration, composition). Specifically, we identify innovations to the balance sheet dimensions, purged of anticipatory effects as reflected in market prices. We use these innovations to estimate announcement effects, based on local projections following from a single equation model for the period 2008:4–2017:6. A multi-equation Bayesian VAR (BVAR) is used for robustness checks. The main innovation of this paper is the use of multiple balance sheet dimensions as monetary policy surprises. By this we do not only analyse isolated effects of shocks to each balance sheet dimension, but also assess the joint effects of shocks to size and duration and size and composition. Most other studies only look at different instruments in isolation. In particular, the interaction between size and duration is of interest, as it reflects the duration extraction channel, which is effective when duration is taken out of the market by the central bank while its balance sheet size rises in tandem.[3]

We find evidence for the importance of the duration extraction channel (the interaction of size and duration as measured by the weighted average maturity balance sheet) for monetary policy transmission. It turns out that in particular combined shocks to the balance sheet dimensions and not so much isolated shocks matter. Specifically, the interaction effect of *size and duration* has a significant negative impact on both the bond yield and exchange rate. It implies a larger negative effect of an increasing balance sheet size on the bond yield and exchange rate when the central bank takes more duration from the market, while increasing its balance sheet and vice versa. These effects are found to be quite persistent. We also find (a somewhat weaker) interaction effect of *size and composition* on the bond yield and exchange rate, which points at a larger positive effect of an increasing balance sheet size on both variables when the asset portfolio becomes more concentrated and a larger negative effect when it becomes more diversified. This outcome suggests that a more diversified central bank portfolio with a growing balance sheet size leads to looser financial conditions (through a lower bond yield and a depreciation of the exchange rate). These outcomes are robust to different model specifications as they also emerge from a BVAR model-based analysis. This suggests that the combined effects of shocks are important for the transmission of non-standard monetary policy measures. The combined effect of size and duration and the fact that the empirical analysis is based on announcements of policy measures, not their implementation, underline the importance of stock effects of central bank balance sheet policies. For isolated shocks in size,

duration or composition we do not find a significant effect on the bond yield, but shocks to size or duration have a significant downward effect on the exchange rate. Finally, isolated shocks to balance sheet size and composition have a significant upward effect on inflation expectations in the single equation approach, but not in the BVAR. This suggests that the effects of balance sheet policies on inflation expectations are harder to trace in a dynamic multi-equation system. Finally, we find that shocks to balance sheet size are associated with a significant positive response of stock returns, of bank stocks in particular.

The findings are relevant since they shed light on effects of balance sheet policies on inflation expectations and main intermediary variables. The relative effects of size, duration and composition could guide decisions on the optimal use of the balance sheet in a post-crisis environment.

The remainder of this paper is structured as follows. Section 1 provides an overview of the literature on the main transmission channels. In section 2 we explain our empirical approach, including the balance sheet metrics, the construction of the monetary policy shock series and the modelling strategy. Section 3 presents the estimation results and section 4 concludes.

1. Literature review

Asset purchases may affect the economy through the portfolio rebalancing channel, which is often cited as the main channel through which quantitative easing (QE) affects financial markets and the economy (Krishnamurthy and Vissing-Jorgensen 2011; D'Amico et al. 2012; Joyce et al. 2012). An important form of portfolio rebalancing is the duration extraction channel (see Vayanos and Vila 2009, for a theoretical model).[4] Through this channel the central bank can alter the yield curve, particularly reducing long-maturity bond yields relative to short-maturity yields (reflected in the term premium), by taking out duration risk from the market. Inflation expectations may increase if lower interest rates relax borrowing and spending constraints and raise the value of assets. The portfolio rebalancing channel works in the context of imperfect asset substitutability, which means that central bank purchases of long-term bonds in exchange for central bank reserves or deposits induce a change in asset prices or consumption (see Bridges and Thomas 2012 for a more detailed explanation). Inflation expectations may increase as a result of higher consumption, which is stimulated by a decline in the intertemporal rate of substitution (the real interest rate falls when bond yields decrease).

Several studies provide empirical support for the transmission of monetary policy measures via the duration channel. For the euro area, Altavilla, Carboni, and Motto (2015) use an event study approach to evaluate the effects of the APP through different transmission channels, including the duration channel. They find that APP announcements lower the whole term structure of the assets analysed (the Bund and, in a broader definition of the duration channel, across all long-term duration bonds measured in CDS-adjusted sovereign bond yields of selected euro area countries) by lowering the duration risk in the market. Blattner and Joyce (2016) consider free-float of government bonds, which weights the amount of outstanding debt in the euro area by maturity structure. According to their macro-finance BVAR model, this channel of the APP raised inflation by 0.3 percentage point in 2016 by reducing the maturity-weighted amount of government bonds outstanding in the market. Andrade et al. (2016) show that the Eurosystem's APP has positive effects on inflation expectations, measured by survey data, attributing this effect to the portfolio rebalancing channel (but also to positive signalling effects of QE announcements). They also find evidence of the capital relief channel, through which banks' capital position benefits from higher prices of sovereign bonds induced by central bank asset purchases. Brunnermeier and Sannikov (2016) have coined this indirect recapitalisation through a price appreciation of bank security holdings as 'stealth recapitalization'. Gambetti and Musso (2017) show in a time-varying parameter VAR with stochastic volatility that stock prices increase by almost 10% after the initial APP announcement, providing empirical support for the portfolio rebalancing channel.[5] Boeckx, Dossche, and Peersman (2017) show in a structural vector autoregression (SVAR) model that equity prices increase and the intra-euro area sovereign spread vis-à-vis Germany declines after unexpected balance sheet expansions, which suggests the presence of portfolio rebalancing. They relate the effects on market prices to changes in the size, not in duration. Moreover, their sample covers the 2007–2014 period, whereas our study also covers large parts of the APP. For the US, Gagnon et al. (2011) find that by reducing the net supply of assets with long duration, the Fed's QE programmes have reduced the term premium by somewhere between 30 and 100 basis points. In an event study framework, Cahill

et al. (2013) find that the duration risk channel accounts for an average decline in yields of about 4.5 basis points per USD 100 billion surprise purchase.[6] D'Amico and King (2013) find a 3.5 basis point flow and 30 basis point stock effect of portfolio rebalancing, while Hamilton and Wu (2012) find a 13 basis point decrease in 10-year Treasury yields if the Federal Reserve sells $400 billion short-term and buys long-term assets of the same amount. Including yield factors as well as Treasury and mortgage-backed securities supply factors into an arbitrage-free term structure model, Li and Wei (2013) document that the Large-Scale Asset Purchases couple with the maturity extension programme depressed long-term yields by around 100 basis points. Ihrig et al. (2012) account for market expectations in a no-arbitrage term structure model and find a reduction of 65 basis points of the 10-year yield induced by several asset purchase programmes of the Federal Reserve between 2008 and 2012.[7] Conducting an event study for Operation Twist, Swanson (2011) provides evidence that Treasury yields and agency bond yields declined following policy announcements. Chen, Cúrdia, and Ferrero (2012) evaluate the Federal Reserve's second large scale asset purchasing programme (LSAP) in a DSGE model with bond market segmentation and find limited evidence for effects of the programme through limits to arbitrage between short- and long-term government bonds. Introducing US QE announcements into a structural vector autoregression model, Meinusch and Tillmann (2016) find a 0.05 percentage points decrease in 10-year US government bond yield (and a positive effect on growth and inflation). Relying on an event study and the two-stage least squares approach by D'Amico and King, Meaning and Zhu (2011) confirm that asset purchases programmes in the US and UK depressed long-term yields, but found a larger impact for the respective first programme compared to latter programmes. Weale and Wieladek (2016) estimate a Bayesian VAR (BVAR) to examine the impact of large scale asset purchases on real GDP and inflation in the UK and the US. They find that the portfolio rebalancing channel was particular important in the US (but not in the UK[8]). For Japan, Schenkelberg and Watzka (2013) provide some evidence of portfolio rebalancing as their QE shock in a structural VAR depresses long-term yields.[9]

Non-standard measures can also impact the economy via the signalling channel, i.e. influence market expectations on the future short-term interest rate and the monetary policy stance (by revealing a changed view on future economic outcomes). In the case of inflation expectations, increases in balance sheet size may increase inflation expectations as it is seen as a signal reinforcing central bank forward guidance to keep an accommodative monetary policy stance for an extended period of time. In theory, signalling a continued loose monetary policy stance should reduce long-term bond yields and lead to a depreciation of the euro. Several studies provide empirical evidence for the signalling channel. For the US, Krishnamurthy and Vissing-Jorgensen (2011) assess different transmission channels of QE1 (2008–2009) and QE2 (2010–11) in the US in an event study framework and find that the signalling channel is of primary importance for transmission, in particular for QE2. Glick and Leduc (2012) suggest that the Fed's asset purchase announcements may have signalled lower expectations for the growth going forward, leading to a depreciation of the dollar. Bauer and Rudebusch (2014) rely on an event study and a model-based analysis, a decomposition of the yield curve into term premium and expectations components, arguing that long rates were depressed as asset purchase announcements changed the market's expectation for the future monetary policy stance. Thorbecke (2017) estimates the effect of the various rounds of LSAPs in the US on inflation expectations in a multi-factor asset pricing framework. He finds that initially LSAP announcements lowered expected inflation – as they were perceived as signalling lower growth and lower inflationary pressures – and only as inflation approached its target did news around LSAPs raise expected inflation. For the euro area, Sahuc (2016) uses a DSGE model to assess the ECB's APP and concludes that the signalling channel was the channel through which the APP affected the economy. Varghese and Zhang (2018) decompose announcement effects of unconventional monetary policies in the euro area into signalling and portfolio rebalancing components and measure the effect on inflation expectations, exchange rates and other variables. They find that the portfolio rebalancing channel has gained importance in driving inflation expectations (up) since the APP was launched in 2014, but that signalling remained the most important channel. As in Gambetti and Musso (2017) we subsume the inflation re-anchoring channel under the signalling channel. Moessner (2015) provides some evidence in this context, analysing the effects of balance sheet policy announcements on selected asset purchase programmes and long-term financing operations by the Eurosystem on market-based measures of inflation expectations in an event study framework. The author finds that the announcement of asset purchase programmes and long-term refinancing operations led to only a slight increase in long-term inflation

expectations, which she sees as confirming that inflation expectations are well anchored. For Japan, Ugai (2007) provides a review of empirical studies on quantitative easing in Japan, arguing that it was mostly the signalling channel (not the portfolio rebalancing channel) through which the policies took effect. In the literature, the signalling channel is the important channel through which the exchange rate is influenced, which suggests that exchange rate effects are mainly driven by changes in market expectations and spill-over effects from changes in other variables, such as bond yields.

