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Faculty of Social Sciences
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MASTER THESIS

**The Impact of Unconventional Monetary
Policy of ECB to Central and Eastern
European Countries: A Panel VAR
Analysis**

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature. This thesis was not used to obtain another academic degree.

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Prague, May 5 , 2015

Signature

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Abstract

In this thesis we examine the macroeconomic interactions of unconventional monetary policy introduced by European Central bank during crisis by estimating a panel vector autoregression. We study impact of such policies using monthly data from 13 Central and Eastern European countries within seven-year period from 2008 to 2014. We find a positive reactions of output and prices to expansionary unconventional monetary policy shock. Our results provide evidence that decrease in shadow policy rate of ECB leads to rise in output as well as temporary rise in inflation, however, the effect on inflation is weaker and less persistent. We also find that unconventional monetary policy positively influences market uncertainty, but we do not find any significant effect on exchange rates. Individual country estimates suggest that the reaction of exchange rates to non-standard monetary policy shock significantly vary across countries.

Keywords	Panel Vector Autoregression, Monetary Policy, ECB, Unconventional Measures, CEE countries
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Abstrakt

V této práci bude zkoumán makroekonomický dopad nekonvenční monetární politiky Evropské centrální banky implementované během krize pomocí modelu panelové vektorové autoregrese. Prověřován bude dopad těchto politik za použití měsíčních dat z 13 zemí střední a východní Evropy za sedmileté období od roku 2008 až 2014. Výsledky ukazují, že reakce výstupu a cen na expanzivní nestandardní monetární politiku jsou pozitivní. Pokles shadow policy rate Evropské centrální banky vede k růstu výstupu i dočasnému růstu cen, ovšem efekt na ceny je slabší a krátkodobější. Analýza také odhaluje pozitivní vztah mezi expanzivní nekonvenční monetární politikou a nejistotou na trhu. Na druhou stranu nebyl prokázán žádný signifikantní dopad této politiky na směnný kurz. Vektorové autoregresní modely odhadnuté pro jednotlivé země ukázaly různorodé reakce směnných kurzů na nestandardní monetární politiku ECB.

Klíčová slova

Panelová vektorová autoregrese, monetární politika, ECB, nekonvenční opatření, země CEE

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Master Thesis Proposal

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Proposed topic	The Impact of Unconventional Monetary Policy of ECB to Central and Eastern European Countries: An Event Study and a VAR Analysis

Motivation Central banks usually maintained monetary policy through changing the short-term nominal interest rates. However the use of this instrument implies a trouble: the short-term interest rate cannot be pushed below zero. When the interest rates are lowered to almost zero, central banks have to resort to other monetary instruments.

During the latest financial crisis many central banks in advanced economies implemented unconventional monetary policies. Many of them have cut their policy rates and got stuck at their effective lower bounds. Consequently, central bank balance sheets replaced interest rates as the main monetary policy instrument.

In recent years we have observed a big increase of interest in examining impacts of unconventional monetary policy measures. My focus is to shed light on how the unconventional monetary policy measures implemented by the European Central Bank affect countries of Central and Eastern Europe. The aim is to measure the financial and macroeconomics impact of unconventional monetary policies.

In the first part of this thesis I will examine the effects of the announcements of the ECB's Outright Monetary Transactions programme in 2012 on government sovereign bond yields of Central and Eastern European countries. I will

use event study approach to examine these effects. In the second part I will investigate macroeconomics effects of unconventional monetary policies of ECB by using vector autoregression approach to a panel of CEE countries.

Hypotheses

Hypothesis 1: The ECB's OMT programme announcements had no effect on sovereign bond yields in Central and Eastern Europe.

Hypothesis 2: The increase in central bank balance sheets at the zero lower bound causes rise in economic activity.

Hypothesis 3: The increase in central bank balance sheets at the zero lower bound causes rise in the price level.

Methodology The first step is to choose a panel of countries. As I mentioned above, this thesis aims to measure impact of the unconventional monetary policy on CEE countries. The economies included in further analysis will be Estonia, Latvia, Lithuania, Poland, Germany, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Slovenia and Croatia. The estimation will take place in two stages.

In the first part of this thesis I will apply event study methodology used by Swanson (2011) and Rivolta (2014). For this purpose I will use daily data on bond yields of selected states. According to Swanson (2011), studying the one or two-day change in sovereign bond yields around the major announcement should be sufficient to provide an unbiased estimate of the effect. I will regress the changes in sovereign bond yields on event dummies and on all other news that could influence bond yields. I consider 2-day event window for OMT announcements, which means that the event dummy has value of 1 in the day of the announcement and the day after and zero otherwise. Then I will test the first hypothesis using two-sided t-test, which means that the null hypothesis is rejected when the value of the test statistics is sufficiently small or sufficiently large.

In the second part of this thesis the evaluation of the macroeconomic effects of unconventional monetary policies will be made by estimating panel VAR model. In this section I will use monthly data over the sample period when central

bank balance sheets operations became the main policy instrument in many countries. I will use a mean group estimator which allows for cross-country heterogeneity and helps to avoid serial correlation. The vector of endogenous variables in the VAR model will include interest rate, inflation, unemployment and central bank assets, where central bank assets represent the unconventional monetary policy instrument. Then by using impulse responses analysis I will try to verify second and third hypothesis.

Expected Contribution Because topic of this thesis is relatively new, there is not much literature dealing with it. Existing literature in the field focuses mainly on the impact of unconventional monetary policy measures on the Western European countries. According to my current knowledge, there has not been published any paper that would study impacts of OMT announcements and other unconventional monetary policy measures on economies of CEE countries. Therefore I will provide an insight into this field. I will provide detailed analysis of the announcements of the ECB's OMT programme as well as analysis of macroeconomic effects of unconventional monetary policies on CEE countries.

Outline

1. Introduction – introduction of the topic, description of the motivation, presentation of the structure of the thesis
2. Literature review – short review of past literature examining impact of OMT announcements and other unconventional monetary policies
3. Data – description of dataset, motivation for using selected variables, data sources
4. Methodology – description of event study approach and structural VAR approach used in further analysis, estimation methods and tests used
5. Results – presentation of results
6. Conclusion – summary of results, discussion about their contribution, motivation for possible future extension of research

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Acronyms

ADF	Augmented Dickey-Fuller
AIC	Akaike's Information Criterion
BoE	Bank of England
BoJ	Bank of Japan
CADF	Cross-sectional Augmented Dickey-Fuller
CB	Central Bank
CBPP	Covered Bonds Purchase Programme
CEE	Central and Eastern European
CPI	Consumer Price Index
EAAP	Expanded Asset Purchase Programme
ECB	European Central Bank
EME	Emerging Market Economies
EU	European Union
FED	Federal Reserve System
FX	Foreign Exchange market
GDP	Gross Domestic Product
GMM	Generalized Method of Moments
HQ	Hannan-Quinn Criterion
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
LTRO	Long Term Refinancing Operation
MCI	Monetary Condition Index
MRO	Main Refinancing Operation
OLS	Ordinary Least Squares
OMT	Outright Monetary Transaction

REER	Real Effective Exchange Rate
RHS	Right Hand Side
SBIC	Schwarz-Bayesian Information Criterion
SMP	Securities Markets Programme
SRTSM	Shadow-Rate Term Structure Model
USA	The United States of America
U.S.	The United States of America
UK	The United Kingdom
UMP	Unconventional Monetary Policy
VAR	Vector Autoregression
VIX	Chicago Board Options Exchange Market Volatility Index
VSTOXX	EURO STOXX 50 Index

Chapter 1

Introduction

Many central banks in advanced economies have been responding to the recent and still prevailing global financial crisis by conducting series of unconventional monetary policy measures. The need to adopt such measures is caused by the occurrence of the following main problems: short-term nominal interest rates have been lowered closer and closer to zero, persistent deflationary pressures exist, and economies do not show signs of recovery. This situation occurred in recent years throughout the world. Many financial authorities were forced to cut their policy rates to historically low levels, near to zero lower bound, and thus expansion of central bank balance sheets replaced interest rates as the key monetary policy instrument. The forms of non-standard measures used by individual central banks in advanced economies significantly differ. There are many reasons why different monetary authorities use different unconventional tools. The main reasons for this dissimilarity could be unique structure of the financial sector in the given region, different competencies of central banks, and also different timing of the crisis. For these and other reasons, the monetary policy in the euro area is quite restrained in comparison with other advanced economies.

The interest of examining the impact of unconventional monetary policies increased in recent years. The impact of unconventional monetary policies on financial markets has been intensively investigated in many papers. These studies are focused on the impact on money markets, swap markets, as well as on long term interest rates and other asset prices. However, only few papers focused on the macroeconomic effects of unconventional policies (e.g. Gambacorta, Hofmann and Peersman (2012), Peersman (2011), Schenkelberg and

Watzka (2011), Meinusch and Tillmann (2014)). These studies investigate mainly the effect of such policies in advanced economies, such as U.S., Japan, or Eurozone. They introduce econometric approaches for analyzing the macroeconomic impact of non-standard policies when the interest rates are near the zero lower bound and thus standard models used for studying the effectiveness of the monetary policy in pre-crisis period are no longer suitable. Majority of the papers use structural vector autoregressive models or some other types of vector autoregression (Block-restricted VAR, Qual VAR) with central bank assets or monetary base as a proxy for unconventional monetary policy instead of short-term interest rate. Few studies deal with cross-border impact of unconventional monetary policies conducted by central banks in advanced economies on emerging markets.

We want to shed light on the macroeconomic impact of non-standard monetary policy implemented by European Central Bank (ECB) during the crisis on central and eastern European countries in this work. This region is highly influenced by euro area policy mainly due to increasing globalization. All these countries have close trade relations with EU; they can be mostly characterized as small open economies with many banks dominated by euro parent banks. According to all these close economic links it seems to be obvious that euro area shocks are transmitted to this region.

We use panel vector autoregression approach to examine interactions between non-standard monetary policy of ECB and economic activity of Central and Eastern European (CEE) countries. We estimate panel vector autoregressive model with monthly data over a sample period 2008-2014, when the unconventional monetary policy tools became to be used in Eurozone. We are motivated to use this methodology by the paper written by Gambacorta, Hofmann and Peersman (2012). The authors used in this paper similar approach to investigate the impact of policies on many advanced economies. Unlike them we use fixed effect estimator with Helmert procedure proposed in paper written by Love and Zicchino (2006) instead of mean group estimator. We discuss these issues in more detailed way in the Section 3.1. In addition to our panel VAR estimates, we propose also individual country estimates.¹

¹Even though we planned to carry out event study analysis to examine the effects of the announcements of the ECB's Outright Monetary Transactions programme in 2012 on government sovereign bond yields, we focused largely on examining the effects of ECB unconventional monetary policy tools using panel VAR.

Wu and Xia (2014) proposed an alternative gauge for unconventional monetary policy to already existing measures such as central bank assets and monetary base. They estimated shadow policy rates for U.S. and Eurozone, which are virtually the same as the policy rates, when the policy rates were not at zero lower bound, but, their estimates of shadow rate could be negative, when the interest rates are close to zero. We use this measure in our benchmark model in this thesis. CEE countries included in our panel are Bulgaria, Czech Republic, Germany, Estonia, Croatia, Latvia, Lithuania, Hungary, Austria, Poland, Romania, Slovenia, and Slovakia.

Our aim is to provide evidence that there exists positive relationship between expansionary unconventional monetary policy shocks and outputs and prices levels in CEE region. We formulate two hypotheses that we are trying to support in Section 2.3. We will endeavor to verify our hypotheses by using impulse responses and variance decompositions.

The thesis is structured as follows. Section 2 describes monetary policy in Eurozone during normal times as well as unconventional monetary policy applied in recent period. We discuss also the differences in approaches to non-standard monetary policy tools between Federal Reserve, Bank of England and European Central Bank. This section concludes with the description how financial crisis affected the countries in CEE region and why the Eurozone monetary shocks could influence their economies. Section 3 forms the fundamental part of our thesis. We discuss the used methodology, apply the VAR and panel VAR approaches to our data and provide impulse response functions and variance decompositions in order to describe our results. Section 4 concludes with discussion of our results and some recommendations for future research.

