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International Spillovers of ECB's Unconventional Monetary Policy: The Effect on Central and Eastern Europe

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Abstract

We examine how unconventional monetary policy of the European Central Bank influences macroeconomic stability in Central and Eastern European economies. We estimate various panel vector autoregressions using monthly data from 2008-2014. Using the shadow policy rate and central bank assets as measures of unconventional policies, we find that output and prices in Central and Eastern Europe temporarily increase following an expansionary unconventional monetary policy shock by the European Central Bank. Using both impulse responses and variance decompositions, we find that the effect of unconventional policies on output is much stronger than the effect on inflation. In addition, our results provide evidence that unconventional policy tends to reduce market uncertainty and domestic interest rates but that the effect on the real exchange rate is not significant.

JEL-Classification: E52, E58
Keywords: Unconventional Monetary Policy, ECB, Central and Eastern Europe, Panel Vector Autoregression

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1 Introduction

Nominal interest rates hit the zero lower bound in many countries during the recent global financial crisis, and a number of central banks implemented unconventional policy measures to provide additional support to restore macroeconomic and financial stability. The European Central Bank (ECB) introduced a number of large scale unconventional policy measures, and several papers have investigated its effects on the euro area economy (Gambacorta et al. (2014), Peersman (2011), Meinusch and Tillmann (2014)).

Although the unconventional policy measures of main central banks are likely to have non-negligible international spillovers, the evidence related to its macroeconomic effects is limited. The evidence on international spillovers is available for unconventional US Federal Reserve policies (Fratzscher et al. (2013), Bauer and Neely (2014), Chen et al. (2015), Neely (2015)) but is very scarce for the policies of the ECB.[1]

Borio and Disyatat (2010) and Chinn (2013) discuss the effectiveness and impact of unconventional policies. Chinn (2013) argues that unconventional policies help to reduce global imbalances by appreciating the currencies in emerging market economies. Dedola et al. (2013) develop an open economy dynamic stochastic general equilibrium model to examine the international effects of domestic unconventional policies. They show that unconventional policies to stabilize the domestic economy are likely to have stabilizing effects for other countries if the countries are financially integrated.

We contribute to this small but growing literature by examining the spillovers from ECB unconventional monetary policy to output and prices in Central and European countries (CEECs). These countries became highly integrated with the euro area – both financially and by trade. For example, foreign ownership of banks in the CEECs is very high, in some countries reaching more than 95% (Allen et al., 2013). The trade of CEECs with euro area countries amounts to approximately two-thirds of their total international trade (Bussiere et al., 2008). In addition, the previous literature has shown that conventional ECB monetary policy has sizable effects on output and prices in the CEECs (Mackowiak (2006), Horvath and Rusnak (2009)). Therefore, we can expect that unconventional ECB monetary policy has a strong effect on the CEECs.

If unconventional ECB monetary policy spills over significantly to the CEECs, it has policy implications for central banks in this region. First, the central banks in the CEECs do not have to loosen their policies as much as they would have to do if the unconventional ECB monetary policy spillovers were weak. Second, the forecasting models used in central banks in the CEECs do not include the effects of unconventional ECB monetary policy spillovers explicitly. As a consequence, it may have a rationale to model unconventional ECB monetary policy within these forecasting models (or within the so–called satellite models to the main forecasting model).

Following Gambacorta et al. (2014), who examine the effect of unconventional ECB monetary policy on the euro area economy, we also use central bank assets to measure unconventional ECB monetary policy. In addition, we use the shadow policy rate by Wu and Xia (2015).

[1] In fact, we are aware only of the discussion paper by Babecká-Kucharèuková et al. (2014), who examine the international macroeconomic effects of unconventional ECB policy.

Wu and Xia (2015) propose an alternative way to measure unconventional monetary policy based on a nonlinear term structure model, which is promising but so far has been rarely applied.[2] The shadow policy rate coincides with the official monetary policy rate if the zero lower bound is not binding.

Using monthly data from 2008–2014, we apply panel vector autoregressions (PVAR) to examine the effect of unconventional ECB monetary policy on economic activity and prices in the CEECs. Our results suggest that output and prices temporarily increase following an expansionary unconventional monetary policy shock. Therefore, the results correspond to the theoretical model of Dedola et al. (2013), whereby under financial integration, stabilization policies undertaken by one country will benefit other countries as well. Many CEECs suffered from severe economic recessions (for example, GDP fell by more than 10% in three Baltic countries in 2009) and struggled with deflationary risks during the crisis. As a consequence, according to our results, unconventional ECB monetary policy contributed to greater macroeconomic stability in these countries by temporarily supporting economic activity and creating inflationary pressures. We subject these results to a number of robustness checks. We use different measures of unconventional EBC policy or different ordering in panel VAR models. Importantly, we also restrict our sample to inflation targeting countries (e.g. those without euro and with floating exchange rate) and jointly include ECB's and domestic interest rates into PVAR model but the results remain largely unchanged.

This paper is structured as follows. Section 2 presents the related literature. Section 3 discusses the measurement of unconventional ECB monetary policies. We describe the panel vector autoregression model in section 4. We provide the results in section 5. Conclusions are presented in section 6. An appendix with additional results follows.

[2] The Federal Reserve Bank of Atlanta hosts the Wu and Xia shadow policy rate estimates and appears to regularly update them at https://www.frbatlanta.org/cqer/research.aspx.

2 Related Literature

We provide a brief review of the literature addressing the unconventional monetary policy of central banks. We focus on the literature examining the effects of unconventional ECB policies, which uses vector autoregression (VAR) models. We refer the reader to Borio and Disyatat (2010) and Chinn (2013) for more comprehensive surveys. Mohanty (2014) provides an overview of the spillovers of unconventional monetary policies into emerging market economies.

