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The effects of unconventional monetary policy in the euro area

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Abstract

We investigate the effects of unconventional monetary policy in the euro area and the individual countries of the euro area. We find that unconventional policy shocks have relatively small effects on output and inflation. At the country level, the responses differ across countries. Those differences correlate with the response of variables measuring financial market stress, the volume of trade in goods to non-euro countries and health of the banking sector in each country: monetary expansions have larger effects in countries where monetary expansions reduce market stress the most, where they trade more outside the euro area and in countries with healthier banks.

JEL Classification: C32; E52
Keywords: Unconventional monetary policy; VAR models; Cross-country differences

1 Introduction

Since shortly after the fall of Lehmann Brothers the conventional instrument of monetary policy, the short-term policy rate, has been at or close to the zero lower bound across the developed world. As such, central banks have been forced into conducting monetary policy through unconventional means, primarily using the quantity of assets on their balance sheets. In theory there are a number of channels through which unconventional monetary policy can affect the real economy (see Andrade et al. [2016] or Haldane et al. [2016] for more details), but the magnitude of those effects in the real world is an empirical question. As yet, there are only a handful of empirical studies that have investigated the effects of unconventional monetary policy (UMP) on output and inflation in the euro area. As our review of this literature in Section 2 shows, most studies find that expansionary UMP does increase output and inflation by a relatively small amount. This paper adds to this relatively scarce literature and, by also looking at the effects of UMP shocks in the individual countries of the euro area, we aim to shed some light on the most important transmission mechanisms.

A key contribution of this paper is to argue that most of the existing empirical studies of the transmission of UMP shocks are likely biased because they use the size of the central banks' balance sheet directly. Balance sheet policies are typically announced in advance for a given period of time: for example the Asset Purchase Programme (APP) of the ECB was unveiled in January 2015 when it was announced that €60bn of assets would be purchased each month until at least September 2016. As Hansen and Sargent [1991] show, this information structure leads to biased estimates (see also Leeper et al. [2013] for an empirical study of the effect of this information structure on estimates of the effects of fiscal policy). Instead, in this paper, we employ a shadow short-rate (from Wu and Xia [2016]), which is derived from market bond rates. Under the assumption of efficient markets, bond rates reflect all currently available information about the future size of the balance sheet. As such, news about future changes to the ECB's balance sheet immediately affects the shadow rate.

We find weak evidence that expansionary unconventional monetary policy shocks increase output growth, but the effects on inflation at the aggregate euro area level are economically insignificant. At the individual country level we find a range of responses across the countries in our sample, and those differences in the magnitudes of output responses are most consistent with the liquidity premium channel, the confidence/uncertainty channel and the exchange rate channel for the transmission of unconventional monetary policy.[1] We also find that larger peak output responses are associated with healthier banking systems at the start of our sample and lower government debts.

The remainder of this paper is as follows. Section 2 briefly describes the existing literature on estimating the effects of unconventional monetary policy in Europe. Section 3 describes our modelling approach for the euro area level models and presents the results. Section 4 describes our country level models and attempts to explain the observed differences between countries. Finally, Section 5 offers some concluding comments.

2 Empirical evidence on unconventional monetary policy in the euro area

The literature on the effects of unconventional monetary policy on the real economy in the euro area is not extensive. As Borio and Zabai [2016] report, there have been considerably more studies undertaken for the US and for the effects of unconventional monetary policy on financial markets. When the effects on financial markets are studied, expansionary policy in the euro area is consistently found to lower long-term yields, reduce spreads and raise equity prices (for example, see Beirne et al. [2011] or Baumeister and Benati [2013] for yields and spreads and Haitsma et al. [2016] for equity). Whether these financial market effects are transmitted through to the real economy is another question. After all, central banks have undertaken unconventional monetary policy because of the deep recession caused by the financial crises that started with the Great Financial Crisis of 2008. In normal times banks pass on financial market developments to the real economy through their lending decisions via a number of transmission channels (see Mishkin [1996]). It is not unreasonable to ask if the transmission of liquidity from financial markets to the real economy has been impaired or amplified because of the weaknesses of banks in many euro area countries since 2008.

[1] Following the classification of Haldane et al. [2016].

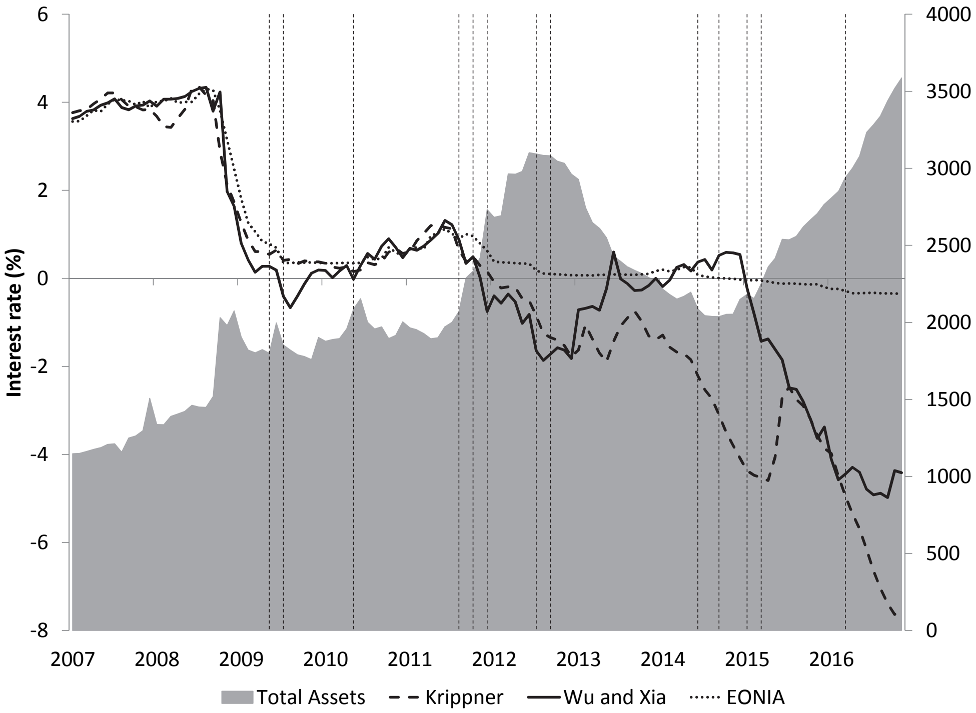
2.1 Shadow rates vs total assets

Empirical studies that examine the effects of unconventional monetary policy on the real economy are faced immediately with a problem: how to measure changes in monetary policy since interest rates have been stuck at the zero lower bound? Traditional time series models used a short-term interbank rate as the instrument of monetary policy, such as the overnight EONIA rate.[2] As Figure 1 shows, the EONIA rate has varied little since 2009 despite large changes in monetary conditions as a result of unconventional monetary policy, which can clearly be seen in the size of the ECB's blanace sheet. A number of studies have employed changes in the size of central banks' balance sheets directly to measure monetary policy (for example Boeckx et al. [2017], Burriel and Galesi [2016], Haldane et al. [2016] or Gambacorta et al. [2014]). However, this is not without problems, since many of those changes were announced some time in advance. For example, when the ECB announced QE in January 2015 it announced that €60bn of assets would be purchased each month until at least September 2016. Therefore, the balance sheet changes in the months following the January announcement were highly predictable in advance to agents in the real economy. This structure to the information available to agents creates an equilibrium with a non-fundamental moving average representation (Hansen and Sargent [1991]). Failing to take this into accunt in a VAR framework leads to biased estimates of the effects of policy. In fact, this is essentially the same problem as the fiscal foresight problem in empirical analyses of the effects of fiscal policy (Leeper et al. [2013]) and is driven by the information set of the econometric model differing significantly from the information set of economic agents in the economy under investigation.