Chapter 2

Background

2.1 Monetary Policy and Crisis in Europe

2.1.1 Monetary Policy of ECB

In this thesis we focus on the impact of the ECB's monetary policy decisions during crisis, thus let us first explain how the monetary policy of Eurosystem works.

The primary objective of ECB according to the Maastricht Treaty is to maintain price stability. More specifically, the main objective of ECB is to keep inflation below, but close to, 2% in the euro area over the medium term. The monetary policy of ECB is based on two pillars. First pillar is based on economic analysis and the second pillar is based on monetary analysis. The evaluation of price stability starts with economic analysis which first identifies short to medium-term risks to price stability and then continues with monetary analysis to assess medium to long-term trends in inflation. Then the governing council takes monetary policy decision based on the collected information obtained during these two analyses.(Břízová, 2014)

Now we focus more on how the central bank of the Eurosystem can conduct its monetary decisions. The main monetary policy instruments of ECB are policy rates, open market operations and minimum reserve requirements. The policy rates should signal the general monetary stance. The main tools used by ECB to pass its policy decisions to the market are: the main refinancing rate, the deposit rate, and the marginal lending rate. The main refinancing rate is equivalent to the U.S. federal funds rate. It determines the rate at which banks can

borrow money from ECB. The Eurosystem refinancing rate influences market interest rates. The marginal lending rate acts as the last resort for companies which are not able to obtain funding on the market. However, firms have to pay higher interest rate to ECB than what is available at interbank market. The deposit rate is paid by ECB for money deposited overnight by euro area banks. Banks use this rate when there is excess of liquidity in the market.(Forexfraud, 2014)

ECB regular open market operations are conducted through Main Refinancing Operation (MRO) and Long Term Refinancing Operation (LTRO). The MROs are one-week liquidity providing operations in euro, carried out through auctions where banks offer their rates and banks offering the higher rates receive funds. The LTROs are three-month liquidity providing operations in euro and it provides additional refinancing to the financial sector. However, the nature and also the duration of these operations were changed during crisis.

The last mentioned monetary policy instrument of ECB is reserve requirement. This instrument sets the minimum fraction of customer deposits and notes that each depository institution must hold it as the reserve. ECB can reduce the minimum reserve ratio in order to avoid liquidity shortages on interbank market. The European Central Bank reduced the minimum reserve ratio during recent financial crisis.

The ECB's monetary strategy also includes communication policy. ECB communicates to the public on various issues, such as explaining its monetary policy decisions, describing how their objectives have been fulfilled, and providing economic forecasts. The central bank communication has become more relevant element of monetary policy during crisis, due to risk of the loss of central bank credibility and reputation.

2.1.2 Unconventional Monetary Policy and ECB

At the onset of the financial crisis, after the collapse of the Lehman Brothers, many economies were encountered with the fall in economic activity and the decline of inflation rates. Also the policy interest rates were reduced to historically low levels. The interbank market did not work properly, due to uncertainty about creditworthiness of other banks.(Haan, Oosterloo and Schoen-

maker, 2012) With the nominal interest rate reaching zero lower bound, any shock that lowers inflation expectation will raise the real interest rate and thus the risk of deflationary spiral arises. The solution of this problem, when zero lower bound is binding, is to reduce the long term interest rates and thus to increase inflation expectations. The main European policy rate - interest rate on the main refinancing operations had been lowered below 1% in May 2009. Also the interbank market in the Eurozone was hit by mutual distrust and thus was inoperative. In these times the unconventional measures became necessary to provide liquidity and to repair the bank-lending channel.

We can divide the crisis into two phases and accordingly we can also divide the sorts of the unconventional monetary policies.

Before the fall of Lehman Brothers, the new facilities of the monetary policy were introduced mainly because of the monetary policy transmission mechanism disruptions. In the first phase of crisis, it was sufficient for the euro area to provide 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 out highly liquid securities, establishing FX swaps with other central banks, and also narrowing corridors around the main policy rate. ECB also intensified its communication policy.

More non-standard measures were introduced in the second phase. The measures included in this phase are namely: purchase of government bonds, purchase of covered bonds or other private assets, forward guidance and FX interventions.

The main reason for using unconventional tools after the bankruptcy of Lehman Brother was reaching zero lower bound on nominal interest rates. The measures used before the collapse were no longer sufficient. The European Central Bank started to use unconventional policy measures to provide extra liquidity in October 2008. ECB started to provide supplementary liquidity to the financial sector even since August 2007, but that was not considered as completely non-standard. First supplementary liquidity measure used by ECB was the announcement of longer-term refinancing operations (three years loan at very

favorable rates) followed by another 3-month LTROs in September 2007 and in February 2008. The next announcement was first 6-months LTRO in March 2008. The first use of the unconventional monetary policy measure by ECB is dated in October 2008, when ECB modified the structure of standard LTRO for a fixed-rate tender procedure with full-allotment. Further used Unconventional Monetary Policy (UMP) tools were three LTROs with 12 months maturity at quarterly frequency and fixed-rate tender procedure with full-allotment (Enhanced Credit Support Programme) in May 2009 and announcement of Covered Bonds Purchase Programme (CBPP) - direct purchase of euro-denominated covered bonds.

ECB introduced more unconventional measures with the Securities Markets Programme (SMP) in May 2010, the announcement of the next 6-months LTRO, and with swap lines with Federal Reserve System (FED). In the second half of the year 2011 there were also another announcements of the SMP, CBPP and numerous 12-, 13- and 36-months LTROs. In August 2012 ECB also announced the Outright Monetary Transaction (OMT) programme. This programme was introduced in order to purchase unlimited amounts of the government bonds of the Euro-area countries with maturity 1-3 years, in other words it was a short-term sovereign bond purchase. This programme was aimed at the countries that are subject to the European Stability Mechanism Programme. Maturity date of quantitative limit were not specified, and this measure was not carried out yet, but even its announcement had significant effect on government bond yields.(Rivolta, 2014)

Due to very low inflation in Eurozone, European Central Bank was forced to launch an Expanded Asset Purchase Programme (EAAP) in January 2015, that encompasses monthly purchases of euro-denominated, investment-grade securities of 60 billion euro (together with existing purchase programmes) on the secondary markets. ECB would like to purchase private and public securities until September 2016 or, until the sustained adjustment in the path of inflation towards the 2% level is observed.(Delivorias, 2015) ECB believes that the quantitative easing programme will revive the euro area economy and hence raise inflation, bringing it back to desired 2% level.

The European Central Bank is often criticized that it exceeds its mandate by buying public debts at secondary market while using unconventional mon-

etary policy instruments and that it could increase inflation expectations and lower the ECB's credibility. Nevertheless these issues did not find support by Schenkelberg and Watzka (2011) and Moessner (2014) in their studies. Another argument could be that SMP was only temporary and that it was implemented with the aim to improve the transmission of the monetary policy. (Szczerbowicz, 2014) Other critics argue that the governments incentives to carry out reforms were weakened by this programme and that they could be tempted to moral hazard.

2.1.3 Comparison of Unconventional Monetary Policy of ECB, FED and Bank of England

The unconventional monetary policy of ECB was focused principally to ensure the liquidity to the banking system, because banks are the main source of credit in the euro area. On the other hand, the Federal Reserve was oriented on non-bank credit markets and on operations involving private sector securities, because the United States are market-based system (almost 75% of the sources of finance for corporations are from non-banking institutions). Bank of England (BoE) adopted mainly purchases of government bonds. (Borio and Disyatat, 2009)

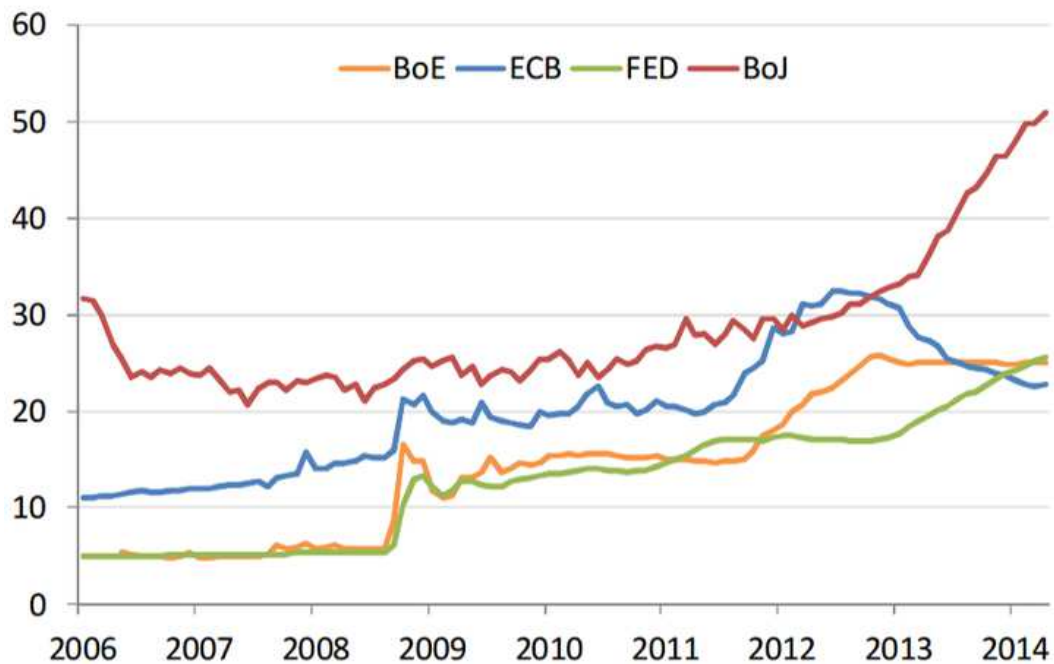
There are many differences between ECB and the other two major central banks, FED and Bank of England. First of all, FED and Bank of England faced different types of crisis. They were confronted with subprime banking crisis and ECB faced sovereign debt crisis. The subprime crisis in the USA erupted with real estate crisis in 2007. There was increasing number of default rates on subprime mortgages due to decrease in housing prices and increase in interest rates. This was followed by the threat of bankruptcy of many banks and implementation of various rescue plans by countries governments. Eurozone sovereign debt crisis started in 2008 with collapse of Iceland's banking system. It was the period when the crisis moved into real economy and also into public budgets of almost all European countries. European countries faced high government structural deficits, increasing debt levels and rising bond yield spreads in government securities.

The second huge difference was that the crisis arrived to Eurozone later, therefore ECB had to deal with the crisis a little bit later than the other two central

banks. The nuisance of ECB is that it does not have single fiscal policy, meaning that ECB has to deal with a lot of different treasury bonds and bill markets. Moreover, ECB has narrower objectives than FED and Bank of England. ECB has only one primary objective – price stability, in contrast to dual mandate – price stability and employment of FED. These objectives limit ECB to use unconventional tools as quantitative easing in such volume.(Dehesa, 2012)

In comparison with other central banks in the world, the non-standard policy of ECB was quite restrained. FED and Bank of England were more radical in quantitative easing, or in other words large-scale asset-purchases programmes, in particular due to their volumes. As a consequence of the large-scale asset-purchases conducted by all major central banks during the crisis there was a major expansion of central bank balance sheets as well as change in their composition. The balance sheet of FED and Bank of England increased three times whereas the balance sheet of ECB became twice as large in 2008-2009 (Figure 2.1). We can clearly see that ECB provided much less liquidity to financial systems than FED or BoE did.

Figure 2.1: Size of balance sheets, in % of GDP



Source: Claeys (2014).

When we look at the main policy rates of the major central banks, we can notice that they significantly varied (Figure 2.2). Because the crisis started in the United States, FED had to react first with lowering the federal funds rate towards zero lower bound. BoE and ECB reacted later. However, ECB lowered its policy rate only around 1% level and in 2011 we can see a slight increase in the rate. This difference could be explained again by distinct mandates of ECB and FED with BoE, because ECB has to give priority to price stability. (Žáček, 2014)

Figure 2.2: Policy rates of FED, ECB and BoE



Source: Author.