Gambacorta et al. (2014) examine the effectiveness of unconventional monetary policy at the zero lower bound and estimate a structural panel VAR with monthly data from eight economies from 2008 to mid–2011. They use central bank assets as a measure of unconventional monetary policy and include four variables in their benchmark VAR specification: real GDP, consumer price index, central bank assets and implied stock market volatility of the national stock market index. They use a mean group estimator to take into account potential cross-country heterogeneity in macroeconomic dynamics as well as monetary transmission mechanisms. Gambacorta et al. (2014) find that the increase in central bank assets leads to a temporary rise in economic activity as well as a temporary rise in the price level. They also find that the response of output to unconventional and conventional monetary policy shocks is largely similar. However, price effects are weaker in the case of unconventional shocks in comparison to conventional monetary policy shocks. Additionally, their individual country results suggest that differences in the effects of unconventional policies across countries are rather small.

Using a structural VAR model, Peersman (2011) investigates whether the transmission mechanism of unconventional monetary policy innovations is different from the traditional interest rate channel in the euro area. Peersman (2011) finds that the effect on economic activity and prices reaches a peak after approximately one year for an interest rate shock and only approximately six months for a shift in the monetary base. These results suggest that the propagation of conventional monetary policy to the economy is more sluggish than the propagation of unconventional monetary policy. Next, his results suggest that the interest rate spreads decline after a rise in the balance sheet of the Eurosystem, but they increase after a fall in the policy rate.

Boeckx et al. (2014) examine the effects of ECB unconventional policies on the euro area economy. Using structural VAR, they find that these policies have been effective and have significantly affected output, prices and bank lending in euro area countries.

Moessner (2014) also examines the impact of unconventional monetary policies but focuses on the effects of ECB balance sheet policy announcements on inflation expectations. Thus, the results shed light on ECB monetary policy credibility, i.e., the extent to which inflation expectations are anchored. Moessner (2014) finds no evidence that the ECB's balance sheet policy announcements to support the economy would result in higher long-term inflation expectations.

Babecká-Kucharèuková et al. (2014) assess the impact of ECB monetary policy on macroeconomic developments in the euro area as well as in six non-euro area EU countries. They construct a monetary conditions index, which they decompose into conventional and unconventional monetary policy measures.

They estimate individual–country VAR models to examine if the effects of conventional and unconventional tools differ. Their results suggest that the reaction of industrial production to the unconventional monetary policy shock is weaker and less significant than the reaction of industrial production to a conventional policy shock. In addition, their results suggest that the response of prices to unconventional monetary policy is much quicker in comparison to the response to conventional monetary policy.

Babecká-Kucharèuková et al. (2014) find only limited evidence for international spillovers from unconventional ECB monetary policy. Output responds to the unconventional monetary policy shock only in selected non-euro area EU countries. In addition, the response of price is insignificant in non-euro area EU countries. They also find that exchange rates react quickly with a peak within a few months and that the exchange rates depreciate after monetary tightening in a majority of countries.

In summary, the available evidence on the effects of unconventional monetary policy suggests that these policies are able to affect output and prices in the euro area and that the effects on output are larger. However, the international spillovers from unconventional ECB monetary policy are rather mild.

3 Measuring ECB's Unconventional Monetary Policy

In this section, we first briefly describe the unconventional monetary policy measures implemented by the ECB during the global financial crisis. In general, these measures are meant to support the European economy and focus on issues such as the functioning of the monetary transmission mechanism, lending activity of commercial banks and deflationary risks. Second, we introduce two measures – the shadow rate and central bank assets – which are used as a proxy for the intensity of unconventional policies in our panel VAR regressions.

To simplify, we divide the crisis into two phases, and accordingly, we can also divide the types of unconventional monetary policy. Before the fall of Lehman Brothers, the new facilities for monetary policy were introduced mainly because of monetary policy transmission mechanism disruptions. In the first phase of the crisis, the ECB provided slightly modified conventional measures. The following measures were widely used in the first phase of the crisis: broadening the range of counterparties and eligible collaterals, extending maturities of refinancing operations, full-allotment fixed-rate tenders, easing conditions for lending liquid securities, establishing foreign exchange swaps with other central banks, and narrowing corridors around the main policy rate. The ECB also intensified its communication policy.

The more non-standard measures were introduced in the second phase of the crisis. The measures included in this phase are the following: purchase of government bonds, purchase of covered bonds or other private assets, forward guidance and foreign exchange interventions.

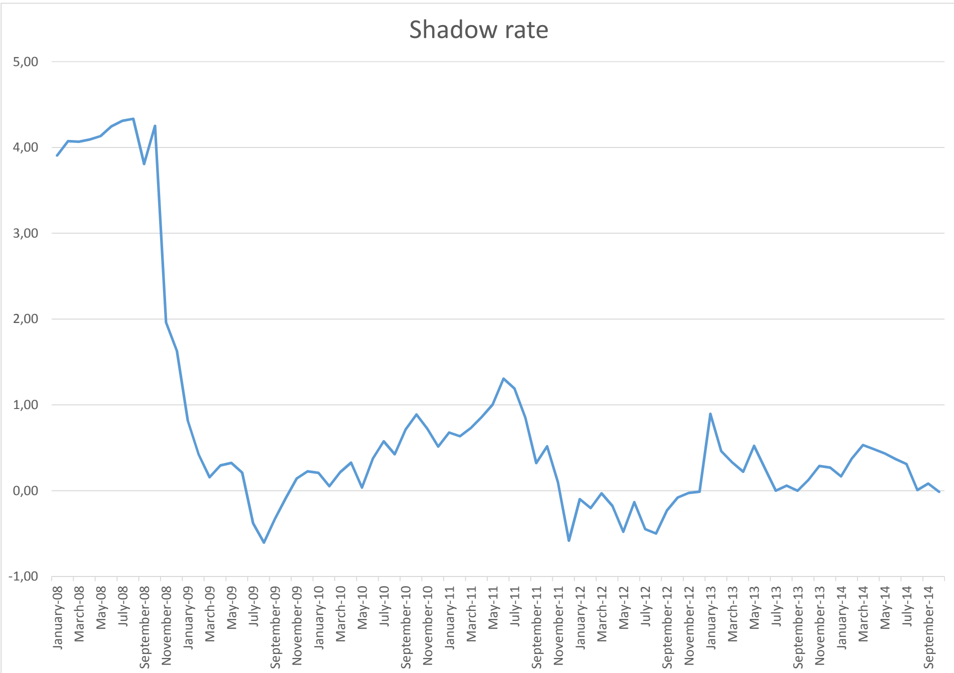
The main reason for using unconventional tools after the bankruptcy of Lehman Brothers was the zero lower bound on nominal interest rates. The ECB started to use unconventional policy measures to provide extra liquidity to the financial sector in October 2008, although some sort of liquidity measures had already been introduced in late summer 2007. The first supplementary liquidity measure used by the ECB was the announcement of longer-term refinancing operations (LTRO; three year loans at very favorable rates) followed by another 3-month LTRO in September 2007 and in February 2008. The next announcement was the first 6-month LTRO in March 2008. The ECB modified the structure of the standard LTRO for a fixed-rate tender procedure with full-allotment in October 2008. Next, the ECB also implemented three LTROs with a 12 month maturity at quarterly frequency and a fixed-rate tender procedure with full-allotment (Enhanced Credit Support Programme) in May 2009 as well as the announcement of CBPP - the direct purchase of euro-denominated covered bonds.