Some studies explore the effects of changes in the composition of the central bank balance sheet. Gambacorta, Hofmann, and Peersman (2014) investigate effects of central bank balance sheet shocks on output and inflation in a panel VAR for eight countries. They find qualitatively similar results (temporary upward effect on output and inflation) for all economies, independent of the composition of the measures and conclude that therefore the composition of the balance sheet plays a minor role in explaining effects of balance sheet policies. Cúrdia and Woodford (2010) show in a DSGE model that credit policy (i.e. targeted asset purchases of different assets, not only Treasuries) are effective when financial markets are distressed, thus pointing to a role for the composition of the balance sheet in achieving monetary policy targets. Krishnamurthy and Vissing-Jorgensen (2011) assess the safety channel of QE (i.e. purchasing assets of different safety classes), which is closely linked to the questions of the composition of the balance sheet. They find a substantial contribution of it to lowering yields in the US in 2009–09 and to a more limited extend in effect in 2010–11. The potential effects of asset composition on inflation expectations, the exchange rate and the average bond yield are not unambiguous. For example, on the one hand, larger asset concentration could raise inflation expectations if the targeted asset class is of particular importance for transmission. On the other hand, lower asset concentration could increase inflation expectations as it would suggest a broad reach of the central bank with support for different, potentially numerous, sectors of the economy at a given moment. In both cases, private borrowing costs would be reduced as market rates compress lending rates and, as a consequence, financial market conditions improve, bolstering economic growth and inflation expectations.

2. Empirical strategy

We first construct metrics of announcements of changes to three balance sheet dimensions, i.e. size, duration and composition. We then use these metrics to construct monetary policy surprise series for the empirical analysis. We estimate a single equation model using local projections, following Jorda (2005), to assess the effects of the monetary policy shocks. Local projections do not require specification and estimation of the unknown true multivariate dynamic system like a VAR. This makes local projections robust to misspecification. We use a multi-equation BVAR model as robustness check. The models are estimated for the period 2008:4–2017:6. We focus on this period for two reasons: First, pre-crisis the balance sheet was not an instrument actively used by the Eurosystem for monetary policy purposes. Second, the availability of pre-crisis data on the balance sheet dimensions is limited, in particular for duration held on the portfolio. This section first presents the balance sheet metrics and data we use, then outlines how the monetary policy shocks are identified and finally presents the modelling approach.

2.1. Balance sheet dimensions and metrics

To empirically disentangle the effect of different balance sheet dimensions on inflation expectations, the average euro area bond yield, the euro exchange rate and stock returns, we further develop the approach of Van den End and Pattipeilohy (2017, hereafter VP (2017)). They use metrics for the size and composition of the central bank balance sheet to analyse their effect on inflation expectations and the exchange rate in a VAR framework. Our paper adds to VP (2017) in four ways. First, we include a duration measure, next to size and composition measures. Second, we rely on local projections from a single-equation regression, complementing their VAR approach, and include interaction effects. Third, we construct measures of shocks to size, duration and composition that are purged from anticipation effects, to obtain exogenous innovations. Fourth, we use a longer sample horizon to include the APP.[10]

Our approach also differs from the one pursued in VP (2017) when it comes to interpreting the balance sheet variables. In their study, the size variable is seen as measure of QE and the composition measure as proxy for credit easing. In Lenza, Reichlin, and Pill (2010), quantitative easing means a policy whereby a central bank increases its balance sheet size without changing the composition of central bank assets. In its purest form, the central bank would increase the size of the balance sheet by adding the same proportion of all asset types to its portfolio. By contrast, credit easing refers to a change in asset composition, while leaving total balance sheet size unchanged, thus substituting one asset class with another. As pointed out by Lenza, Reichlin, and Pill (2010) this distinction was rather accurate prior to 2008, but has become more blurred since unconventional policies that affect both size and composition of the balance sheet at the same time have been enacted. For example, credit easing policies, can increase concentration and size simultaneously. Lenza, Reichlin, and Pill (2010) emphasise this for the ECB's 'enhanced credit support' measures introduced in 2009, supporting banks and money markets at the same time.[11] Likewise, QE – e.g. through the APP in the euro area – can lift concentration when it targets a particular asset class such as government bonds, while it is also reflected in a larger balance sheet size. We therefore distinguish between size and composition effects and do not see them necessarily as proxies for quantitative and credit easing. Overall, even though our approach may not perfectly separate size, duration and composition effects, it provides some tentative insights on whether or not effects differ and, if so, what implications this could have for the use of the balance sheet in the long run.[12] We use three metrics of the Eurosystem balance sheet in our analysis. One for balance sheet size, one for the duration held in the portfolio and one for the composition of the balance sheet. The balance sheet data for the size, duration and composition metrics are from the ECB.

We focus on announcements regarding the implementation of non-standard measures, not on implementation effects in the sense of flow effects.[13] Announcement effects are usually estimated by event studies, which focus on the effects of policy announcements on financial market prices based on high frequency data (see e.g. Altavilla, Carboni, and Motto 2015). Such studies are mostly confined to a very short window over which the effects of the event are measured and thus do not capture the persistence of the effects. To account for persistent effects, we follow Hesse, Hofmann, and Weber (2017), who include cumulative asset purchase announcement series in a BVAR model to estimate the effect on GDP, inflation, bond yields and stock prices in the US and UK.[14] In our case, the cumulative sum of the announcements is constructed by adding up the nominal amounts of long-term refinancing operations (LTROs) and asset purchases on the balance sheet over the announced horizon at the date of the announcement.[15] For example, the Eurosystem's corporate sector purchase programme was announced in March 2016, but implemented as of June 2016. In our metric, the programme enters the balance sheet in March (and remains constant over the remainder of the sample period). Our approach to construct the cumulative metrics differs somewhat from Hesse, Hofmann, and Weber (2017), as in the euro area not all operational features of the unconventional measures were announced upon introduction of a measure.[16] Thus, our metrics are proxies of market expectations formed at announcement dates, not a perfect measure of them. We use the metrics to construct exogenous monetary policy shocks in the next section, accounting for expectations ahead of announcements that are reflected in market prices. Thus, while the measures of balance sheet policies do not account for the build-up of expectations ahead of announcements, we do account for anticipatory effects when constructing the monetary policy shocks.

Size is measured by total assets related to monetary policy instruments on the Eurosystem balance sheet scaled by euro area GDP for each month in the sample (based on real GDP, quarterly data, interpolated, EA-19 fixed composition, source: Datastream).

Composition is reflected by the Herfindahl index (*HI*) of the distribution of Eurosystem asset holdings. We only include assets that relate directly to monetary policy measures (on a euro area aggregate level).[17] The *HI* statistic is determined for each month in the sample (end-of-month). *HI* is size neutral, since it is normalised by the balance sheet size as follows:

$$HI = \sum \left(\frac{x_j}{\sum x_j} \right)^2$$

where x_j, for $j = 1 \ldots n$ reflects the different asset classes in the Eurosystem's monetary policy portfolio. Specifically, it reflects assets related to refinancing operations (main refinancing operation (MROs) and LTROs),

fine-tuning operations, marginal lending and asset purchases (the Covered Bond Purchase Programmes (CBPP) 1–3, the Securities Markets Programme (SMP), the Asset-backed Securities Purchases Programme (ABSPP), the Public Sector Purchase Programme (PSPP)[18] and the Corporate Sector Purchase Programme (CSPP)).[19] Metric *HI* ranges between close to 0 and 1. An increase of *HI* reflects increased asset concentration in the Eurosystem's asset portfolio. The extreme case of $HI = 1$ would mean that the central bank only holds a single type of asset. If the index is close to zero, it indicates that the central bank holds almost equal shares of each asset class in its portfolio.

Duration is measured by the weighted average maturity of LTROs and asset purchases.[20] This indicator is created by weighting the maturity (m_j) of the (6 month, 1, 3 and 4 years) LTROs and the purchased assets by their outstanding amounts (k_j).[21]

$$Dur = \frac{\sum (m_j * k_j)}{\sum k_j}$$

The composition measure evolves in five phases (Figure 1). First, concentration increases in 2008 and, to a greater extent, 2009. When the Eurosystem introduced LTROs with maturities longer than the previously standard three months to support the funding liquidity of banks, these became the most dominant monetary policy instrument. Second, concentration decreases in late 2010, driven by the maturing of the 12-month LTROs (which had been decided upon in May 2009; see Eser et al. 2014 for further information) and a somewhat stronger recourse to the main refinancing operations by banks. Third, concentration increases again in late-2011 and in 2012, mostly driven by long-term refinancing operations. Fourth, concentration decreases between 2014 and 2015 due to the ending of the three years LTROs. Finally, concentration takes an upward trend at the start of 2015, this time driven by the PSPP. Figure 1 depicts the relationship between asset holdings related to selected monetary policy operations and the composition measure. Between 2010 and mid-2014 concentration was mostly driven by developments in the LTROs. However, as of mid-2014 purchases of different asset classes start diversifying the portfolio more strongly. Thus, interestingly, the LTROs led to a stronger rise of the *HI* index (i.e. higher
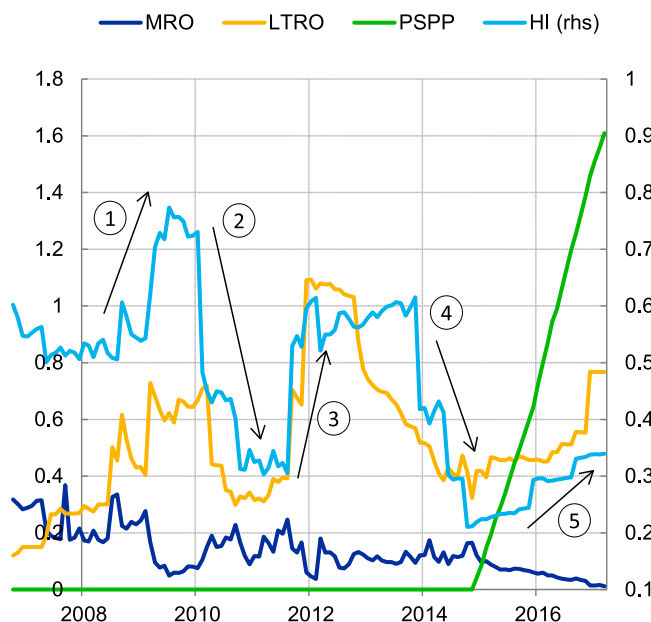
Figure 1. Balance sheet composition and selected monetary policy instruments of the Eurosystem.
Notes: Here the Public Sector Purchase Programme (PSPP) reflects both government and supranational bonds. Over the full sample period, the *HI* metric is positively correlated with the main refinancing operations (MROs; 0.1) and the long-term refinancing operations (LTROs; 0.5). The latter relationship strengthens in the period since March 2015 (to 0.7). The correlation with the PSPP is large and positive (0.8) since March 2015 (first month with non-zero PSPP assets on the balance sheet). Source: Datastream, ECB, own calculations.

Table 1. Relative share of monetary policy instruments in the Eurosystem's total monetary policy-related assets, *HI*.