An alternative approach to using the balance sheet directly is to use financial market prices to infer an indicator for the stance of monetary policy. Since financial market prices adjust immediately to any new information the changes observed in these measures reflect only new information and therefore new shocks. As such, using these prices as the measure of monetary policy does not suffer from the foresight problem in the way that using the balance sheet does. The main alternative to using the central banks' balance sheet directly is to use a shadow short-rate as proposed by Wu and Xia

[2]The assumption behind using an interbank rate rather than the policy rate was that, whilst the central bank moved the policy rate in discrete steps, by signalling information about the future path of the policy rate the central bank could steer interbank rates, which reflect all currently available information about the future direction of the policy rate.

Figure 1: Measures of monetary policy since 2007



Note: The dashed vertical lines denote key UMP announcements.

[2016] and Krippner [2015b].[3] Figure 1 also shows the shadow short-rates of Wu and Xia and Krippner for the euro area. In contrast to the EONIA rate, these rates show considerable movement during the zero lower bound period. Both of these shadow rates are calculated as a decomposition of the observed yield curve into a shadow yield curve plus an option which pays out cash following Black [1995]. The shadow short-rate is the interest rate at the short-term end of the shadow yield curve (see Wu and Xia [2016], Krippner [2015b] or Damjanović and Masten [2016] for more details).

The difference between the two shadow rates concerns their estimation: the Wu and Xia measure has one fewer constraint on the empirical specification than the Krippner measure (Krippner [2015a]). This gives rise to a trade-off between letting the data speak and the risk of overfitting the data.

[3]More recent research has proposed estimating shadow short-rates with a time varying lower bound for interest rates. See Lemke and Vladu [2017] for more details.

Krippner [2015a] argues convincingly that for the US, the more restricted specification leads to a better measure of the stance of monetary because key unconventional monetary policy announcements are followed by his shadow rate moving in the direction that would be expected a priori. We follow this procedure for the euro area and we argue that the Wu and Xia [2016] measure better tracks our a priori beliefs about the significant monetary events in our sample. One of the key episodes in our sample is the announcement and implementation of the APP in January 2015 (announcement) and March 2015 (first purchases). In the following months the Krippner shadow rate indicates an almost 200 basis points tightening of monetary policy, which we view as implausible. In contrast, the Wu and Xia rate indicates a significant easing of monetary conditions in this period. As such, for the euro area we argue that the Wu and Xia shadow rate is the better measure of the stance of monetary policy.[4]

2.2 Euro area evidence

Despite the bias introduced by foresight most studies of the effects of UMP on output and prices in the euro area employ the size of ECB's balance sheet as the measure of the stance of monetary policy. The first paper to do this was Gambacorta et al. [2014]. They used a panel of countries for the sample period 2008 to 2011 and found significant expansionary effects from an increase in central bank's balance sheets: increasing the balance sheet by 3% increased euro area output by between 0.06% and 0.15% and increased prices by between 0.06% and 0.11%. However, much of what we consider unconventional monetary policy has taken place after the sample period of Gambacorta et al. [2014] ended. Therefore many of the more unconventional monetary policies, including QE, are excluded from their analysis.

More recent papers focusing on the euro area and employing the size of the ECB's balance sheet are Boeckx et al. [2017], Burriel and Galesi [2016], Haldane et al. [2016], Gambetti and Musso [2017] and Wieladek and Garcia Pascual [2016]. Boeckx et al. [2017] use a SVAR model identified with a combination of zero and sign restrictions for the period from 2007 to 2014 and measure unconventional monetary policy by the total assets on the ECB's balance sheet. They identify changes in policy by looking at the signs of the responses to changes in the assets of the ECB. They find that a 1.5%

[4] It has been reported by Damjanović and Masten [2016] that this choice can make a significant difference for estimates of the effects of unconventional monetary policy shocks.

increase in the size of the ECB's balance sheet increases both output and prices by about 0.1%. Burriel and Galesi [2016] use a global VAR model for the countries of the euro area and focus on the balance sheet of the ECB as their measure of monetary policy (they do also report some results using the Wu and Xia shadow rate instead of the size of the balance sheet, see below). The estimates of Burriel and Galesi [2016] may suffer from misspecification because they specify their models using the yearly growth rates of output and prices but do not take account of the moving average process this introduces into the residuals. Even so, their results at the euro area level also have a similar magnitude to other studies: 1% faster growth of ECB assets is followed by a peak output growth response of almost 0.1% and inflation 0.05% higher.

Haldane et al. [2016] report results from four different schemes for identifying unconventional monetary policy shocks based on the total assets held on the balance sheet for a number of central banks, including the ECB, for the period 2009 to 2015. Their results for the euro area often have the wrong sign compared to what theory would predict and none of their results are statistically significant. Following this, Wieladek and Garcia Pascual [2016] use the same models as Haldane et al. [2016] but estimate them on data for the period 2012 to 2016. Over this sample period their results are statistically significant and the response to a 1% asset purchase shock in the euro area is to raise output by between 0.07% and 0.15%, depending on the model used. The magnitude of the price level results are similar with peak responses between 0.05% and 0.1%.

Wieladek and Garcia Pascual [2016] also use their models to investigate through which transmission channels UMP works. They argue in favour of the portfolio balance channel because they observe significant responses of long-term government bond yields and they interpret movements in futures rates following a UMP shock as evidence in favour of the signalling channel. They also find evidence in favour of the exchange rate channel.

Whilst the papers described above are concerned with UMP in general, Gambetti and Musso [2017] focus on the effects of the announcement of the APP in January 2015. They employ a time varying parameters VAR model with the unexpected component of the APP announcement identified through sign and zero restrictions combined with a restriction on the magnitude of the change in the ECB's balance sheet. They find that the APP shock initially had a larger effect on output than inflation before the effect of the APP shock on inflation increased significantly over the medium term.

To our knowledge, the only papers to use a shadow short-rate instead of the size of the ECB's balance sheet are Burriel and Galesi [2016] and Damjanović and Masten [2016]. Burriel and Galesi [2016] report that a 25 basis points reduction in the shadow rate increases output growth by up to 2.5% and inflation by 0.1%, although as with their balance sheet based VAR model described above these results also come from a model that does not take into account the moving average process that modelling yearly growth rates of output and prices introduces. Damjanović and Masten [2016] use a simple three variable VAR model with output, prices and the shadow short-rate of Krippner as the measure of unconventional monetary policy. They report that an unconventional monetary policy shock that raises the shadow rate by 100 basis points lowers euro area output by about 0.7% and lowers prices by about 0.2%.

2.3 Country level evidence

These papers also report the effects on individual euro area countries. For example, Boeckx et al. [2017] report significant variation in output responses across euro area countries, with crisis countries having small or even negative responses to expansionary unconventional monetary policy shocks and non-crisis having significantly larger responses. Interestingly, they report that the Netherlands has almost no output response at all. Boeckx et al. [2017] explain the cross country differences by noting the high correlation between the peak output response and bank capital ratios: countries with well capitalised banks have experienced larger output effects from expansionary unconventional monetary policy shocks.