The ECB introduced additional unconventional measures with the Securities Markets Programme (SMP) in May 2010, the announcement of the next 6-month LTRO, and swap lines with the FED. In the second half of the year 2011, there were other announcements of the SMP and CBPP and numerous 12-, 13- and 36-month LTROs. The ECB announced the Outright Monetary Transactions (OMT) program in August 2012. This program was introduced to purchase unlimited amounts of government bonds from euro-area countries with a maturity of 1-3 years to restore the functioning of the monetary transmission mechanism. The OMT program was aimed at the countries that are subject to the European Stability Mechanism Programme.

The maturity dates of the quantitative limit were not specified, and although this measure has not yet been carried out, its announcement had a strong effect on government bond yields(Rivolta, 2014), which exhibited a marked decline.

To reduce deflationary risks in the euro area, the ECB launched an Expanded Asset Purchase Programme (EAPP) in January 2015, which encompasses monthly purchases of euro-denominated, investment-grade securities of 60 billion euro (together with the existing purchase program) on the secondary markets. The ECB aims to purchase private and public securities until September 2016 or until sustained adjustment in the path of inflation toward the 2% level is observed(Delivorias, 2015). The ECB believes that the quantitative easing program will revive the euro area economy and hence raise inflation, bringing it back to a level compatible with the ECB's definition of price stability.

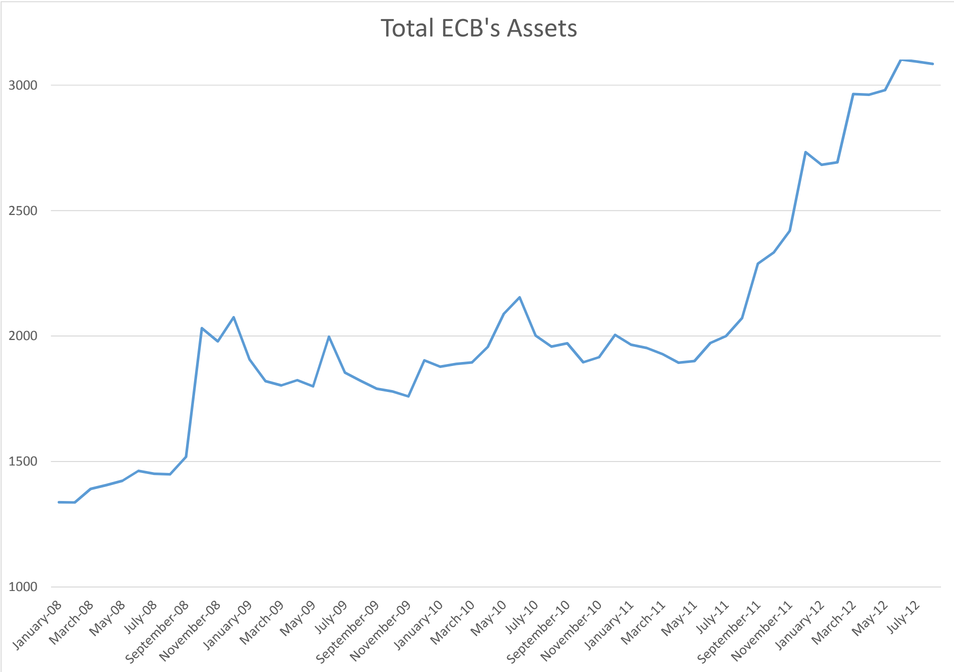
Figure 1: The development of ECB's shadow policy rate



As shown above, the ECB implemented numerous unconventional measures during the crisis. We use two measures to summarize the ECB's unconventional policies. First, we use a measure of the shadow policy rate. The shadow rate largely coincides with the policy rate if the rate is above zero. Unlike the policy rate, the shadow rate can be negative (more on the construction of the shadow rate below). Second, we use central bank assets, which is a typical measure to assess the scale of unconventional monetary policy Gambacorta et al. (2014).

Wu and Xia (2015) propose how to measure the macroeconomic impact of monetary policy at the zero lower bound. They generate a shadow monetary policy rate based on the nonlinear term structure model (SRTSM) and examine its behavior in a factor–augmented vector autoregression model of the US economy.

Figure 2: European Central Bank's assets



Their results suggest that the actions used by the US FED to stimulate the economy at the onset of the financial crisis succeeded in lowering the unemployment rate. Wu and Xia (2015) also report the shadow policy rate for the euro area.[3] See also Krippner (2013) and Lombardi and Zhu (2014), who show that the shadow policy rate helps identify monetary policy shocks in VAR models.

Figure 1 shows the development of the shadow policy rate. The shadow policy rate becomes negative in May 2009, reflecting the use of unconventional monetary policy measures by the ECB and the adoption of three LTROs with 12 month maturity at quarterly frequency and fixed rate tender with full-allotment. The unconventional measures announced in the second half of 2011 were effective in lowering the shadow rate below -0.5% in December 2011. The shadow rate went back to zero afterward.

Following Gambacorta et al. (2014), we also use the ECB's balance sheet to assess the intensity of unconventional monetary policy. The size of balance sheets increased markedly after the policy rates were lowered in the beginning of 2009. The size of the central bank balance sheet is typically captured by central bank assets or by the monetary base. However, the expansion of the monetary base was not proportional to the increase in central bank assets, mainly due to sterilization, and therefore, we prefer using central bank assets in our empirical analysis.