Time	MRO	LTRO	CBPP	SMP	ABSPP	PSPP	CSPP	*HI*
				Instrument share				
2008:4	36.97%	63.03%	–	–	–	–	–	0.534
2009:6	18.73%	81.27%	–	–	–	–	–	0.621
2014:6	14.78%	58.24%	6.34%	20.64%	–	–	–	0.415
2017:6	0.41%	26.99%	8.29%	3.47%	0.85%	56.60%	3.40%	0.339

Note: MRO are the main refinancing operations, LTRO the long-term refinancing operations, CBPP the covered bond purchase programmes. SMP is the Securities Markets Programme, ABSPP the asset-backed securities purchase programme and CSPP the Corporate Sector Purchase Programmes. *HI* is the composition variable, i.e. the Herfindahl index, described in Section 2.1. In the *HI* the CBPP 1–3 and the purchases of government vs supranational organisations' bonds under the PSPP are included separately instead of in aggregate terms in this table.
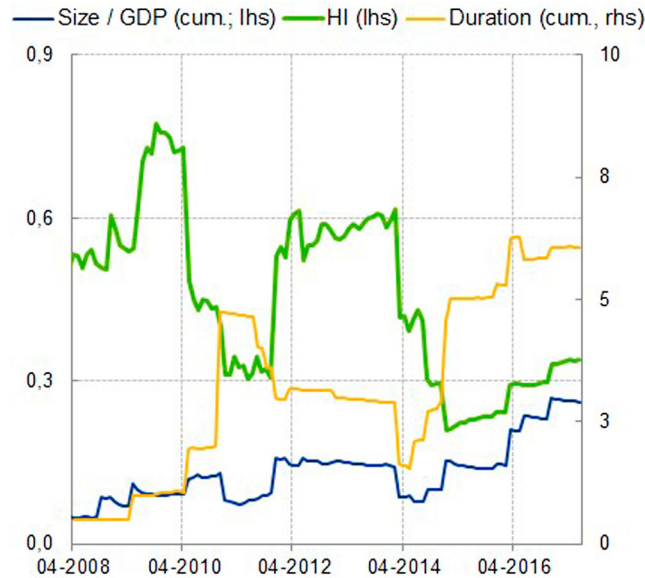
Figure 2. Announcement-based measures of Eurosystem balance sheet size, duration and composition (2008:4 –2017:6).
Note: Size is the Eurosystem balance sheet size as a fraction of euro area GDP. HI is the Herfindahl index. Duration is the remaining weighted average maturity in years. Sources: Datastream, ECB, own calculations.

concentration) than the APP, where, next to government bonds, purchases of various asset classes decreased portfolio concentration. While Figure 1 only shows the PSPP, the other purchase programmes may explain why concentration is not affected more strongly by the APP until late in the reference period. A more complete chart is included in Appendix B. The relative share of the monetary policy instruments constituting the concentration index together with the *HI* are presented in Table 1.

The size measure shows three expansions: a smaller one in 2008, a large one in 2011–2013 and an even larger one since the beginning of 2015 (Figures 2 and 3). The first increase relates to the crisis measures conducted to support market and funding liquidity during the stress conditions following the Lehman collapse. In the case of the ECB this was reflected in increased recourse to the MROs, the marginal lending facility and, to the largest extent, to the LTROs that were offered to support the funding liquidity of banks. The second increase in 2011–2013 was related to LTROs and, to a much more limited extent, the SMP.[22] The third and largest expansion in the size of the ECB's balance sheet is associated with the APP.

The duration evolves in two large waves over the sample period. First, it increased sharply in 2010, owing to the purchases of bonds under the CBPP and SMP.[23] Second, duration has increased even more from mid-2014 onwards, when ECB introduced measures to provide additional monetary policy accommodation to support
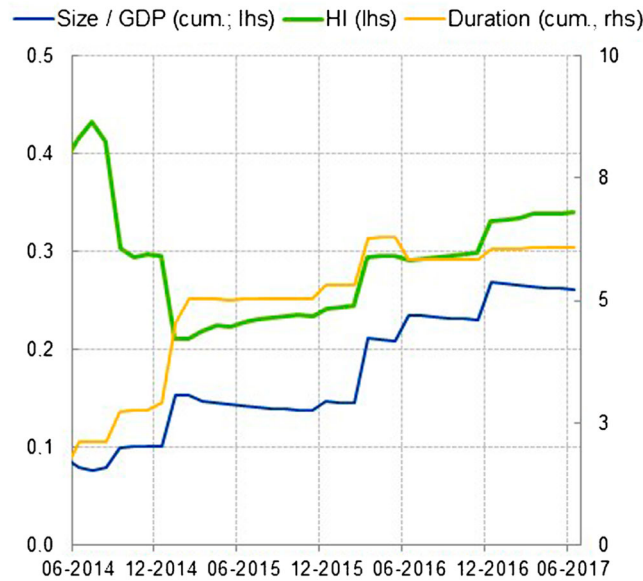
Figure 3. Announcement-based measures of Eurosystem balance sheet size, duration and composition (2014:6 –2017:6).
Note: Size is the Eurosystem balance sheet size as a fraction of euro area GDP. HI is the Herfindahl index. Duration is the remaining weighted average maturity in years. Sources: Datastream, ECB, own calculations.

lending to the real economy. In particular the TLTROs and the asset purchased under the APP have led to an increase of duration on the Eurosystem's balance sheet.

Over the whole sample period the size and composition metrics show a slight negative correlation (−0.28, in non-cumulative terms), reflecting the fact that the Eurosystem increased its balance sheet size, while also diversifying its asset side (i.e. an increase in the size measure and a decrease in *HI*, meaning a decrease in concentration). The correlation turns positive with increasing asset purchases, especially since 2015 (correlation of 0.63 for the period 2015:1–2017:6). This implies an increase in balance sheet size with a concurrent increase in asset concentration, induced by primarily purchasing a single asset class, i.e. government bonds (see also Figures 2 and 3). The size and duration measures are positively correlated (0.67 over the whole period, in non-cumulative terms) and show an increasing co-movement since 2015, when government bond purchases increasingly extracted duration from the market (correlation of 0.86). The composition and duration measures are negatively correlated over the full sample period (−0.77). The correlation turns positive over the short sample (0.33), implying that increasing concentration through asset purchases and LTROs went hand in hand with increased duration on the balance sheet. Multicollinearity - in the sense that one balance sheet variable falsely captures the effect of the other variable – is not found to be an issue, as indicated by variance inflation factors.[24]

2.2. Identification of monetary policy shocks

To identify monetary policy shocks to size, duration and composition, we construct three series of exogenous monetary policy surprises. Particularly if financial market variables are included in a model of monetary policy shocks, simultaneity can be an issue since monetary policy changes not only influence financial variables, but they may be responding to them as well. To identify the effects of changes to policy the shocks should thus be made exogenous. Inspired Cloyne and Hürthen (2016), we identify innovations to monetary policy purged of anticipatory effects that are reflected in market prices (M_t) by taking the residuals of equation (1) as the monetary policy surprise,

$$BS_t = \rho\, BS_{j,\,t-1} + ((1 - \rho)(\alpha + \beta\, M_t)) + \varepsilon_t \qquad (1)$$

where BS is a vector of the balance sheet metrics, with $j =$ size, composition and duration. Equation (1) reflects a statistical relationship which market participants may take into account to anticipate changes in the balance sheet of the central bank. It includes a smoothing parameter ρ to capture the gradualism of balance sheet policies, while variable (M_t) captures forward looking information on the central bank balance sheet that is reflected in market prices. Equation (1) is estimated for each balance sheet dimension j separately and each of those estimations includes a specific market variable M_t.[25] The equation is not embedded in a structural model, but only represents a statistical approach to identify monetary policy innovations.

The choice of variable M_t is based on the following reasoning. We assume that market expectations on balance sheet size is reflected in the long-term euro average bond yield, expectations on duration in the term premium and expectations on balance sheet composition in the range of credit spreads of various market segments.[26] Expectations on the balance sheet size are reflected in the bond yield. The change of the central bank's asset duration affects the term premium through the duration channel (see section 1). Expectations on balance sheet composition reflect the market's assessment about the market segments in which the central bank intervenes, for instance to alleviate market stress by credit easing measures. This will affect credit spreads in those market segments. So equation (1) estimated for size includes the bond yield as variable M_t, for duration the term premium spread and for composition the credit spread.

The estimation outcomes presented in Table 2 show that the β coefficient in all three versions of equation (1) is significant and has the expected sign (negative sign of the bond yield indicating that a declining yield anticipates a larger balance sheet; negative sign of the term spread indicating that a lower term spread anticipates higher duration and positive sign of the spread range indicating that a smaller spread range indicates more asset diversification – so lower HI – and vice versa).

Or measures of unexpected shocks to the balances sheet measures, the residual series of equation (1) estimated with $j =$ size, composition and duration, are shown in Figure 4. The spikes in the series of shocks correspond to the swings in the balance sheet metrics as depicted in Figure 2 (e.g. the two downward spikes in the size residual correspond to falls in the size measure in Figure 2 in January 2011 and April 2014, the latter possibly being related to the announcement that the Governing Council was anonymous in its commitment to

Table 2. Estimation outcome of monetary policy surprise equation (1)

BS_t	Size	Dur	HI
	(M_t: bond yield)	(M_t: term premium)	(M_t: spread range)
ρ	0.93***	0.97***	0.94***
α	0.29***	2.65*	0.26**
β	**−0.05****	**−2.45***	**0.01***
Obs	124	124	124
R^2	0.94	0.97	0.92
Durban Watson statistic	2.19	1.88	1.93

The estimation outcomes are based on equation (1), $BS_t = \rho BS_{j,t-1} + ((1 - \rho)(\alpha + \beta M_t)) + \varepsilon_t$.
***, **, * denote significance at 10%, 5%, 1% confidence level.

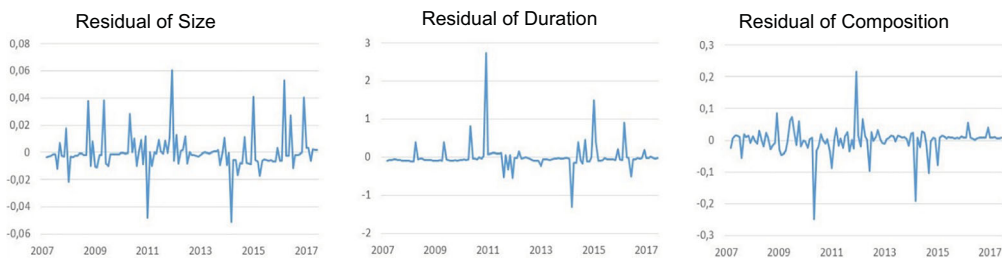Figure 4. Residual of Size / Residual of Duration / Residual of Composition

