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The ECB's unconventional monetary policy and the role of exchange rate regimes in cross-country spillovers

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Abstract
We study the impact of the ECB's large scale asset purchase programme on selected euro area and neighbouring countries. The effects of the programme are assessed by conducting an event study as well as by estimating a structural VAR model using a shadow short rate as a measure of the monetary policy stance. We find that the programme has contributed to reducing longer-term bond yields in the euro area as well as in neighbouring countries. As a consequence of the fixed exchange rate regime, Danish sovereign bond yields have been tracking those of Germany very closely. Countries with a floating exchange rate have experienced an appreciation in response to the asset purchases. The effect on the Danish krone has been neutralised by central bank intervention in the foreign exchange market. A counterfactual exercise shows that the ECB's unconventional monetary policy in the beginning of 2015 reduced the term spread in Denmark by at least 50 basis points.

Resume
Vi undersøger effekten af ECB's opkøbsprogram for udvalgte lande i euroområdet og udvalgte nabolande. Effekten af programmet undersøges ved en hændelsesanalyse og ved at estimere en strukturel VAR-model, hvor en kort skyggerente benyttes som mål for den pengepolitiske stilling. Vi finder, at opkøbsprogrammet har bidraget til at reducere de lange renter i euroområdet og i de omkringliggende lande. Som følge af fastkursregimet følger renterne på danske statsobligationer renterne i Tyskland tæt. Lande med en flydende valutakurs har oplevet en styrkelse af valutakursen som reaktion på opkøbene. Den danske krone har været uændret som følge af Nationalbankens interventioner i valutamarkedet. En kontrafaktisk analyse viser, at ECB's opkøbsprogram i begyndelsen af 2015 reducerede løbetidspræmien på danske obligationer med mindst 50 basispoint.

Key words
Unconventional monetary policy; Quantitative easing; Exchange rate regimes; Shadow short rates; Spillovers; Event study; VAR models.

JEL classification
E43; E44; E52; F31; F41.

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The authors alone are responsible for any remaining errors.

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1 Introduction

After the global financial crisis monetary policy interest rates across the world were reduced to levels close to their effective lower bound. With more monetary stimulus being needed, it has become common for central banks to resort to large scale asset purchases, often referred to as quantitative easing, QE. Since 2008 QE programmes have been conducted by, among others, the Federal Reserve, Fed, the European Central Bank, ECB, the Bank of England and the Bank of Japan. QE programmes are one of a variety of unconventional monetary policy tools available to central banks.

The ECB announced on 22 January 2015 that it would start buying public sector debt under its large scale asset purchase programme, APP. The purpose of the programme was to achieve the ECB's target of inflation rates below, but close to, 2 per cent over the medium term. The announcement implied that the Eurosystem in March 2015 would start to purchase euro-denominated investment-grade securities issued by euro area governments, agencies and European institutions in the secondary market. This is known as the public sector purchase programme, PSPP.

In the paper we study the impact of the PSPP on financial markets of selected euro area and neighbouring countries. There is an extensive empirical literature assessing the effects of QE on financial markets and the wider economy. The consensus from the various studies is that QE has had a substantial impact on financial markets. Moreover, it is generally seen as having been effective in stimulating economic activity and boosting inflation by reducing longer-term yields. This is the case across different economic regions and the result has been established using different empirical methods.[1]

In a financially integrated world where capital is internationally mobile, monetary and financial conditions are transmitted across countries. This implies that a QE programme carried out by the ECB is likely to also affect countries that are not members of the euro area. However, the extent to which individual countries are affected is likely to depend on their exchange rate regime. According to the so-called trilemma in international economics it is possible for a country to have either a fixed exchange rate or an independent monetary policy.[2] It is not possible to have both unless international capital mobility is suspended. This suggests that the monetary conditions of a country with a fixed exchange rate against the euro should be directly affected by changes to the ECB's monetary policy stance that come about as a result of QE. Countries with a floating exchange rate are potentially more insulated, but even these countries are likely to experience some degree of spillover from the euro area as investors rebalance their portfolios.

With this in mind, the aim of the paper is to assess the effects of the ECB's PSPP on financial markets across countries. The countries are grouped according to their exchange rate regimes.

The effects of QE are assessed using two different approaches. First, an event study is conducted. This allows us to directly assess the implications of QE-related statements by the ECB on sovereign bond yields and on exchange rates. Second, we estimate a structural vector autoregressive, SVAR, model to look more broadly at the implications of the ECB's unconventional policies. With unconventional measures being used to provide additional monetary stimulus, changes to the monetary policy stance are not fully captured by changes to the short-term monetary policy rate. To that end, the SVAR uses a shadow short rate, SSR, as a measure of the monetary policy stance. The SSR can be thought of as a proxy for how the central bank has

[1] For a review of the literature, see section 3.
[2] See Obstfeld, Shambaugh and Taylor (2005).

managed to influence market expectations about monetary policy as measures of the SSR are derived from yield curves, cf. Krippner (2015b).

We find evidence that the PSPP has contributed to reducing longer-term bond yields. For euro area countries the reduction has been strongest in the 'periphery' countries, while it has been more modest in the 'core'.[3] Reflecting the fixed exchange rate regime, Danish sovereign bond yields have been tracking those of the 'core' euro area countries very closely in response to QE-related announcements.

The event study suggests that Danish 9-year government bond yields declined by 30 basis points in direct response to ECB communication in the months leading up to the introduction of the PSPP. The total decline in yields was somewhat larger. This reflects that market participants also adjusted their expectations regarding a QE programme in days with no communication by the ECB, e.g. in response to data releases. From the VAR study we derive a measure of the total effect of the additional monetary stimulus from the ECB's QE programme in the beginning of 2015. We find that this has reduced the Danish term spread by at least 50 basis points.

The results imply that while Danmarks Nationalbank has not in itself been directly engaged in a QE programme, the Danish monetary policy stance has continued to mirror that of the euro area, as is the case when only conventional monetary policy tools are used. Nevertheless, some unconventional measures have been taken by Danmarks Nationalbank. These include a temporary suspension of the issuance of government bonds from January-October 2015. By reducing the supply of bonds available to private investors it had implications similar to those of a QE programme.

Whereas sovereign yields in countries with a floating exchange rate have also clearly been reduced as an effect of the ECB's QE programme, their co-movement with the yields of the 'core' countries is substantially less pronounced compared to the case of Denmark.

Turning to the implications for exchange rates, countries with a floating exchange rate have experienced an appreciation in response to ECB's PSPP. This implies that stimuli to the economy coming from lower yields have been attenuated by a stronger exchange rate. Consistent with the exchange rate peg, the Danish krone has been roughly unaffected by QE. Instead, the impact has been showing up in central bank interventions in the foreign exchange market with the objective of keeping the Danish krone away from appreciating.

The remainder of this paper is organized as follows. Section 2 discusses the potential effects of QE and how they are transmitted across countries. In section 3 we review the empirical literature on the effects of QE before presenting our main results from the event study and the VAR analyses in section 4 and 5, respectively. Section 6 concludes.

2 The impact of the ECB's asset purchases on financial markets

2.1 QE announcements and the yield curve

Longer-term yields reflect market participants' expectations of future monetary policy interest rates. To the extent that a change in the central bank's policy rate is perceived to be persistent, this implies that by changing short-term policy rates, central banks also affect interest rates further along the yield curve. In a world without uncertainty the expectation hypothesis implies that the nominal yield to maturity, $i_{n,t}$, at

[3] We define core countries as Germany, Netherlands, Finland and France. Periphery countries are Portugal, Spain and Italy.

time t to maturity n can be written as

$$(1 + i_{n,t})^n = \prod_{i=0}^{n-1} (1 + i_{t+i}) \tag{2.1}$$

where i_t is the one-period interest rate. Equation (2.1) implies that the yields received investing in a long term bond and rolling a short term bond are identical, cf. Walsh (2010). Adjusting a short term policy rate and communicating its views on the prospects for the economy are the key mechanisms through which a central bank affects expectations of longer-term yields in normal times. This allows it to control monetary and financial conditions, thereby managing private sector demand in the economy.[4] This is what enables it to achieve its inflation objectives.

In addition to expectations of future short-term rates, longer-term interest rates are affected by various premia. Such premia compensate investors for the fact that investing in a longer-maturity asset exposes them to risks that they could avoid by investing in short-term assets such as interest rate swaps. This includes risks related to default, liquidity and uncertainty about inflation. In addition, different types of investors may have preferences for assets with specific maturity, geographical location or asset class. This is often referred to as preferred habitat.[5] Preferred habitat preferences may reflect the regulatory treatment, cf. Greenwood and Vayanos (2010). It can also reflect that investors are biased in favour of holding domestically issued financial assets as documented by Lewis (1999).

In recent years many central banks have reduced short-term interest rates to levels close to their effective lower bound in response to persistently low inflation and weak demand. When central banks are constrained by the lower bound they cannot affect the longer end of the yield curve by reducing short term interest rates further. As more stimuli have been deemed necessary, they have resorted to a number of alternative measures with a view to reducing longer-term yields. One such measure is forward guidance, where the central bank attempts to influence yields by informing the public of its intentions. A credible pledge to keep short term interest rates low for a sustained period of time can lead to a reduction in longer-term yields.

Since 2008 a number of leading central banks have turned to large scale purchases of financial assets in an attempt to suppress longer-term yields. These include the Federal Reserve, the ECB, the Bank of England and the Bank of Japan.

The reduction in yields resulting from QE can come about through various channels.[6] When the central bank purchases government bonds, the supply of government bonds available to private investors is reduced. As a consequence, prices on sovereign bonds rise and yields decline. The central bank issues central bank deposits in exchange for bonds, which leads to an expansion of the central bank's balance sheet.

Since QE reduces the supply of bonds available to private investors, a fraction of the investors will have to leave the market for government bonds. According to the *portfolio rebalancing channel*, the central bank deposits acquired by the banks will be used to buy other assets such as mortgage bonds, corporate bonds, stocks, etc. This rebalancing of portfolios arises from changes in the relative prices of different assets. This

[4] See Woodford (2005).
[5] See Modigliani and Sutch (1966).
[6] See e.g. Krishnamurthy and Vissing-Jorgensen (2011) and Christensen and Rudebusch (2012) for an extensive discussion of the channels.

means that the decline in yields will spread across asset classes, resulting in a wider reduction in yields and increasing values of existing portfolios held by the households and corporations. This helps support consumption and investment.

By purchasing sovereign bonds and keeping them on its balance sheet, the central bank exposes itself to losses if interest rates increase. QE can thereby strengthen the credibility surrounding the central bank's promise to keep interest rates low for an extended period. This is the mechanism behind the *signaling channel*, which works by reducing expectations of future short rates.

2.2 Cross-country spillovers

In a financially integrated world where capital is internationally mobile, monetary and financial conditions are transmitted across countries. This gives rise to the so-called trilemma in international economics, cf. e.g. Obstfeld, Shambaugh and Taylor (2005). According to the trilemma, it is possible for a country to have either a fixed exchange rate or an independent monetary policy, i.e. to be able to set interest rates without necessarily taking into account monetary policies of other countries. However, it is not possible to have both unless international capital mobility is suspended. This can be seen from the uncovered interest rate parity

$$r - r^* = E\dot{s} + RP \tag{2.2}$$

which implies that if the domestic interest rate, r, adjusted for the risk premium, RP, is higher than the foreign interest rate, r^*, the domestic exchange rate, s, defined as domestic currency per unit of foreign currency, would be expected to depreciate.[7] Otherwise expected returns would not be equalised across currencies. A monetary policy shock abroad that changes the foreign interest rate, r^*, should, in this very stylized example, be met by either a change in the domestic interest rate, a change in the exchange rate or both to ensure that the risk-adjusted return is identical across countries. This suggests that if the domestic central bank wants to maintain a fixed exchange rate it cannot independently decide on its own interest rate. Instead the monetary policy stance is determined abroad.