[3] The series is freely available at the Federal Reserve Bank of Atlanta:https://www.frbatlanta.org/cqer/research.aspx or at the website of Jing Cythia Wu: http://faculty.chicagobooth.edu/jing.wu/index.html.

Figure 2 displays total ECB assets. The development of central bank assets reveals a strong growth within the whole sample period, reflecting the use of unconventional monetary policy measures. The size of the balance sheet more than doubled between the years 2008 and 2014.

4 Panel Vector Autoregression

The p-lag reduced panel VAR model has the general form

$$y_{i,t} = \mu + \sum_{j=1}^{p} \mathbf{\Pi_j} y_{i,t-j} + e_{i,t} \tag{1}$$

where $y_{i,t}$ is a vector of endogenous variables for each unit i in time t. μ is a constant, Π_j are parameter to be estimated and $e_{i,t}$ is an error term, which includes the unobserved country characteristics. As in Gambacorta et al. (2014), in the benchmark case, the vector of endogenous variables $y_{i,t}$ contains four key macroeconomic variables with the following recursive ordering: real GDP, consumer price index, shadow policy rate, and implied volatility index of the national stock market index. In the extended model, we add the exchange rate to the middle of the ordering. The ordering corresponds to the typical ordering in the empirical monetary policy transmission literature. Real GDP is placed first because the state of the economy does not react immediately to all other variables included. A similar situation occurs with inflation, which takes second place in our ordering. We order the real effective exchange rate in the third place because it reacts with a lag to interest rate shocks. The interest rates affect GDP and inflation with a lag, and accordingly, we put the shadow rate in the fourth place. When we use central bank assets as a measure of unconventional monetary policy, it takes fourth place instead of the shadow rate. The implied stock market volatility is placed at the end of our ordering because volatility is rather a reaction to some shocks than their source (Grossmann et al., 2014).

The panel VAR includes the following Central and Eastern European countries: Bulgaria, Croatia, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia and Slovakia. We label this set of countries all full sample. Since some countries already became a member of euro area, we subsequently restrict our sample to the countries without euro and with floating exchange rate: Croatia, Czech Republic, Hungary, Poland and Romania. As regards the restricted sample, all these countries have an identical monetary policy regime – inflation targeting. In addition, we include domestic short–term interest rate for the restricted sample. Including jointly domestic interest rates with shadow rate provides a conservative test about the importance of the effect of shadow rate given that domestic interest rates and shadow rate are likely to be correlated.

The panel VAR procedure applied by Love and Zicchino (2006) introduces the fixed effect to allow for individual heterogeneity of the cross-sectional unit. However, it is well known that the fixed effect estimator is not consistent in a dynamic panel. The fixed effects are correlated with the regressors through the lags of the dependent variables (Boubtane et al., 2013). We consider the method proposed in Love and Zicchino (2006) to address this issue. We use forward mean differencing to remove the fixed effect (Helmert procedure); this approach is used for the panel VAR estimation in Boubtane et al. (2013). Because the deviations are orthogonal, we can use the lagged regressors as instruments and estimate the coefficients by the generalized methods of moments (Boubtane et al., 2013).

Once we estimate the coefficients in our fixed–effects panel VAR, we compute impulse responses and the forecast variance decompositions using Cholesky decomposition. The confidence intervals are generated by Monte Carlo simulations with 500 replications. We use the package originally provided by Love and Zicchino (2006) and recently updated by Abrigo and Love.[4]

To assess the interactions between unconventional monetary policy, the economic activity, uncertainty and real exchange rates, we estimate the following panel VAR models:

$$\textbf{Model 1}: X_{it} = (Y_{it}, P_{it}, s_t, iVol_t) \tag{2}$$

$$\textbf{Model 2}: X_{it} = (Y_{it}, P_{it}, EX_{it}, s_t, iVol_t) \tag{3}$$

$$\textbf{Model 3}: X_{it} = (Y_{it}, P_{it}, iVol_t, s_t) \tag{4}$$

$$\textbf{Model 4}: X_{it} = (Y_{it}, P_{it}, ta_t, iVol_t) \tag{5}$$

$$\textbf{Model 5}: X_{it} = (Y_{it}, P_{it}, i_t, s_t, iVol_t) \tag{6}$$

where Y represents the real GDP index, P denotes the CPI index, s is the shadow policy rate, $iVol$ stands for the implied volatility index, EX is the real effective exchange rate, ta represents total central bank assets and i denotes the domestic short–term interest rate. These specifications largely follow Gambacorta et al. (2014) but in addition, we have a model 5, which also includes domestic interest rate. We estimate the model 5 for our restricted sample, for which we include only (inflation targeting) countries without euro as a legal tender and with floating exchange rate.

[4] The package is freely downloadable from https://sites.google.com/a/hawaii.edu/inessalove/home/pvar.

5 Data

We use monthly data over the period 2008-2014 for 11 Central and Eastern European countries. Following Gambacorta et al. (2014), we choose January 2008 as the starting date. Our time coverage is approximately seven years. Note that Gambacorta et al. (2014) use a shorter period (4 years) for their panel VAR. The source of our data is the Bank for International Settlements, Eurostat, Federal Reserve Economic Data, Cinthy Wu's website and STOXX. We use the real GDP index, consumer price index, shadow policy rate, volume of European central bank assets, implied volatility index, real exchange rate and domestic interest rates in our model.

Real GDP data and the consumer price index are seasonally adjusted with the base year 2005. In the case of GDP, we interpolate the quarterly values into monthly frequency using the cubic spline interpolation. To assess the uncertainty in European financial markets, we use the VSTOXX index. The index tracks the one month implied volatility of the Euro STOXX 50 index, which is Europe's leading Blue-chip index for the euro area. Next, we use the real effective exchange rates. We use two measures to gauge unconventional monetary policy by the ECB: the shadow policy rate, as proposed by Wu and Xia (2015), and seasonally adjusted central bank assets (in billions of euros). We use 3 months money market rate as the measure of domestic interest rates. Table 1 reports the summary statistics. In addition, we present the panel unit root and panel cointegration tests in the Appendix and discuss our choice of estimating the panel VAR model in levels.