Figure 4. Unexpected Eurosystem balance sheet shocks (BS_j^e).
Note: Figure 4 shows the measure of the monetary policy surprises, i.e. the residuals (ε_t) of equation (1) ($BS_t = \rho BS_{j,t-1} + ((1 - \rho)(\alpha + \beta M_t)) + \varepsilon_t$) for the three balance sheet metrics; i.e. j = size, composition and duration.
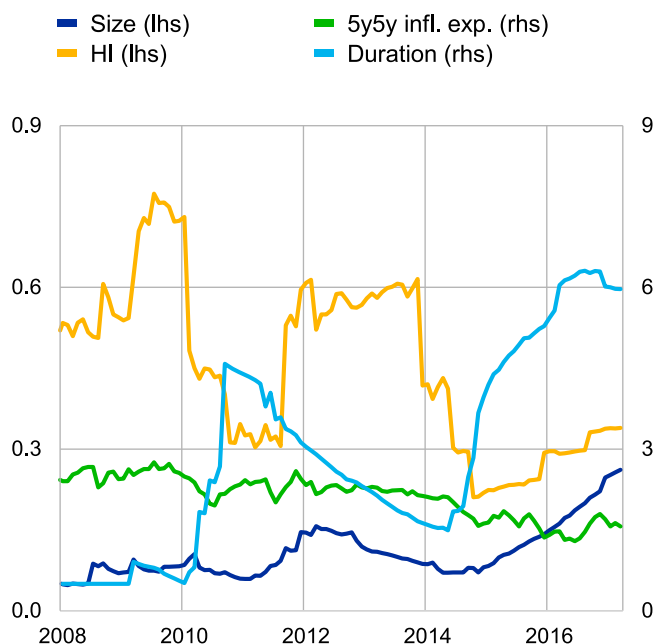
Figure 5. Eurosystem balance sheet metrics and inflation expectations.
Notes: Size is the Eurosystem balance sheet size as a fraction of euro area GDP. HI is the Herfindahl index. Duration is the remaining weighted average maturity in years. All three measures are cumulated measures of the balance sheet dimensions upon announcement. Inflation expectations are 5 yr/5 yr forward inflation-indexed swaps. Sources: Datastream, ECB, own calculations.

using also unconventional instruments within its mandate if need be at the April 2014 press conference).[27] The large upward spike in the duration residual corresponds to the increase of the duration measure at end-2010, related to the CBPP and the SMP, and the upward spike in the composition residual with the increase of the composition measure at end-2011 related to the announcement of long-term refinancing operations. The shocks ϵ, in the remainder of the paper denoted as BS_j^ε, are in standardised values included in the single equation model in the next section and the BVAR model for robustness tests in APPENDIX C.

We estimate the effects of the balance sheet metrics on long-term inflation expectations, based on 5 yr/5 yr forward inflation indexed swaps. Figure 5 visualises the relationship between the metrics and inflation expectations. We also estimate the models for the exchange rate and the 10-year euro area benchmark government bond yield, given their importance as transmission channels of balance sheet policies to inflation and inflation expectations. The exchange rate is defined as the nominal broad effective exchange rate of the euro. In robustness checks we also take into account the real bond yield and the real exchange rate. The other response variables that are included in the model are stock prices, in particular the return of the aggregate EUROSTOXX index, the euro area bank stock index (EUROSTOXX banks) and the non-financial industrial stock index (EUROSTOXX industrials). The stock indices are included in terms of annual log returns. As control variables we include HICP inflation, the HICP energy index, the output gap, the ECB policy rate (MRO rate) and the VIX index to control for the influence of financial market volatility on inflation (expectations) and monetary policy measures. The output gap is taken from Oxford Economics, which is interpolated from quarterly data. The average euro area bond yield is from the ECB and all remaining data from Datastream.

2.3. Estimation method

We estimate the effects of shocks to the balance sheet metrics on inflation expectations, the bond yield and the exchange rate with a single equation model. We estimate the following model versions:

$$Y_t = \alpha + \beta_1 BS_{j,t-n}^\varepsilon + \gamma X_{t-n} + \varepsilon_t \tag{2}$$

$$Y_t = \alpha + \beta_1 BS^{\varepsilon}_{j,t-n} + \beta_2 Z_{a,t-n} + \gamma X_{t-n} + \varepsilon_t \qquad (3)$$

where Y_t are long-term inflation expectations, the bond yield or the exchange rate, BS^{ε}_j is a vector of unexpected balance sheet shocks with $j = $ size, composition and duration (cf. section 2.1). X_t is a vector of the control variables described in section 2.3. Equation (2) captures the shocks to the balance sheet variables in isolation, while equation (3) includes interaction effects between the balance sheet dimensions. Specifically, Z_a reflects interaction terms, one between unexpected shocks in size and composition of the balance sheet, and one between size and duration. The interaction terms capture the mutual dependence of the balance sheet metrics. Note that the interaction terms are separately included in equation (3), but that the constituent terms of the balance sheet dimensions j are all included in BS^{ε}_j in order to cleanly specify the model.

The effects of the balance sheet shocks are assessed using local projections, following Jorda (2005). Local projections are based on sequential regressions of the endogenous variable shifted several steps (n) ahead and therefore have many points of commonality with direct multi-step forecasting. This produces impulse responses, while it does not require specification and estimation of the unknown true multivariate dynamic system like a VAR. This makes local projections robust to misspecification. In order to cleanly identify the shock to each balance sheet dimension and to distinguish them from conventional monetary policy shocks, we include the three balance sheet shocks and the policy rate simultaneously in the regressions.

We first estimate equation (2) with the three unexpected balance sheet shocks (for the subsequent lags $n = 1..12$) and the other control variables (two lags) included. Second, we estimate equation (3) with an interaction term (with $a = $ size∗composition, or $a = $ size∗duration). Equations (2) and (3) are estimated for long-term inflation expectations over the period 2008:4–2017:6. All variables, including the interaction terms, are included in terms of levels.

For the interaction term of size and duration, a positive impulse response to a shock in size would imply a larger positive effect on inflation expectations when the central bank absorbs more duration from the market, while balance sheet size increases. A negative response would imply a larger negative effect of size increases when duration increases. In terms of the duration metric, a positive impulse response would imply a stronger positive effect of increasing duration on inflation expectations when balance sheet size grows, while a negative response would point to a stronger negative effect of a higher duration when balance sheet size grows. For the regressions with the interaction term of size and concentration similar reasoning applies.

3. Results

3.1. Responses of macro variables

Figure 6 presents the results in terms of the impulse responses following from the local projections analysis based on equations (2) and (3), i.e. the response of inflation expectations, the bond yield and the exchange rate to a one standard deviation shock in the balance sheet dimensions. The results in particular underline the importance of the duration extraction channel, through which balance sheet policies can affect inflation expectations and market prices.

For shocks to balance sheet size, we find a significant positive reaction of inflation expectations (Figure 6, row i., column A). The responses become significant after around 6 months. One way of interpreting this finding is that it may indicate the successful transmission of balance sheet policies via size through the signalling channel, for example in line with the findings by Thorbecke (2017), Sahuc (2016) or Moessner (2015). A positive reaction of inflation expectations to asset purchase announcements is also consistent with the findings of Hofmann and Zhu (2013) for the US and the UK. The average peak response of inflation expectation (around 18 basis points) that we find is quite limited. Other studies also find limited effects. Andrade et al. (2016) estimate that the announcement of the ECB's asset purchase programme led to a 9 basis points increase of long-term inflation forecasts between 2015Q1 and 2015Q3. This is in line with Moessner (2015) and VP (2017) for the euro area and Guidolin and Neely (2010) for the US, who find that asset purchase programmes only led a slight increase in long-term inflation expectations. We also find a significant positive response of the exchange rate to a shock in size after 11 months (Figure 6, row i., column C). This is surprising as we would have expected a depreciation of the exchange rate; however, local projections become less reliable at
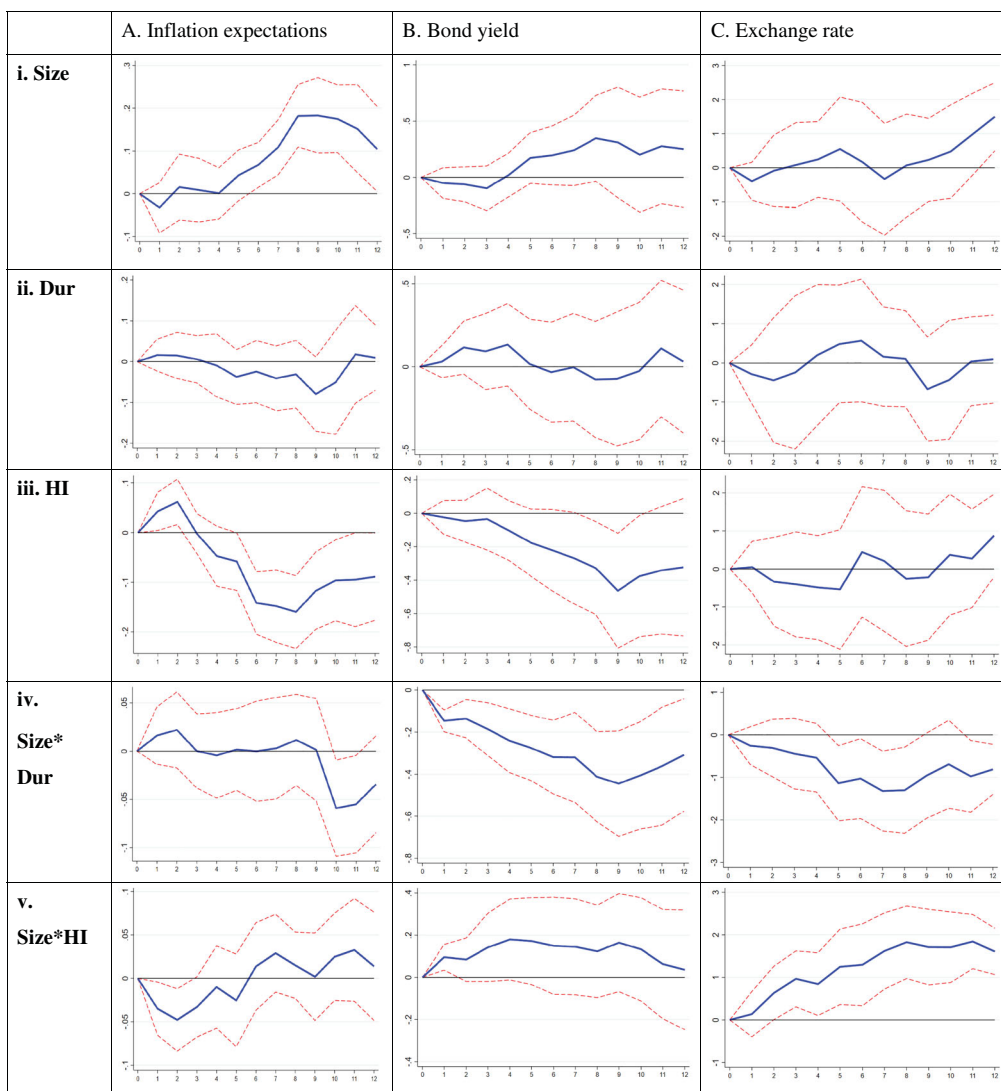
Figure 6. Impulse responses to a one standard deviation shock in size (i), duration (ii), composition (iii), size∗duration (iv) and size∗ composition (v).

Notes: Figure 6 presents the estimation results using local projections to assess changes in the Eurosystem balance sheet dimensions (size, duration, composition), size interacted with duration and composition interacted with the size. Rows i., ii. and iii. are based on equation (2), while rows iv. and v. are based on equation (3). The red dotted lines are the 90% confidence intervals. The number of months is shown on the x-axis. The y-axis shows the impulse responses in percentage points. The variables are included in levels.

longer horizons since the error terms incorporate the additional uncertainty existing in long-term forecasts (Jorda 2005).