The finding that bank capital explains the cross-country differences in transmission is shared by Burriel and Galesi [2016]. They find that the crisis countries of Greece, Spain, Portugal and Cyprus are in the group with the smallest output responses to expansionary unconventional monetary policy shocks. Once again, the Netherlands is more similar to this group than to those that have the largest responses. Given the similarity of the cross country differences to those reported by Boeckx et al. [2017] it should come as no surprise that the most important factor for explaining the differences is once again bank capital.

Wieladek and Garcia Pascual [2016] also look at some of the member countries of the euro area with the same four identification schemes they also used at the euro area level. Of the five countries they report results for, Italy always has the smallest peak output response and Spain always has the largest response to an unconventional monetary policy shock. France, Germany and Portugal are similar to each other and are between Italy and Spain. Wieladek and Garcia Pascual [2016] argue that the cross country differences are linked to their mortgage finance systems: Spain has a high mortgage to GDP ratio and a lot of floating rate mortgage debt (95% of mortgage debt in Spain is linked to the 12 month euribor rate), whilst at the other end Italy has a very low share of mortgages to GDP.

Whilst not including such a broad set of countries, Damjanović and Masten [2016] do compare the effects of unconventional monetary policy in Italy and Spain. In line with Wieladek and Garcia Pascual [2016] they find that Spain has a larger response than Italy. They report that a positive 100 basis points shock to the euro area shadow rate lowers GDP in Italy by about 0.3%, but lowers Spanish GDP by almost 0.6%.

The existing literature for the euro area suggests that unconventional monetary policy has had some effect on the real economy and has been expansionary. The existing results also suggest that the effects are different across countries. Furthermore, those differences are typically correlated with bank capital ratios: countries with weakly capitalised banks have experienced less stimulus from expansionary unconventional monetary policy shocks.

3 Identifying unconventional monetary policy shocks at the euro area level

Our approach to modelling the asymmetrical effects across countries of the ECB's unconventional monetary policy is a two-step approach. Firstly, we identify a series of exogenous monetary policy shocks at the euro area level in a dedicated euro area level SVAR model. The second step consists of taking the identified UMP shocks from the euro area model and estimating the responses to these shocks in country level VARX models. This section details the euro area model.

3.1 Identifying unconventional monetary policy shocks in a VAR framework

Typically, econometric analysis with VAR models starts with the reduced form[5], where each dependent variable is regressed on its own lags and on the lags of the other variables. In vector notation, this can be expressed by:

$$\mathbf{y_t} = \mathbf{c} + \mathbf{A_1 y_{t-1}} + \mathbf{A_2 y_{t-2}} + \cdots + \mathbf{A_p y_{t-p}} + \mathbf{u_t} \tag{1}$$

where $\mathbf{y_t}$ represents an $n \times 1$ vector containing the endogenous variables — GDP growth, HICP inflation, a measure of financial stress, the shadow short-rate, the EONIA-MRO spread and growth of equity prices — at quarter t, $\mathbf{c}$ is a vector of constant terms, $\mathbf{A_p}$ are $n \times n$ matrices of coefficients, while $\mathbf{u_t}$ are the reduced-form error terms with zero mean and covariance matrix $\mathbf{\Sigma}$. We include two lags of the endogenous variable even though both AIC and SBC recommended one lag. However, since adding an extra unnecessary lag only results in a loss of estimation efficiency whilst excluding a necessary lag is a misspecification, we opt for two lags. However, to isolate cause and effect requires that we use the structural form rather than the reduced form given in equation (1). The structural form is given by

$$\mathbf{A_0^\star y_t} = \mathbf{k} + \mathbf{A_1^\star y_{t-1}} + \mathbf{A_2^\star y_{t-2}} + \cdots + \mathbf{A_p^\star y_{t-p}} + \epsilon_\mathbf{t} \tag{2}$$

where $\mathbf{A_0^\star}$ is an $n \times n$ matrix containing the contemporaneous reactions of the variables to the structural shocks, $\mathbf{A_p^\star}$ are $n \times n$ matrices of structural coefficients for system (1) and $\epsilon_\mathbf{t}$ is an $n \times 1$ vector of structural innovations with $E[\epsilon_\mathbf{t}\epsilon_\mathbf{t}'] = \mathbf{I}$. The structural form and the reduced form are related through $\mathbf{A_0^{\star}}^{-1}\mathbf{A_0^{\star}}^{-1'} = \mathbf{\Sigma}$. By itself, system (2) is unidentified, and thus the practitioner must use economic theory to apply $\frac{n(n-1)}{2}$ extra restrictions on $\mathbf{A_0^\star}$.

In this paper we identify unconventional monetary policy shocks through a combination of zero and sign restrictions using the algorithm of Arias et al. [2014]. This allows us to supplement the standard zero restrictions commonly employed in VARs with sign restrictions to disentangle the movements of the financial variables. The richer information set provided by the financial variables should enable us to better identify unconventional monetary policy shocks in our short sample period. After all, as we described above, there is considerably more evidence for what unconventional monetary policy does

[5]For a more detailed introduction to the SVAR (and also VAR) model see Lütkepohl and Krätzig [2004] and Hamilton [1994].

to financial quantities than for the macroeconomic effects. In our empirical specification the reduced form is estimated using Bayesian methods, following Uhlig [2005]. His approach specifies a Normal-Wishart prior such that the posterior estimates are equivalent to OLS estimates of the system. This is a very weak prior since it imposes no specific prior knowledge.[6] Given a draw from the posterior distribution of the reduced form parameters, we use the algorithm of Arias et al. [2014] to collect 1000 draws from the posterior distribution of the structural parameters that satisfy our sign and zero restrictions.

3.2 Data

The time period since the start of unconventional monetary policy is short, which raises issues of how well the models can be estimated and, therefore, how well they can recover truly exogenous monetary policy shocks from the data. To mitigate this we use monthly data, which is the approach followed by all of the studies discussed in the previous section, except for Gambetti and Musso [2017].[7]

We use monthly data for the period January 2009 to November 2016. During this period the ECB has intensively employed non-standard monetary policy measures. For our euro area SVAR model we use 6 endogenous variables: month-on-month output growth, month-on-month inflation, the CISS index of systemic financial stress of Holló et al. [2012], the short-term shadow rate of Wu and Xia [2016], the EONIA-MRO spread and the month-on-month growth of real equity prices as given by the Eurostoxx 50 index.

Output growth and inflation are standard variables in monetary policy VARs. In particular, our monthly output growth series is constructed using a Chow-Lin decomposition where monthly industrial production and wholesale and retail sales are the reference series.[8] As described above in Section 2,

[6]See Uhlig [2005] p410 for details.

[7]This is a common approach in the literature but is not without its drawbacks. The key drawback is that GDP is only measured at the quarterly frequency so a monthly output series either requires some statistical interpolation or using another series such as industrial production as a proxy. Both approaches effectively mean that our output measure is subject to measurement error. Therefore, when the ECB is setting monetary policy, policy makers might be looking at different output measures than the ones we include in our empirical specification.

[8]This approach is also followed by Burriel and Galesi [2016], although it isn't the only

the key indicator of unconventional monetary policy is the short-term shadow rate of Wu and Xia [2016]. We include the CISS measure of financial system stress of Holló et al. [2012] for several reasons. First, it is often reported that euro area monetary policy systematically responded to financial system shocks, hence controlling for these systematic responses is necessary to recover the exogenous component of monetary policy. Second, the CISS index may capture relevant effects of international factors which strike the eurozone as a whole, such as global uncertainty or developments in commodity markets. The important role of financial distress for the euro area has been documented in Kremer [2016]. We include a spread and equity prices since many authors have reported finding consistent responses of these variables to unconventional monetary policy shocks (Beirne et al. [2011], Baumeister and Benati [2013] and Haitsma et al. [2016]). As such, including these variables give our model significant additional information for identifying the policy shocks.