Notes: We use data from Federal Reserve Economic Data, BoE and Eurostat.

The central banks have two options how to help economy in recession. As Mody (2014b) said in his article, they can actively stimulate the economy by reducing its main interest rates or, they can passively promote lending. The first option also supports decline in the long term interest rates followed by increase in investment. However, when the interest rate reaches zero lower bound, central banks cannot lower them below zero. They could use quantitative easing to lower the long-term interest rates. The latter method is based on providing funds to banks to allow them to be able to lend more. The stumbling block to the second option is that there is no guarantee that banks will use their funds for new lending. (Mody, 2014b)

During the recent crisis, ECB provided less active stimulus in contrast to the other central banks. The reduction of interest rates was slower than in BoE and FED and as the only central bank during crisis ECB has increased its policy rates in 2011. The purchase of assets to influence long-term rates was not conducted at all by ECB till 2015, even when many economists think that it helped the United States and other countries such as Japan and UK that used it. However, as we already mentioned, ECB has limited mandate to promote quantitative easing and also there are arguments that quantitative easing

could reduce the incentives for government to stop spending and to do more for boosting their economies.(Randow, 2015)

2.2 The Central and Eastern European Countries

The global financial crisis strongly affected the countries in Central and Eastern Europe. In this section we focus on development of key macroeconomic indicators during the period of financial crisis. Figures A.1-A.6 show the evolution of macroeconomic variables, volatility indicators and exchange rates in all countries involved in our investigation. From the graphs we can clearly see that the impact of crisis differs across countries. There are variety of explanations for these differences across CEE countries. The state of the economies prior to the crisis seems to be important in subsequent magnitude of affection. Countries that had grown strongly before crisis at unsustainable levels and had exhibited signs of overheating were more affected. Also openness of the economy and the exchange rate regime could have played important role.

Figure A.1 reveals that all countries recorded significant decline in Gross Domestic Product (GDP) growth from September 2008. Only Poland had positive GDP growth during 2008-2009. On the other hand, Baltic States and Bulgaria exhibit the sharpest decline in GDP growth. It could have been caused by their strong and unsustainable growth in the period prior crisis. In most of the CEE countries, the decline in GDP growth slowed down in first half of 2010. Some countries such as Czech Republic, Estonia and Lithuania even started to grow. Otherwise countries such as Croatia continued in decline.

As we can see from Figure A.1 and Figure A.2, there is some correlation between the decline in economic activity and decline in CPI. The largest decline we notice in Baltic States and Bulgaria, mainly in countries with high inflation rate prior crisis. Inflation started to rise in most countries since September 2012, but in the third quarter of 2013 there was again significant decline in inflation rate in Romania, Latvia and Hungary. At the end of the 2014 there were still some countries including Croatia, Estonia and Germany, which displayed negative inflation rates.

Figure A.3 reveals huge differences in exchange rates development across CEE countries. Some countries, especially Poland, Hungary and Czech Republic,

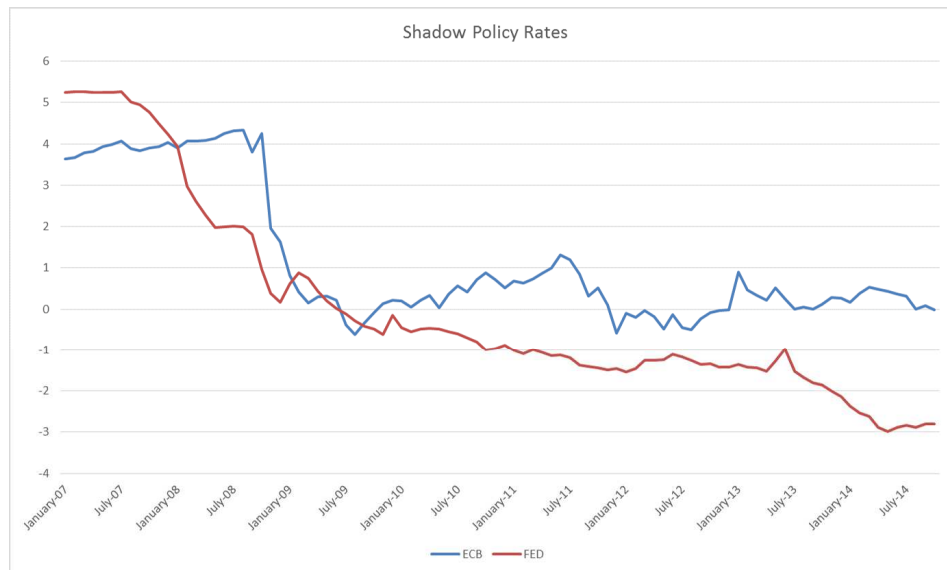
recorded sharp depreciation of their currencies at the end of the 2008 and beginning of 2009. Otherwise, countries led by Bulgaria, Latvia and Lithuania strengthened their exchange rates. This can be explained by different exchange rate regimes. Generally, countries with fixed exchange regimes were more affected by decline in export. The development of exchange rates continued by weakening of almost all CEE currencies in the middle of 2010. Another depreciation we could observe in Poland, Hungary, Croatia and Germany at the end of 2011. At the end of 2013 Czech Republic weakened its currency.

Figures A.4 and A.5 show evolution of implied volatility index and shadow policy rate. The development of European implied volatility index VSTOXX reveals three periods of large volatility and uncertainty. In the fourth quarter of 2008 and first half of 2009 the values of the index were high above 30, which shows the onset of the financial crisis. Second spike we observe in the third quarter of 2010, when European leaders failed to resolve the Greek debt crisis. The last significant rise in volatility was recorded in the second half of 2011, when the European sovereign debt crisis started.

The last Figure A.6 displays total ECB's assets. The development of central bank assets reveals a strong growth within whole considered period, which reflects that unconventional monetary policy measures to provide liquidity to financial system were conducted. We can see from the figure that the size of the balance sheet of the European central bank more than doubled between the years 2008 and 2014.

In May 2009, the shadow policy rate turned negative reflecting the use of unconventional monetary policy measures by ECB, adopting 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 -0.58% in December 2011. Then the shadow rate turned back to around zero.

Figure 2.3: Shadow policy rates of FED and ECB



Source: Author.

Notes: We use data from Wu and Xia (2014).

When we compare estimated shadow rates for ECB and for FED, we can see significant difference between them (Figure 2.3). The quantitative easing conducted by FED in early 2009 was successive in lowering shadow rate below zero. The U.S. shadow rate remains deeply negative till 2014 because of weak economy. On the other hand, ECB's shadow rate became negative only for two short periods and much less deeply than the rate of FED. This indicates that the unconventional monetary policy in euro area was less effective and did not have so supportive effect. In combination with low inflation in some countries in the euro area it could be real problem, because low inflation rate causes higher real shadow rate. The main reason for these differences should be different unconventional measures applied by ECB and FED and also different timing. (Mody, 2014a)

We can see from the development graphs that financial crisis affected CEE countries as well as other EU countries. All countries in the region suffered from decline in GDP growth and low inflation. The problem with low inflation rates still persists. However, at the second half of 2014, there were numerous countries from CEE region such as Poland, Czech Republic, Slovakia, Romania and Hungary, that exhibited impressive growth. We also conclude that unconventional monetary policy of ECB was hesitant and less supportive than in U.S..

2.2.1 The Effect of the Unconventional Monetary Policy Implemented by ECB

The unconventional monetary policy applied by ECB could have significant effect on CEE countries. Many of them could benefit directly from ECB's policies, such as Poland and Hungary - that agreed repurchase transactions to provide support to central bank for the purpose of euro liquidity provision. (Botezatu and Diaconescu, 2014) Also many banks from CEE region are dominated by euro parent banks which could benefit from ECB's policies. This region is very closely connected to the euro area and the trade with euro area is really important for all the countries, so the impact of the unconventional monetary policies may be reflected also by this channel. (Asmussen, 2013)

There are many studies that support the claim about transmission of monetary shocks from ECB to other European countries. For example, Wierzbrowska (2015) applies VAR methodology to analyze the effect of ECB's monetary policy shocks and euro area output and inflation shocks on the EU member states from CEE region. She finds out that domestic interest rates of CEE countries are highly dependent on changes in the main ECB's policy rate.

Jiménez-Rodríguez, Morales-Zumaquero and Egert (2010) investigate in their paper the impact of international shocks on macroeconomic developments in selected CEE countries also using VAR model. They find out that the response of industrial production to a positive interest rate shock from euro area is negative in almost all countries, but with very small magnitude. Also reduction in price levels occurs in almost all countries.

Mohanty (2014) finds evidence that the interest rates are highly correlated

globally. He also states that Emerging Market Economies (EME) may follow advanced economies in lowering rates, because appreciation of their currencies could have negative effect on output that is immediate, in contrary to the lagged positive trade effect. Also historical data illustrate that EME countries take this approach. All countries move their policy rates closely with the federal funds rate and surprisingly, in countries with floating exchange rates we can also observe this tendency.

2.3 Hypotheses

We want to shed light on following issues in this paper. We try to uncover if there is any significant relationship between unconventional monetary policy of ECB and overall economic activity of CEE countries and hence decide if the unconventional monetary policy measures implemented by ECB are supportive for economies in Central and Eastern Europe.

We want to focus on the following two questions: Does decrease in shadow policy rate cause higher output? Does decrease in shadow policy rate contribute to higher inflation? We study whether the unconventional monetary policy is effective by estimating the effects of exogenous shocks to shadow policy rate of ECB, conditioning on the overall macroeconomic situation, financial turmoil measured by implied volatility index and exchange rate movements. We focus on the verification of the following two hypotheses in this thesis.

Hypothesis 1: The decrease in the shadow policy rate at the zero lower bound causes rise in economic activity.

Motivation: The traditional expansive monetary policy is used to increase economic growth. We want to find out whether the unconventional measures implemented during crisis had similar effects.

Hypothesis 2: The decrease in the shadow policy rate sheets at the zero lower bound causes rise in the price level.

Motivation: The conventional expansive monetary policy generally increases inflation. We think that the unconventional monetary policy might have the same stabilizing effect.

We want to analyze these relations, their magnitude and persistence, using panel vector autoregression approach, mainly by looking at impulse responses functions and the forecast variance decompositions.

2.4 Related Literature

We provide a brief review of literature dealing with unconventional monetary policy of central banks which we use in our thesis. First we discuss the literature engaged in macroeconomic effect of unconventional monetary policy and then we analyze the literature describing various panel VAR model techniques.

The main inventive study about effectiveness of unconventional monetary policy at zero lower bound was written by Gambacorta, Hofmann and Peersman (2012). They estimated a structural panel VAR with monthly data from eight economies over the period since the beginning of the global financial crisis. They used central bank assets as a measure of unconventional monetary policy. They included 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. We decided to use similar variables in our thesis, however in the benchmark model we use rather shadow policy rate. We use central bank assets only for robustness check. They used mean group estimator to take into account potential cross-country heterogeneity in macroeconomic dynamics as well as monetary transmission mechanism. They examined that increase in central bank assets leads to temporary rise in economic activity as well as temporary rise in the price level. Secondly they found out that the estimated output effects were qualitatively similar to the effects of conventional monetary policy, but the impact on the price level was lower and less persistent. Thirdly their individual country results pointed out that there are no huge differences in the effects of unconventional policies across countries.

Peersman (2011) investigated whether the transmission mechanism of the unconventional monetary policy innovations is different compared to traditional interest rate in the euro area. The methodology used in his work was also structural VAR model. He found out that the effect on economic activity and prices reaches a peak after about one year for an interest rate shock, however only about six months for a shift in monetary base. The other finding presented

in his work is that the interest rate spreads charged by banks decline after a rise in the balance sheet of the Eurosystem, but they increase after a fall in the policy rate. The last finding was that there is no evidence of short-run liquidity effect after interest rate innovation, however, the credit multiplier declines after the balance sheet shock. He stated that the pass-through of the expansion of central bank balance sheet is more sluggish compared to standard interest rate innovation.