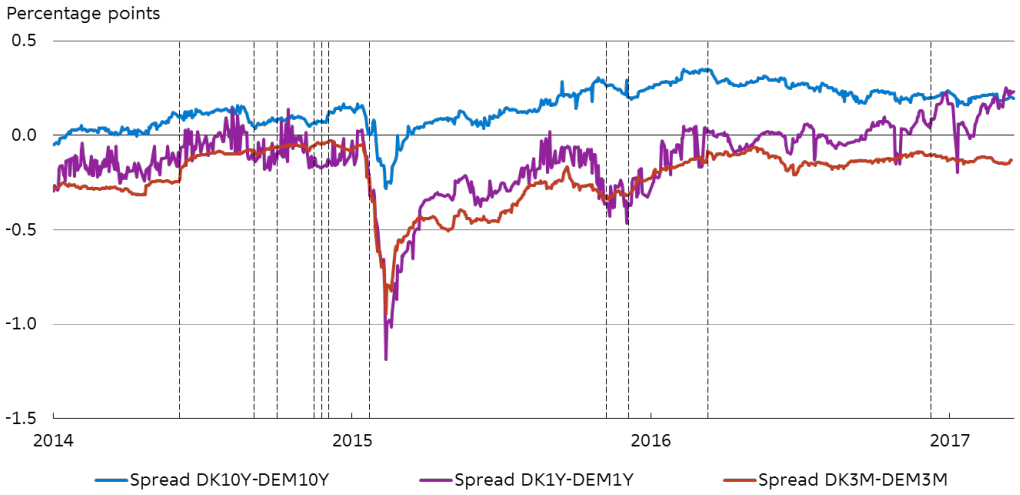
Denmark is a prime example of a country with a fixed exchange rate, having operated with an unchanged central parity vis-a-vis the euro and prior to that to the German mark since 1987. The exchange rate peg implies that Danish monetary policy rates closely follow those of the ECB.[8] Substantial divergence in policy rates are only seen on occasions with substantial pressure on the krone to either depreciate or appreciate. As longer-term interest rates reflect expectations of future policy rates, these also tend to co-move. To the extent that Danish government bond yields deviate from their euro area counterparts this reflects factors such as liquidity, risk and term premia as well as preferred habitat. As Danish public finances are sound, bonds issued by the Danish government are likely to carry very little credit risk. Moreover, they are highly liquid. These characteristics imply that Danish government bonds are close substitutes to those issued by the governments of 'core' euro area countries.

The ECB's PSPP has worked by reducing longer-term yields in the euro area countries. As the supply of euro area bonds to private investors is reduced as a consequence of the ECB's purchases, some investors are likely to invest in Danish bonds as an alternative.[9] This suggests that we should see a similar decline in yields on

[7] $E\dot{s}$ denotes the expected rate of depreciation.
[8] See Spange and Toftdahl (2014) for an exposition of the Danish monetary policy regime.
[9] Coeure (2017) discusses how the ECB's APP led euro area investors to rebalance their portfolios into foreign government bonds.

Danish government bonds. Figure 1 confirms that the spread between Danish and German yields stayed roughly constant in the months leading up to the announcement of the QE programme. This continued after the purchases were initiated. The vertical lines illustrate dates at which the ECB has made announcements that market participants have interpreted as revealing information regarding the introduction of the PSPP. These will form the basis for the event study presented in section 4, which analyses more formally how the PSPP has affected yields.

Figure 1: Spread between Danish and German bonds



Note: Dashed lines depict announcements regarding ECB's APP. Source: Nordea Analytics and Altavilla et al. (2015).

To acquire Danish bonds, investors first need to acquire DKK. In the long run the DKK/EUR rate is fully determined by monetary policy. The monetary policy rule implies that Danmarks Nationalbank stabilises the krone close to the central parity of 7.46038. But in the short run the DKK/EUR exchange rate is affected by capital flows. Often banks will initially absorb an increased demand for DKK by market participants by changing their own foreign exchange positions. This behaviour of banks in itself helps keep to the krone stable. But a more pronounced increase in the demand for DKK tends to put upward pressure on the exchange rate. In the short run this may not be fully offset by interventions in the foreign exchange market by Danmarks Nationalbank, cf. Spange and Sørensen (2016). So the ECB's PSPP may temporarily lead to a slight strengthening of the DKK/EUR exchange rate.

The trilemma suggests that countries with a floating exchange rate have authority to conduct an independent monetary policy. This implies that their central banks are able to influence their domestic yield curves by shaping the public's expectation regarding future monetary policy rates. However, if a large central bank, such as the ECB, signals via QE that it wants to reduce longer-term yields, market participants may expect a similar response in countries outside of the euro area. This could be because a foreign monetary expansion leads to an appreciation of the domestic currency, leading to lower inflation and weaker demand. Moreover, the expectations of QE by the ECB may affect yields in non-euro area countries via the portfolio rebalancing channel.

So the intentions of the ECB to conduct QE may have led to declines in interest rates elsewhere, in particular in countries that are closely integrated with the euro area. Moreover, research by Rey (2013) suggests that

the trilemma is in fact a dilemma: in a world with free capital flows, even countries with a floating exchange rate are unable to insulate their domestic monetary conditions from external influences. In particular, she argues that monetary conditions are driven by a global cycle. This suggests that it is an empirical question to what extent bond yields in countries with a floating exchange rate are affected by the ECB's PSPP. We expect the exchange rate of these countries' currencies to appreciate.

3 Related literature

In the literature, two approaches have typically been used to assess the impact of unconventional monetary policies. These are, respectively, the event study approach and the VAR approach. An event study assesses the effect of QE on the basis of the reactions in financial market variables around a set of events. The events are typically different types of communication by the central bank that are perceived by market participants as revealing new information on the central bank's intentions regarding QE.

To the extent that the information is not fully expected by market participants, it will be reflected in changes in prices and interest rates. The effect of a QE programme is assessed by adding up the responses to each individual piece of news. While the approach links developments in financial markets directly to QE-related events, it has a shortcoming in that it ignores developments that take place outside of the immediate aftermath of the events. If financial market participants adjust their expectations regarding a QE programme in response to a data release this will not be included in the effect. Moreover, the approach ignores any flow-related impact of the actual asset purchases being carried out.

VAR-based studies have been used extensively in the literature on the effects of monetary policy. By specifying a system of equations describing the interactions between key economic and financial variables, the effects of anticipated as well as unanticipated changes in the monetary policy stance can be identified by imposing restrictions founded in economic theory.

A key challenge when applying VAR models to assess the effect of unconventional monetary policy at the effective lower bound is that changes in the monetary policy stance are not captured by changes to the central bank's monetary policy rate. Instead, QE will provide additional stimulus without any reaction in policy rates. As an alternative measure of the monetary policy stance, a so-called shadow short rate can be applied.

In the paper we use both approaches. This section presents key studies using either of the two approaches. Particular focus is on recent studies that have considered international dimensions of QE programmes.

3.1 Event-based studies

On the basis of an event study, Gagnon et al. (2010) evaluate the first wave of the Fed's large scale asset purchases that were announced in 2008 and have come to be referred to as LSAP1. The authors find that LSAP1 led to persistent declines in longer-term interest rates, including interest rates on financial assets not included in the programme. They argue that the purchases primarily worked via reducing risk premia, including term premia, with the reduction in the 10-year term premium being between 30 and 100 basis points.

Krishnamurthy and Vissing-Jorgensen (2011) evaluate the effect the Fed's first two programs for purchasing long-term treasuries and other long-term bonds, LSAP1 and LSAP2. The authors find that the programmes

led to significant declines in yields of different types of assets, with LSAP1 and LSAP2 having reduced 10-year treasury yields by around 100 and 30 basis points, respectively. They argue that quantitative easing works through several channels that affect particular assets differently and that the effect on particular assets depend critically on which assets are purchased. Joyce et al. (2011) carry out an event study to evaluate the impact of the Bank of England's QE programme that began in March 2009 on financial markets in the United Kingdom. The study suggests that QE may have reduced gilt yields by about 100 basis points with the largest part coming through a portfolio rebalancing channel.

Altavilla et al. (2015) focus on the euro area and in particular on the effects of the ECB's APP announced in 2015. The effect on sovereign bond yields for Germany, France, Italy and Spain are considered, and the study finds that these effects have been sizeable. There are indications that the APP programme reduced yields on Italian and Spanish sovereign bonds with a 10-year maturity by between 60 and 80 basis points between September 2014 and March 2015 while the impact on German and French yields was somewhat smaller. There have also been clear spillovers to non-targeted assets. To reconcile the sizeable effects with the fact that the programme was announced at a time of low financial distress, the authors set up a model showing that while low financial distress weakens certain transmission channels as typically suggested in the literature, it has reinforced other channels. They also argue that the low degree of financial stress has facilitated spillovers to non-targeted assets.

Recently, a number of studies have used event studies to assess the spillover effects of ECB's unconventional monetary policies on non-euro area countries. IMF (2016) assesses the implications for five non-euro area EU countries: Denmark, Hungary, Poland, Sweden and the Czech Republic. The study includes the PSPP as well as previous measures aimed at improving liquidity in the banking sector and measures targeted at sovereign debt markets with the aim of supporting the transmission mechanism of monetary policy. Based on more than 70 events since 2007 the authors find a two-day decline in bond yields following the events of 1.5-2.5 basis points in most countries and 4 basis points in Hungary. They also find that while the reaction of the DKK/EUR exchange was negligible as a consequence of the Danish exchange rate peg, the exchange rates of the other countries tended to appreciate following the events.

Ciarlone and Colabella (2016) assess the spillover effects of the ECB's unconventional monetary policy on four central and eastern European non-euro area countries over the period 2007-15. The authors find evidence of strong spillovers to sovereign bond yields in all four countries. The spillovers relating to the securities markets programme, SMP, were the most pronounced whereas those from the OMT as well as the PSPP, that we study in this paper, were rather limited. Finally, Falagiarda et al. (2015) assess the spillovers from ECB's unconventional monetary policy on 11 central and eastern European countries over the period 2008-15. They find a statistically significant effect of ECB announcements on financial variables in these countries, including sovereign bond yields.

By comparing the asset purchase programmes of the Fed, the Bank of England, the Swedish Riksbank and the Swiss National Bank, Rios and Shamloo (2017) make the point that a QE programme implemented by a large country is more effective than one of a small country. This reflects that QE has a significant global element. While asset purchases of a large central bank have an effect on global term premia and thereby on global yields, the purchases of a small central bank primarily affect domestic yields. Investors in bonds issued by a small country where yields are being suppressed by QE therefore have an incentive to substitute into higher yielding bonds issued by other countries. This partly offsets the effect of the central bank's bond

purchases.