3.3 Identification scheme

Table 1 shows the identifying restrictions that we use. We impose the restrictions on the month when the shock occurs, for all subsequent months the model is unrestricted. Although this paper focuses on unconventional monetary policy shocks, other structural innovations are included in the model since they may help recover true structural shocks (Paustian [2007] and Peersman [2005]).

The first two aggregate shocks are aggregate demand and supply shocks. They are intended to capture important factors driving fluctuations in the real economy and are included in the model to ensure that the unconventional monetary policy shocks are exogenous rather than endogenous responses to macroeconomic conditions. The restrictions used to identify aggregate shocks are well established in the literature on the basis of standard theoretical models (see Peersman and Straub [2009] for a good summary). After an aggregate supply shock, inflation and output move in opposite directions, while they move in the same direction after an aggregate demand shock.[9]

option. For example, Haldane et al. [2016] use the monthly GDP indicator from Euro-Coin, which has the drawback that is is explicitly designed to be a smooth series tracking the underlying trend in output rather than output itself.

[9]What matters are the *relative* sign restrictions imposed on the variables. For instance, an aggregate demand shock can be denoted by all pluses or all minuses without changing the meaning incorporated in the structural shock.

Table 1: Identification scheme

Shocks/Variables	Inflation	Output growth	CISS	Shadow rate	EONIA-MRO spread	Equity prices growth
Aggregate demand	+	+	?	0	?	?
Aggregate supply	-	+	?	0	?	?
Financial stress	0	0	+	-	+	-
Unconventional monetary policy	0	0	?	+	+	-
Undefined	?	?	?	?	?	?
Equity price	0	0	0	0	0	+

We also identify three financial shocks: financial market stress, equity price shocks and unconventional monetary policy shocks. Since we are using monthly data, we assume that financial shocks have no contemporaneous effect on output and inflation. Most quarterly macro models incorporate sticky prices, and a lagged response of output to financial or monetary disturbances is a common assumption in VAR models. The financial stress shock increases the observed index of financial stress, increases spreads and lowers equity prices, which prompts the central bank to ease policy, thus lowering the shadow rate. The equity price shock is designed to capture the volatility in equity prices that isn't easily explained by the other variables. In other words, it is a recognition that there is significant noise in equity price series relative to the underlying 'fundamentals' captured by the other variables.

To identify unconventional monetary policy shocks, we first follow most of the literature on monetary policy by assuming that output and prices only respond with a lag to monetary disturbances (see, for example, Christiano et al. [2005]). We also assume that, due to publication lags in economic statistics, unconventional monetary policy does not respond within the same month to changes in output growth and inflation (see Kim and Roubini [2000] or Elbourne and de Haan [2006] for monetary VARs employing this restriction).[10] Importantly, since the existing literature on the effects of un-

[10]Of course, policy makers respond to their best estimates of current inflation and output growth when setting policy, but their best estimates are based on real time data availability, which is significantly different to the definitive time series data we use here. This assumption that policy only responds with a lag is intended to reflect that reality.

conventional monetary policy provides conclusive evidence that spreads and equity prices respond quickly and consistently to unconventional monetary policy shocks, we use this information to help identify unconventional monetary policy shocks by requiring that contractionary UMP shocks immediately raise spreads and lower equity prices.

The remaining shock is left unidentified to soak up the sources of variation not captured by our main shocks.

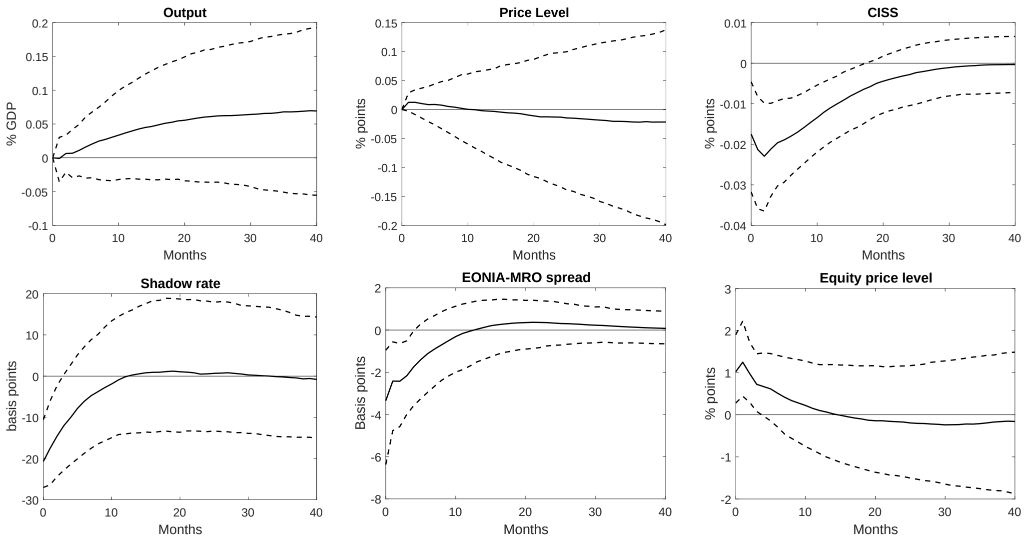
3.4 Euro area impulse responses

Figure 2 presents the impulse response functions of the variables in the model to an expansionary one standard deviation unconventional monetary shock. An expansionary UMP shock lowers the shadow rate by about 20 basis points on impact, and then the effect fades out gradually and returns to the baseline after 10 months. The output growth response is small, reaching a peak of 0.05% of GDP after 20 months. The price level response is neglible. Comparing these responses to those previously reported in the literature for one standard deviation balance sheet shocks we can see that our estimates, although a similar order of magnitude to those reported for balance sheet shocks, are smaller than those discussed in Section 2. As with all of the papers described in Section 2 we also find larger output responses than price responses.

The other response that we didn't constrain to be either positive or negative in our identification scheme was the CISS measure of systemic stress. The impulse response of CISS in Figure 2 is negative, indicating that an expansionary UMP leads to a reduction of financial system stress. During our sample period the ECB was often concerned with ensuring the stability and functioning of the financial system - this response is evidence that UMP has been successful at reducing financial market dysfunction.

The signs of the contemporaneous response of the remaining variables were constrained in our identification scheme. From one month after the shock they are unconstrained and they all return gradually to the baseline after about 10 months.

Figure 2: Effects of unconventional monetary policy shocks in the euro area



Note: The solid line depicts the median response at each horizon across all accepted models, while the dashed lines represent the middle 68% of models. The output, price level and equity price responses are accumulated responses from the underlying growth rate responses.