While we do not find a significant effects following from isolated shocks to duration (measured by the weighted average maturity, WAM, of the portfolio) on inflation expectations, the bond yield and exchange rate (Figure 6, row ii.), we do find significant effects of shocks to the duration interacted with balance sheet size, in particular for market prices.[28] The results show a significant negative impact of a rise in the WAM in tandem with an increase of size of the balance sheet on the bond yield and the exchange rate, in line with expectations. The bond yield declines by (a maximum of) more than 40 basis points after 9 months, while the exchange rate index declines by a maximum of 125 basis points after 7 months (Figure 6, row iv). This implies a larger

negative effect of an increasing balance sheet size on the bond yield and exchange rate when the central bank takes more duration from the market and vice versa. The effects are quite persistent. The effects on the bond yield are comparable to effects determined in other studies. For example, Altavilla et al. (2015) find a reduction of 37 basis points two days after APP announcements for German Bund yields at 20-year maturities and a reduction of 44 basis points or Spanish CDS-adjusted yields. For the UK, Joyce et al. (2011) find a cumulative impact of QE announcements between February 2009 and February 2010 on gilt yields of almost 100 basis points. These are the outcomes of event studies with a very short horizon. Thus, a comparison with our results – which measure a persistent effect based on a different data frequency – is not straightforward. Eser et al. (2019) do estimate the long-term stock effects of the APP and find downward effects that range from 50 to 100 basis points on the euro area 10-year term premium. These are discounted stock effects based on a term structure model of the yield curve, enhanced with bond supply factors. Comparing the results of other studies with the outcomes of our model indicates that the size of the effects depends on the data used and on the modelling approach.

Focusing on the composition of the balance sheet, the outcomes of the impulse responses show that inflation expectations respond significantly negative to isolated shocks in composition (Figure 6, row iii., column A). This negative response means that increased diversification on the asset side of the balance sheet (HI declines, for instance due to credit easing in an increasing number of market segments) shifts inflation expectations upward. We also find a significant response of the bond yield after a shock to the composition of the balance sheet. The composition shock depresses the bond yield between months seven and ten, indicating that increased concentration of the portfolio (HI up) leads to a lower yield. The last row in Figure 6 shows that the interaction of balance sheet size and composition matters. First, inflation expectations (column A) respond negatively to a size-composition shock, meaning that inflation expectations decrease with increasing size and asset concentration (HI up), but increase if the central bank targets several asset classes simultaneously (HI down). However, the effect fades out rather quickly, which makes it difficult to draw strong policy conclusions. Second, column B indicates a very small and quickly fading significant positive impact of increasing asset concentration and balance sheet size on the bond yield. This flip-side of the results suggests that the yield declines if asset diversification increases (HI down) and balance sheet size rises. Finally, column C shows a significant positive effect of a size-composition shock on the exchange rate. It implies a larger positive effect of an increasing balance sheet size on the exchange rate when the asset portfolio becomes more concentrated (HI up) and a larger negative effect if the asset side of the balance sheet becomes more diversified (HI down). This outcome suggests that an increasing balance sheet size in tandem with a change in balance sheet composition leads to looser financial conditions (through a lower bond yield and a depreciation of the exchange rate) if the central bank becomes active in more different market segments.[29] The outcomes (from Figure 6, rows iv. and v.) indicate that interactions between the different dimensions of the central bank balance sheet are relevant for the impact of balance sheet policies.

3.2. Responses of stock returns

We also simulate the response of stock returns to a shock in the balance sheet dimensions. This could shed light on how unconventional monetary policy impacts the aggregate economy (reflected in the aggregate stock index, EUROSTOXX) and on how certain sectors of the economy may respond differently to different monetary policy shocks. In particular, we analyse the response of the euro area banking sector, measured by the EUROSTOXX banks index and the non-financial industrial sector, measures by the EUROSTOXX industrials stock index.

For shocks to balance sheet size, we find a significant positive reaction of all three stock index returns (Figure 7, row i., columns A, B and C). The responses become significant after around 6 months and peak at 9 months. In terms of size, the stock return responses are comparable to the response of inflation expectation (Figure 6, row i., column A). The findings suggest that balance sheet policies via size also affect stock prices through the signalling channel. Bank stock returns respond relatively more strongly to shocks in size than aggregate or industrial stock returns. This may reflect that the banking sector benefited more directly from an expansion of the ECB balance sheet than other sectors. The increased ECB refinancing operations improved
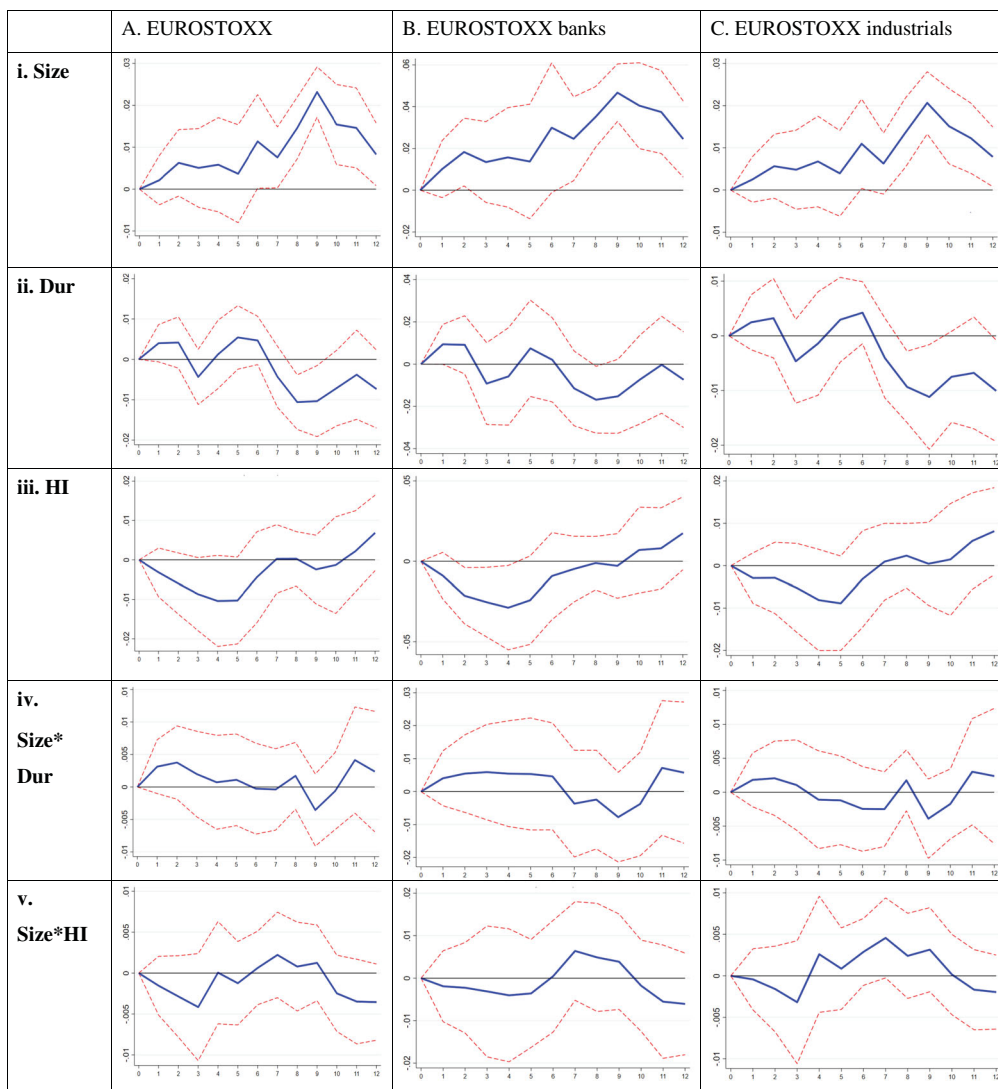
Figure 7. Impulse responses to a one standard deviation shock in size (i), duration (ii), composition (iii), size∗duration (iv) and size∗composition (v).

Notes: Figure 7 presents the estimation results using local projections to assess changes in the balance sheet dimensions (size, duration, composition), size interacted with duration and composition interacted with the size. Rows i., ii. and iii. are based on equation (2), while rows iv. and v. are based on equation (3). The red dotted lines are the 90% confidence intervals. The number of months is shown on the x-axis. The y-axis shows the impulse responses in log returns. The variables are included in levels.

bank's liquidity and funding situation, while asset purchases have the potential to strengthen banks' capital position. This interpretation is in line with Andrade et al. (2016), who find that banks' stock prices benefitted from central bank asset purchases through the capital relief channel.

Following a shock in duration, the stock returns respond positively in the first month, but (borderline) significant negatively after 8–9 months (Figure 7, row ii., columns A, B and C). While it is surprising that bank stock returns do not really show a different response than the returns of the aggregate stock index – given that banks' maturity transformation function and profitability may be affected by duration extraction and the associated flattening of the yield curve -, this might relate to hedging of maturity risk by banks, which makes them less sensitive to yield curve changes (Chaudron 2016). Bank stock returns do not significantly respond to shocks to
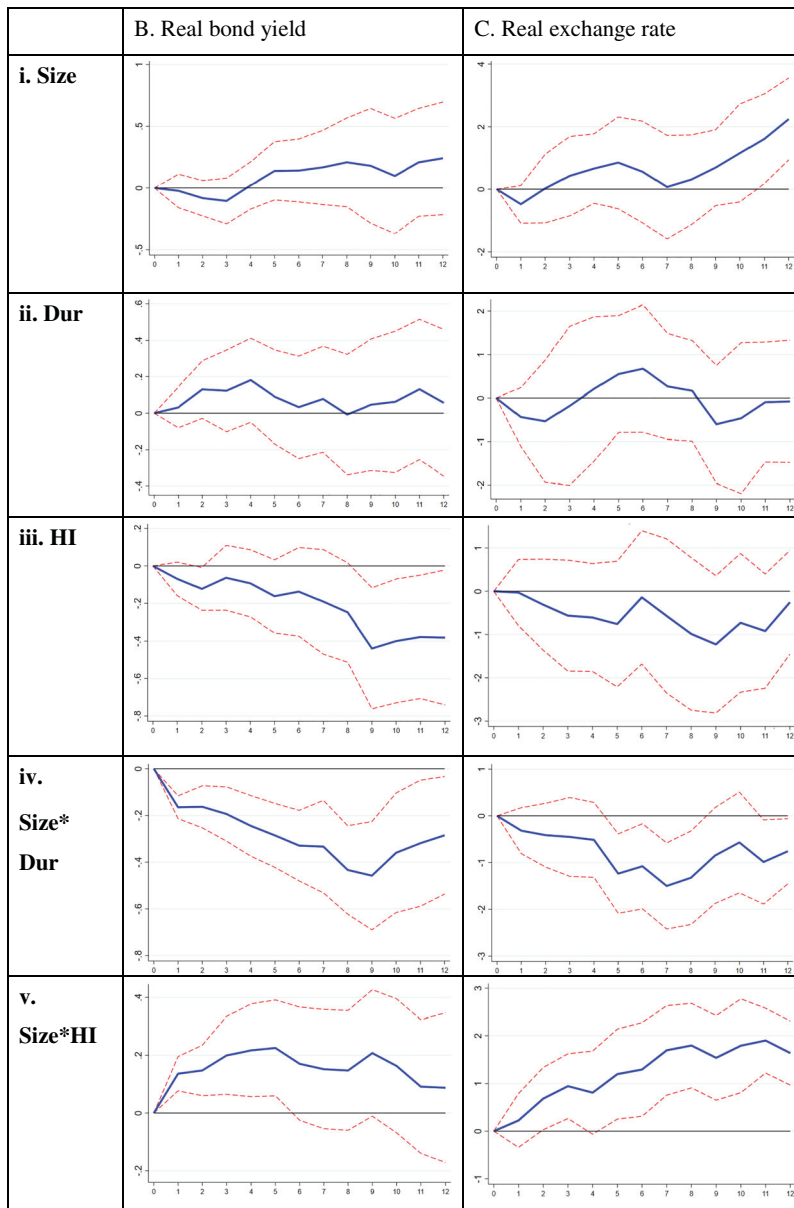
Figure 8. Impulse responses to a one standard deviation shock in size (i), duration (ii), composition (iii), size∗duration (iv) and size∗ composition (v).