Hansen et al. (2013) study the effects on Denmark of the ECB's initial unconventional monetary policy measures that took place in 2008-12. This includes measures aimed at improving banks' liquidity and financing situation and measures aimed at supporting the monetary transmission mechanism. The authors find that the measures to improve the liquidity situation in the euro area led to a significant widening of the spread between Danish and German sovereign bond yields, whereas the measures targeted at sovereign debt markets worked to reduce yields.

3.2 VAR-based studies

The VAR-based literature analysing the international transmission of shocks has been around for some time. Kim (2001) and Canova (2005) identify monetary policy shocks in the US and analyse how the identified monetary policy shocks are transmitted abroad. They find a significant effect of US monetary policy shocks abroad.

In recent years as central banks have engaged in unconventional monetary policies, different types of VAR models have been applied to identify the effect of these new policy instruments. A key challenge associated with VAR models is that, in times when unconventional monetary policies are implemented, the monetary policy stance is not summarized by the short-term interest rates, since unconventional monetary policy measures aim at reducing longer-term interest rates more directly. Most papers use the fact that yield curves reflect all information available to market participants at any given day, and therefore incorporate unobservable effects, such as the effects of higher probability of QE.

A common measure used in the VAR literature on the effects of unconventional monetary policy is the shadow short rate, SSR.[10] Wu and Xia (2016) develop an SSR for the US, and show using a factor-augmented VAR model that unconventional monetary policy has affected the real economy in the same way as conventional. The various models of the SSR are generally sensitive to the model specification and deliver different estimates of the SSR. Wu and Xia (2016), however, note that the dynamics point to the same economic conclusions, regardless of the specific model and estimation technique.

Lombardi and Zhu (2014) estimate the impact and the transmission of unconventional monetary policy for the US economy using an estimated shadow short rate based on a large set of variables, They find that unconventional monetary policies have been effective tool to stimulate the economy. Francis et al. (2016) propose using a shadow rate as a measure of monetary policy and finds that the Fed's use of balance sheet policies have been a successful instrument in boosting inflation and the real economy. Damjanovic and Masten (2016) develop an SSR for the euro area and estimate the effect of unconventional monetary policy shocks in the euro area. The effects of these shocks on the real economy are found to be equivalent with conventional monetary policy shocks.

A number of studies have focused on the cross-country spillovers of unconventional monetary policy. Chen et al. (2017) find that US shocks generate larger spillover effects compared to euro area shocks. This is done within a global vector error correction model. Potjagilo (2017) employs a factor VAR model to analyse

[10] These models build on the idea introduced in Black (1995). In these models the term structure is modelled by using the value of the option of going into cash, when the short rate hits the lower bound. For different approaches see Wu and Xia (2016), Lemke and Vladu (2016), Christensen and Rudebusch (2013), Bauer and Rudebusch (2016), Wu and Xia (2017), Krippner (2013a), Krippner (2013b), Krippner (2015b) and Krippner (2015a)

the effect of monetary policy shocks outside the euro area. Countries are divided into groups based on their exchange rate regime and the responses to a monetary policy shock are compared. The paper finds heterogeneous effects of monetary policy shocks for countries with flexible and fixed exchange rate regimes. The spillovers to the real economy and to interest rates are larger for countries with a fixed exchange rate regime. However, Bluwstein and Canova (2016) find that the response of ECB's unconventional monetary policy in non-euro area countries on inflation and output is independent of the exchange rate regime.

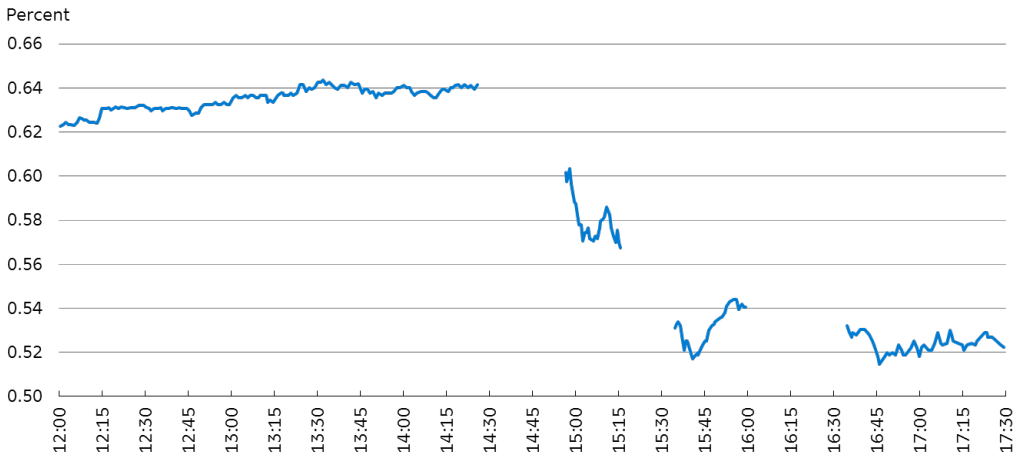
IMF (2016) uses a country level VAR and a global VAR to estimate the spillovers from unconventional monetary policy from the ECB on Denmark, Poland and Sweden. They find insignificant responses of 10-year interest rates following a shock to the SSR. Burriel and Galesi (2016) examine the effect of ECB's policies across the euro area and finds heterogeneous effects from unconventional monetary policies across countries in the Euro Area. Countries with a less fragile banking system are affected more by the unconventional monetary policy measures.

4 Event study

The first purchases related to the ECB's large scale public sector asset purchase programme, PSPP, were conducted on 6 March 2015. However, due to the forward-looking nature of financial markets, the introduction of the PSPP was being factored into prices of financial assets well before any actual purchases were made by the ECB. Figure 2 shows how the yield on a specific Danish 10-year government bond evolved during 22 January 2015 when the PSPP was announced. The figure is based on quoted prices from primary dealers on the MTS platform.[11] The announcement was made by ECB President Draghi at a press conference starting at 2.30 p.m. In the hours before the press conference yields were stable. However, shortly before the press conference began, the primary dealers withdrew their quotes. This is often observed in the minutes leading up to substantial announcements of market sensitive news. When quoted prices reoccurred at 2.56 p.m., yields had declined by approximately 4 basis points. Throughout the afternoon there were further declines in yields and extended time intervals where no prices were quoted. By the end of the day yields were 12 basis points lower compared to just before the press conference.

[11] MTS is one of Europe's leading electronic fixed income trading markets, with over 500 unique counterparties and average daily volumes exceeding EUR 100 billion.

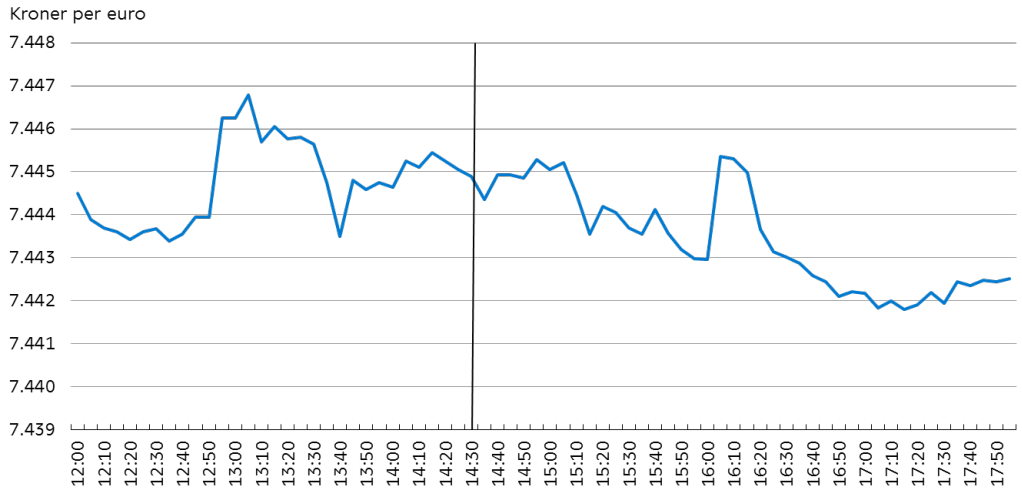
Figure 2: Yield on a Danish 10-year government bond, 22 January 2015



Note: Breaks in the blue line indicate periods where no prices were quoted. Source: MTS.

Whereas Danish sovereign bond yields clearly responded to the introduction of the PSPP, there were no visible reaction in the DKK/EUR exchange rate around the time of the announcement, cf. figure 3. However, it should be noted that the announcement was made at a time with substantial capital inflows leading to pressure on the krone to appreciate. This was met by frequent interventions by Danmarks Nationalbank in the foreign exchange market. Developments in the DKK/EUR exchange rate during this period were therefore heavily influenced by Danmarks Nationalbank's strategy for its foreign exchange interventions. The capital inflows had been triggered by the decision of the Swiss National Bank one week earlier to abandon the floor under the Swiss franc vis-a-vis the euro.[12]

Figure 3: Exchange rate DKK/EUR on 22 January 2015



Source: Olsendata.

[12]See Danmarks Nationalbank (2015) for a discussion of the pressure on the krone in January-February 2015.

4.1 Bond yields

The official announcement of the PSPP programme was only the last element in a series of communication by the ECB that gradually shaped market participants' expectation of the programme. To assess the total impact of the ECB's communication regarding its PSPP programme on sovereign bond yields we have conducted an event study. An event refers to a piece of ECB communication that has been interpreted by market participants as revealing news about the ECB's intentions regarding the introduction and the design of the programme.

The event study calculates the change in yields in a short window immediately following the events. Markets for government bonds are highly liquid, as are foreign exchange markets. This suggests that prices respond rapidly to news, suggesting that a one-day event window is appropriate. However, as some of the events take place quite late in the afternoon we follow the bulk of the literature and also consider a two-day window to ensure that we capture the full market reaction.

The set of events follow from Altavilla et al. (2015) and it is listed in table A.1 in Appendix A. The events primarily encompass ECB press conferences and speeches by President Draghi. All events occur between September 2014 and March 2015, which is a period that experienced a substantial decline in yields across the euro area economies. The decline in yields was the key objective of the PSPP, whereas the ECB's earlier unconventional monetary policy measures had primarily been aimed at improving the monetary transmission mechanism.

Table 1 presents the cumulated impact of PSPP-related announcements on 9-year zero-coupon sovereign bond yields for Denmark as well as for four 'core' euro area countries (Germany, the Netherlands, Finland and France), three 'periphery' euro area countries (Portugal, Spain and Italy), two countries with a floating exchange rate (Sweden and the United Kingdom), which will be referred to as the 'floaters', and one country with a managed float (Switzerland).[13] The announcements have been associated with a modest decline in yields in Denmark totalling 16 or 30 basis points across the 17 events depending on whether a one-day or a two-day is considered. This is similar to the effect on yields in the four 'core' euro area countries. The results illustrates UIP, cf. equation (2.2): for a country with a fixed exchange rate, risk-adjusted interest rates will follow those of the anchor country. The 'periphery' countries all experienced somewhat larger declines

Table 1: Cumulative changes in government bond yields around first 17 event days, September 2014-March 2015 (basis points)

		Core				Periphery			Floating		Managed float
	DNK	DEU	NLD	FIN	FRA	PRT	ESP	ITA	SWE	GBR	CHE
one-day change	-16	-17	-22	-24	-27	-103	-75	-83	-9	-27	3
two-day change	-30	-28	-36	-38	-34	-107	-75	-87	-23	-38	-29

Note: The countries are DNK: Denmark, DEU: Germany NLD: Netherlands, FIN: Finland, FRA: France, PRT: Portugal, ESP: Spain, ITA: Italy, SWE: Sweden, GBR: United Kingdom, CHE: Switzerland.
Source: Thomson Reuters Datastream and own calculations.

in yields, ranging from 0.75 to a full percentage point. This may suggest that risk premia have been affected by the PSPP. Even for the 'floaters' we find indications that the PSPP has reduced yields, suggesting that adopting a floating exchange rate does not insulate domestic financial condition from the impact of foreign

[13] Data are from Thomson Reuters Datastream.

monetary policy. This supports the findings by Rey (2013) that changes in financial conditions are to a large extent a global phenomenon.