4 The effects of UMP shocks in individual euro area countries

To investigate the effects of unconventional monetary policy at the individual country level, we take the identified policy shocks from the euro area model and include these as an exogenous variable in country level VARX models. The shocks we use are the median target shocks proposed by Fry and Pagan [2011]. These shocks come from a single model in the zero and sign algorithm that generates a historical decomposition closest to the median of all historical decompositions from all models that satisfy our zero and sign restrictions. For each country we estimate a VARX model

$$\mathbf{y_t} = \mathbf{c} + \mathbf{A_1}\mathbf{y_{t-1}} + \cdots + \mathbf{A_p}\mathbf{y_{t-p}} + \mathbf{\Gamma} x_t + \mathbf{u_t} \tag{3}$$

where $\mathbf{y_t}$ is a vector of endogenous variables: log output, log price level, Sovereign CISS and the 10 year government bond yield, x_t is the UMP shock in period t identified previously in the euro area model and $\mathbf{u_t}$ are reduced-form country-level errors. To keep things consistent with the identification scheme for the euro area model we impose that the unconventional monetary policy shocks do not have a contemporaneous effect on output and prices at the country level either. That is, the first two elements of $\mathbf{\Gamma}$ are restricted to zero. To impose these restrictions requires that we estimate the country level VARX models with feasible generalised least squares, as described in Lütkepohl [2005][11]. As with the euro area model we include two lags of the endogenous variables.[12]

4.1 Data

For each country our monthly output series is a Chow-Lin interpolation of quarterly GDP based on monthly industrial production and retail sales. This was done using seasonally and calendar adjusted data on GDP, retail sales and industrial production from Eurostat. Data on the monthly price level (HICP) and on the 10-year government bond yield are also from Eurostat. As a measure of sovereign risk and dysfunction in sovereign bond markets in each country, we make use of the Sovereign Composite Index of Systematic Stress from the ECB's Statistical Data Warehouse.

4.2 Country level impulse response functions

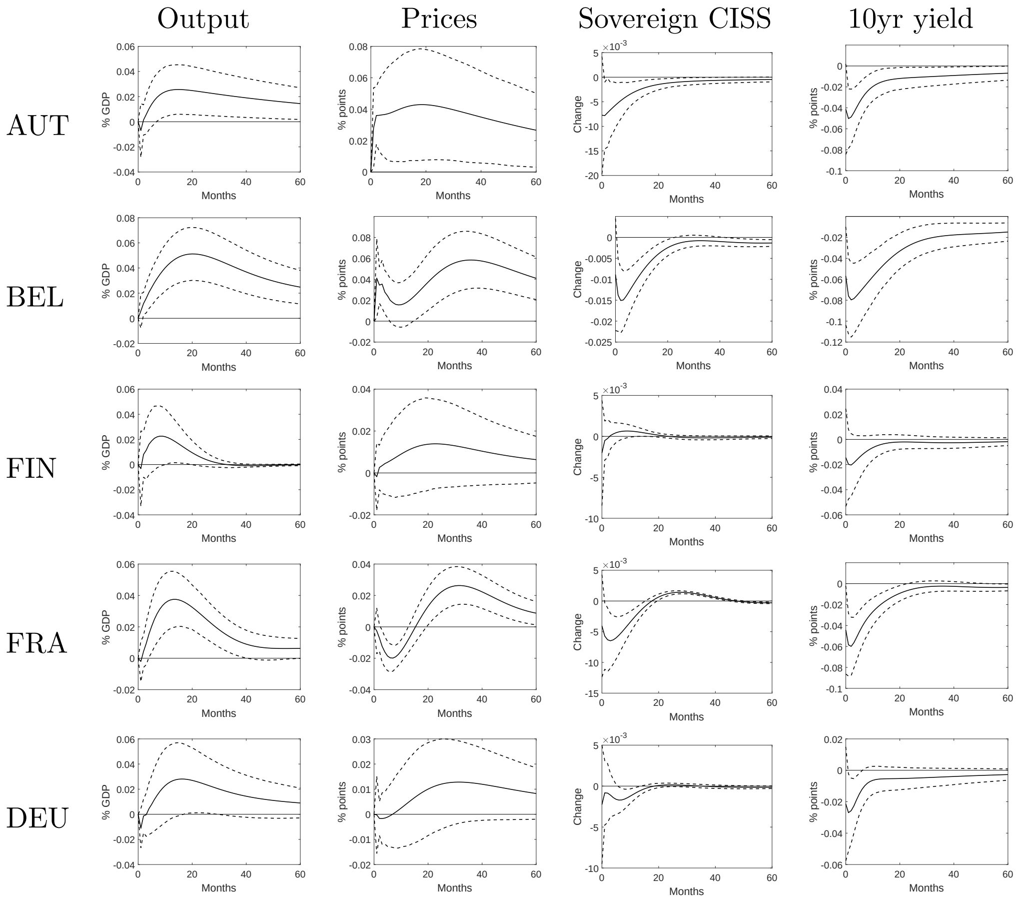
Figure 3 shows the impulse response functions for individual countries for output, prices, sovereign CISS and the 10-year government bond yield to a one standard deviation expansionary UMP shock at the euro area level. Almost all output and price level responses follow the commonly found hump shaped expansion in response to a monetary disturbance. The exceptions are Italy, where the central estimate for output is negative and Portugal for the price level, albeit the magnitude of these responses are small and not statistically significant. Both of these countries were acutely affected by the sovereign debt crisis. An expansionary UMP shock lowers the sovereign CISS index and long-term government bond yields in all countries except for Italy (sovereign CISS), Greece and Portugal (long-term government bond yields). All three are 'crisis' countries and both of Greece and Portugal received a bail-out.

[11] pp396-7.

[12] The SBC indicated one lag for all models. However, since adding an extra unnecessary lag only results in a loss of estimation efficiency whilst excluding a necessary lag is a misspecification, we opted for two lags. The AIC, which is known to overparameterise in small samples suggested two lags for most countries.

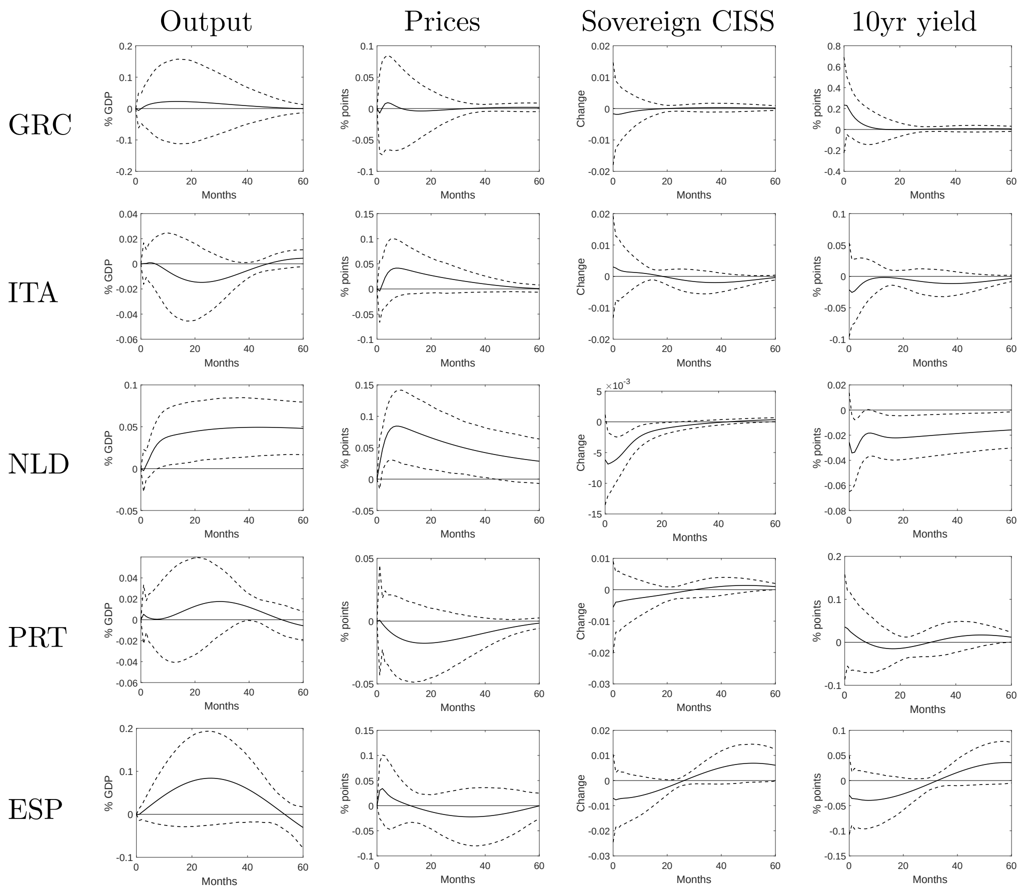
The responses also show economically significant differences between the countries. The peak output responses in the Netherlands, Belgium and Spain are more than twice as large as in the crisis countries of Italy, Portugal and Greece. Likewise, Portugal and Greece have price level responses less than one-fifth of the peak responses in Belgium and the Netherlands. Portugal and Greece also have economically significantly smaller responses for government bond yields, especially compared to Belgium.