Notes: Figure 8 presents the estimation results using local projections to assess changes in the balance sheet dimensions (size, duration, composition), size interacted with duration and composition interacted with the size. Rows i., ii. and iii. are based on equation (2), while rows iv. and v. are based on equation (3). The red dotted lines are the 90% confidence intervals. The number of months is shown on the x-axis. The y-axis shows the impulse responses in percentage points. The variables are included in levels.

duration interacted with balance sheet size, similar to the aggregate and industrial stock returns (Figure 7, row iv., columns A, B and C).

Bank stock returns do show a significant reaction to isolated shocks in composition (Figure 7, row iii., column B). The negative response means that increased diversification on the asset side of the central bank balance sheet (HI declines, for instance due to credit easing in an increasing number of market segments) raises banks' stock returns. This could reflect the beneficial effects on banks' activities of the diminishing stress in *several* specific

market segments on which banks rely, such as the covered bond and asset-backed securities markets. We do not find a significant response of industrial stock returns to composition shocks or a joint size-composition effect on either stock index.

3.3. Robustness tests

As a robustness test, we simulate the impulse responses for the bond yield and the exchange rate in real terms to shed light on the question how these variables impact the real economy and ultimately inflation. The real bond yield is defined as the 10-year euro area benchmark government bond yield deflated by long-term expected inflation expectations (based on 5 yr/5 yr forward inflation indexed swaps). The real exchange rate is defined as the real broad effective exchange rate of the euro. The outcomes in Figure 8 are similar to the outcomes with the bond yield and exchange rate in nominal terms. Like those outcomes, the impulse responses of the real bond yield and the real exchange rate indicate that interactions between the different dimensions of the central bank balance sheet are relevant for the impact of balance sheet policies.

As another robustness test we estimate the effects of central bank balance sheet policies with a BVAR model (see Appendix C). The impulse responses of the BVAR generally confirm the main result of the local projections method. Based on the BVAR model, we find that the interaction of duration with balance sheet size has a significant negative impact on the bond yield and a depreciating effect on the exchange rate, similar to the outcomes of the local projections. The effects are quite persistent. Based on the BVAR model we also find significant effects of changes to the interaction of size and composition on market prices. The robustness check thus indicates that the effects of considering the interaction of different balance sheet metrics remain even in a different model set-up. We find less evidence of significant effects following from shocks to one balance sheet dimension in isolation. After a shock to size, there are no significant responses of inflation and the bond yield in the BVAR simulations. Shocks to size or duration are followed by a significant depreciation of the euro exchange rate in the first one or two months. Such a brief negative response is also generated by the local projections estimations, although based on that method, these effects are not statistically significant. Based on the BVAR, we do not find significant effects of changes in the balance sheet composition in isolation on inflation expectations, the bond yield or the exchange rate. The results of the robustness test may suggest that it is more difficult to find effects of balance sheet policies on inflation expectations in a dynamic multi-equation system, like the BVAR.

4. Conclusion

Our analysis provides insights on the persistence of changes in balance sheet size, duration and composition on inflation expectations, the exchange rate, the euro area bond yield and stock returns, as well as on the interaction between the three dimensions of the central bank balance sheet. The main outcome we find is that the interaction of size and duration and of size and composition have significant effects on the bond yield and exchange rate. This suggests that both financial market variables are particularly sensitive to the combined impact of shocks to the balance sheet dimensions and not so much to isolated shocks. The estimation results for the bond yield in particular provide empirical evidence for the importance of the duration extraction channel and the stock effects of central bank balance sheet policies for the transmission of non-standard monetary policy measures. We find that shocks to balance sheet size are associated with a significant positive reaction of stock returns, of bank stocks in particular. The similarities between the outcomes of the local projections and the BVAR model indicate that the outcomes with regard to the interaction terms (i.e. the effect of changes in the size/duration and the size/composition interaction) are robust to a different model set-up.

The paper provides three main policy insights. First, balance sheet policies – in particular through the interaction between size and duration – seem effective in influencing the bond yield, exchange rate and stock returns. Although neither variable is a policy target, they ultimately affect the inflation rate. Second, stock effects seem to matter for the transmission of balance sheet policies. Third, it seems useful to consider the interaction effects in future decisions on the use of different monetary policy instruments. At the same time, while we provide an

attempt to empirically disentangle the size, duration and composition dimension of the balance sheet, it may prove to be difficult to do so in practice.

Notes

1. We focus on inflation expectations as we expect a more contemporaneous response of expectations than of realised inflation to announcement shocks to the balance sheet.
2. The Eurosystem had launched the first covered bonds purchase programme in 2009 and the second one in 2011. The asset-backed securities purchase programme and the third covered bond purchase programme were introduced in October 2014.
3. Note that duration can also be extracted without changes in the balance sheet size if the central bank sells short-term and buys long-term bonds.
4. We will focus in particular on the duration risk channel as a form of portfolio rebalancing, and not on other variants of portfolio rebalancing such as the local supply or the asset valuation channel. For the duration risk channel, asset purchases depress yields of all securities of a given duration. In contrast, in the local supply approach, only securities purchased would be affected and not-purchased securities would remain unaffected (cf. Bauer and Rudebusch 2014 for a discussion and Joyce et al. 2011, for evidence for the UK). For a further discussion see e.g. Cahill et al. (2013) or Andrade et al. (2016).
5. They further provide support for the exchange rate channel, the inflation re-anchoring channel and the credit channel.
6. The paper states that the duration risk and the local supply channel together account for about -9 basis points impact on yields (per $100 billion purchase) and account to equal extents for this result.
7. The first and second large scale asset purchases, the MBS reinvestment programme into Treasury securities, the maturity extension programme and agency MBS reinvestment programme and the second maturity extension programme.
8. They argue in the UK transmission worked mainly through the risk taking channel.
9. They also note that portfolio rebalancing towards foreign assets via the exchange rate channel was limited.
10. As discussed in the previous section, our sample is 2008:4 to 2017:6, while VP (2017) focus on 2007:1 to 2014:12.
11. These measures included liquidity management measures (fixed rate full allotment, widening of the collateral base, lengthening of maturities for refinancing operations and the provision of liquidity in foreign currencies) and the covered bond purchase programme (cf. Trichet 2009 as referred to in Lenza, Reichlin, and Pill 2010).
12. To note, our concentration measure assesses concentration from an instrument perspective, defining concentration in terms of the relative share of assets associated with each of the different monetary policy instruments of total monetary policy-related asset holdings, not in terms of underlying transaction modality. Thus, we only treat the extension of credit against a sovereign bond as collateral differently from a purchase of a sovereign bond in so far as the transactions are related to different monetary policy instruments. While this lies beyond the scope of this paper, a concentration measure further distinguishing transaction modalities could complement our analysis.
13. See e.g. De Santis and Holm-Hadulla (2017) for an event study that analyses implementation ('flow') effects on bond yields.
14. The cumulative sum of asset purchase announcements is constructed by Hesse, Hofmann, and Weber (2017) by adding up the announced purchases of assets in the asset purchase programmes at the announcement date.
15. See Appendix A for the announcement and implementation dates. For the LTROs this approach is applied for the 1, 3 and 4 years refinancing operations. The cumulative sum of the uptake in the LTROs is taken over the announced horizon of the programme; thereafter the non-cumulative amounts are taken. The cumulative amount is not known ex-ante since the uptake in the LTROs is determined by the demand of banks. Our approach implicitly assumes that market expectations on the uptake upon announcement of the LTROs are similar to the actual uptake.
16. For instance the horizon over which assets are purchased in the asset purchasing programmes other than the APP (like the SMP and the first covered bond purchasing programmes) was not announced ex ante. If the horizon is not announced ex-ante – for instance because it is presented as an open-ended programme - we assume that it is equal to the implementation period. Furthermore, by not calculating the present value of the expected amounts of the programmes we implicitly assume that the discount factor is zero percent. This assumption is motivated by the high uncertainty about the time preference of investors, which is basically unknown.
17. Compared to VP (2017) we restrict the asset classes included in the composition metric further to only cover those asset classes with direct links to monetary policy, thus e.g. excluding emergency liquidity assistance-related assets and asset related to the Agreement on Net Financial Assets (ANFA). Thus, the index is used in its most restricted form and could be further extended in future research, e.g. to include non-monetary policy-related assets and foreign exchange reserves.
18. The three Covered Bond Purchase programmes and purchases of government bonds vs bonds issued by supranational organisations under the PSPP are all included separately in the HI metric to reflect the metric's broadest configuration.
19. The index does not reflect Outright Monetary Transactions as assets on the ECB's portfolio linked to them are zero throughout the period of analysis.
20. The duration measure excludes MROs and asset-backed securities; the latter for data availability reasons.
21. The duration, measured as the remaining weighted average maturity (WAM) of LTROs is proxied by assuming that the maturity of the LTRO decreases linearly over the period in which the operation is outstanding. The duration of purchased assets is based on the observed remaining weighted average maturity (WAM) of the asset classes.

22. At the start of the rise (i.e. in April 2011) these two asset classes accounted for 34% of total assets, while amounting to 44% at the peak in April 2012.

23. In 2010 the 6 months and 1 year LTROs expired, while the amount of long-term assets purchased under the CBPP and SMP expanded. This explains why in 2010 duration increases, while size remains quite stable.

24. Variance inflation factors for the coefficients of the balance sheet variables for size, duration and composition regressed on inflation expectations in one single equation model remain below critical levels (which by rule of thumb is around 5).

25. As a robustness check we also included a dummy variable to control for announcement effects (dummy being 1 in a month in which a new (or adjusted) conventional or unconventional monetary policy measure was announced by the ECB and 0 otherwise). The dummy variable is not significant in any of the model estimations, so we left it out from the baseline regression. Another reason for doing this is that market prices are assumed to capture announcement effects as well.

26. The term spread is proxied by the difference between the 10 years euro area bond yield and the sum of real GDP growth and inflation, both expected 5–10 years ahead (source Consensus Economics). The range of credit spreads is calculated by the standard deviation of the spread on financial and non-financial corporate BBB bonds, covered bonds, asset backed securities and an index of government bonds of Greece, Ireland, Italy, Portugal and Spain (spread with regard to German government bond yield with comparable maturity, own calculation based on data from Datastream).