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
GDP	103.54	5.7102	93.130	125.47
CPI	125.76	12.692	105.50	155.41
REER	100.30	3.7029	86.790	122.00
Shadow rate	0.7611	1.3316	−0.6052	4.3342
Total CB assets	2155.5	464.18	1336.8	3102.2
VSTOXX	26.608	9.700	14.487	63.272
Interest rate	4.509	3.102	0.350	18.210

6 Results

First, we provide the results for the full sample of 11 Central and Eastern European countries. Second, we restrict our sample to 5 countries, which target inflation and as a result, do not have euro as a legal tender and maintain flexible exchange rate.

6.1 Full Sample: Central and Eastern European Countries

We examine the effect of unconventional ECB monetary policy on the CEECs. Figure 3 displays the impulse responses to an orthogonalized one standard deviation shock to the shadow rate with 95% confidence intervals using our **Model 1**. The panel VAR includes three lags, which is set based on information criteria. Our results suggest that a lower ECB shadow rate is associated with stronger economic activity in the CEECs. The peak response of GDP is approximately one year after the shock. Therefore, according to our results, the CEECs benefited from loose ECB monetary policy curbing the decline in economic activity during the crisis.

Figure 3: Impulse responses to shadow rate shock: Model 1

Note: The solid line shows the impulse responses. The dashed lines indicate 95% confidence intervals. The shock is defined as unexpected decrease in shadow rate.

Our results also indicate that a lower ECB shadow rate increases prices in the CEECs. The prices appear to respond much faster than the output, but economically, the effect on prices is much weaker. Looking at the magnitude of the effects, we observe that the peak effect of an unconventional monetary policy shock on output is approximately two times larger than the effect on the price level.

This finding is in line with Gambacorta et al. (2014). They find that the effect of an unconventional ECB monetary policy shock on output in the euro area is approximately three times larger than the effect on prices. Schenkelberg and Watzka (2011) obtain similar results when examining the effect of the Bank of Japan's quantitative easing. Gambacorta et al. (2014) put forward the reason for a weaker price level response. The regressions are estimated over the period of recession, where the aggregate supply function is potentially convex due to downward rigidity in nominal wages and prices. This implies that the changes in aggregate demand driven by monetary policy would have a weaker effect on the price level and a stronger effect on output.

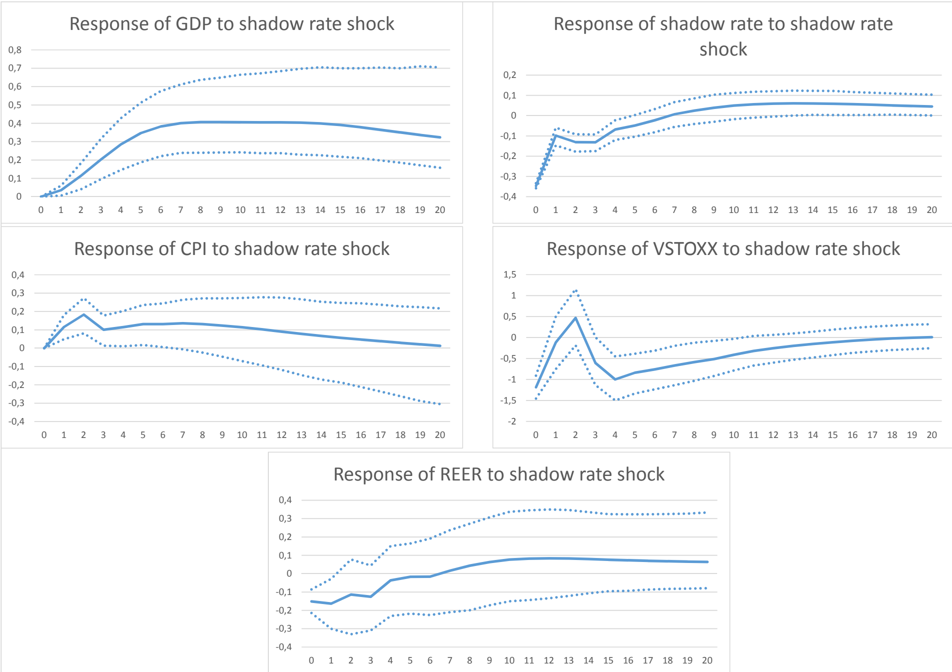
Next, we present the results on the effect of the shadow rate on market uncertainty. The results suggest that uncertainty increases somewhat immediately after the shock but then decreases over a longer time period, suggesting that unconventional monetary policy helps reduce market uncertainty.

Babecká-Kucharèuková et al. (2014) also examine the spillover effect of the unconventional ECB monetary policy. Using the individual country VAR estimations, they find that the effect of unconventional ECB monetary policy on output and prices in the CEECs is rather weak, country–specific and often insignificant. Therefore, our panel VAR results stand in contrast to the results provided by Babecká-Kucharèuková et al. (2014) because we show that the spillover effects of unconventional ECB monetary policy are rather strong, especially for output. Of course, it is far from easy to hypothesize about the reason why the results differ. It may be the case that estimating individual country VAR models at the monthly frequency with approximately 175 observations and 8 variables require a low number of lags to maintain some degrees of freedom (note that we use three lags). In addition, Babecká-Kucharèuková et al. (2014) use the data from 1999 to 2014, while the implementation of unconventional policies started not sooner than during the global financial crisis, i.e. not sooner than in the summer of 2007. The results about insignificance of spillover effects of unconventional ECB policy policy are also somewhat surprising in the light of previous evidence documenting important international spillovers of conventional ECB policy (Horvath and Rusnak, 2009; Mackowiak, 2006) as well as in the light of previous evidence showing the considerable international spillovers of unconventional US Fed policies (Fratzscher et al. (2013), Chen et al. (2015), Neely (2015)).

We extend **Model 1**, including the real effective exchange rate in order to examine the robustness of our results. We present the results in Figure 4, which shows the impulse responses to the unexpected decrease in the shadow rate using **Model 2**. The results from **Model 1** remain largely unchanged. In addition, our results suggest that the real exchange rate does not react significantly to an unconventional monetary shock.