Figure 3: Effects of unconventional monetary policy shocks in individual countries



Note: The dashed lines represent 90% bootstrapped confidence intervals calculated with 1000 replications under the assumption that the exogenous time series of UMP shocks is fixed.

Figure 3: Effects of unconventional monetary policy shocks in individual countries (continued)



Note: The dashed lines represent 90% bootstrapped confidence intervals calculated with 1000 replications under the assumption that the exogenous time series of UMP shocks is fixed.

4.3 Explaining cross-country differences

The previous section provided some evidence of economically significant differences in the effects of UMP shocks across countries. Because different countries have different economic structures, these cross-country differences contain information about the relative importance of the various channels through which unconventional monetary policy may work. To that end, this section compares the cross-sectional pattern of the output responses with various theories that have been proposed for why UMP has real effects.

4.3.1 The channels of unconventional monetary policy

In standard monetary models the stance of monetary policy can be fully described by the current and expected future short-term policy rate. These determine the present value of returns from holding assets so any policy that reallocates assets between different agents in the economy has no effect on the present value of returns and is therefore irrelevant (see Wallace [1981], Eggertsson and Woodford [2003] or Cúrdia and Woodford [2011]). For balance sheet polices to have real effects requires there to be frictions in financial markets that are not included in standard monetary models. Haldane et al. [2016] lists six channels and their associated frictions which have been proposed in the literature for why balance sheet policies can have real effects.

The *policy signalling channel* works by signalling extra information about future short-term rates and relies on agents having imperfect information about how monetary policy will behave in future. By providing a credible signal about the future path of the nominal interest rate UMP can influence consumption and investment decisions today. In essence, this channel is a variant of forward guidance and relies on all of the standard channels working in the future. If this is the most important channel countries who are most likely to benefit the most from future lower rates should have the biggest effects.

However, it might be difficult to find evidence for the policy signalling channel in a VAR framework because the signalling value of small deviations around the policy stance predicted by the policy rule is questionable. In the case where the UMP shocks identified in the VAR framework are random unexpected noise around the predictable part of monetary policy then agents shouldn't learn anything about the future path of nominal interest rates from the random disturbances.

The *portfolio balance channel* requires market participants to have a preferred habitat or that there are limits to arbitrage. It is often argued that because assets of different maturity are not perfect substitutes there are limits to arbitrage. If the portfolio balance channel is the dominant channel then countries with more longer term debt should be the most affected by UMP.

The *liquidity premium channel* requires markets to be dysfunctional with abnormally high liquidity premia. Because the central bank can improve liquidity and reduce liquidity premia, UMP can restore normality to financial markets and increase credit intermediation. As such, if the liquidity premium channel is the dominant transmission channel we should expect countries where UMP reduces market stress measures the most to also have the largest output effects.

The *exchange rate channel* works the same way as with conventional monetary policy. That is, expansionary UMP causes an exchange rate depreciation which boosts exports and reduces imports. If the exchange rate channel is the dominant channel then countries that trade the most with non-euro countries should respond the most.

The *confidence/uncertainty channel* works through UMP reducing market volatility or by convincing market participants that future economic performance will be better. As such, UMP reduces the risk of bad economic outcomes and should have larger effects in countries where the risk of bad economic outcomes is reduced the most.

The final channel listed by Haldane et al. [2016], the *bank lending channel*, relies on some economic agents having no substitutes for bank loans, hence when UMP increases the price of assets on banks' balance sheets the extra loans these banks can make add to the aggregate quantity of loans. Banks with weak balance sheets are the most constrained by the value of their assets. Hence weak banks' lending behaviour is most dependent on the changes in the value of the assets they hold caused by UMP shocks. Moreover, it is typically small firms and households who are most likely to have no alternatives to bank loans. Hence, we should expect larger effects of UMP in countries with weaker banks and more small firms.

As Wieladek and Garcia Pascual [2016] reported, when an economy is close to potential economic stimulus is more likely to end up as increased inflation rather than extra output. As such we should also expect UMP to have larger output effects in countries with bigger output gaps.

4.3.2 Cross-country correlations

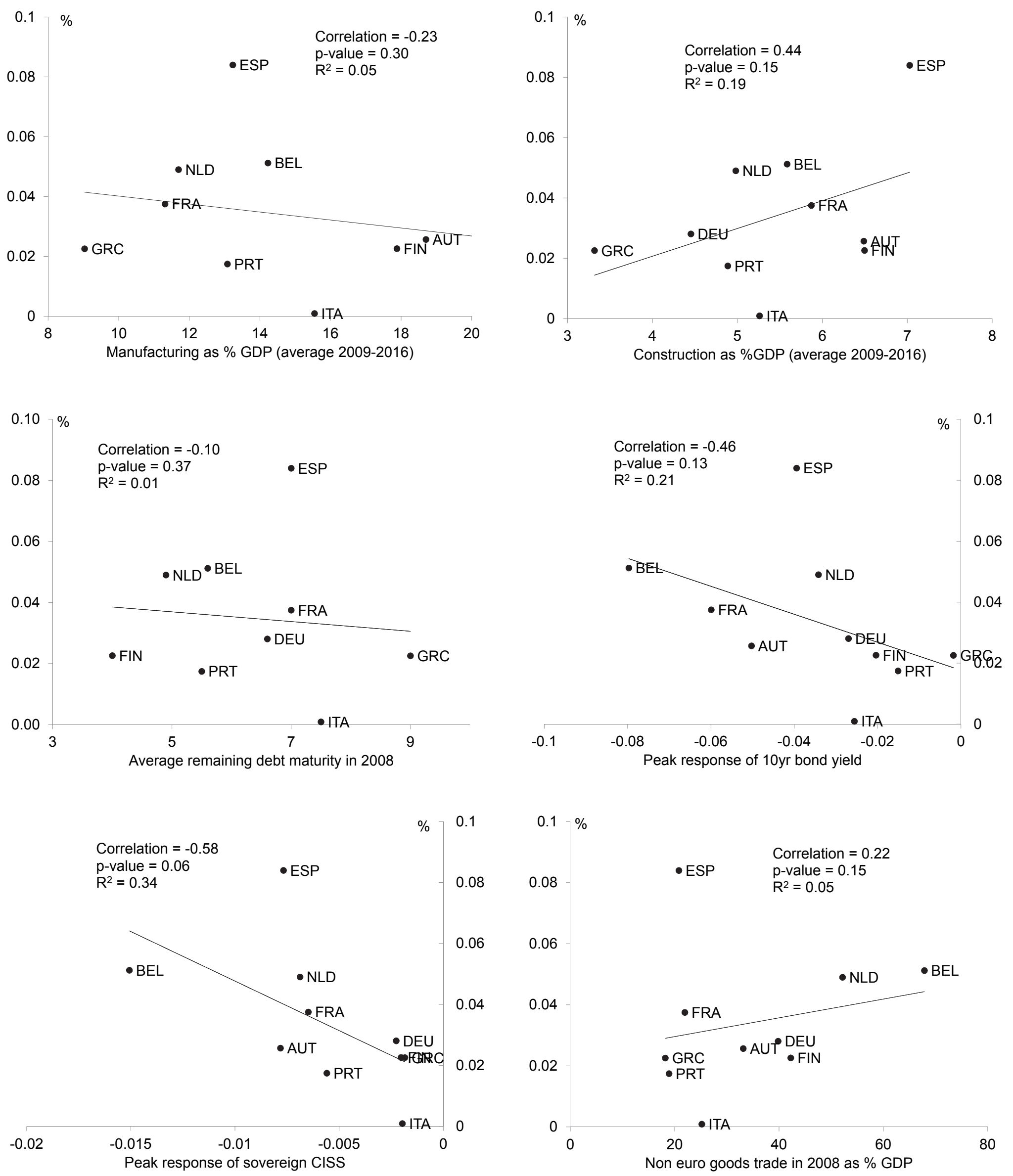
To get an idea which channels are the most important Figure 4 shows some cross-correlations between the magnitude of the country level responses and indicator variables that proxy the expected strength of the various channels. Cross-correlations are, of course, only suited to identifying the dominant channels, since any weaker channels will not be visible due to the effects of the stronger channels.[13] We show cross-correlations here because 10 cross-country observations are too few for regression analysis.