27. See Introductory statement to the press conference (with Q&A) of 3 April 2014.

28. The interaction of size with duration has an insignificant effect on inflation expectations (Figure 6, row iv., column A. Note that the effect is briefly significant after 10 months, but we notice that local projections become less reliable at longer horizons).

29. Note that the impulse response functions in Figure 6, row ii depict an *increase* in concentration, therefore the signs of the effect on bond yields and the exchange rate are positive.

30. The BVAR estimations were conducted with the BEAR toolbox, developed by Dieppe, Legrand, and Van Roye (2016).

31. Note that the impulse response functions in Figure c, row iv. depict an *increase* in concentration, therefore the signs of the effect on bond yields and the exchange rate are positive.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Altavilla, C. A., G. Carboni, and R. Motto. 2015. Asset Purchase Programmes and Financial Markets: Lessons from the Euro Area, ECB Working Paper, 1864.

Andrade, P., J. Breckenfelder, F. De Fiore, P. Karadi, and O. Tristani. 2016. The ECB's Asset Purchase Programme: An Early Assessment, ECB Working Paper, 1956.

Bauer, M. D., and G. D. Rudebusch. 2014. "The Signalling Channel for Federal Reserve Bond Purchases." *International Journal of Central Banking* 10 (3): 233–289.

Blattner, T. S., and M. A. S. Joyce. 2016. Net Debt Supply Shocks in the Euro Area and the Implications for QE, ECB Working Paper, 1957.

Boeckx, J., M. Dossche, and G. Peersman. 2017. "Effectiveness and Transmission of the ECB's Balance Sheet Policies." *International Journal of Central Banking* 13 (1): 297–333.

Bridges, J., and R. Thomas. 2012. The Impact of QE on the UK Economy - Some Supportive Monetarist Arithmetic, Bank of England working paper, 442.

Brunnermeier, M. K., and Y. Sannikov. 2016. The I Theory of Money. Working Paper.

Cahill, M. E., S. D'Amico, C. Li, and J. S. Searsa. 2013. Duration Risk versus Local Supply Channel in Treasury Yields: Evidence from the Federal Reserve's Asset Purchase Announcements, Federal Reserve Board Finance and Economics Discussion paper, 2013–35.

Chaudron, R. 2016. Bank Profitability and Risk Taking in a Prolonged Environment of Low Interest Rates: A Study of Interest Rate Risk in the Banking Book of Dutch Banks, DNB working paper, 526.

Chen, H., V. Cúrdia, and A. Ferrero. 2012. "The Macroeconomic Effects of Large-Scale Asset Purchase Programmes." *The Economic Journal* 122 (564): F289–F315.

Cloyne, J., and P. Hürthen. 2016. "The Macroeconomic Effects of Monetary Policy: A New Measure for the United Kingdom." *American Economic Journal: Macroeconomics* 8 (4): 75–102.

Cúrdia, V., and M. Woodford. 2010. The Central Bank Balance Sheet as an Instrument of Monetary Policy, NBER Working Paper, 16208.

D'Amico, S., W. English, D. López-Salido, and E. Nelson. 2012. "The Federal Reserve's Large-Scale Asset Purchase Programmes: Rationale and Effects." *The Economic Journal* 122 (564): 415–446.

D'Amico, S., and T. B. King. 2013. "Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply." *Journal of Financial Economics* 108 (2): 425–448.

De Santis, R. A., and F. Holm-Hadulla. 2017. Flow effects of central bank asset purchases on euro area sovereign bond yields: evidence from a natural experiment, ECB Working Paper, 2052.

Dieppe, A., R. Legrand, and B. Van Roye. 2016. The BEAR toolbox, ECB Working Paper, 1934.

ECB. 2015. The Role of the Central Bank Balance Sheet in Monetary Policy, Economic Bulletin Issue 4/2015.

Eser, F., M. Carmona Amaro, S. Iacobelli, and M. Rubens. 2014. The Use of the Eurosystem's Monetary Policy Instruments and Operational Framework since 2009, ECB Occasional Paper, 135.

Eser, F., W. Lemke, K. Nyholm, S. Radde, and A. Vladu. 2019. Tracing the Impact of the ECB's Asset Purchase Programme on the Yield Curve, ECB Working Paper, 2293.

Gagnon, J., M. Raskin, J. Remache, and B. Sack. 2011. "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases." *International Journal of Central Banking* 7 (1): 3–43.

Gambacorta, L., B. Hofmann, and G. Peersman. 2014. "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis." *Journal of Money Credit and Banking* 46 (4): 615–642.

Gambetti, L., and A. Musso. 2017. The Macroeconomic Impact of the ECB's Expanded Asset Purchase Programme (APP), ECB Working Paper, 2075.

Glick, R., and S. Leduc. 2012. "Central Bank Announcements of Asset Purchases and the Impact on Global Financial and Commodity Markets." *Journal of International Money and Finance* 31 (8): 2078–2102.

Guidolin, M., and C. J. Neely. 2010. The Effects of Large-Scale Asset Purchases on TIPS Inflation Expectations, National Economic Trends, Federal Reserve Bank of St. Louis.

Hamilton, J. D., and J. C. Wu. 2012. "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment." *Journal of Money, Credit and Banking* 44 (1): 3–46.

Hartmann, P., and F. Smets. 2018. The First Twenty Years of the European Central Bank: Monetary Policy, ECB Working Paper, 2219.

Hesse, H., B. Hofmann, and J. Weber. 2017. The Macroeconomic Effects of Asset Purchases Revisited, BIS Working Paper, 680.

Hofmann, B., and F. Zhu. 2013. Central Bank Asset Purchases and Inflation Expectations, BIS Quarterly Review, March 2013.

Ihrig, J., E. Klee, C. Li, B. Schulte, and M. Wei. 2012. Expectations about the Federal Reserve's Balance Sheet and the Term Structure of Interest Rates, Finance and Economics Discussion Series, Federal Reserve Board, Washington, D. C.

Jorda, O. 2005. "Estimation and Inference of Impulse Responses by Local Projections." *American Economic Review* 95 (1): 161–182.

Joyce, M., A. Lasaosa, I. Stevens, and M. Tong. 2011. "The Financial Market Impact of Quantitative Easing in the United Kingdom." *International Journal of Central Banking* 7 (3): 113–161.

Joyce, M., D. Miles, A. Scott, and D. Vayanos. 2012. "Quantitative Easing and Other Unconventional Monetary Policy: an Introduction." *The Economic Journal* 122 (564): 271–288.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2011. The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy, Brookings Papers on Economic Activity, Fall 2011, 215–287.

Lenza, M., L. Reichlin, and H. Pill. 2010. "Monetary Policy in Exceptional Times." *Economic Policy* 25 (4): 295–339.

Li, C., and M. Wei. 2013. "Term Structure Modelling with Supply Factors and the Federal Reserve's Large-Scale Asset Purchase Programs." *International Journal of Central Banking* 9 (1): 3–93.

Meaning, J., and F. Zhu. 2011. The Impact of Recent Central Bank Asset Purchase Programmes, BIS Quarterly Review, December 2011.

Meinusch, A., and P. Tillmann. 2016. "The Macroeconomic Impact of Unconventional Monetary Policy Shocks." *Journal of Macroeconomics* 47: 58–67.

Moessner, R. 2015. "Effects of ECB Balance Sheet Policy Announcements on Inflation Expectations." *Applied Economic Letters* 22 (6): 483–487.

Peersman, G., and F. Smets. 2001. *The monetary transmission mechanism in the euro area: more evidence from VAR analysis, ECB Working Paper.*

Sahuc, J. G. 2016. "The ECB's Asset Purchase Programme: A Model-Based Evaluation." *Economics Letters* 145: 136–140.

Schenkelberg, H., and S. Watzka. 2013. "Real Effects of Quantitative Easing at the Zero Lower Bound: Structural VAR-Based Evidence from Japan." *Journal of International Money and Finance* 33: 327–357.

Swanson, E. T. 2011. Let's Twist Again: A High-Frequency Event-Study Analysis of Operation Twist and Its Implications for QE2, Brookings Papers on Economic Activity, Spring 2011.

Thorbecke, W. 2017. The Effect of the Fed's Large-scale Asset Purchases on Inflation Expectations, PRIETI Discussion Paper, 17-E-097.

Trichet, J.-C. 2009. The ECB's Enhanced Credit Support. Keynote address at the University of Munich / IFO symposium, https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp1253.pdf.

Ugai, H. 2007. Effects of the Quantitative Easing Policy: A Survey of Empirical Analyses, Monetary and Economic Studies, March 2007.

Van den End, J. W., and C. Pattipeilohy. 2017. "Central Bank Balance Sheet Policies and Inflation Expectations." *Open Economies Review* 28: 499–522.

Varghese, R., and Y. S. Zhang. 2018. A New Wave of ECB's Unconventional Monetary Policies: Domestic Impact and Spillovers, IMF Working Paper WP/18/11.

Vayanos, D., and J. L. Vila. 2009. A Preferred-Habitat Model of the Term Structure of Interest Rates, NBER Working Paper 15487.

Weale, M., and T. Wieladek. 2016. "What are the Macroeconomic Effects of Asset Purchases?" *Journal of Monetary Economics* 79 (C): 81–93.

Appendices

Appendix A

A.1. Announcement and implementation dates of the Eurosystem's monetary programmes

Programme	Announced	Implemented (month of start)	Details
LTRO1y	07-05-2009	June 09	3 operations (June, Sept, Dec 2009)
LTRO1y	06-10-2011	Oct 11	2 operations (Oct, Dec 2011; the latter was replaced by VLTRO1)
VLTRO1	08-12-2011	Dec 11	
VLTRO2	08-12-2011	Feb 11	
TLTRO1	05-06-2014	Sep 14	
TLTRO2	10-03-2016	Jun 16	
CBPP1	07-05-2009	Jul 09	
SMP	10-05-2010	May 10	
CBPP2	06-10-2011	Nov 11	
ABSPP	04-09-2014	Nov 14	
CBPP3	04-09-2014	Oct 14	
CSPP	10-03-2016	Jun 16	
APP	22-01-2015	Mar 15	
APP extension	03-12-2015	Dec 15	extended to Mar 2017
APP extension	10-03-2016	Apr 16	net asset purchases raised from EUR 60 to 80 bn per month
APP extension	08-12-2016	Apr 17	extended to Dec 2017; net asset purchases reduced from EUR 80 to 60 bn per month
APP extension	26-10-2017	Jan 18	extended to Sep 2018; net asset purchases reduced from EUR 60 to 30 bn per month

Notes: LTRO = long-term refinancing operations; VLTRO = very-long-term refinancing operations; TLRO = targeted long-term refinancing operations; CBPP = Covered Bond Purchase Programme; SMP = Securities Markets Programme; ABSPP = Asset-backed Securities Purchase Programme; CSPP = Corporate Sector Purchase Programme; APP = Asset Purchase Programme.