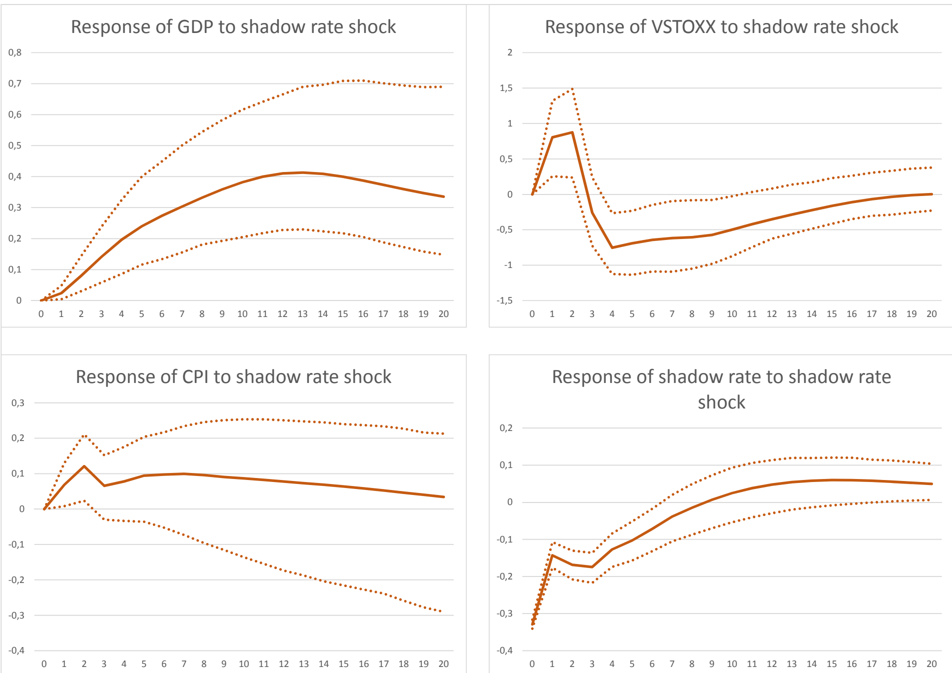
Next, we estimate **Model 3** to assess the robustness of our baseline results further. **Model 3** employs a different ordering of the variables, as in Gambacorta et al. (2014). Gambacorta et al. (2014) suggest that the ECB responded almost immediately through unconventional policies to address financial market uncertainty. However, they also argue that this ordering could be biased because monetary policy interventions should be allowed to immediately influence financial market sentiment.

Figure 4: Impulse responses to shadow rate shock: Model 2



Note: The solid line shows the impulse response. The dashed lines indicate the 95% confidence interval. The shock is defined as unexpected decrease in shadow rate.

Figure 5: Impulse responses to shadow rate shock: Model 3

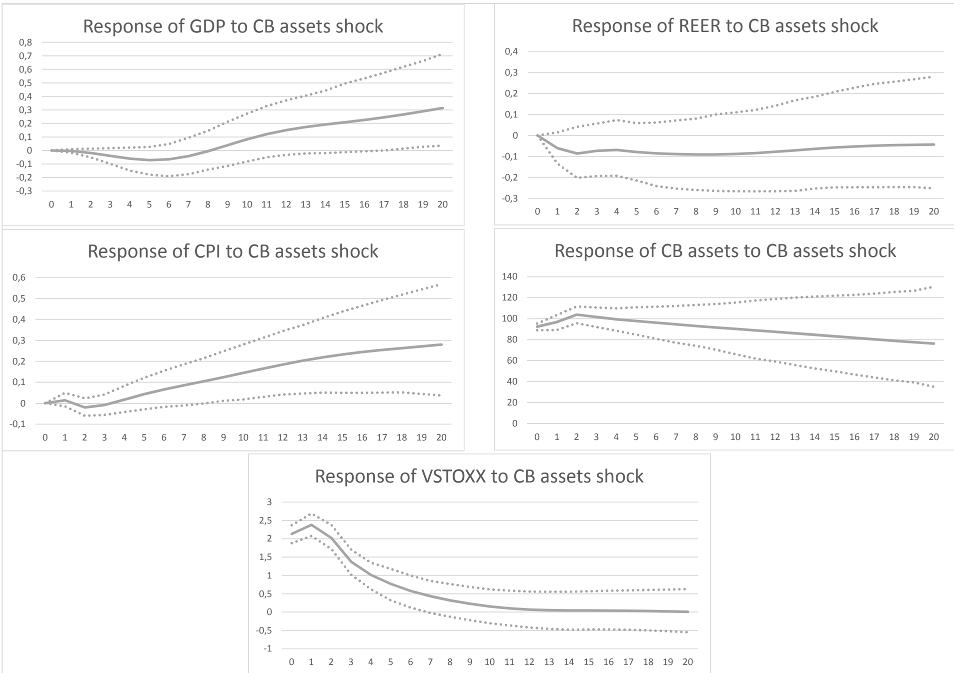


Note: The solid line shows the impulse response. The dashed lines indicate the 95% confidence interval. The shock is defined as unexpected decrease in shadow rate.

Figure 5 presents the impulse responses based on the following ordering of variables: $\mathbf{Model\ 3}$: $X_{it} = (Y_{it}, P_{it}, iVol_t, s_t)$.

The responses to a negative shock to the shadow rate obtained by **Model 3** are largely similar to those obtained by **Model 1**. The only difference is in the response of the implied volatility index, which appears to be more significant. Therefore, this change in the ordering does not have an effect on the interpretation of our results.