Germany, France, Italy and Spain are all included in the study by Altavilla et al. (2015). As we use their set of events, it is unsurprising that our results are very similar to what they find. The studies by IMF (2016), Ciarlone and Colabella (2016) and Falagiarda et al. (2015) all cover a longer time period and include different sets of countries and events compared to our study. This makes a comparison of the magnitudes less straightforward. Comparing the average decline in yields for each event in the present study with the results reported by IMF (2016) suggests that the effects found in this paper are somewhat smaller than those reported by the IMF. This is especially the case as the IMF study tends to find larger effects of the PSPP-related announcements compared to those relating to the earlier programmes.

For the countries in the analysis there has been a gradual decline in yields over the period under consideration. We test for whether changes in yields on days with PSPP-related announcements differ from average daily changes over that period. The test therefore indicates whether the announcements have implied a decline in yields above the general trend. To do so, we regress the daily change in yields on a constant term and on the contemporaneous and (in the case of two-day change) the first lag of a dummy variable for whether there was an announcement, i.e.

$$\Delta Y_t = \alpha + \delta_1 D_t + \delta_2 D_{t-1} + u_t \tag{4.1}$$

ΔY_t is the daily change in sovereign bond yields and D_t is a dummy variable that takes the value 1 on days where there is an PSPP-related event and 0 otherwise, and u_t is an error term. The regression is estimated on daily data from the beginning of 2014 to June 2015 using ordinary least squares. α measures the average daily change in yields for this period. Statistical significance is based on an F-test of whether the sum of the coefficients on the dummy variable, δ_1 and δ_2, is equal to zero, using robust standard errors to take account of heteroskedasticity and autocorrelation. In the specification for one-day changes where the term $\delta_2 D_{t-1}$ is excluded from (4.1) we test whether δ_1=0. The test statistics are reported in Table 2 and the results are mixed.

In assessing significance it is crucial whether or not (4.1) includes the constant term, α. If α is not included the announcement effects appear substantially more statistically significant. This reflects the gradual decline in yields over the relevant period. A test for whether the change in yields in the immediate aftermath of the events has differed from the change in yields on other days is therefore different from simply testing whether the change in yields following the event has been negative.

Table 2: Test for whether change in government bond yield differs from average change, September 2014-March 2015 (F-statistics using HACSE, (1,356) d.f.)

		Core				Periphery			Floating		Managed float
	DNK	DEU	NLD	FIN	FRA	PRT	ESP	ITA	SWE	GBR	CHE
one-day change (δ_1=0)	1.19	0.83	1.59	2.23	2.39	8.86***	8.25***	8.79***	0.00	3.44*	–
two-day change (δ_1+δ_2=0)	0.97	0.67	1.34	1.69	1.09	3.02*	2.55	4.09**	0.10	2.09	1.52

*Note: Asterisks denote significance in test for whether total change differs from average change over same number of days: *** 1 percent,** 5 percent and * 10 percent level.*
Source: Thomson Reuters Datastream and own calculations.

The event study focuses narrowly on financial market developments around specific announcements. To the extent that market participants reassess their expectations regarding the PSPP outside of the announcement windows, this is not captured. If relevant events are omitted, this would bias the measure of the total effect either upwards or downwards depending on the impact of these events. Moreover, it cannot be ruled out that changes in yields within the event windows partly reflect factors other than the announcements. This could be particularly relevant for Sweden, the United Kingdom and Switzerland, where the monetary policy regimes imply that yields are likely to be driven to a large extent by domestic factors including releases of economic indicators as well as central bank communication. Finally, it should be noted that flow effects associated with the actual asset purchases are not captured.

The fact that the combined effect of the PSPP announcements on Danish sovereign yields is similar to the effect on 'core' does not in itself imply that the responses to the individual events are also similar. Table 3 therefore shows the correlation between the reaction of German yields and yields of each of the countries in the study to the 17 events. The table illustrates that across the 17 events Danish and German yields correlate very strongly – and even more so than those of the 'core' euro area countries. This may reflect that Danish sovereign bonds have kept their AAA rating with all the rating agencies throughout the financial crisis. The yields of the countries with floating exchange rates also show a clear positive correlation with Germany. Simply looking at the correlation between yields in two countries is likely to always give rise to positive co-movements as global shocks to inflation and economic activity are likely to create co-movements in expectations in domestic monetary policies. However, by focusing only on the windows following the 17 events, the co-movement detected here is likely to reflect to a large extent reactions to the PSPP.

Table 3: Correlation with change in German yields based on 17 events

		Core			Periphery			Floating		Managed float
	DNK	NLD	FIN	FRA	PRT	ESP	ITA	SWE	GBR	CHE
one-day change	0.98	0.92	0.95	0.86	0.53	0.56	0.44	0.69	0.63	0.70
two-day change	0.99	0.95	0.96	0.92	0.54	0.59	0.47	0.83	0.52	0.62

Note: The countries are DNK: Denmark, DEU: Germany NLD: Netherlands, FIN: Finland, FRA: France, PRT: Portugal, ESP: Spain, ITA: Italy, SWE: Sweden, GBR: United Kingdom, CHE: Switzerland.
Source: Thomson Reuters and own calculations.

4.1.1 Effects of changes to the PSPP

Since the first PSPP-related purchases were carried out on 9 March 2015, the ECB has announced changes to the programme on four occasions.[14] On 9 November 2015 the issue share limit was raised from 25 to 33 percent, thereby enlarging the universe of purchasable assets. At the press conference on 3 December an extension of the programme was announced, implying that it would run until at least the end of March 2017. Initially the ECB had intended that the asset purchases should be conducted until end-September 2016 and in any case until there was a sustained adjustment in the path of inflation consistent with the ECB's aim of achieving inflation rates below, but close to, 2 percent over the medium term.

On 10 March 2016 it was announced that the monthly purchases would be expanded to 80 billion euro, up from the initial 60 billion. And finally, on 8 December 2016, while it was announced that the monthly purchases would be reduced back to 60 billion, the program was extended further until at least the end of

[14]The four adjustments are listed in table A.2 in Appendix A.

December 2017. Moreover, the minimum remaining maturity for eligible securities was decreased from two years to one year and purchases of securities under the PSPP with a yield to maturity below the interest rate on the ECB's deposit facility were permitted to the extent necessary.

Table 4 shows the reactions to the announcements of government bond yields for the countries included in this paper.

Table 4: Cumulative changes in government bond yields around adjustments to the PSPP, 2015-2016 (basis points)

		Core				Periphery			Floating		Managed float
	DNK	DEU	NLD	FIN	FRA	PRT	ESP	ITA	SWE	GBR	CHE
9 November 2015	-7	-7	-8	-9	-8	7	-6	-10	-2	0	-5
3 December 2015	23	22	22	23	23	22	24	27	21	19	16
10 March 2016	3	4	4	2	0	-20	-7	-8	8	10	5
8 December 2016	1	1	3	3	5	35	7	13	2	8	2
Sum of above	19	20	21	19	20	44	18	22	29	36	18

Note: The countries are DNK: Denmark, DEU: Germany NLD: Netherlands, FIN: Finland, FRA: France, PRT: Portugal, ESP: Spain, ITA: Italy, SWE: Sweden, GBR: United Kingdom, CHE: Switzerland. Two-day windows.
Source: Thomson Reuters and own calculations.

The response of yields to the adjustments to the PSPP programme has been mixed. Whereas the decision to increase the ECB's issue share limit was associated with a decline in yields across the euro area as well as in Denmark, yields rose following the announcement on 3 December that the Governing Council had decided to extend the APP until at least the end of March 2017 and that the interest rate on the deposit facility would be reduced by 10 basis points. The increase in yields reflects that market participants had expected the ECB to announce an expansion of the monthly purchases. The announcement in March 2016 to increase the monthly purchases to 80 billion euro was associated with declines in yields in the periphery countries, whereas yields rose slightly in Denmark and in 'core'. As the monthly purchases were scaled back to 60 billion, yields rose in 'periphery' whereas the response in 'core' was very muted.

In total, the adjustments to the programme have been associated with modest increases in yields in spite of the fact that only the fourth announcement contains an element that can be seen as contractionary, i.e. the decision to scale back the monthly purchases. This illustrates that the event study is not able to adjust for what is already being expected by market participants. As is the case with the 17 events leading up to the introduction of the PSPP programme, Danish yields have closely tracked those of 'core', whereas the reaction of 'periphery' has differed somewhat in relation to the two last announcements. We also observe that yields in 'floaters' have tended to co-move with those of 'core'.

4.2 Exchange rates

Table 5 presents the impact of the 17 events leading up to the introduction of the PSPP programme on the exchange rates between the euro and the national currencies of the non-euro area economies in this paper. Exchange rates are measured as daily closing spot rates. A negative number indicates an appreciation of the currency in question. As Danmarks Nationalbank has pegged the Danish krone to the euro, the impact on the DKK/EUR exchange rate is negligible whereas both the SEK and the GBP have been strengthened somewhat by the ECB's APP.

However, testing for statistical significance by replacing government bond yields with exchange rates in (4.1) and conducting an F-test on the δ coefficients, the announcements turn out to be insignificant. Looking

at one-day changes, the CHF has been roughly unaffected, whereas the two-day change indicates a substantial appreciation. This reflects that one of the events took place on the day before the announcement by the Swiss National Bank that the floor under the CHF/EUR exchange rate would be discontinued. This announcement led to a sharp appreciation of the CHF. IMF (2016) also finds evidence that the ECB's unconventional monetary policy has tended to strengthen the SEK although the statistical significance is not clear.

Table 5: Cumulative changes in exchange rates around first 17 event days, September 2014-March 2015 (percent)

	DKK/EUR	SEK/EUR	GBP/EUR	CHF/EUR
one-day change	-0.03	-1.00	-1.72	0.17
two-day change	-0.17	-1.05	-3.44	-13.47

Source: Thomson Reuters Datastream and own calculations.

To the extent that expectations of a PSPP programme by the ECB had resulted in a tendency for the DKK to appreciate against the euro, Danmarks Nationalbank would, according to its reaction function, have been expected to issue DKK against foreign currency. However, it is difficult to link the specific events considered in this paper with increased foreign exchange interventions. In fact, intervention activity in the latter half of 2014 was very limited, totalling only DKK 7 billion. This contrasts sharply with the first two months of 2015 when Danmarks Nationalbank issued DKK against foreign currency totalling DKK 275 billion.

The large volumes of foreign exchange intervention in January and February 2015 reflect speculative pressures for the krone to appreciate that emerged following the decision of the Swiss National Bank to discontinue the minimum exchange rate of the Swiss franc against the euro. This appears to have prompted some foreign investors to buy kroner in the expectation that Denmark would abandon its exchange rate peg, while some domestic investors decided to hedge against potential losses in case of krone appreciation, thereby adding to the pressure, cf. Raffnsøe et al. (2016).