Schenkelberg and Watzka (2011) also used structural VAR approach to study real effects of quantitative easing when zero lower bound was binding the economy. They use Japanese data from the year 1995. They estimated various VAR models and they included following variables in the benchmark VAR: Consumer price index, Japanese industrial production index, reserves and the 10-year yield of Japanese government bonds. They also estimated additional specification where the model contains also the real effective exchange rate of the Yen against other currencies. We use similar specification in our work, but with single countries real effective exchange rates. They found out that quantitative easing shock temporarily rises the output and that the effect on inflation is not significant. These are similar findings to which Gambacorta, Hofmann and Peersman (2012) came as mentioned above. Schenkelberg and Watzka (2011) proposed that Japanese quantitative easing was successful in stimulating the economic activity at zero lower bound in the short run and that it also did not lead to increase in inflation.

Meinusch and Tillmann (2014) studied the macroeconomic effects of the Federal Reserve's unconventional monetary policies. They used Qual VAR model - a multivariate dynamic probit model, to combine binary information about unconventional monetary policy announcements with standard monetary policy VAR. They plotted impulse responses to quantitative easing shocks. The findings obtained in this paper are that quantitative easing shocks have large impact on real and nominal interest rates as well as on financial conditions. On the other hand, they found an evidence that the quantitative easing shocks have smaller impact on real activity.

Another paper dealing with the impact of the unconventional monetary policies focuses on the effects of the ECB's balance sheet policy announcements on the inflation expectations. Moessner (2014) investigated the effect of the ECB's

balance sheet policy announcements on the ECB's monetary policy credibility. He found out that there is no evidence to assume that the ECB's balance sheet policy announcements bring higher long-term inflation expectations, thus the ECB's monetary policy credibility is not harmed.

Mohanty (2014) wanted to reveal answers on variety questions regarding to the effect of unconventional monetary policies in advanced economies to emerging market economies. He investigated whether and how do external monetary conditions influence the economies and also if they become a source of risk for monetary and financial stability in EMEs. He also focused on the response of national central banks to these shocks and on the increasing international role of emerging market currencies. He stated that interest rates and asset prices become increasingly globally correlated in recent years and thus the EMEs have been heavily influenced by interest rates in advanced economies. The second point of his research has more difficult answer. The policymakers cannot respond to international spillovers without involving tradeoffs. They can let the exchange rate to appreciate after lowering the foreign interest rates, but appreciation carries risks. Looking at the last part of his investigation, he found out that the emerging market currencies may become more traded in the global markets in the future, but only a few have the potential to become major international currencies.

Babecká-Kucharčuková, Claeys and Vašíček (2014) tried to assess the impact of ECB's monetary policy on macroeconomic developments in euro area as well as in six non-euro area EU countries. They constructed Monetary Condition Index (MCI) that can be decomposed into conventional and unconventional monetary policy measures. They estimated block-restricted VAR model with the MCI components from conventional and unconventional monetary policy to study if the effect of conventional and unconventional tools differs. Their estimated reaction of euro area economic activity is in contrast to other studies. Their results suggest that the reaction of industrial production to shock to unconventional monetary policy is weaker and less significant than the reaction to conventional policy. Moreover, they suggest that the response of prices to unconventional monetary policy is much quicker.

For the individual non-euro area countries Babecká-Kucharčuková, Claeys and Vašíček (2014) found out that the response of output and prices to the two MCI

components significantly differs. The reaction of output to ECB's non-standard monetary policy could be found only for some countries, however, the reaction of prices was completely insignificant. They also figured out that exchange rates reacted quickly with peak within a few months and that the exchange rates depreciates after monetary tightening in majority of countries.

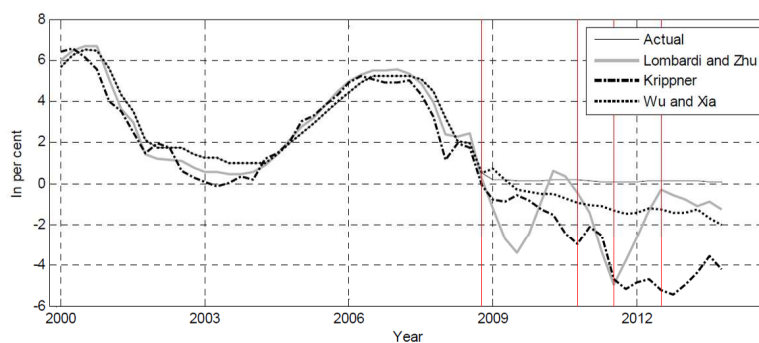
Wu and Xia (2014) wanted to investigate how to measure the macroeconomic impact of monetary policy at the zero lower bound. They introduced an approximation that makes a nonlinear term structure model (SRTSM) tractable for an analysis of an economy stuck at zero lower bound for interest rates. They used for their research shadow rate for United States derived from the SRTSM model to construct a new measure for the monetary policy when the federal fund's rate is close to zero. They proposed policy rate series that can be used in a VAR models instead of federal funds rate. Wu has also available data of shadow rate for European Central Bank at her website, so we apply this measure in our thesis according to their pattern. They used this measure to investigate the unconventional monetary policy's impact on the real economy. Their estimated results suggest that the actions used by FED to stimulate the economy on the onset of the financial crisis succeeded in lowering the unemployment rate.

Lombardi and Zhu (2014) also proposed a new shadow policy rate for the United States in their paper. They showed that their shadow rate can be used in structural VAR models and that it helps to identify monetary policy shocks. Their shadow policy rate is a little bit different from the one introduced by Wu and Xia, but the pattern is similar. Another framework for measuring shadow market rate was invented by Krippner (2013) for the United States. His estimate of shadow rate is significantly different from the one constructed by Wu and Xia in the period when the zero lower bound was binding. We decided to use Wu and Xia's measure because their approximation does not contain any simulation error - it is discrete-time formula directly applied to the one-month ahead forward rate. You can see the comparison of the estimations of shadow rates below (Figure 2.4).

Figure 2.4: Estimates of shadow federal funds rate

Alternative estimates of the shadow federal funds rate¹

In per cent



¹ The red vertical lines correspond to the dates of introduction of the major asset purchase programmes implemented by the Federal Reserve: LSAP1 (November 2008), LSAP2 (November 2010), MEP (September 2011) and LSAP3 (September 2012).

Sources: Federal Reserve, Krippner (2013a), Wu and Xia (2014), authors' calculations.

Source: Lombardi and Zhu (2014)

Babecká-Kucharčuková, Claeys and Vašíček (2014) followed studies of Lombardi and Zhu (2014) and Wu and Xia (2014). They used similar approach in their paper about spillover effect of ECB's monetary policy outside the euro area. They used factor analysis to construct a synthetic measure of the monetary conditions for the euro area. This index is based on interest rates, spreads, monetary aggregates, selected ECB's balance sheet items and the exchange rate. This index is similar to a shadow rate, and is composed of factors that allow to distinguish between conventional and unconventional policy measures. They can thus study the differences in transmission between conventional and unconventional monetary policies.

There is a wide range of possible approaches how to investigate the macroeconomic effects of the unconventional monetary policies in existing literature. To sum it up, the mostly used access is to construct panel VAR model, with monthly data and the size of the balance sheet of the central bank as a measure for unconventional monetary policy. There is also a competitive approach how to measure unconventional monetary policy that uses shadow policy rate proposed by Wu and Xia. Majority of studies focus on the unconventional monetary policy used by FED after the collapse of Lehman Brothers. The findings of mentioned authors more or less coincide. The most prevailing conclusions are that the actions used by FED to stimulate the economy lead to temporary rise in economic activity and that the effect on inflation is not significant. In

this thesis we want to investigate whether the effect of the ECB's unconventional monetary policy to CEE countries was similar in nature.

Now we briefly introduce crucial studies dealing with the panel VAR methodology. Rebucci (2010) dealt with the estimating VAR models with long stationary heterogeneous panels. He compared the fixed effect and the mean group estimators. He concluded that the mean group estimator can be used only if the panel is sufficiently long. He recommended to use both the fixed effect and mean group estimators for research analysis and then compare the estimates. If the estimates are close, fixed effect estimator should be more reliable, because it is more efficient due to smaller standard errors. However, if they differ and we have sufficiently long panel, we should use the mean group estimator.

Love and Zicchino (2006) examined the financial development and dynamic investment behavior using panel VAR approach. They used impulse response functions to be able to separate the fundamental factors from all the financial factors that influence the investments. They combined VAR approach with panel-data approach and created an estimation routine for STATA, which we use in this thesis as well. They used forward mean differencing, the Helmert procedure, to take away the fixed effects and then estimate the model using the generalized method of moments. They also used Cholesky decomposition to attain orthogonalized residuals, which is equivalent to transforming the reduced form of VAR to recursive form for identification purposes. Boubtane, Coulibaly and Rault (2013) and Babecký et al. (2011) also used this estimation procedure in their studies.

The already mentioned study written by Gambacorta, Hofmann and Peersman (2012) represented second candidate for estimation panel vector autoregressive models – the mean group estimator. The mean group estimator first estimates a group-specific regression and then averages the estimated coefficients across groups. The mean group estimator takes into account potential cross-country heterogeneity and does not require the coefficients on the endogenous variables to be the same across countries.

Assenmacher-Wesche and Gerlach (2008) also used panel VAR approach in their paper. Their study about the responses of residential property and equity prices, inflation and economic activity to monetary shocks applied panel VAR

approach as well as individual-country VARs. We also want to investigate panel VAR and VAR models for individual economies in this thesis. They followed the approach of Iacoviello (2002) to estimate VAR models for individual countries and mean group estimator for estimation of panel VAR.

The last study introduced in this section was written by Goodhart and Hofmann (2008). They analyzed linkages between money, credit, house prices and economic activity in industrialized countries also by applying panel VAR approach. They used standard fixed effect panel estimator for estimating their panel VAR. However, these estimator could be biased in dynamic panels with small time dimension, so we want to avoid the use of standard fixed effect estimator in our thesis and overcome this issue by using Love and Zicchino (2006)'s estimation procedure.

Chapter 3

Macroeconomic Effects of Unconventional Monetary Policy

In this section we want to shed light on macroeconomic effects of unconventional monetary policy of ECB. There are likely some interdependences across countries in our panel and we have to deal with it adequately. Two prevailing methods how to take into account these international linkages can be found in existing literature. First method uses multi-country dynamic stochastic general equilibrium model and the second one uses the panel VAR model.(Canova and Ciccarelli, 2013) We decided to use the panel VAR technique because it is widely used as a tool to study the macroeconomic effect of monetary policy shocks. This approach helps us to uncover the dynamic effect of unconventional monetary policy innovations.

We employ a panel structural vector autoregressive model using monthly data over the 2008 to 2014 period, because during this period the ECB's target rate has been very close to zero and the unconventional monetary policy tools instead of standard conventional ones have been applied. We include all Central and Eastern European countries for which we are able to find appropriate data. Our panel VAR model contains four macroeconomic variables that are likely to be affected by monetary policy shocks. We estimate several models to be able to assess the stability of results. Our first panel VAR model includes real GDP, consumer price index, shadow policy rate and implied stock market volatility of the national stock market index. In the second panel VAR model we add the real effective exchange rate of the countries' currencies against other currencies. In the third model we switch the order of our variables so as to verify whether

it was correctly determined according to Cholesky decomposition. In the last panel VAR model we use central bank assets as a gauge for unconventional monetary policy to find out if our model is robust to the choice of the proxy for monetary policy. We use fixed effect estimator with Helmert transformation procedure according to Love and Zicchino (2006).

We provide also VAR estimates for individual economies. The individual country VAR estimates could bring some additional information about effectiveness of the unconventional monetary policy. We could observe if the effects differ across countries and whether they overlap with the panel VAR.