Figure 6: Impulse responses to CB assets shock: Model 4

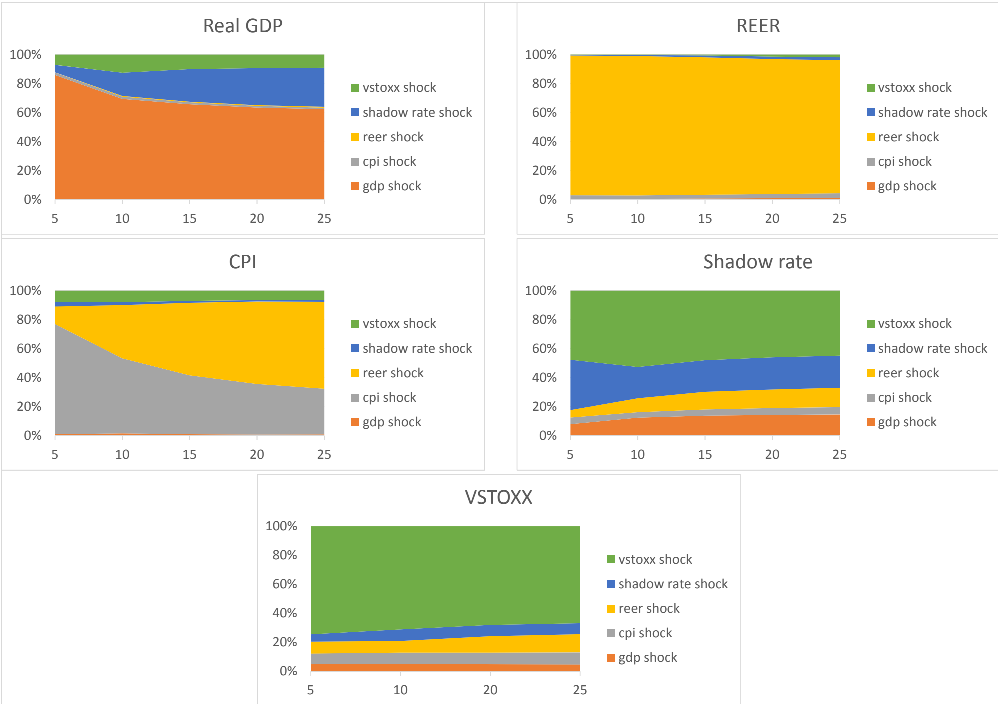


Note: The solid line shows the impulse response. The dashed lines indicate the 95% confidence interval. The shock is defined as unexpected increase in central bank assets.

Next, we use the central bank assets to measure unconventional monetary policy. We present the results using **Model 4** in Figure 6. The results suggest that economic activity and prices increase after an unexpected increase in the central bank assets. Therefore, these results are largely in line with our baseline results using **Model 1** with the shadow rate, although the peak response of output appears to occur a bit earlier. However, our results indicate that market uncertainty increases, which is at odds with our baseline results.

Variance decompositions represent another method for interpreting the VAR estimates. We present the results in Figure 7 based on **Model 2**. The figure displays the proportions 5, 10, 15, 20 and 25 months after the shocks. The results largely correspond to our results based on impulse response analysis. We find that the shadow rate shocks account for approximately 5-28% of the fluctuations in output depending on the forecast horizon. This is an economically important effect. In contrast, the shadow rate helps explain only approximately 2-4% of the forecast error in the variance of prices.

Figure 7: Forecast error variance decompositions



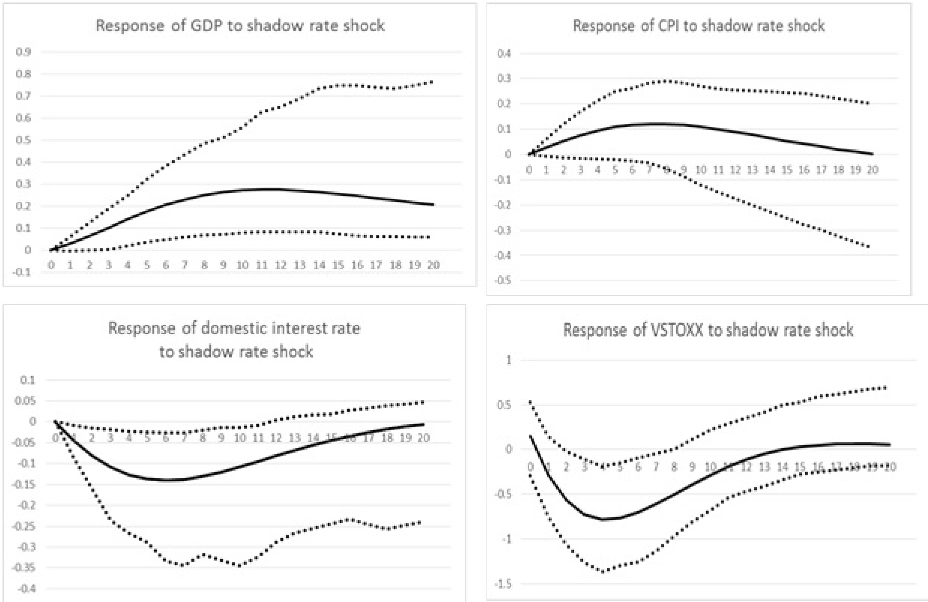
Interestingly, we find that the variations in the shadow rate are driven mainly by the innovations to the implied volatility index (approximately 50%) and also by shocks to the real effective exchange rate (approximately 10%). The innovations in the shadow rate only account for approximately 7% of the implied volatility variations and approximately 2% of the variations in the real exchange rate.

In summary, our panel VAR results show that economic activity in the CEECs is significantly affected by unconventional ECB monetary policy. The peak response of output occurs with a lag of approximately one year or a bit earlier. According to our estimates, ECB policy explains approximately 20% of the output fluctuations in the CEECs. The unconventional ECB monetary policy also has an effect on prices in the CEECs, but the effect is not so economically important. Overall, our results show that the ECB's policies have international spillovers, which are strong, especially for output fluctuations.

6.2 Restricted Sample: Non-Euro Area Countries with Floating Exchange Rate

We estimate **Model 5** for our restricted sample. The restricted sample does not include countries, which adopted euro before or during our sample period or maintain fixed exchange rate regime. The **Model 5** additionally includes domestic short–term interest rates along with the shadow rate.

Figure 8: Impulse responses to shadow rate shock: Model 5



Note: The solid line shows the impulse response. The dashed lines indicate the 95% confidence interval. The shock is defined as unexpected decrease in shadow rate.