The decision to discontinue the minimum exchange rate reflected the view of the Swiss National Bank that the overvaluation of the Swiss franc had decreased. The overvaluation of the franc had together with an extremely high level of uncertainty on the financial markets been the reason behind the introduction of the minimum exchange rate.[15] The weakening of the Swiss effective exchange rate was a consequence of the weakening of the euro, which to some extent reflected that market participants had come to expect that the ECB was about to introduce a PSPP programme. So the sharp flows of capital into Denmark in January and February 2015 and the associated interventions in the foreign exchange market can be seen as being at least partly a consequence of the PSPP.

5 VAR approach

Structural VAR models are commonly used to analyse the effects of monetary policy on the macro economy. In recent years, VAR models have been used to assess the effectiveness of unconventional monetary policies. However, due to central banks' use of unconventional monetary policy instruments, a standard monetary VAR where the policy rate is used as a measure of the monetary policy stance is not likely to deliver a sufficient description of the effect of monetary policy on the real economy and financial spillovers.

[15] See press release of the Swiss National Bank 15 January 2015, https://www.snb.ch/en/mmr/reference/pre20150115/source/pre20150115.en.pdf.

Nevertheless, the identification of monetary policy shocks known from the monetary VAR literature, see Christiano et al (1999), can still be used.[16] The challenge in times of unconventional monetary policy is to come up with a measure of the monetary policy stance that summarizes the stance, when unconventional monetary policy is implemented.

In this section we use the structural VAR approach to estimate the effect of ECB monetary policy shocks on Denmark. We then compare the results to other countries. We use an SSR as a measure of the monetary policy stance.

5.1 Empirical method

We apply a standard structural VAR model to identify monetary policy shocks in the euro area. It is assumed that the ECB conducts monetary policy by reacting to inflation and the real economy. To identify the structural shock a recursive ordering of the endogenous variables is used. More specifically, it is assumed that monetary policy reacts contemporaneously to changes in output and inflation, while inflation and output only react with a lag to changes in the monetary policy stance. The structural parameters are obtained from a Cholesky decomposition of the reduced form variance-covariance matrix. The identification of monetary policy shocks rests upon the assumption that we are controlling for all information used by the ECB when they determine the monetary policy stance.

For the spillover analysis we treat the non-euro area country in question as a small open economy, i.e. we assume that it does not affect the euro area. This implies that we can include the euro area as a block in the VAR model. The small open economy assumption is modelled by block exogeneity, which means that the model is estimated with zero restrictions on the contemporaneous matrix and the lagged matrices. The small open economy assumption has been used in a number of papers, see Cushman and Zha (1997), Canova (2005) and Mackowiak (2007). More recently, Bluwstein and Canova (2016) use the block exogeneity assumption to analyse the spillovers from unconventional monetary policies.

Unconventional monetary policies have aimed at reducing long term rates directly, whereas conventional monetary policies aim at reducing short rates and thereby affecting long term rates through expectations of future short-term rates, cf. section 2.1. This means that conventional and unconventional monetary policies are likely to affect financial variables differently. Under conventional monetary policy, a monetary policy shock has a larger effect on short-term interest rates compared to long-term interest rates, cf. Evans and Marshall (1998). An unconventional monetary policy shock will impact long-term rates more than short-term rates since asset purchases change relative prices and induce a rebalancing of investors' portfolios. These differences between unconventional and conventional monetary policies imply that we will focus our estimation on a relatively short time horizon.

To avoid proliferation of parameters the model is estimated in two steps. In the first step, the euro area block is estimated in order to identify the structural shock to the ECB's monetary policy. In the second step, the spillovers are estimated by fitting a VAR to the variables of interest for the non-euro area country, using the identified monetary policy shock as a regressor. Spillovers are identified by assuming that there is no effect of inflation and the real economy on financial variables outside the euro area except through monetary policy. Since we are not using shocks to industrial production and inflation, this reduces the number of parameters to be estimated and allows us to use a relatively short estimation period.

[16] For an application in the case of Denmark, see Beier and Storgaard (2006).

We use the structural shock to the ECB's monetary policy stance to identify spillovers to non-euro area countries. Since we are not interested in the effect of domestic shocks and focus only on the effect of the ECB's unconventional policies on domestic financial variables, we do not need a detailed identification strategy in the second step and the ordering of financial variables is arbitrary. We assume that monetary policy shocks affect financial variables on impact.

5.2 Estimation procedure

For the euro area, we estimate a standard monetary VARX model given by equation (5.1). The model is estimated on a monthly frequency with data from 2008-16:

$$\begin{bmatrix} IP_t \\ \pi_t \\ SSR_t \end{bmatrix} = A(L) \begin{bmatrix} IP_{t-1} \\ \pi_{t-1} \\ SSR_{t-1} \end{bmatrix} + \beta X_t + u_t, \tag{5.1}$$

where IP_t is industrial production, π_t is inflation, and SSR_t denotes the shadow short rate. $A(L)$ is the lag polynomial. The term βX_t captures the effect of exogenous variables, where we include a linear trend and the year-on-year growth in a world commodity price index. The impulse responses of the estimated model are reported in section 5.4.1. The estimation period for the euro area is chosen such that we avoid including the build-up of the financial crisis. We use data from the unconventional and conventional period to identify monetary policy shocks since Wu and Xia (2016) show that the effect of monetary policy shocks on the real economy and inflation is similar across the two periods. The model is estimated using two lags as suggested by the Ljungbox test, AIC, and BIC. The structural shocks are identified using the following ordering of the variables: *Industrial Production*, *Inflation*, *Shadow short rate*.

In the second step, we analyse the spillovers of monetary policy shocks to neighbouring economies. Since we focus on financial variables and conventional and unconventional monetary policy affect these differently, we estimate the model in the period where unconventional monetary policy has been dominant. Specifically we use data from 2010-16. To account for the estimation error of the estimated structural shock, we apply a two-step bootstrap procedure, see Appendix B. We include the term spread measured as the 10-year yield subtracted the 3-month yield, the change in the exchange rate, and, if available, foreign exchange interventions. In the baseline model we do not include the monetary policy rate or any measure of economic activity or prices. If the non-euro area country of interest changes its monetary policy rate this would be reflected in the term spread. This means that we indirectly control for changes in the monetary policy interest rate. Spillovers are analysed by estimating the VARX model given by equation (5.2)

$$\begin{aligned} \begin{bmatrix} Term\ spread_t \\ \Delta Exchange\ rate_t \\ FX\ interventions_t \end{bmatrix} =& A(L) \begin{bmatrix} Term\ spread_{t-1} \\ \Delta Exchange\ rate_{t-1} \\ FX\ interventions_{t-1} \end{bmatrix} \\ &+ \beta X_t + \eta_t, \end{aligned} \tag{5.2}$$

where X_t contains the same variables as in equation (5.1) as well as a term $w_{SSR,t}$ which is the structural shocks obtained from the first step.

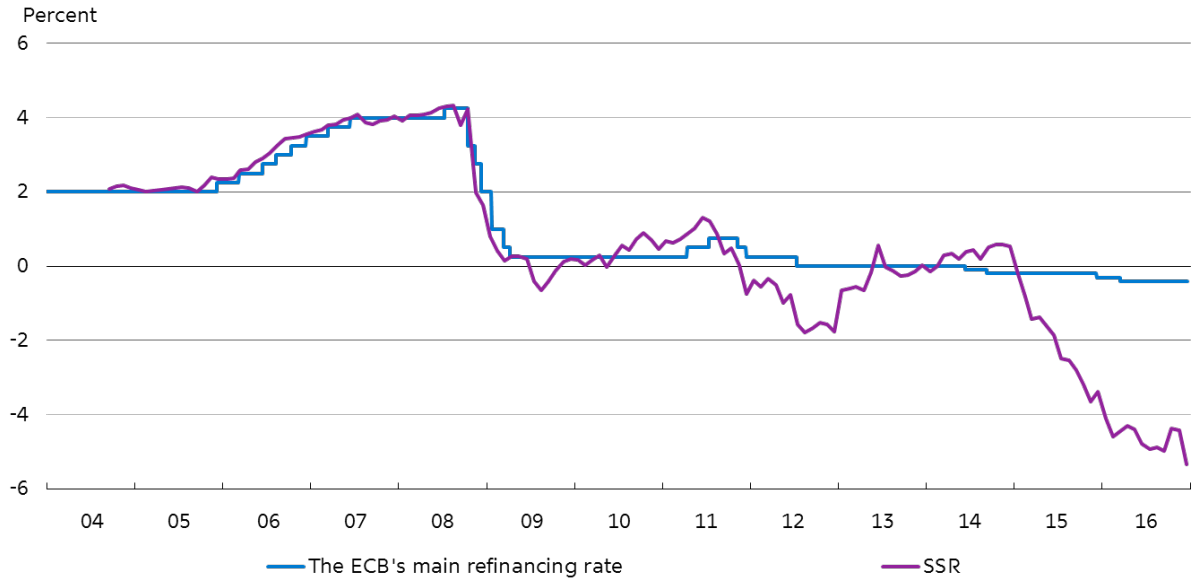
On impact the impulse response will be the coefficient on the SSR structural shocks in the model given by

equation (5.2). Impulse responses at longer lags are obtained by iterating equation (5.2) forward. The model is estimated using one lag as suggested by the Ljungbox test, AIC, and BIC.

5.3 Data

The VAR model is estimated using data at a monthly frequency. As a measure of the monetary policy stance we include the SSR for the euro area obtained from Wu and Xia.[17] SSRs are estimated using observed yield curve data. This implies that they capture central bank policies that aim at reducing longer-term rates. A fall in the SSR can therefore be observed without any reduction in the monetary policy rate. The SSR is an appealing measure of the monetary policy stance as it coincides with the monetary policy rate before unconventional monetary policy measures were implemented, see figure 4. Since the beginning of 2015 the SSR has gone far into negative territory. This reflects the very accommodative monetary policy in the euro area.

Figure 4: Euro area shadow short rate and policy rate



Source: Wu and Xia and ECB.

As a measure of economic activity we use the gap between industrial production and its trend obtained by HP-filtering the seasonally adjusted industrial production index obtained from Eurostat. The inflation rate is calculated as the year-on-year growth rate in the harmonized consumer price index in the euro area. We control for exogenous movements in oil and other commodity prices by including the year-on-year growth in the Thomson Reuters commodity price index as an exogenous variable.

For the Danish block we include the term spread measured as the difference between 10-year government bonds and 3-month money market rates. We include the change in the log of the exchange rate (EUR/DKK) as well as FX interventions by Danmarks Nationalbank. For the comparison of responses across countries we use the term spread and the change in the log exchange rate. Variables are obtained from Danmarks

[17] https://sites.google.com/site/jingcynthiawu/home/wu-xia-shadow-rates

Nationalbank, Eurostat, Thomson Reuters Datastream and Nordea Analytics. Data on Swiss interventions are proxied by the change in domestic and foreign banks sight deposits at the Swiss National Bank.