The section is structured as follows. In the first part of it we focus on methodology of our empirical research; we briefly describe the measure used for unconventional monetary policy as well as the variables used in our models. Then we describe panel VAR model and individual country VAR models. We also provide optimal lag length selection analysis and some stability tests in this section. The second part focuses on empirical research; we look at the estimated results and provide impulse responses and variance decomposition analysis.

3.1 Methodology

The VAR model has been used as a technique for the analysis of the macroeconomic effects of monetary policy innovations. We want to study impact of unconventional monetary policy shocks on some related macroeconomic variables. Panel data methods help us to capture also cross-sectional dimension in addition to standard VAR approach. First we introduce tools for measuring the unconventional monetary policy and then we describe VAR models and their application to panel data.

3.1.1 Measuring Unconventional Monetary Policy

Two ways how to measure unconventional monetary policy are commonly used in existing literature.

First approach based on central bank's balance sheets was used for example in the paper written by Gambacorta, Hofmann and Peersman (2012). The size of central bank balance sheet of ECB rapidly increased after the policy rates were

lowered in the beginning of 2009. The size of central bank balance sheet can be described by central bank assets or by monetary base. However, the expansion of monetary base was not proportional to the increase in central bank assets, mainly due to sterilization. Gambacorta, Hofmann and Peersman (2012) used central bank assets in their work, because they better reflect unconventional measures than the monetary base. We use the volume of European central bank assets to check robustness in our VAR analysis.

However in this thesis we use the measure for unconventional monetary policy introduced by Wu and Xia (2014). In their work *Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound* they came up with an innovative approach how to measure the unconventional monetary policy. They proposed a simple analytical representation for bond prices in the multi-factor shadow rate term structure model, first proposed by Black (1995). They suggested to use a hybrid of the historical policy rate and the shadow rate when the policy rate remained stuck at the zero lower bound. The shadow rate shows what the policy rate would be if it could be negative, based on asset purchases and other unconventional tools. We can use their shadow rate for ECB instead of policy rate in our VAR to study the relationship between unconventional monetary policy and the real economy, because in the whole period the zero lower bound was binding. For further details how the shadow rate was constructed see Wu and Xia (2014).

We decide to use shadow rate instead of central bank assets for our benchmark model mainly because it is an innovative approach not much used so far in literature. Moreover as Wu and Xia (2014) showed in their paper it is a powerful tool to describe the recent behavior of interest rates. More advantageously it has very similar pattern as interest rates usually used in these types of analyses. The results of Wu and Xia's analysis confirmed that the shadow rate correlates with macroeconomic variables when the policy rate was lowered to its effective lower bound in the very similar way as the policy rate in normal times. Also Krippner (2013) and Lombardi and Zhu (2014) show that in VAR models the shadow policy rate helps to identify monetary policy shocks.

3.1.2 VAR Model and Panel VAR Model

Vector autoregressive models were popularized by Sims (1980) and became widely used in applied macroeconomics. VAR models are based on the idea that all variables are treated as endogenous and interdependent but also some exogenous variables could be included.(Canova and Ciccarelli, 2013) A VAR model is useful mainly for providing empirical evidence of the response of macroeconomic variables to various exogenous shocks.(Iacoviello, 2008) VAR models became very popular because they are easy to use and interpret; they are used for macroeconomic forecasting and policy analysis.

The p-lag VAR model for y_t has the form (in matrix notation)

$$\mathbf{B}y_t = \mathbf{\Gamma}_0 + \sum_{i=1}^p \mathbf{\Gamma}_i y_{t-i} + \epsilon_t \quad (3.1)$$

Where y_t is vector containing our variables and ϵ_t are structural shocks. For example let us assume that the vector y_t contains two endogenous variables. For such model holds

$$\mathbf{B} = \begin{pmatrix} 1 & -b_{12} \\ -b_{21} & 1 \end{pmatrix}, y_t = \begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix}, b = \begin{pmatrix} b_{10} \\ b_{20} \end{pmatrix}, \mathbf{\Gamma} = \begin{pmatrix} \gamma_{11}^i & \gamma_{12}^i \\ \gamma_{21}^i & \gamma_{22}^i \end{pmatrix}, \epsilon_t = \begin{pmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{pmatrix} \quad (3.2)$$

This is so called structural form of VAR. However, the structural form cannot be estimated via OLS because the variables are correlated with error terms ($Cov(y_1, \epsilon_{2t}) \neq 0$ and $Cov(y_2, \epsilon_{1t}) \neq 0$), which means that the endogeneity assumption of Gauss-Markov theorem is violated. Thus we derive the reduced form of VAR by premultiplying the model by matrix B^{-1}

$$y_t = \mu + \sum_{i=1}^p \mathbf{\Pi}_i y_{t-i} + e_t \quad (3.3)$$

Where $\mu = \mathbf{B}^{-1}\mathbf{\Gamma}_0$, $\mathbf{\Pi}_i = \mathbf{B}^{-1}\mathbf{\Gamma}_i$ and $e_t = \mathbf{B}^{-1}\epsilon_t$. This model is commonly referred as reduced form of VAR, which means that each equation contains only lagged values of all other variables in the system. Each equation contains the same set of deterministic variables and the coefficients can be now estimated by OLS. However the error terms of the equations are now correlated across equations, which means that we cannot identify the structural parameters from the residuals of these equations. The VAR is under identified and we have to impose some identification restrictions to derive structural form from reduced

one. This can be done by Cholesky decomposition of the variance-covariance matrix of residuals and this is equivalent to transforming the system into a recursive VAR. Grossmann, Love and Orlov (2014) The recursive VAR is based on the idea that error term from each equation is uncorrelated with the error term from the preceding equation. This can be obtained easily by excluding some of the contemporaneous variables from the RHS of the equations. This recursive ordering means that the variables placed earlier in the ordering affect all the following variables contemporaneously and the variables that are placed later affect the previous variables with a lag.

In case of panel VAR models we add cross sectional dimension to the representation. The p-lag reduced panel VAR model has the form

$$y_{i,t} = \mu_i + \sum_{j=1}^p \Pi_{i,j} y_{i,t-j} + e_{i,t} \quad (3.4)$$

Where $y_{i,t}$ is a vector of endogenous variables for each unit i and μ_i and $\Pi_{i,j}$ may depend on the unit. As Canova and Ciccarelli said in their paper, panel VAR model has these three characteristics features:

”First, lags of all endogenous variables of all units enter the model for unit i : we call this feature ”dynamic interdependencies”. Second, $e_{i,t}$ are generally correlated across i : we call this feature ”static interdependences”. . . . Third, the intercept, the slope and the variance of the shocks $u_{i,t}$ [here: $e_{i,t}$] may be unit specific: we call this feature ”cross sectional heterogeneity”.(Canova and Ciccarelli, 2013, p.8)

In the benchmark, the vector of endogenous variables $y_{i,t}$ contains four key macroeconomic variables with following recursive ordering: real GDP, consumer price index, shadow policy rate, and the implied volatility index of the national stock market index. In the extended model we add exchange rate to the middle of the ordering. We choose this ordering due to the following reasons. The real GDP is placed first because the state of the economy does not react immediately to all other variables included. The similar situation is with inflation, which takes second place in our ordering. This ordering of the first two variables is widely used in literature. We order the real effective exchange rate on the third place, because it reacts with a lag to interest rate shocks. The policy variables as interest rates also affect GDP and inflation only with a lag, because it takes time till they become effective, thus we put shadow rate on the fourth place. When

we use central bank assets as a measure of unconventional monetary policy, it takes fourth place instead 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, Love and Orlov (2014) The panel VAR includes 13 Central and Eastern European countries: Bulgaria, Czech Republic, Germany, Estonia, Croatia, Latvia, Lithuania, Hungary, Austria, Poland, Romania, Slovenia and Slovakia. We cannot include all of the CEE region because some data are not available for the rest of CEE countries.

3.1.3 Fixed Effect and Mean Group Estimators

There are two estimators widely used for estimation of panel vector autoregressive models with possible heterogeneous datasets, the fixed effect and the mean group estimators. We decide to use them both and compare our results as it is recommended in Rebucci (2010). He also advises that we should use mean group estimator only if our panel dataset is sufficiently long (at least 60 time observations). Our dataset fulfills this requirement, since we have 82 time observations for each country and each variable. When we see after estimation is completed that results of both estimators are almost the same, the fixed effect estimator should be used, because it is more efficient. If the results essentially differ, we should trust to the mean group estimator results. (Rebucci, 2010)

However we know that in a dynamic panel (as our model undoubtedly is) the fixed effect estimator is not consistent. The fixed effects are correlated with the regressors through lags of the dependent variables. (Boubtane, Coulibaly and Rault, 2013) We consider method proposed in Love and Zicchino (2006) to deal with this issue. We use forward mean differencing to remove the fixed effect (Helmert procedure) – this approach was used for panel VAR estimation in Boubtane, Coulibaly and Rault (2013). We try to use also mean group estimator described in Pesaran and Smith (1995) - it was applied for panel VAR estimation in already mentioned paper written by Gambacorta, Hofmann and Peersman (2012). However their routine did not work for such a large dataset as we have. Thus we decide to use only Love and Zicchino (2006) methodology rather than to reduce the dataset.¹

¹We are very grateful to Gert Peersman, who provide his mean group estimator routine for RATS to us. Unfortunately we are able to run only panel VAR with 4 variables and 8 countries.

Fixed Effect Estimation

The panel VAR procedure applied by Love and Zicchino (2006) introduces fixed effects to allow for individual heterogeneity of cross-sectional unit. To get rid of correlation between fixed effects and the regressors, they use forward mean-differencing, also known as Helmert procedure. In this procedure all variables are transformed in deviations from forward means. Because the deviations are orthogonal, we can use lagged regressors as instruments and estimate the coefficients by GMM. (Boubtane, Coulibaly and Rault, 2013)

Once the coefficients are estimated, we compute impulse-response functions and the forecast variance decompositions. Impulse response functions show the reaction of one endogenous variable over time to a shock in another variable in the model holding all other shocks equal to zero. The variance decompositions describe the percent of variation in one endogenous variable that is explained by the shock to another variable in the system, accumulated over time. We use Cholesky decomposition in order to compute the impulse responses and variance decompositions.

For whole procedure we use the package provided by Love and Zicchino (2006). The impulse response functions are constructed from the estimated VAR coefficients, calculated standard errors and generated confidence intervals (confidence intervals are generated by Monte Carlo simulations with 500 replications).

3.1.4 Data

We use monthly data over the period 2008-2014 for 13 Central and Eastern European countries. We choose January 2008 as the starting date because in this year ECB started to use the unconventional monetary policy measures. Gambacorta, Hofmann and Peersman (2012) used even shorter period (4 years) for their econometric analysis, thus we think that our seven-year period is sufficient for our purposes. We use data that are available for public from Bank for International Settlements, Eurostat, Federal Reserve Economic Data, Wu's websites and from STOXX websites. We are inspired by the paper written by Gambacorta, Hofmann and Peersman (2012) when selecting the variables. We use real GDP index, consumer price index, shadow policy rate, volume of European central bank assets, implied volatility index and exchange rate in our

model. The description of all variables used in the models and the reasons why we chose them are as follows:

The real GDP index is used to measure economic activity of the countries. Because only yearly and quarterly data of GDP are available, we had to use interpolation procedure to convert quarterly figures into monthly ones. We used cubic spline interpolation, which is the most common way how to deal with this issue in econometric researches. We start with 29 quarterly data observations from the year 2008 to 2014 and we wish to draw a cubic polynomial in each space between them to connect the two consecutive points. The first two derivatives at these points have to be continuous to ensure that the connecting curve is smooth. The mathematical solution of this problem gives a system of equations, we solve it and we end with 82 monthly observations for each country. For the whole procedure we use STATA routine available at Columbia Economics website. (Columbia Economics, 2010) Values of real GDP are seasonally adjusted with base year 2005.

The CPI index is also used to measure overall economic activity of the countries. We use its seasonally adjusted values with base year 2005.

The VSTOXX index, the most popular European volatility index that is considered as the “European VIX”, is used to measure evolution in European financial risk aversion and uncertainty. This index tracks one month implied volatility of the Euro STOXX 50 index.