This is important exercise to investigate if we still find spillover effects of unconventional ECB policy given that domestic short–term rates are likely to be correlated with shadow rate (the correlation coefficient between these two series in our panel is 0.3). Before estimating the VAR model, we set the number of lag to 1 based on information criteria and find the panel VAR stable, as all eigenvalues lie inside the unit circle.

We present the results in Figure 8. The results are largely in line with our baseline findings. The similarity of results for the full and restricted sample suggest that pooling the countries and estimating panel VAR is a reasonable choice. Lower shadow rate is associated with greater economic activity, higher prices and lower market uncertainty. The speed of propagation of shadow rate shocks is largely similar to those observed for the full sample. In addition, unexpected decrease in shadow rate lowers domestic short–term interest rate in inflation targeting countries in Central and Eastern Europe. The maximum effect occurs after approximately six months. In addition, we also conduct forecast error variance decomposition (these results are available upon request). The shadow rate explains about 10% in the GDP, 4% in the CPI, 6% in domestic interest rates. Therefore, the results remain largely unchanged except that shadow rate now explains 10% instead of 20% in the variation of GDP but still this is a sizable effect.

7 Concluding Remarks

We empirically examine the spillover effects of unconventional monetary policy implemented by the ECB during the global financial crisis using the panel VAR model. Despite the obvious importance of this topic for policy, the spillover effects of unconventional ECB monetary policy to foreign countries has been rarely examined.

We use monthly data for 2008–2014 and examine the impact on output and prices in 11 Central and Eastern European countries. Our panel VAR specifications largely follow Gambacorta et al. (2014); i.e., along with the measure of (foreign) unconventional policy, we include the measure of economic activity, prices, real exchange rates, domestic interest rates and market uncertainty (using the implied volatility index).

We employ two measures of the intensity of unconventional policies, namely, 1) the shadow rate from the non–linear term structure model of Wu and Xia (2015) and 2) central bank assets. Using the shadow rate to approximate the unconventional monetary policy when policy rates are near the zero lower bound is novel, but it has been shown to be successful in identifying monetary policy shocks; see, for example, Wu and Xia (2015), Krippner (2013) and Lombardi and Zhu (2014). Central bank assets have frequently been used to capture the intensity of unconventional policies (Gambacorta et al., 2014).

Our results suggest that there are sizable spillover effects from unconventional ECB policy measures. This is a new result because Babecká-Kucharèuková et al. (2014), who, to the best of our knowledge, are the only paper examining the macroeconomic consequences of international spillovers of unconventional ECB policy measures, find rather weak spillover effects. According to our results, the unconventional measures strengthened economic activity in the CEECs. We find that the peak response of output in the CEECs occurs with a lag of approximately one year and that unconventional ECB measures help explain approximately 10–20% of output fluctuations in the CEECs. Our results suggest that unconventional ECB measures also affect prices in the CEECs, but the effect is approximately two times weaker than the effect on output, which corresponds to the findings of Gambacorta et al. (2014). Overall, our empirical results provide support for the theoretical model of Dedola et al. (2013), who show that domestic unconventional measures will have stabilization effects in foreign countries if the countries are financially integrated. Our results showing the international spillover effect of unconventional ECB policy measures also correspond to the previous evidence on the importance of international spillover effects of the US FED (Fratzscher et al. (2013), Chen et al. (2015), Neely (2015)).

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Appendix

Table A1: CADF panel unit root test

Time series	Value of test statistic	P-value
GDP	–2.502	0.006***
CPI	–0.445	0.328
REER	–3.360	0.000***

Notes: The test statistic is the Cross-sectional Augmented Dickey Fuller of Pesaran (2007); H_0: time series has a unit root; number of lags = 3; $(***)$ denotes significance at the 1% significance level.

We first apply the Pesaran cross-sectional dependence (CADF) panel unit root test. The null hypothesis of the unit root is rejected for GDP and the real effective exchange rate but not for the consumer price index; see Table A1.

Table A2: KPSS test

Time series	Value of test statistic
VSTOXX	1.11***
Shadow rate	1.12***
Total CB assets	1.54***

Notes: H_0: time series is stationary; number of lags = 2; asymptotic critical values with no trend: $10\% :\ 0.347, 5\% :\ 0.463, 1\% :\ 0.739$; $(***)$ denotes significance at the 1% significance level.

We also have non-panel variables in our data set - the implied volatility index, the shadow rate of the ECB and the total central bank assets that are common for all countries. Because these are not panel variables, we apply unit root tests for univariate time series. We estimate the Kwiatkowski-Phillips-Schmidt-Shin test (H_0: series is stationary). We reject the H_0 for all series, which suggests that these series are non-stationary.

Sims et al. (1990) emphasize that non–stationary time series should not be transformed into the first differences when estimating the VAR model. Differencing the series may result in a loss of information about trend movements of variables. Following Sims et al. (1990) and Gambacorta et al. (2014), we decide not to use first differences due to the possible loss of some useful information included in the data and also because of the overall stability of our models as well as possible cointegration, which is discussed later.

The overall stability of the system is sufficient to interpret the VAR model results. We test the stability of the VAR system by examining the stability condition and find that the modulus of each eigenvalue is strictly less than 1 and thus the estimates satisfy the eigenvalue stability condition. This means that our models are stable even without using first differences. We conclude that the system is stationary as a whole, and we proceed with the estimation of the VAR in levels.

We also conduct several cointegration tests. In the case of cointegration, first differencing might not be suitable because of the loss of information.

We apply panel cointegration tests developed by Westerlund (2007). The null hypothesis of these tests states that there is no cointegration within the panel. We reject the null hypothesis of no cointegration at 10% and 1% significance levels in two tests. This is another reason why we decide to continue with the original values of the variables instead of the differenced ones. As in Gambacorta et al. (2014), we do not model the cointegration explicitly.

Table A3: Panel cointegration tests

Statistic	Value of test statistic	P-value
G_t	–2.850	0.063*
G_a	–7.928	0.991
P_t	–10.832	0.002***
P_a	–9.657	0.434

Notes: H_0: the cointegration is not present between time series; the G_t and G_a statistics test whether cointegration exists for at least one cross–sectional unit; the P_t and P_a statistics test whether cointegration exists for the panel as a whole; $(*)$ and $(**)$ denote significance at the 10% and 5% significance levels, respectively.