5.4 Results

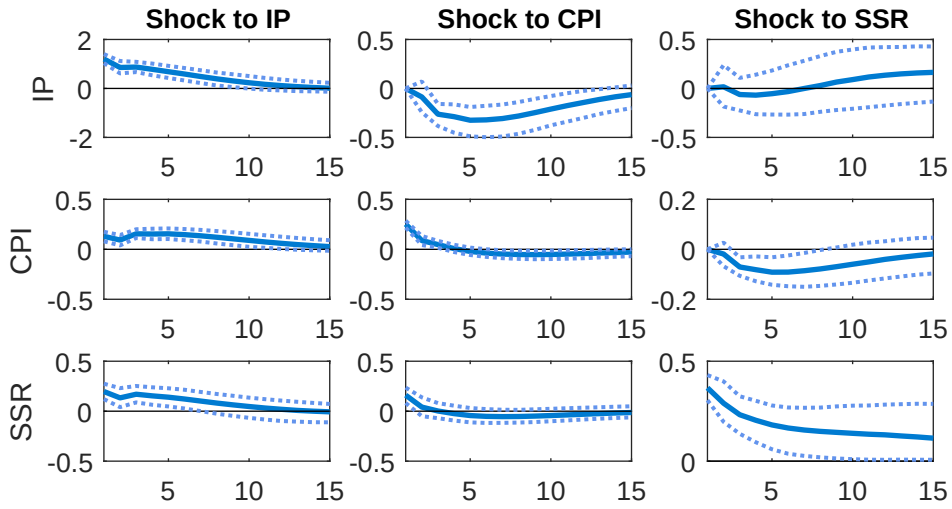
5.4.1 Euro area block

We expect the following relationship between monetary policy variables, prices and the real economy to hold:

- An expansion in economic activity will lead to an increase in prices. Since the ECB's mandate is to maintain price stability, an economic expansion will lead to a contraction of monetary policy.
- An increase in prices will lead to a reduction in economic activity as goods become more expensive. This will lead to a contraction of the monetary policy stance.
- An unexpected contraction of the monetary policy stance will lead to a fall in prices and economic activity.

Figure 5 shows the impulse responses for the euro area block of the VARX model. The impulse responses

Figure 5: Impulse responses from a one-standard deviation contractionary shock



Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

confirm our expectations. A shock to industrial production leads to an increase in prices and a contraction of the monetary policy stance. A positive shock to inflation leads to a fall in industrial production and a contraction of the monetary policy stance. Lastly, an unexpected contraction of the monetary policy stance leads to a fall in prices whereas the effect on economic activity is insignificant.

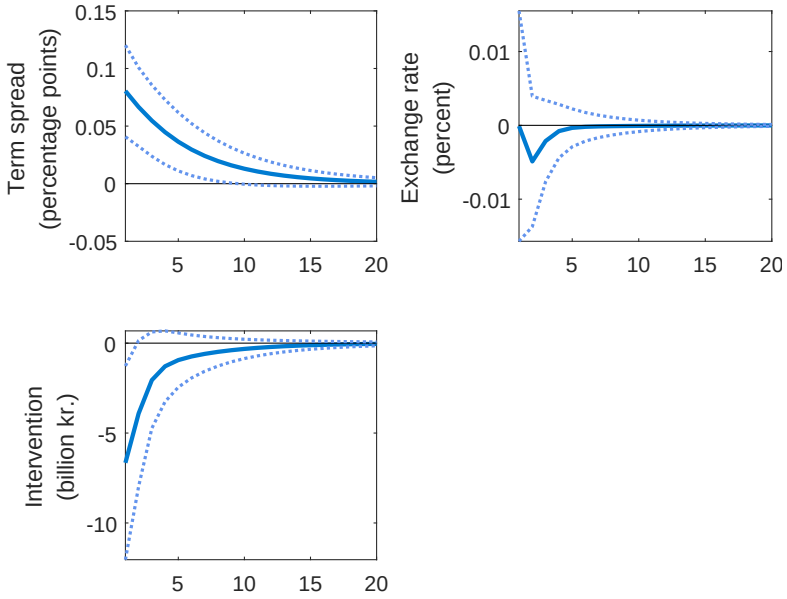
Comparing the shock to economic activity with the shock to prices we see that the contraction in the monetary policy stance lasts longer for the real economy shock compared to the inflation shock. This is due to the response of prices following a shock to the real economy. The drop in economic activity helps attenuate the effect from a price shock.

5.4.2 Spillovers to Denmark

We estimate the spillovers to Denmark from a structural shock to ECB's monetary policy. Figure 6 shows the impulse responses from a one-standard deviation shock to the SSR. A contractionary shock to the monetary policy stance in the euro area leads to a steeper slope of the yield curve in Denmark. Specifically, a 0.4 percentage point increase in the SSR leads to a 0.1 percentage point increase in the spread between the 10-year rate and the 3-month rate. This highlights that unconventional monetary policy has a different effect on financial markets compared to conventional. Under conventional monetary policy, a contractionary shock to the SSR should lead to a reduction in the term spread.

When long term interest rates change in the euro area the uncovered interest rate parity, equation (2.2), suggests that this should be met by a change in the domestic interest rate and/or the exchange rate. Our interpretation is that the spillovers to the Danish term spread from a monetary policy shock in the euro area arise from a rebalancing of investors' portfolios as Danish government bonds are close substitutes to bonds issued by governments of 'core' euro area countries, cf. section 4. As investors purchase Danish government bonds this leads to a similar increase in Danish bond prices as in the euro area. Secondly, the monetary policy shock does not affect the exchange rate. This follows from the uncovered interest rate parity. Finally, a 0.4 percentage point increase in the SSR leads to sale of euros against Danish kroner of ~ 7 billion kr. by Danmarks Nationalbank.

Figure 6: Impulse responses from a one-standard deviation contractionary shock



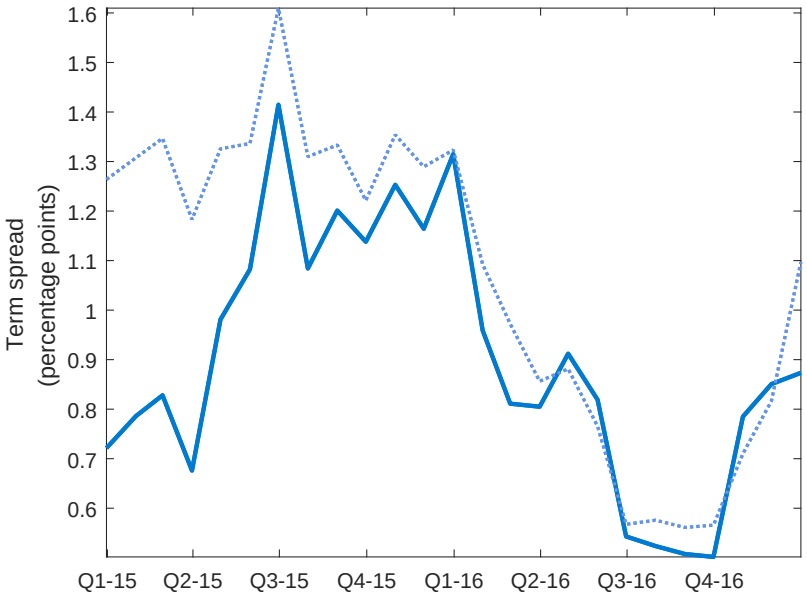
Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

As investors rebalance their portfolios and buy Danish government bonds following a monetary policy expansion, the krone will tend to appreciate. This has in the period under consideration been offset by interventions by Danmarks Nationalbank.

5.4.3 Quantifying the unanticipated effect of ECB QE

In order to quantify the effect of the ECB's QE program we perform a counterfactual analysis covering the period 2015-2016. We do this by looking at an alternative world where the monetary policy shocks are set to zero. This counterfactual exercise allows us to show the effect of unexpected monetary easing, i.e. the deviation from the estimated monetary policy rule. The counterfactual exercise shows that the unexpected shocks to monetary policy reduced the term spread in Denmark in the beginning of 2015 by at least 50 basis points, cf. figure 7. This suggests that the PSPP was partly unanticipated. From medio 2015 market

Figure 7: Observed and counterfactual Danish term spread



Note: Dotted line: Monetary policy shocks restricted to zero 2015-2016. Solid line: Term spread .

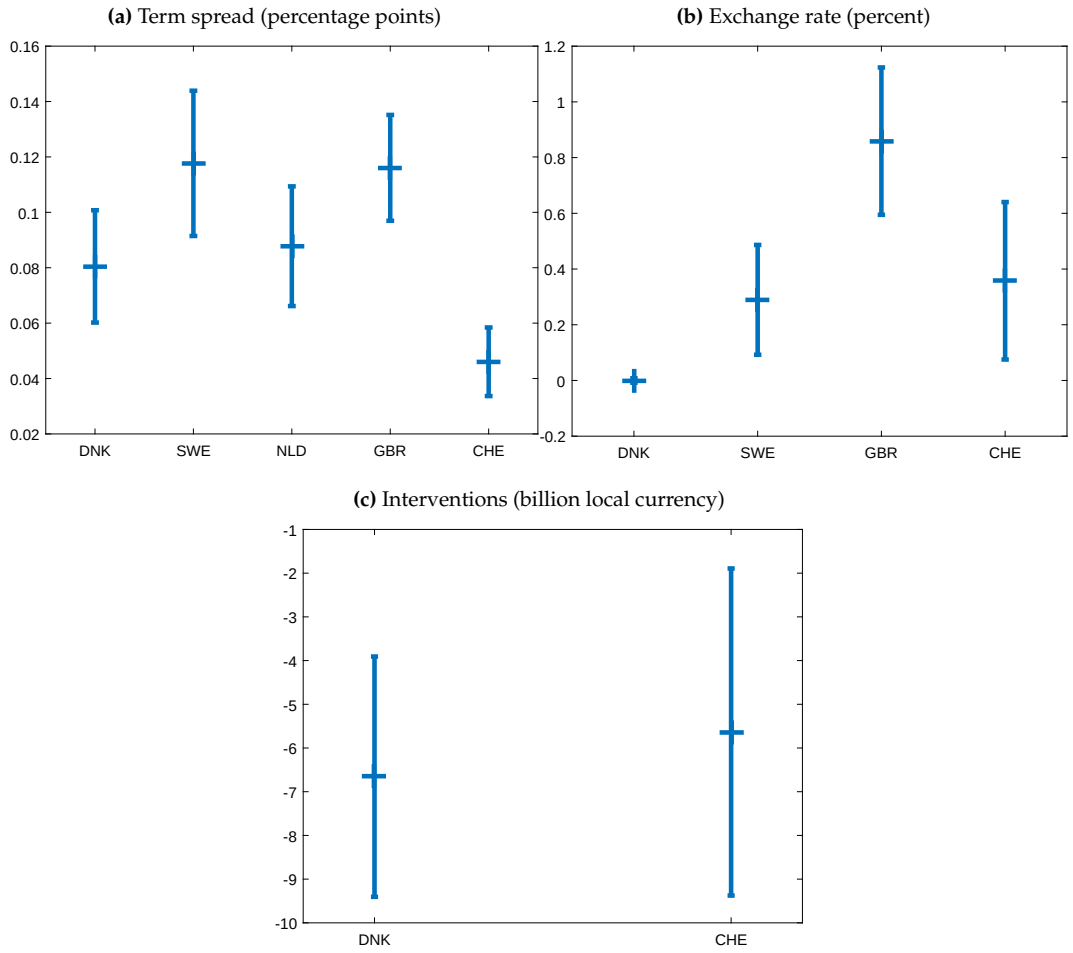
participants are no longer surprised by the unconventional measures, and hence the counterfactual and observed term spreads coincide. It should be pointed out that the exercise does not answer the question of what would have happened without an ECB QE program. Since the expectations of a QE program will in itself reduce the term spread the total effect of the QE program (unexpected as well as expected) is likely to be larger than suggested by the counterfactual analysis. While the exercise supports the results from the event study in section 4, the effect of the PSPP is larger in the counterfactual analysis compared to the event study. This could reflect that the VAR model controls for unanticipated changes in the monetary policy stance on days not considered in the event study.