The real effective exchange rate variable is used because changes in monetary policy may have stabilizing impact on exchange rates. We use real effective exchange rate of the countries’ currencies against other currencies. Weights are based on trade in 2008-2010 and their base year is 2010.

The shadow policy rate is a new measure, proposed by Wu and Xia (2014), for the monetary policy when the main policy rate is close to zero. We use this measure as a proxy for unconventional monetary policy.

The central bank assets are used as another gauge for unconventional monetary policy. The central bank assets for Euro Area (in billions of Euros) are seasonally adjusted.

Table 3.1: Descriptive statistics

<i>Variable</i>	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	9.7004	14.487	63.272

Source: Author.

Table 3.1 reports the summary statistics and the figures A.1 - A.6 in the Appendix A report the evolution of our variables over the period 2008-2014.

3.1.5 Stationarity Testing

Stationarity is one of the crucial assumptions in univariate time series analysis. A process is said to be weakly or covariance stationary, if the first and second moments are time invariant.

$$E(y_t) = E(y_t - 1) = \mu \quad (3.5)$$

$$Var(y_t) = \sigma^2 < \infty \quad (3.6)$$

$$Cov(y_t, y_{t-1}) = \gamma_k, \forall t, k \quad (3.7)$$

The last equation (3.7) states that autocovariances do not depend on the time itself, which means constant autocovariances for each lag. If the series is stationary, its structure does not change over time. There are plenty of reasons why we need to work with stationary series in econometrics model. When the series is not stationary, the persistence of shocks is infinite. Also we can encounter a problem with spurious regression, when two variables are trending over time. Moreover the standard assumptions for asymptotic analysis are not valid for non-stationary time series. To sum it up, non-stationary data cannot be modeled and forecasted by most models. To achieve reliable results, we have to transformed non-stationary data into stationary ones.

There are different types of non-stationary processes. Maybe most basic examples are random walk with and without drift and deterministic trend. Random walk can be transformed to a stationary series by differencing procedure,

subtracting y_{t-1} from y_t . The process with deterministic trend need to be detrended (by subtracting the trend) to attain stationarity. Random walk with a drift and deterministic trend has to be detrended and also differenced to become stationary.

However, time series in VAR models need not to be stationary. For some parts of our analysis (such as impulse responses and variance decompositions) stationarity of the whole system is required. Moreover, differencing and also other transformations needed to achieve stationarity can waste some useful information included in data in levels, so we should avoid it, unless it is necessary. We have to run some stationarity tests to decide whether transformations of our series are needed.

The stationarity in panel data studies is also of great importance, but testing for it is more complicated there than in univariate time series. The main advantage of using panel unit root tests is that the panel approach increases the power of the test relative to the time series unit root tests. However there are several complications when we use panel data for unit root testing. First issue is a potential unobserved heterogeneity often present in panel data. Also cross sectional independence is often an inappropriate assumption. Third problem is the interpretation of the outcomes, when the null hypothesis of the unit root is rejected.

Applying standard Dickey-Fuller test to panels brings bias which is not present in univariate series. There are two classes of panel unit-root tests, first and second generation unit root tests, which differ in the assumption of the cross-sectional independence. In the first generation, there is imposed restriction that all cross-sections are independent, while second generation of panel unit-root tests relaxes this assumption. First generation tests are biased if they are applied to panels with cross-sectional dependency. (Breitung and Pesaran, 2005)

Table 3.2: CADF panel unit root test

<i>Time series</i>	Value of test statistic	P-value
GDP	-2.502	0.006***
CPI	-0.445	0.328
REER	-3.360	0.000***

Source: Author.

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; three asterisks (***) denote the significance at 1% significance level. We reject the null hypothesis in most cases.

We implement Pesaran cross-sectional dependence (CADF) test to our dataset to decide whether we should use first or second generation panel unit-root tests. The null hypothesis of cross-sectional independence is strongly rejected for all our time series at 1% significance level. To detect non-stationarity of our panel time series we apply Pesaran unit-root test, which is augmented version of the usual ADF test with unit root as the null hypothesis. We introduce three lags to allow for serial correlation in residuals for each variable and we include a time trend in the estimated equation for CPI. For CPI, we cannot reject the null hypothesis even at 10% significance level. These results pointed out that original values of CPI form non-stationary time series.

Table 3.3: ADF test

<i>Time series</i>	Value of test statistic	P-Value
VSTOXX	-2.58*	0.0971
Shadow rate	-2.354	0.1552
Total CB assets	-1.771	0.395

Source: Author.

Notes: H_0 : time series has a unit root and the series is non-stationary; number of lags = 2; asymptotic critical values with no intercept, no trend are: 1% : -2.56, 5% : -1.95, 10% : -1.62; an asterisk (*) denotes significance at 10% significance level. We fail to reject the null hypothesis in most cases.

Table 3.4: KPSS test

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

Source: Author.

Notes: H_0 : time series is stationary; number of lags = 2; asymptotic critical values with no trend are: 10% : 0.347, 5% : 0.463, 1% : 0.739; three asterisks (***) denote the significance at 1% significance level. We reject the null hypothesis in all cases.

We have also non-panel variables in our data set - implied volatility index, shadow rate of ECB and the total central bank assets that are common for all countries. Because these are not panel variables, we have to apply standard unit root testing procedures for univariate time series. We carry out two unit root tests, Augmented Dickey-Fuller test (H_0 : series is not stationary) and Kwiatkowski-Phillips-Schmidt-Shin test (H_0 : series is stationary). We reject the null hypothesis of Augmented Dickey-Fuller test for implied volatility index; however we cannot reject the null hypothesis in case of shadow rate and central bank assets. Moreover we reject the H_0 for all non-panel variables in case of KPSS test, which points out that our original data values might be non-stationary.

Four of our six variables look like they are non-stationary, thus we should use first differences of our time series to detect stationarity. There is, however, a debate between econometricians whether the individual time series included in

the VAR model need to be stationary. From previous paragraph we know, that they should be stationary for statistical purposes. On the other hand, Sims (1980) argued against transformation of the time series into first differences, because the aim of a VAR analysis is to reveal common relations between variables and by differencing we can lose important information about movements of variables. We decide not to use first differences in this thesis due to possibility of loss some useful information included in data and also due to overall stationarity of our models and due to possible cointegration discussed later.

The overall stability of the system is sufficient for interpreting the VAR model results. The stability of the system means constancy of parameters throughout the sample period. It can be tested after estimation is completed. We detect the stability of VAR process by checking the stability condition and we find out 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 systems are stationary as a whole and we proceed the estimation of the VAR in original data values.

Now we should continue with applying some cointegration tests. If the variables are non-stationary themselves, but a linear combination of them is stationary, then we say the variables are cointegrated. If the variables were cointegrated, then the simple vector autoregression in first differences would not be suitable for analysis, and we should proceed the estimation using variables in original data values or, we can include in the model an error correction term. We apply panel cointegration tests developed by Westerlund (2007). The null hypothesis of these tests says that there is no cointegration within the panel. We manage to 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 original values of the variables instead of differenced ones.

Table 3.5: Panel cointegration tests

<i>Statistic</i>	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

Source: Author.

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 individual variable; the P_t and P_a statistics test whether the cointegration exists for the panel as a whole; an asterisk (*) denotes significance at the 10% significance level, double asterisk (**) denotes significance at the 5% level. We fail to reject the null hypothesis in two cases.

3.2 Econometric Investigation

In order to estimate the interaction between unconventional monetary policy, the economic activity, financial turmoil and exchange rates we investigate the following systems of variables:

$$\text{Model 1 : } X_{it} = (Y_{it}, P_{it}, s_t, iVol_t) \quad (3.8)$$

$$\text{Model 2 : } X_{it} = (Y_{it}, P_{it}, EX_{it}, s_t, iVol_t) \quad (3.9)$$

$$\text{Model 3 : } X_{it} = (Y_{it}, P_{it}, iVol_t, s_t) \quad (3.10)$$

$$\text{Model 4 : } X_{it} = (Y_{it}, P_{it}, ta_t, iVol_t) \quad (3.11)$$

Where Y is real GDP index, P is CPI index, s is shadow policy rate, $iVol$ is implied volatility index, EX is real effective exchange rate and ta represents total central bank assets. All variables are used in original data values.

3.2.1 Lag Length Selection

Because selection of the correct lag length is essential for panel VAR, we have to decide how many lags of dependent variables we include. Usually for all endogenous variables the same number of lags is used in all equations. We should find some trade-off between too large number of lags, which could cause loss of degrees of freedom, increase in the mean square forecast errors of the model and reduction of the estimation precision of the impulse responses, and

too small number of lags, which fails to capture the system's dynamics and often generates autocorrelated errors.(Boubtane, Coulibaly and Rault, 2013)

The lag length in vector autoregression is usually selected by using a statistical criterion. There are also another methods how to select correct lag length, for example cross-equation restrictions or some rule of thumb formulas. We decide to use the method based on information criteria.

The information criterion is sum of two parts. First part represents fall in the residual sum of squares of each equation caused by increase in the number of lags and the second part represents increase in the value of the penalty term caused by the loss of degrees of freedom from adding extra parameters. This means that when we add additional lag into our system, the residual sum of squares decreases but the penalty increases.(Brooks, 2008) We want to minimize both terms and hence minimize the information criterion to select the best lag length for the model.

The most commonly used information criteria are Akaike's Information Criterion (AIC), Schwarz-Bayesian Information Criterion (SBIC), and Hannan-Quinn Criterion (HQ). The question is, which criterion we should prefer if they suggest different lag number. Usually, due to parsimony, the model with fewer parameters is preferred. The AIC is based mainly on log likelihood function, so it could fail to choose the most parsimonious model. On the other hand, SBIC incorporates higher penalty term. This finding suggests that SBIC should choose the more parsimonious model than AIC. However, lag order selection also depends on the purpose of VAR estimation. Ivanov and Kilian (2005) compared lag order selection criteria for VAR impulse responses analysis and they recommended to use AIC for monthly VAR models, because it produces the most accurate impulse response estimates.(Ivanov and Lutz, 2005) We decide to use all these three information criteria, which can be defined as

$$\text{AIC} = \log \det(\hat{\Sigma}) + \frac{2k'}{T} \quad (3.12)$$

$$\text{SBIC} = \log \det(\hat{\Sigma}) + \frac{k'}{T} \log(T) \quad (3.13)$$

$$\text{HQ} = \log \det(\hat{\Sigma}) + \frac{2k'}{T} \log(\log(T)) \quad (3.14)$$

where $\hat{\Sigma}$ is the variance-covariance matrix of residuals, T is the number of observations and k' is the total number of regressors in all equations. (Brooks, 2008)

We compute information criteria for all countries separately to determine the optimal number of lags for our VAR, considering the upper bound 4 lags. We decide to include three lags of dependent variables in our model, according to information criteria averaged across countries and taken into consideration the requirement for parsimony.

3.2.2 Estimation Results

Due to large amount of estimated coefficients in VAR models, we do not use them to interpret our results. Instead of this we use Granger causality tests, impulse responses functions and variance decompositions to examine relationships between our variables. For this part of analysis a stable system is required and as we stated already in Section 3.1.5, all our models satisfy this assumption.