As described above, if the policy signalling channel is the dominant mechanism through which UMP affects the macroeconomy, then we would expect the largest output effects in those countries most affected by normal monetary policy shocks. Georgiadis [2015] reports that changes in interest rates have larger effects in countries where the output share of sectors that are interest sensitive is greater. Specifically, Georgiadis [2015] found that euro area countries with larger shares of manufacturing and construction have larger output effects from conventional monetary policy shocks, although the relationship was not statistically significant for construction. The first two correlations in Figure 4 compares the peak output responses to UMP shocks with the manufacturing and construction shares. We find no relationship between the peak output effect and the manufacturing share. The correlation between the peak output effect and the construction share is positive but it is not quite statistically significant at conventional levels of significance. Moreover, the positive relationship is highly dependent on just one observation: the peak response in Spain, which is an outlier in our estimates. All in all, our results argue against the policy signalling channel being the main transmission channel.

The next correlation looks at whether there is a relationship between the average remaining maturity of outstanding government debt and the peak output effect. We find no evidence of a relationship, which is suggestive that the portfolio balance channel is not the dominant channel. We do, however, find countries that had larger peak output effects also had larger responses of the ten year government bond yield in our country VARX models, although it isn't quite statistically significant. As Wieladek and Garcia Pascual [2016] note, significant movements in long-term bond yields is a prerequisite for the portfolio balance channel. Even so, we would expect the portfolio balance channel to show up in countries where the relative proportion of outstanding long-term debt changes the most.

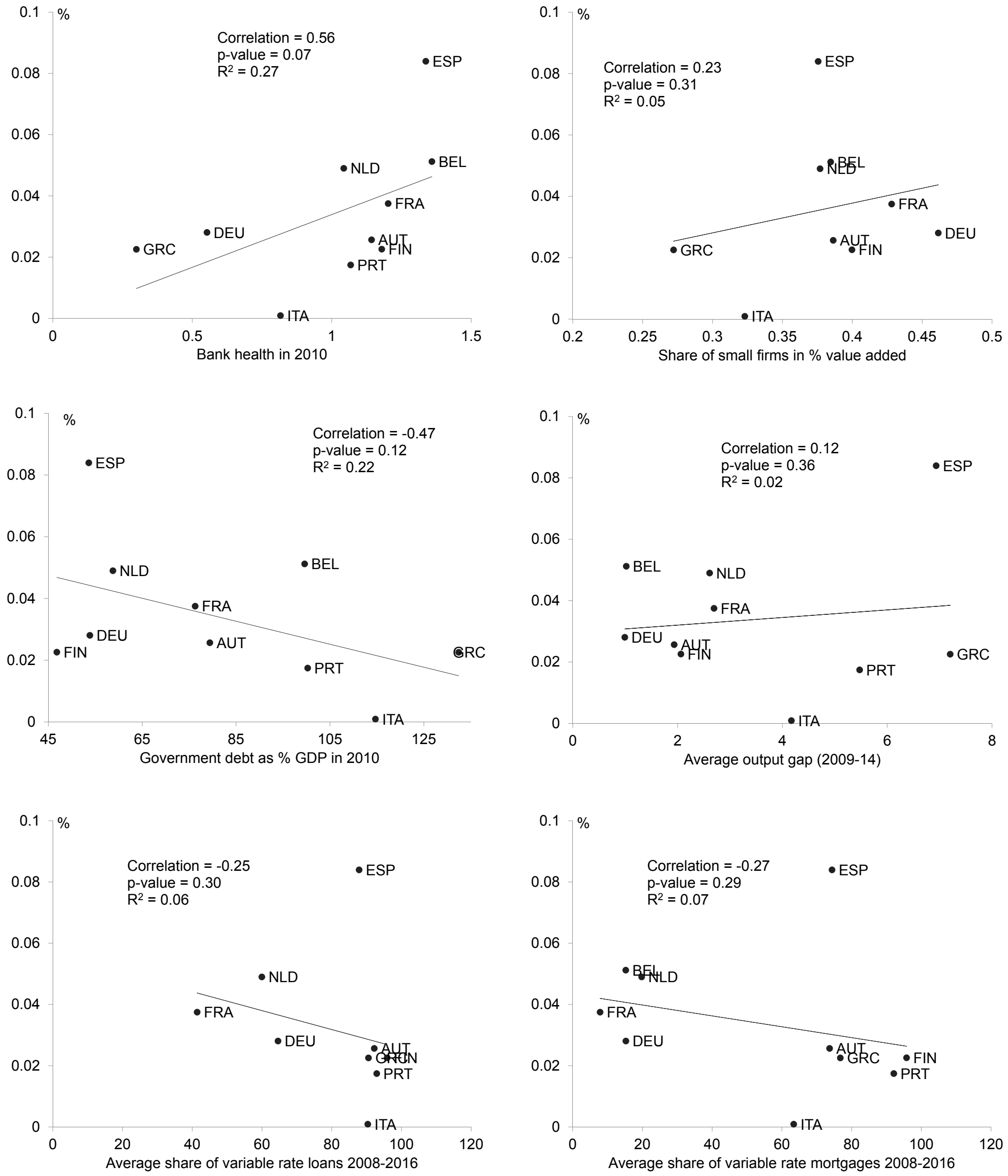
[13]Even for the dominant channels the noise generated by the weaker channels will, on average, lower the statistical significance of the correlations. However, we also perform multiple cross-correlations which, of course, raises the probably of finding correlations with apparently significant correlations. It's not clear how to balance these two factors to produce a measure of the true statistical significance, so we report standard p-values. In any case, the purpose of this section is to highlight channels that are very unlikely to be the dominant transmission channel.