5.4.4 Comparison across countries

In this section we compare the spillovers to Denmark with those to other countries. The comparison of the responses to monetary policy shocks across countries uses the same methodology as outlined in section

5.1 and 5.2.[18] The model is estimated for the Netherlands, the United Kingdom, Sweden and Switzerland. Denmark and Switzerland are the only countries that have intervened in the foreign exchange market, so we only consider the response of FX interventions for these countries. Figure 8 shows the impact effect of the term spread, exchange rate and FX interventions. In panel 8a the impact effect of the term spread is compared across countries. For Sweden, the Netherlands and the United Kingdom the response to a shock to the SSR is of the same magnitude, and across these countries the confidence intervals are overlapping. The response of the Swiss term spread is, however, more muted. The point estimates are larger for countries with a floating exchange rate compared to the euro area country, the Netherlands, and the pegging country, Denmark. The point estimate is also smaller in Switzerland, which possibly reflects the Swiss National Banks management of the exchange rate in a part of the period under consideration.

Figure 8: Impact effect of a one-standard deviation contractionary shock to the SSR



Note: Bars depict the estimated impact effect of a shock to the SSR and the 95 percent confidence interval on each side. DNK: Denmark, SWE: Sweden, NLD: Netherlands, GBR: United Kingdom and CHE: Switzerland

[18] We do not need to control for developments in prices and economic activity as they do not enter in the reaction function of Danmarks Nationalbank. In the case of countries with a floating exchange rate, leaving out prices and measures of the real economy could pose an omitted variables bias. Nevertheless, in order to avoid proliferation of parameters the model is estimated without economic activity and prices. Another potential shortcoming is that the assumption of no feedback from the non-euro country becomes questionable as the size of the country increases.

Turning to the impact effect on the change in the exchange rate against the euro shown in panel 8b, we see that the effect is much larger for the floating rate countries compared to Denmark where the effect is zero. The largest effect is in the United Kingdom. Switzerland experiences an effect on the exchange rate of the same magnitude as Sweden.

Panel 8c compares the results for foreign exchange interventions. A contraction of the monetary policy stance of one-standard deviation leads to sale of euros against kroner in Denmark of about 7 billion kroner to support the krone. The Swiss National Bank drains liquidity from sight deposits of the magnitude of 6 billion Swiss francs. This indicates that it has intervened in the foreign exchange market as a result of the loosening of monetary policy in the euro area and bought euros.[19]

The results suggest that a contraction of the monetary policy stance by the ECB leads to a steepening of the yield curve for all countries under consideration. The direct spillovers from a monetary policy shock are of similar magnitude for yields across the neighbouring countries.

The overall stimuli imported from the ECB's unconventional monetary policies are, however, dependent on the exchange rate regime. This follows from the interest rate parity in equation (2.2). For floating exchange rate regimes the likely effect on the real economy of an expansionary shock to the ECB's monetary policy is attenuated by an appreciation of the currency. In Denmark, the effect is more direct as the krone is linked to the euro, and Denmark fully imports the effect of unconventional monetary policy measures undertaken by the ECB. The analysis suggests that countries with a floating exchange rate are affected by monetary policy shocks from the ECB.

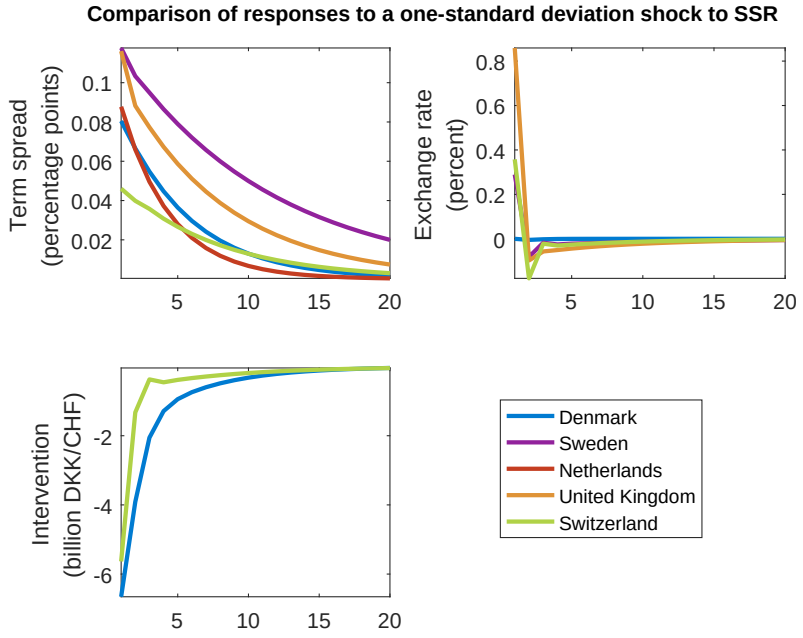
The effect on Switzerland is different compared to the other countries. This may reflect that the Swiss National Bank has changed its monetary policy regime in the period under consideration. Also, it could reflect Switzerland's position as a safe haven.

The dynamics in response to the ECB monetary policy shock are shown in figure 9. The effect of a monetary policy contraction is on impact an increase in the term spread followed by a gradual reduction. The exchange rate jumps (depreciation) on impact and stays at this weaker level.[20]

[19] Changes in sight deposits can reflect factors other than FX interventions.

[20] It should be noted that the assumption of no feedback from the non-euro country modelled by block exogeneity becomes questionable as the size of the country increases. We will, however, ignore these problems in the baseline model.

Figure 9: Impulse responses from a one-standard deviation contractionary shock



Note: Figures depict one-standard deviation shocks.

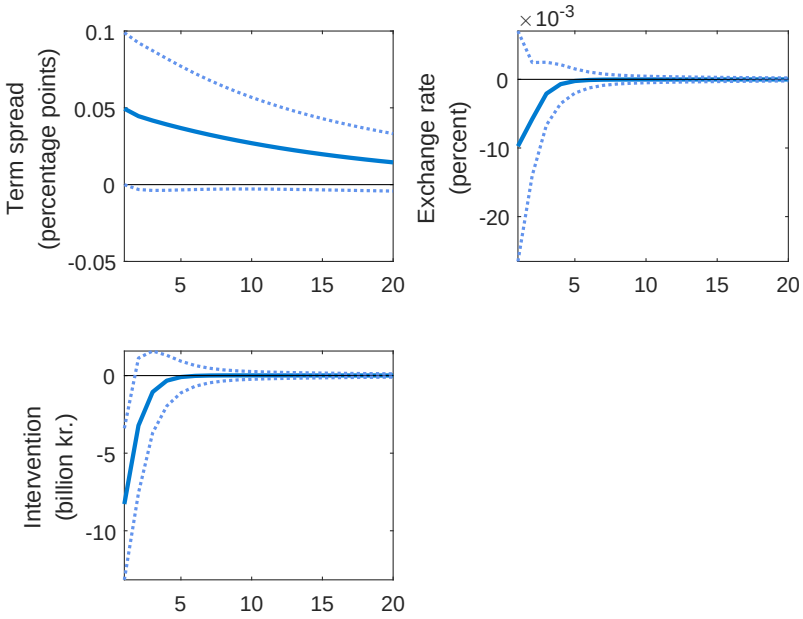
5.5 Robustness

In this section we conduct a series of robustness checks for the model for Denmark.

5.5.1 Estimation period and one-step approach

As a first robustness check the effects of the estimation period are investigated. The estimation period is expanded to 2008-16 and the model is estimated in two steps. Figure 10 shows the resulting impulse responses. This robustness check highlights that the estimation period is crucial for a successful analysis of the effect of unconventional monetary policy on financial variables. In recent years the goal of monetary policy has shifted from reducing short-term interest rates to long term interest rates. The effect of ECB monetary policy shocks on the term spread thereby becomes more muted when the conventional and unconventional monetary policy periods are mixed together. The difference between the estimated effect of monetary policy shocks on the yield curve in our study and IMF (2016) can thereby reflect that in IMF (2016) the conventional and unconventional periods are considered jointly.

Figure 10: Impulse responses from a one-standard deviation contractionary shock to SSR



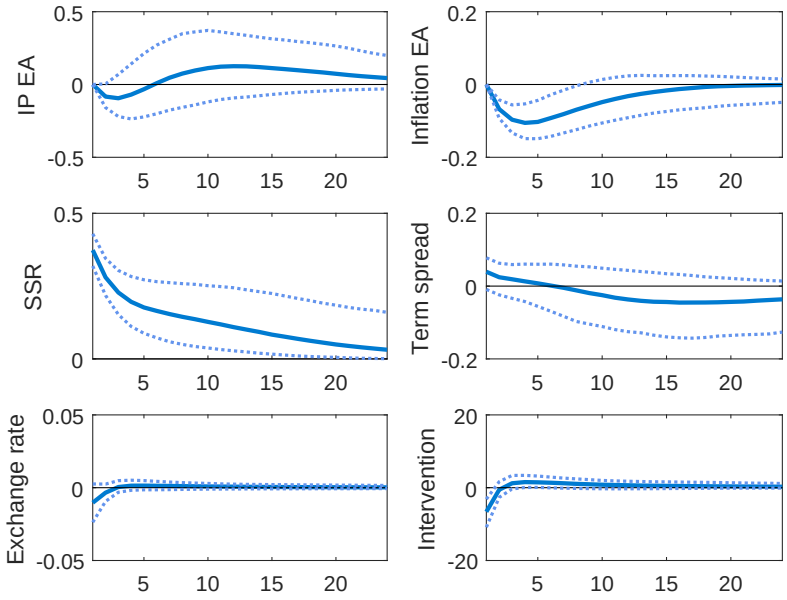
Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

As a further robustness check the spillovers to Denmark are estimated in one step by applying a strong form of block exogeneity. This exercise allows us to see whether the two-step procedure, and hence throwing out the structural shocks to industrial production and inflation, gives a sufficient description of the effect of monetary policy shocks to Denmark. We restrict the contemporaneous and lagged matrices to have block exogeneity which implies that there is no feedback from Danish variables to the euro area. The assumption of block exogeneity implies a natural ordering within the euro area block first and the Danish block second.[21] Since this estimation procedure expands the amount of parameters we expand the estimation period to 2008-16. Figure 11 depicts the impulse responses of the SSR estimated in one step.

Comparing the impulse responses in figure 11 and in figure 10 it becomes clear that financial variables in Denmark are not affected by allowing for shocks to prices and economic activity. The two-step procedure thereby seems to give a sufficient description of the spillovers.

[21] The estimation carried out in one step is similar in nature to the country VARs employed in IMF (2016).