The idea of the causality test is to reveal if the change in one variable has some impact on the changes in other variables that is to say if correlation between current value of one variable and past values of the others. It is important to say that the word causality does not mean that movements of one variable cause movements of another in this particular case. (Brooks, 2008) We can say that variable x Granger cause variable y if the null hypothesis that the coefficients on the lags of variable x in the VAR equation can be excluded from the VAR equation of variable y is rejected by Wald test. (Another interpretation of the null hypotheses is that variable x has no explanatory power on the current values of y .) (Goodhart and Hofmann, 2008)

Table 3.6: Granger causality tests

$GDP \rightarrow CPI$	$GDP \rightarrow REER$	$GDP \rightarrow shadow\ rate$	$GDP \rightarrow VSTOXX$
0***	0.848	0.001***	0.001***
$CPI \rightarrow GDP$	$CPI \rightarrow REER$	$CPI \rightarrow shadow\ rate$	$CPI \rightarrow VSTOXX$
0.321	0***	0.027	0***
$REER \rightarrow GDP$	$REER \rightarrow CPI$	$REER \rightarrow shadow\ rate$	$REER \rightarrow VSTOXX$
0.04**	0.261	0.197	0***
$shadow\ rate \rightarrow GDP$	$shadow\ rate \rightarrow CPI$	$shadow\ rate \rightarrow REER$	$sh.\ rate \rightarrow VSTOXX$
0.026**	0***	0.023**	0***
$VSTOXX \rightarrow GDP$	$VSTOXX \rightarrow CPI$	$VSTOXX \rightarrow REER$	$VSTOXX \rightarrow sh.\ rate$
0.004***	0.014**	0.002***	0***

Source: Author.

Notes: H_0 : variable x does not Granger-cause y; an asterisk (*) denotes significance at the 10% level and double asterisk (**) denotes significance at the 5% level.

Table 3.6 displays results from the Granger causality tests. There is significant evidence of multidirectional causality between implied volatility index and all other variables included in the model. There is also strong evidence of bidirectional causality between shadow rate and output. Output is found to have significant effect on future inflation and inflation has significant effect on future exchange rate. Also shadow rate significantly affects future inflation and exchange rates. These test, however, do not tell us anything about magnitude or direction of the effects, they mean only that there is some correlation between variables. To reveal the dynamic interactions in our system, we present below impulse response functions and forecast error variance decompositions.

Impulse Responses

The impulse response functions let us know the response of one variable to a shock in another variable in a system. They trace out the response of the dependent variables to a one-unit increase or one-standard deviation increase in the current value of one of the VAR errors, assuming that the error becomes again zero in the next period and that all other errors in the system are equal to zero. (Iacoviello, 2008) We used Cholesky ordering of variables for impulse responses analysis, because the errors should be uncorrelated across equations, when we want to change one error holding other errors fixed.

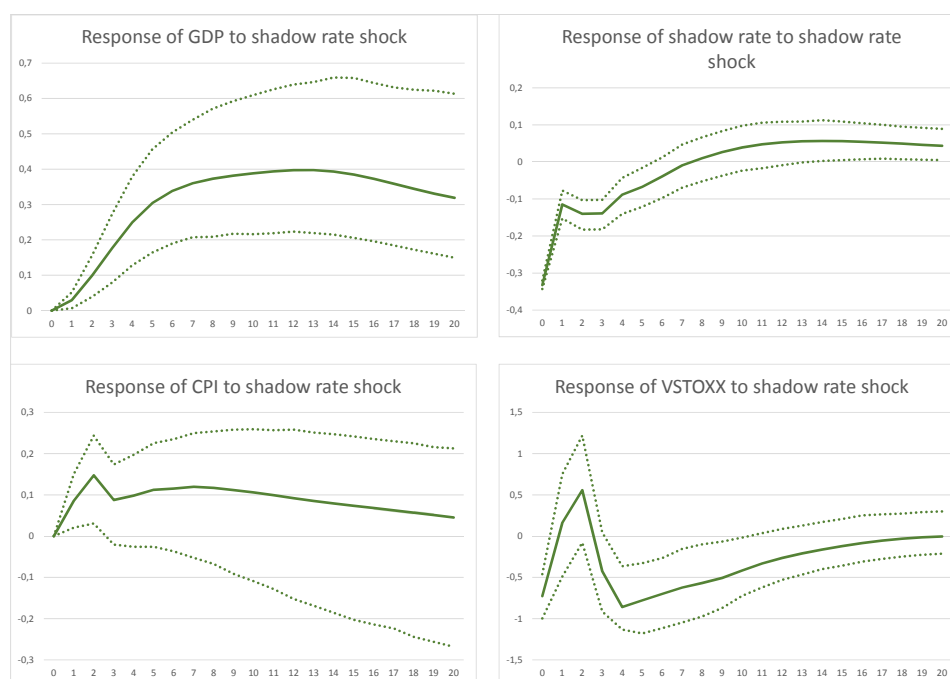
We impose a one-standard deviation shock for every variable from each equation separately and observe the system response to this shock. For panel VAR,

we use 95% (or +/- two standard errors) confidence bands and for individual country VARs we use 68% (or +/- one standard error) confidence intervals. We decide to use these intervals because the panel VAR impulse responses are estimated more precisely due to pooled data. On the other hand, the impulse responses for individual economies are estimated less precisely, because of small data samples in combination with estimation of a large number of parameters. (Assenmacher-Wesche and Gerlach, 2008) We consider the period for impulse responses to be 20 months long, which should be enough to examine the responses of variables to various shocks.

The Evidence from Panel VAR

The VAR model described in previous section was first estimated as panel VAR with three lags and **Model 1** ordering of variables. Figure 3.1 displays the im-

Figure 3.1: Impulse responses to shadow rate shock: **Model 1**



Source: Author. The solid line shows the impulse responses. The dashed lines indicate 95% confidence interval.

pulse responses to an orthogonalised one standard deviation shock to shadow rate with a two standard error confidence intervals. For better interpretation of an unconventional monetary policy shocks we impose negative shock to shadow rate instead of positive shock which is usually done by most of statisti-

cal packages. The response of shadow rate suggests that the negative shock is characterized by temporary decrease in shadow rate that fades out after about 7 months. The dynamic effects of a negative shadow rate shock indicate that all other variables included in the model increase. The responses of output are highly significant with peak after 14 months. Then it declines towards zero in relatively small pace and does not reach it until the end of our considered period. The response of GDP seems to be permanent. This confirms our first hypothesis that the decrease in shadow rate has a positive impact on GDP and that the unconventional monetary policy measures of ECB are effective in supporting the macroeconomies also in CEE countries.

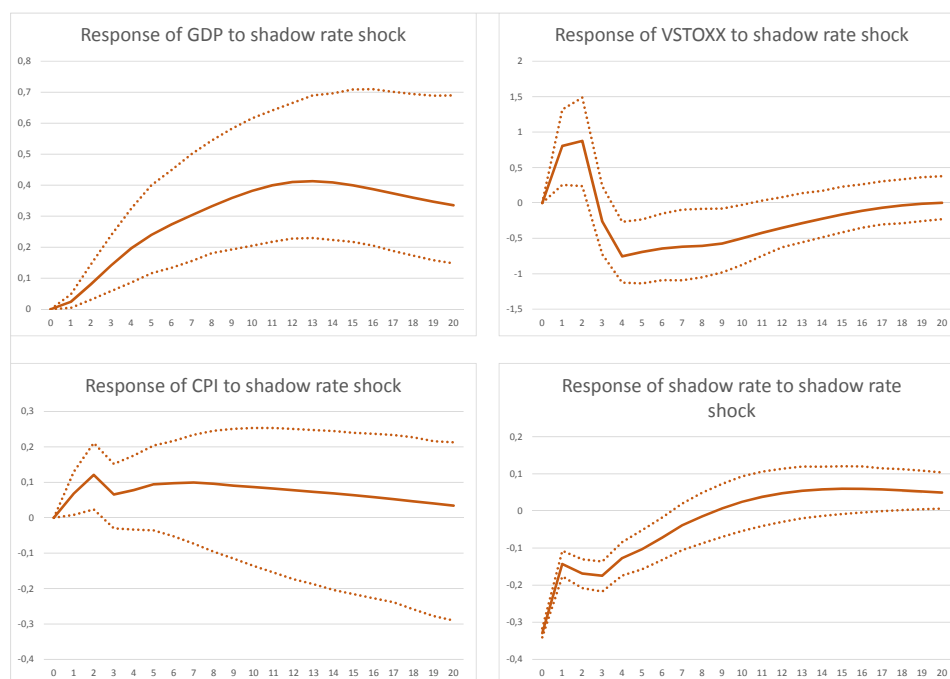
The effect of the shadow rate shock on price level is significant only in first three months. In first two months there is significant increase in prices which is in line with our prior expectations. However, the peak of this effect occurs far earlier than the peak of effect on output, after about two months. Moreover, the effect on prices is more temporary, we can see significant decline in price level after three months and then prices gradually decrease for the remainder of the period.

When we look at the magnitude of the effects, we can see that the peak effect of an unconventional monetary policy shock on output is two times larger than the effect on price level. This difference is in line with findings of Gambacorta, Hofmann and Peersman (2012). They found out that the effect of unconventional monetary policy shock on output is even three times larger than the effect on prices. Similar results were obtained by Schenkelberg and Watzka (2011) in their study about Bank of Japan's quantitative easing. Gambacorta, Hofmann and Peersman (2012) suggested that the reason for weaker price level response should be that the effects were estimated over 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 weaker effect on price level and stronger effect on output.

The last graph presented in Figure 3.1 shows the effect of shadow rate shock to implied volatility index. The effect on stock market volatility index is significant only at the beginning of the period and between 4th and 9th months. The implied stock market volatility index falls at the beginning of the period,

then there is slight insignificant increase with peak after 2 months and then it returns to be negative for the remaining 18 months. This decrease in implied stock market volatility could be explained as that the unconventional monetary policy of ECB also contributes to lowering the economic uncertainty.

Figure 3.2: Impulse responses to shadow rate shock: **Model 3**



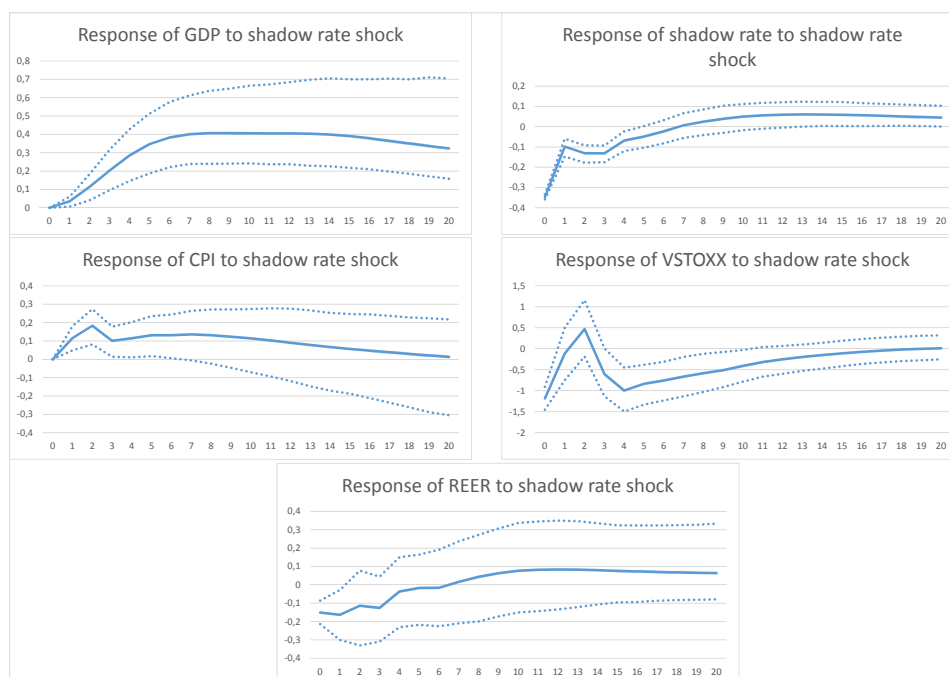
Source: Author. The solid line shows the impulse responses. The dashed lines indicate 95% confidence interval.

In order to assess robustness of our results we try to estimate also a model with different ordering of our variables. Figure 3.2 presents impulse responses with following ordering of variables: **Model 3** : $X_{it} = (Y_{it}, P_{it}, iVol_t, s_t)$. We decided to try also this variable ordering because it is in line with Gambacorta, Hofmann and Peersman (2012). They suggested that central banks responded almost immediately through unconventional policies to fix up financial market uncertainty. However, they also argued that this ordering could be biased, because monetary policy interventions should be allowed to immediately influence financial market sentiment.