Appendix B

B.1. Additional information on the composition metric: extension of Figure 1

Figure B. Eurosystem balance sheet composition and monetary policy instruments
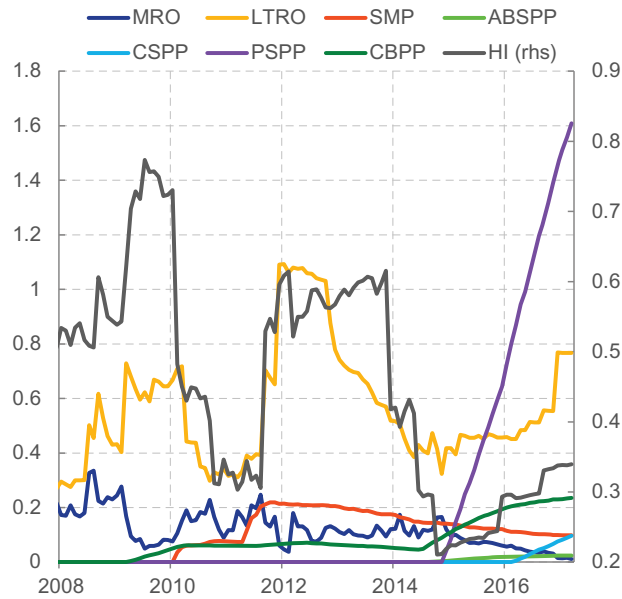
Notes: MRO = main refinancing operations. LTRO = long-term refinancing operations. SMP = Securities Markets Programme. ABSPP = Asset-backed Securities Purchase Programme. CSPP = Corporate Sector Purchase Programme. PSPP = Public Sector Purchase Programme. CBPP = Covered Bond Purchase Programme. HI is the Herfindahl index outlined in Section 2.1. 'PSPP' reflects both government and supranational bonds and the CBPP all covered bond purchases programmes together. All instrument data is in millions of euro. Source: Datastream, ECB, own calculations.

Appendix C

C.1. Robustness check based on Bayesian VAR model

As a robustness check of the outcomes of the local projections method, we also estimate the effects of central bank balance sheet policies with a BVAR model:

$$Y_t = A_0 + B(L)Y_t + C(L)X_t + \varepsilon_t \qquad (4)$$

where Y_t is a vector of endogenous variables, X_t a vector of exogenous variables, A_0 a vector of intercepts, $B(L)$ and $C(L)$ are matrix polynomials in the lag operator whose order is 1 (based on lag selection criteria) and ε_t is the vector of error terms. All variables are included in levels, as done for the local projections.

Given the relatively large number of variables and the relatively short sample, we shrink the parameter space of the reduced-form VAR using Bayesian techniques. An advantage of using Bayesian methods to estimate the VAR is that it addresses the potential problem of underestimating persistence, which arises when using the conditional likelihood instead of the exact likelihood. Bayesian prior shrinkage allows reducing the number of lags, which limits overparameterisation and addresses the small sample bias. On the prior distribution of the parameters we use the independent normal-Wishart prior. It assumes that both the coefficients and model residuals are unknown and follow a multivariate normal distribution, with no assumed dependence between residual variance and coefficient variance.[30]

The BVAR model is estimated with the three unexpected balance sheet shocks (BS_j^ε) and the policy rate simultaneously included, in order to cleanly distinguish the shock to each balance sheet dimension and to distinguish them from conventional monetary policy shocks. The model is also estimated in an extended version with either the interaction term size∗duration, or size∗composition included. In addition to those variables, vector Y_t contains realised and expected inflation, the long-term government bond yield, the exchange rate, the output gap and the policy rate (as described in section 2.3). By treating these variables as endogenous, the model captures the reciprocal interaction between realised and expected inflation as well as between the other variables. As exogenous variables we include the country specific energy price index (CPI energy index) and the VIX index.

The model is identified using Cholesky decomposition. The ordering of the endogenous variables follows the consensus in the macro-VAR literature that monetary policy (both the interest rates and the balance sheet measures) affect inflation and output only with a lag, while monetary policy may react contemporaneously to those variables (see e.g. Peersman and Smets, 2001). The bond yield is ordered after the monetary policy variables, while the exchange rate is ordered last and is therefore allowed to respond contemporaneously to macroeconomic and monetary policy shocks. The assumption that the bond yield and the exchange rate do not instantaneously affect the balance sheet variables is underpinned by the construction of exogenous monetary policy surprises as described in section 2.2. Expected inflation is ordered before realised inflation, assuming a forward-looking New Keynesian Phillips curve, whereby companies adjust their prices immediately following changes in inflation expectations. Below we report the outcomes of the impulse responses following from a one standard deviation innovation in the model variables.

For **size** shocks (Figure C, row i.), we do not find significant responses of inflation and the bond yield, but we do find a significant negative response of the exchange rate. For the **duration** (row ii.) of the portfolio, the results suggest a downward impact on the exchange rate. Shocks to size or duration are followed by a depreciation of the euro exchange rate, in line with existing literature (e.g. Boeckx, Dossche, and Peersman 2017; Gambetti and Musso 2017). As duration is the weighted average maturity, the specification in row ii., column C speaks for the effectiveness of duration extraction by changing the portfolio while leaving the size constant, e.g. by selling short-term and buying long-term bonds (e.g. the U. S. Federal Reserve System's Operation Twist). Moreover, the outcomes indicate that the interaction of duration with balance sheet size has a significant negative impact on the bond yield and a depreciating effect on the exchange rate, similar to the outcomes of the local projections and in line with expectations. The effects are quite persistent.

For **composition**, we do not find significant effects of changes in the balance sheet composition in isolation on inflation expectations, the bond yield or the exchange rate. Only when considering changes in balance sheet size and concentration together, do we find significant effects on market prices. The interaction term of size and composition has a borderline significant positive impact on the bond yield and the exchange rate (row v, panels B and C), similar to the outcomes of the local projections. This suggests that an increasing balance sheet size in tandem with a change in balance sheet composition leads to looser financial conditions (through a lower bond yield and a depreciation of the exchange rate) if the central bank becomes active in more different market segments.[31] No significant effect is found on inflation expectations (panel A, row iv).

The outcomes indicate that the effects following from shocks in size∗duration and size∗composition are robust to a different model set-up. However, we find no evidence of significant effects following from shocks to one balance sheet dimension in isolation, e.g. the effect of size and composition shocks on inflation expectations (rows i. and iii., panel A). This may suggest that it is more difficult to find effects of balance sheet policies on inflation expectations in a dynamic multi-equation system, like the BVAR. At the same time, the analysis cannot account for the counterfactual, e.g. it is unknown how inflation expectations would have evolved in absence of the policies. In conclusion, the results underline the importance of the duration extraction channel for the transmission of balance sheet shocks and suggests that market prices are particularly sensitive to the combined impact of shocks to different balance sheet dimensions, and not so much to isolated shocks.

Figure C. Impulse responses to a one standard deviation shock in size (i), duration (ii), composition (iii), size∗duration (iv) and size∗composition (v) based on the BVAR model.
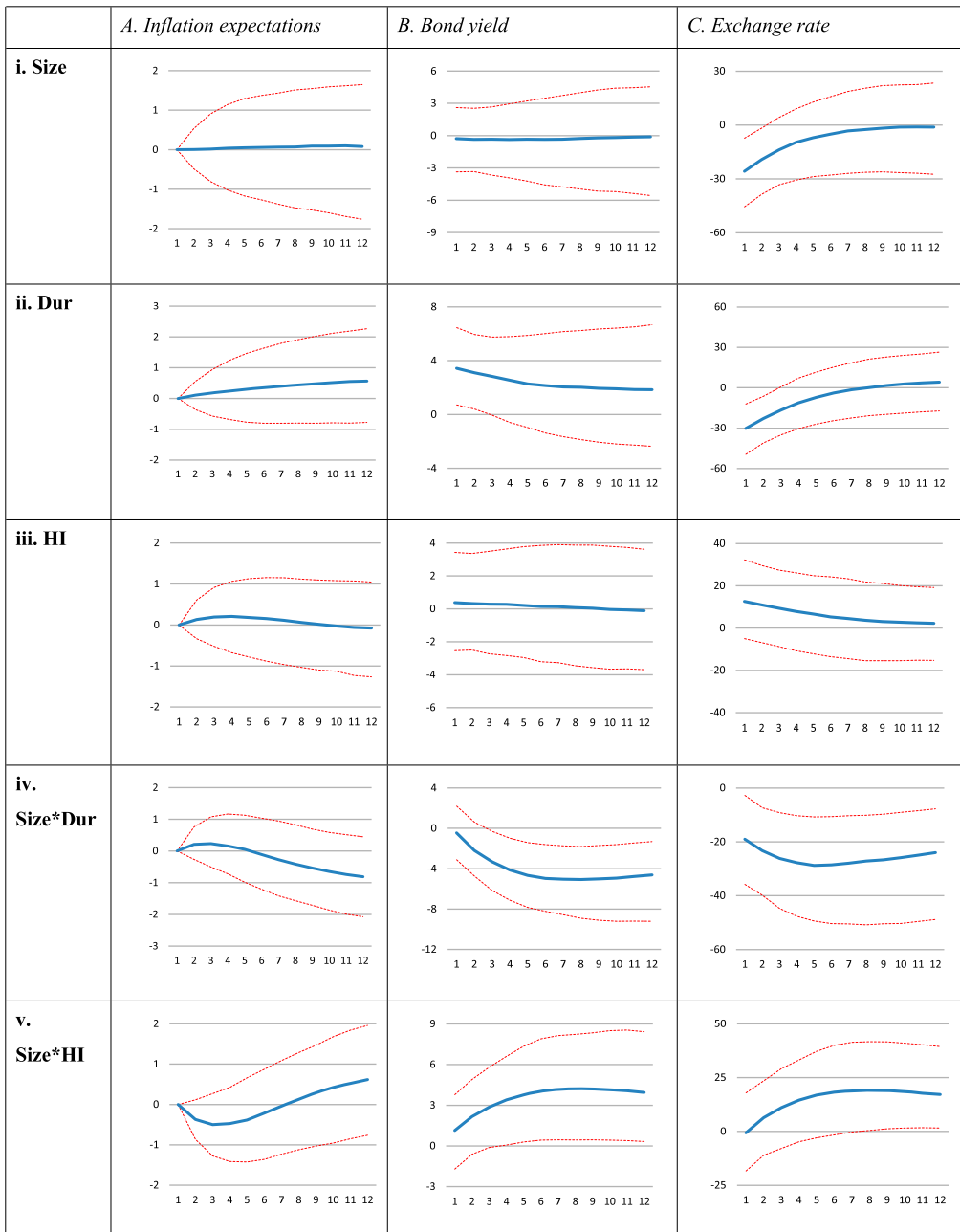
Notes: Figure c presents the estimation results from the Bayesian VAR model to assess changes in the balance sheet dimensions (size, duration, composition), size interacted with duration and composition interacted with the size. Rows i., ii. and iii. assess the balance sheet dimension in isolation, while rows iv. and v. reflect joint effects of the respective different dimensions. The red dotted lines are the 90% confidence intervals. The number of months is shown on the x-axis. The y-axis shows the impulse response in basis points.