Figure 11: Impulse-responses from a one-standard deviation contractionary shock to SSR



Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

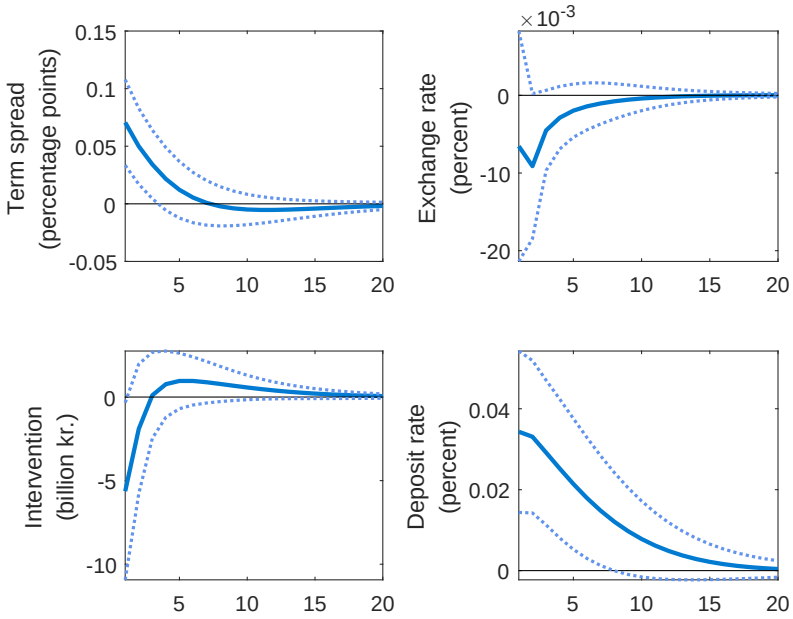
5.5.2 Additional variables

One possible drawback of the parsimonious model is that it does not necessarily take into account other events occurring in the estimation period. For instance we do not directly control for the Swiss National Bank's decision to abandon its exchange rate floor vis-a-vis the euro. Since this took place in the same month that the ECB announced its expanded APP, disentangling the effects is challenging. This event is controlled for by including a dummy as exogenous regressor in January and February 2015, when the Swiss decision to abandon its exchange rate floor led to massive foreign exchange rate interventions by Danmarks Nationalbank. The inclusion of these dummies does not change the dynamics of the model.

Using the two-step procedure, we check whether the inclusion of the monetary policy interest rate changes the overall dynamics of the model. The resulting impulse responses are shown in figure 12. Overall the responses are in line with the baseline model. However, it appears that a monetary policy contraction by the ECB implies an increase in the monetary policy rate in Denmark. The effect on the term spread is unchanged, which reflects that the long end of the curve has fallen more than the short end.

As further robustness checks we included industrial production and inflation in the model for Denmark. This does not change the results.

Figure 12: Impulse responses from a one-standard deviation contractionary shock to the SSR



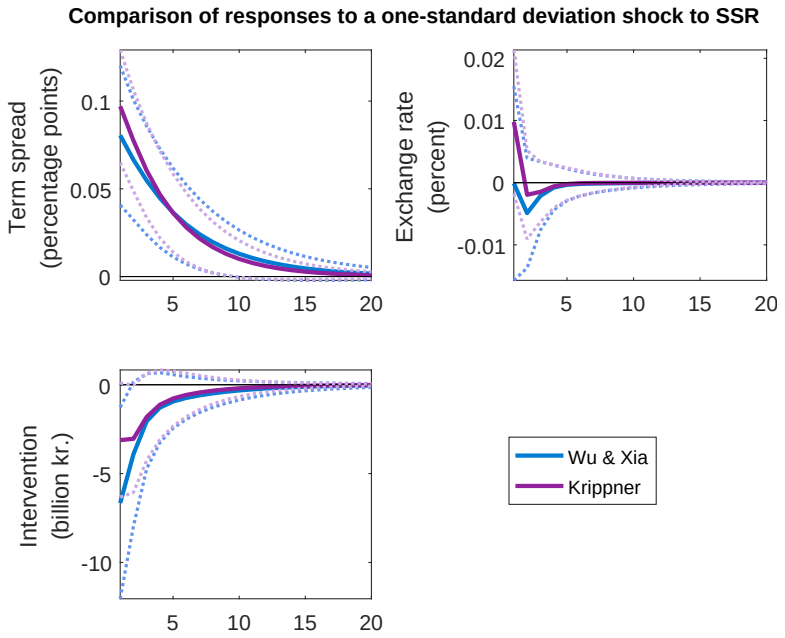
Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

5.5.3 Alternative measures of the monetary policy stance

As highlighted in section 3.2 the SSR model is sensitive to the estimation procedure and the underlying assumptions. As a robustness check we therefore compare whether our results are dependent upon a specific measure of the SSR. The spillovers to Denmark are estimated using an alternative SSR measure following Krippner (2015b).[22] The resulting impulse responses are compared to the baseline model in figure 13. The impulse responses based on the alternative measure of the SSR are of similar magnitude and direction. The impulse responses for the term spread are similar. The effect on the exchange rate is somewhat larger but still insignificant. The effect on interventions is a little smaller but falls within the same region as for the baseline model.

[22] http://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-comparison-of-international-monetary-policy-measures

Figure 13: Impulse responses from a one-standard deviation contractionary shock using Krippner's SSR



Note: Figures depict one-standard deviation shocks. Dotted lines show 95 percent confidence intervals.

6 Concluding remarks

With short-term interest rates close to their effective lower bound, a number of central banks have resorted to unconventional monetary policies. This paper explores the spillover effects of the ECB's unconventional monetary policy on selected euro area and non-euro area economies. Using an event study we assess the implications for government bond yields and exchange rates of ECB communication in the months leading up to the introduction of the PSPP. The event study confirms that yields have tended to decline in anticipation of the PSPP. However, the effect has differed across countries within the euro area. Whereas the effects in 'core' euro area countries have been relatively modest, the effects have been more pronounced in 'periphery' countries. This may suggest that the PSPP has had an effect on risk premia.

In a financially integrated world, monetary policy actions are transmitted across countries. The trilemma in international economics suggests that these may depend critically on the countries' exchange rate regimes. Whereas a country with a floating exchange rate can in principle pursue an independent monetary policy, a country with an exchange rate peg effectively surrenders its monetary autonomy to the anchor country.

The paper confirms that Denmark, having pegged its currency to the euro, has continued to import the monetary policy stance of the euro area. Despite not conducting its own QE programme, Danish sovereign bond yields have followed very closely those of 'core' euro area countries such as Germany. Countries with a floating exchange rate, such as Sweden and the United Kingdom, have also seen their sovereign yields decline in anticipation of the PSPP, suggesting that having a floating exchange rate does not insulate a country from changes in global financial conditions. However, their co-movement with those of the 'core' euro area countries has been substantially less pronounced. Moreover, their bilateral exchange rates vis-a-

vis the euro have tended to strengthen.

The results from the event study are corroborated by a VAR analysis. Using an SSR as a measure of the monetary policy stance of the ECB, we identify the effects of monetary policy shocks over the period 2008-16. The model finds that a monetary expansion by the ECB leads to a pick-up in inflation in the euro area. The identified monetary policy shocks are used to investigate the spillovers to non-euro area countries in the period 2010-16. The analysis confirms that long-term interest rates in non-euro area countries have been impacted by the ECB's unconventional monetary policy. Moreover, countries with a floating exchange rate tend to experience an appreciation of their exchange rates following a monetary policy shock. For the case of Denmark, the fixed exchange rate implies that a monetary expansion by the ECB is reflected in interventions by Danmarks Nationalbank in the foreign exchange market.

Appendices

A List of events

The table lists the 17 events used for the event study in section 4. The events are taken directly from Altavilla et al. (2015).

Table A.1: List of events

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

The table lists the 4 events associated with adjustments to the ongoing QE programme used for the event study in section 4.

Table A.2: Adjustment events

Date	Event
November 9, 2015	Increase in issue share limit from 25 to 33 percent
December 3, 2015	Extension of programme until at least the end of March 2017
March 10, 2016	Expansion of monthly purchases to EUR 80 billion
December 8, 2016	Reduction of monthly purchases to EUR 60 billion, extension of programme until at least the end of December 2017, decrease in minimum remaining maturity for eligible securities, permission to purchase securities with a yield to maturity below the interest rate on the ECB's deposit facility

Source: ECB.

B Estimation and inference using a two-step bootstrap procedure

This section outlines the bootstrap procedure used to calculate confidence intervals of the impulse responses. In the first step, we estimate the euro area block, equation (5.1), by OLS and obtain the structural shocks from the Cholesky decomposition of the OLS residuals, $\hat{u}_t$. The Cholesky decomposition is $\hat{B}\hat{B}' = \hat{\Sigma}$, where $\hat{\Sigma}$ is the estimated error covariance matrix, and $\hat{B}$ is the lower triangular Cholesky decomposition matrix. Denote the structural shock to the SSR as $w_{SSR,t}$. In the second step, we estimate the VARX model for the non-euro area country, eq. (5.2), by OLS, using the estimated structural shocks, $\hat{w}_{SSR,t}$, as one of the regressors in X_t. The impulse responses at horizon $t+h$ is $\frac{\partial Y_{t+h}}{\partial w_{SSR,t}} = A(L)^h \beta_{SSR}$, with $A(L)^0 = I$. We denote the estimated impulse response at horizon h as $\widehat{IRF}(h)$.

We use a two-step Wild bootstrap procedure to conduct inference of the impulse responses. We use $B = 9999$ replications. All bootstrap samples and statistics are denoted with an asterisk *. The procedure can be summarized as follows:

For $b = 1, ...B$;

1. Draw a bootstrap sample, $\hat{u}_t^*$, of the residuals from eq. (5.1) , $\hat{u}_t$, where $\hat{u}_t^* = \begin{cases} \hat{u}_t & \text{wp. } \frac{1}{2} \\ -\hat{u}_t & \text{wp. } \frac{1}{2} \end{cases}$.
2. Calculate the Cholesky decompostion of the bootstrap residuals, $\hat{B}^*\hat{B}^{*\prime} = \hat{\Sigma}^*$, and calculate the resulting bootstrap sample of the structural shocks to the SSR, $\hat{w}^*_{SSR,t}$.
3. Draw a bootstrap sample, $\hat{\eta}_t^*$, of the residuals $\hat{\eta}_t$ from eq. (5.2), where $\hat{\eta}_t^* = \begin{cases} \hat{\eta}_t & \text{wp. } \frac{1}{2} \\ -\hat{\eta}_t & \text{wp. } \frac{1}{2} \end{cases}$.
4. Draw a bootstrap sample of $Y_{t,DK}$, calculated as $Y^*_{t,DK} = \widehat{A(L)} Y^*_{t-1,DK} + \hat{\beta} X_t^* + \hat{\eta}_t^*$, where $(\widehat{A(L)}, \hat{\beta})$ are the estimated OLS parameters, and $X_t^* = \{trend, commodity_t, \hat{w}_t^*\}$. The starting values for $Y^*_{t,DK}$ are the actual observations, $Y_{t,DK}$.
5. Estimate eq. (5.2) using $\hat{Y}_t^*, X_t^*$, and calculate the impulse response $\widehat{IRF}(h)^*$.

The percentile interval for $\widehat{IRF}(h)$ is calculated as $[\widehat{IRF}(h) \pm z_{\gamma/2}\hat{\sigma}(\widehat{IRF}(h)^*)]$, where $\hat{\sigma}(\widehat{IRF}(h)^*)$ is the

standard deviation of the bootstrap impulse responses at horizon h, and $z_{\gamma/2}$ is the relevant percentile of the standard normal distribution.

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