Figure 4: Cross-correlations of peak output effect



In so far as dysfunction raises the risk premia on sovereign bonds, the change in the ten year government bond yield also measures how much a UMP shock reduces market dysfunction. Another more direct measure of market dysfunction is the peak effect on the sovereign CISS indicator in our country VARX models. For both of these indicators we find that countries

Figure 4: Cross-correlations of peak output effect (continued)



that had larger reductions in market dysfunction had larger peak output responses. The relationship with the peak effect on sovereign CISS is statistically significant at the 10% level and for the ten year bond yield it is borderline statistically significant. Furthermore, neither of the correlations is driven by the large output response observed for Spain, since their sovereign CISS and ten year bond yield responses are close to the average. These correlations could point towards either the liquidity premium channel or the confidence/uncertainty channel being an important transmission channel.

To evaluate the importance of the exchange rate channel we have created an openness variable that is the sum of goods exports and imports to non-euro countries[14]. As expected, we find that countries that trade more with non-euro countries have experienced larger output effects from UMP shocks, although the relationship only has a p-value of 0.15. However, the Spanish data point is working strongly against finding a positive relationship. The most obvious evidence against the exchange rate channel would appear to be the small response of euro area inflation that we and others have reported following UMP shocks, as one would expect exchange rate changes to pass through into domestic prices. However, Comunale and Kunovac [2017] provide evidence that the pass through of exchange rate movements to HICP inflation in the euro area is limited, which means our inflation responses cannot rule out the exchange rate channel.

We also find statistically significant correlations between the peak output responses from our country level models and a number of indicators associated with bank health. The bank health variable in Figure 4 is the average of non-performing loans, return on equity and return on assets in 2010[15]. We find a significantly positive relationship with our bank health indicator and a negative correlation with government debt, which is of borderline statistical significance. The latter may also be indicative of bank health because of the link between the health of government finances in the euro area are highly intertwined with the health of the banks who hold their debt. This relationship between bank health and the effectiveness of UMP mirrors that reported earlier by the studies described in Section 2. However, compared to the predictions made by the bank lending channel, these relationships have the wrong sign: countries with healthier banks have larger responses to UMP shocks. Can we explain this anomaly? Firstly, we can speculate that these policies may depend non-linearly on economic circumstances. One issue with

[14]This includes Bulgaria and Denmark as euro countries since their exchange rates are tied closely to the euro. We include only trade in goods as the trade in services data from UN Comtrade wasn't complete for all of the countries in our sample.

[15]We chose 2010 because it is close to the start of our sample period and therefore unlikely to have been overly influenced by the UMP we are studying. We chose 2010 over 2009 because the latter year was the main year of the Great Recession and some indicators for 2009 are not indicative of more normal times.

European banks is the link between weak banks and weak sovereigns where European banks' asset holdings are strongly biased in favour of the debt of their own sovereigns. If market participants perceive that a bank's solvability depends on their sovereign receiving a bailout and a small change in market rates still leaves their sovereign in need of a bailout, then the small change in market conditions that follow a UMP shock will still leave that bank constrained. Hence countries with large outstanding government debts should not react in the same way to the bank lending channel. Another possibility is that recent regulatory changes and market participant's perceptions of the riskiness of banks in general has forced banks to build up their capital. In countries with healthy banks already at or close to the new capital standards the increased value of assets on their balance sheets can be used to finance new lending. For countries with weak banks the effects of UMP shocks will increase the value of the assets on their balance sheets but these gains will more likely be used to build up sufficient capital to satisfy market participants or new regulations. Obviously our sample period of UMP also includes the TLTRO programme where changes in the central bank's balance sheet were conditional on the receiving banks making new loans. However, it is unclear how fungible the TLTRO loans were with other loans on banks' balance sheets in practice.

We also find a statistically insignificant positive relationship between the importance of small firms in an economy and the peak output effects, which is the sign predicted by the bank lending channel. Additionally, we find no evidence of a relationship between the size of output gaps and the effectiveness of UMP shocks. Finally, in contrast to Wieladek and Garcia Pascual [2016] we find no relationship between the share of variable rate loans (either all loans or just mortgage loans) and the peak output effects.

5 Conclusion

In this paper we have estimated the effects of unconventional monetary policy shocks in the euro area in an SVAR framework using zero and sign restrictions for identification. We have found weak evidence that expansionary unconventional monetary policy shocks increase output growth, but the effects on inflation at the aggregate euro area level are economically insignificant. We have taken the identified monetary policy shocks and employed these in country level models to gain more insight into the transmission of unconventional monetary policy. We have found a range of responses across the countries in our sample, and those differences in the magnitudes of output responses are most consistent with the liquidity premium channel, the confidence/uncertainty channel and the exchange rate channel. We also found that larger peak output responses are associated with healthier banking systems at the start of our sample and lower government debts.

These results are naturally subject to a considerable degree of uncertainty. The sample period is short, which make precise estimation difficult, and correlation is not causation. Nonetheless, our empirical evidence is consistent with some of the main theories for the transmission of unconventional monetary policy.

6 Appendix: Data sources

Tables 2, 3 and 4 describe the data sources for the euro area model, the country VARX models and the cross-correlations, respectively.

Table 2: Euro area data

Variable	Description and sources
Real GDP growth	Month-on-month rate of growth of real GDP. Real GDP is quarterly, so we construct a monthly measure by Chow-Lin interpolation using monthly industrial production and the volume of sales in wholesale and retail trade as the reference series. Data on real GDP, industrial production, and volume of sales in wholesale and retail trade come from Eurostat.
HICP inflation	Month-on-month rate of growth of Harmonised Index of Consumer Price (HICP). HICP data come from Eurostat.
EONIA-MRO spread	Spread between the Euro OverNight Index Average (EONIA) and the MRO rate. Data on EONIA come from the Statistical Data Warehouse of the ECB.
CISS index	Index of Composite Index of Systemic Stress as developed in Holló et al. [2012], the index ranges from 0 (no stress) to 1 (total stress). Data come from the Statistical Data Warehouse of the ECB.
Equity prices	Month-on-month rate of growth of real equity prices. We use monthly Eurostoxx 50 data from Datastream, divided by HICP.
Shadow interest rate	Data come from Wu and Xia [2016], and available Wu's website.

Table 3: VARX data

Variable	Description and sources
Real GDP	Monthly real GDP. Real GDP are at quarterly frequency, and we construct monthly measures using a Chow-Lin interpolation procedure where monthly industrial production and the volume of retail sales. Data on real GDP, industrial production, and volume of retail sales come from Eurostat.
HICP	Monthly Harmonised Index of Consumer Price (HICP) from Eurostat.
Sovereign CISS index	Sovereign debt market component of the Composite Index of Systemic Stress as developed in Holló et al. [2012], from the Statistical Data Warehouse of the ECB.
Ten year government bond yield	From Eurostat.

Table 4: Data for cross-country correlations

Variable	Description	Data Source
Manufacturing share	Share of manufacturing in total value added (2009-2016)	World Bank
Construction share	Share of construction in total value added (2009-2016)	OECD
Remaining debt maturity	Average remaining maturity of government debt (2008)	ECB (BIS for Germany)
Goods trade openness	Goods exports plus imports to non-euro countries as a % of GDP (average 2009-2016)	UN Comtrade
Bank health	Bank health (average of non-performing loans, return on equity and return on assets)	ECB
Small firms	One minus share of firms larger than 250 employees in value added (average 2010-2015)	Eurostat
Government debt	Central government debt as percentage of GDP (2010)	World Bank
Output gap	Average output gap (2009-2014)	OECD
Share of variable loans	Share of all new loans to households and non-financial corporations with fixed interest period up to 12 months (average 2008-2016)	ECB
Share of variable mortgages	Share of all new mortgage loans to households with fixed interest period up to 12 months (average 2008-2016)	ECB

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