The responses to a negative shock to shadow rate obtained by **Model 3** are similar to those obtained by **Model 1**. The only difference is in response of implied volatility index that seems to be more significant. There is visible significant increase of the index at the beginning of the period with peak after two

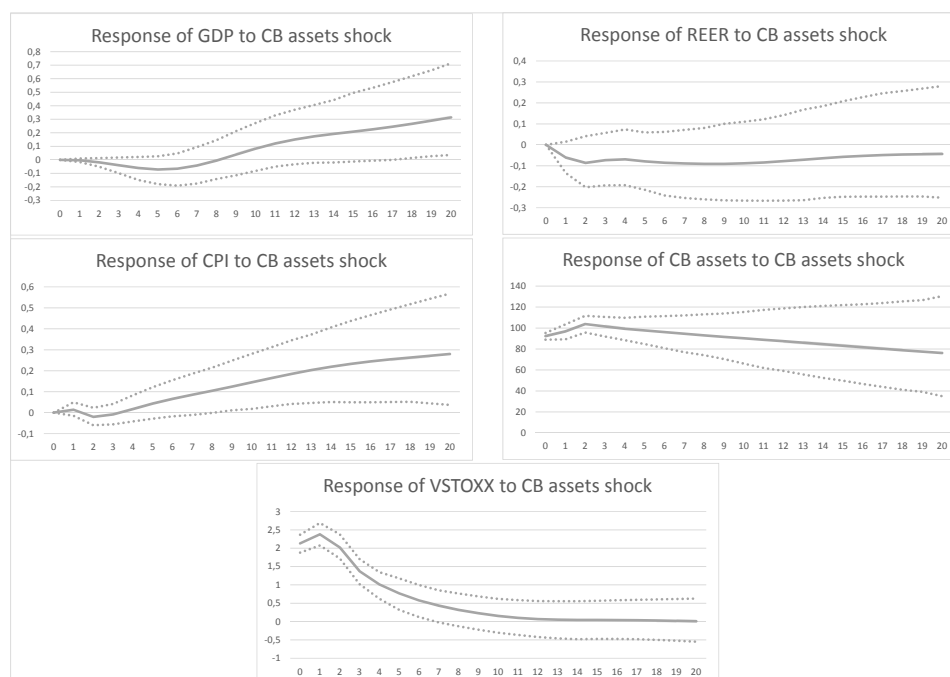
months. Then there is decline in the index with peak after four months and then the index slowly returns to the baseline. We can conclude that changes in variable ordering has no substantial effect on the results.

Figure 3.3: Impulse responses to shadow rate shock: **Model 2**



Source: Author. The solid line shows the impulse responses. The dashed lines indicate 95% confidence interval.

For robustness purposes we also include alternative specifications of the benchmark model. We include real effective exchange rate as additional variable that might help us in explaining the transmission of the unconventional monetary shock. Figure 3.3 shows the impulse responses to the shadow rate shock of using **Model 2**. As we can see in the figure, the output and prices still rise, but the effect on prices is significant for a longer time - about 7 months. The responses of shadow rate and implied volatility index are very similar to those obtained in benchmark specification. The exchange rate does not react significantly to unconventional monetary shock for almost entire period. However, we can see slight depreciation for the whole horizon (the increase in the value of the real effective exchange rate can be interpreted as depreciation of the currency).

Figure 3.4: Impulse responses to CB assets shock: **Model 4**

Source: Author. The solid line shows the impulse responses. The dashed lines indicate 95% confidence interval.

We also try to use central bank assets as a proxy for unconventional monetary policy to assess the robustness of our results. The results using **Model 4** turn out to be robust to the use of different measures for unconventional monetary policy. Figure 3.4 shows the effects of a positive shock to the central bank assets. We impose positive shock there for better interpretation of the expansive unconventional monetary shock. The responses of output and prices are positive as in case of negative shock to shadow policy rate. The figure indicates that the effects last for a longer time. When we try to use longer horizon for impulse responses, the responses of output and price level start to return to the baseline with slow pace. The results also show that reaction of output is somewhat smaller and negative at the beginning of the period when we use central bank assets. The confidence intervals presented in the figure show, however, that for the first twelve months the reaction of output is insignificant.

The main difference in the results if we use central bank assets instead of shadow rate is the effect on implied volatility index, which is in this case highly significant and positive with a peak after one month and then gradually declining towards zero. The results including central bank assets should be, however,

interpreted with caution, as the model has problems to converge.

Our panel VAR models confirm that output and prices in CEE countries increase in response to negative shock in shadow rate and that this increases are significant. Also positive shock in central bank assets is followed by significant increase in both output and inflation, however, these effects manifest themselves after considerable length of time. When assessing the effect of unconventional monetary policy shock on the other two variables included in our model, the significance of reactions is not so strong. We observe slow depreciation of currencies lasting throughout the whole period and we obtained mixed results of the reaction of implied volatility index.

The Evidence from Individual Country Estimates

In this section we present results of individual country VARs, with three lags and using order of variables according to **Model 2** specification. Figures B.1 - B.13 in Appendix B display the impulse responses to a negative orthogonalised one standard deviation shock to shadow rate with a one standard error confidence intervals. We decide to use 68% confidence intervals, because the impulse responses would have been insignificant, when we have used 95% confidence intervals, due to our small data sample. We want to discuss the similarities as well as differences in reactions to the unconventional monetary policy shocks that are present between these countries.

As we can see from the figures, the most similar is the reaction of output. In majority of the countries, output starts rising after a few months after the shock and the reaction remains positive until the end of the period. The only difference we can see in Romania, where the effect is negative with rising tendency in the second half of the considered period. The timing of the response is, however, different over the countries. The effect in Czech Republic and Bulgaria was firstly negative and only after three quarters it becomes positive and remains so for the rest of the horizon. When we look at typical shocks hitting the economies, the strongest response can be seen in Baltic States and Germany.

There are bigger differences in responses of inflation. There are some countries in which the response of inflation is positive for the whole period, but there are also countries in which the reaction is negative or mixed. The effect

on inflation is also not significant in Hungary and Romania. The reaction is positive and increasing for the whole period in Slovakia, Austria, Germany, Czech Republic and in Slovenia. In Hungary and Croatia we have much slower growth and after few months of rising inflation rate starts to decline. Looking at the results in Baltic States we can observe high similarity of the responses with our panel VAR, the effect is positive with a peak after two months and then it starts to decline. Only in Bulgaria we have negative response of inflation for the whole considered period, however, this effect is not significant. When we focus on magnitude of the response to typical shadow rate shock hitting the economy, the response is greatest in Latvia, Lithuania and in Slovakia.

It is visible from the figures that prices react slower than output to unconventional monetary shock in most countries. Another relevant distinction between output and price responses noticeable among countries is difference between magnitudes of responses. In Baltic States and also in Germany we can observe that output response is stronger than price level response, the peak of the output response is about 2 times larger than the peak of the effect on prices in these countries. In the other countries, the responses of output and prices have similar magnitudes.

The most crucial difference we can observe when we look at the reactions of real effective exchange rates. In most countries, exchange rate effects occur very quickly, with peak effect within first half of the year. There are two groups of countries, in which the effect significantly differs, or in other words, the reaction is exactly the opposite. In first group of countries, we can observe slight depreciation that lasts for few months after the monetary shock and then appreciation until the end of the period. These countries include Bulgaria, Croatia, Latvia, and Lithuania. The other countries experience appreciation in first months after the shock and then their currencies depreciate for the rest of the considered period. These countries are Romania, Germany, Poland, Slovakia, Austria, Slovenia, and Czech Republic. These two groups can be also characterized as countries with fixed exchange rate regimes and countries with floating rate regimes.

The differences between them thus can be interpreted that in countries with floating exchange rate regimes the real effective exchange rate appreciates at first, which is in line with our expectations, because in the short term (1-2

months) period the price levels are rather fixed and thus nominal exchange rate reacts. This is in line with Mohanty (2014) findings that when the exchange rate floats, a fall in foreign interest rate leads to an appreciation of the domestic currency. On the other hand, when we consider countries with fixed exchange rate regimes, these appreciation does not occur. On the contrary we can observe slight depreciation, which could be caused by stronger reaction of foreign price levels than reaction of domestic prices to negative shadow rate shock. This huge differences in responses of real effective exchange rates can be the reason for insignificance of the real exchange rate response in our panel VAR.

The effect of unconventional monetary policy shock to shadow rate is very similar for all countries to the reaction we obtain by panel VAR. There is significant drop in the shadow rate at the beginning and after few months it becomes positive with a declining trend. The shadow rate returns to the benchmark at the end of the considered period.

The reaction of implied volatility index is also very similar in all countries. In first quarter we observe significant increase in volatility, however, then the effect becomes negative for the two or three quarters and returns to the zero at the end of the period. This reaction is in accordance with our findings obtained by panel VAR.

The slightly different results at country level suggest that in our panel significant cross-country heterogeneity appears, mainly in the responses of real effective exchange rates. However, the effects on other variables are qualitatively similar across majority of countries, even though they are sometimes insignificant.

Forecast Error Variance Decompositions

Variance decompositions represent another method for interpreting VAR system results. By computing variance decompositions we can examine the relative importance of unconventional monetary policy shock for the other variables included in our model. Variance decompositions let us examine proportion of the movements in the dependent variables that are caused by their own shocks and proportion of the movements that are caused by shocks to the other variables. (Brooks, 2008) The shock to the one dependent variable will affect this

variable and also will be transmitted to all other variables in the VAR system. We are interested in the variance shares of the shadow rate shock, because they can be interpreted as measures of the quantitative effect of unconventional monetary policy shocks on the macroeconomy. (Schenkelberg and Watzka, 2011)

Figure C.1 and tables C.1 - C.5 in Appendix C shows the variance decompositions of the panel VAR with **Model 2** variable ordering. The figure displays the proportions 5, 10, 15, 20 and 25 months after the shocks. The decomposition indicates that the shadow rate shocks explain some of the fluctuations in the prices and output. The shadow rate shocks account for about 5-28% fluctuations in output, which points out that they are relatively important in explaining substantial part of output variation. However, they explain only around 2-4% of the forecast error in variance of prices. They are not even main contributor to the variations of the shadow rate. The variations in shadow rate are driven mainly by innovations to implied volatility index (around 50%) and also by shocks to real effective interest rate (around 10%). The volatility shocks also explain substantial part of output variable, around 13%. The innovations in shadow rate account only for 7% from implied volatility variations and only for 2% from exchange rate variations.

In summary, the variance decompositions show us how important are shocks to one variable in explaining variations in other variables. We find evidence that outputs of CEE countries are influenced by European shadow policy rate. On the other hand, we find only weak evidence that the unconventional monetary policy significantly influences the price levels in CEE region.

Chapter 4

Conclusions

This thesis examines empirically the macroeconomic effectiveness of unconventional monetary policy introduced by ECB during crisis. We study impact of such policies on 13 CEE countries. We use monthly data over the period, when ECB used non-standard monetary policy tools. We explore these impacts using panel VAR techniques and also simple VAR approach for individual country estimates. We use output, prices, real effective exchange rates, implied volatility index of stock market and shadow policy rate in our models. For robustness check we also include total central bank assets instead of shadow rate. In our VAR models we use three lags of our variables, derived from information criteria and parsimony.

Our results indicate that unconventional monetary policy of ECB has a significant positive effect on economic activity in CEE countries. We find that the decrease in shadow rate leads to significant temporary rise in inflation. Similarly, our results indicate that the expansionary unconventional monetary policy shock of ECB has a positive effect on output, which is more persistent than the reaction of prices. These results support both our hypotheses. However, the peak effect of a negative shadow rate shock on prices is two times smaller than the peak effect on output. Similar results were obtained by Schenkelberg and Watzka (2011) and Gambacorta, Hofmann and Peersman (2012). These findings can be attributed to the fact that we estimated our models over period of recession, when the changes in aggregate demand driven by monetary policy shocks have weaker effect on price level and stronger effect on output.

We also provide some robustness check. We estimated our panel VAR model

with central bank assets as a gauge for non-standard monetary policy instead of shadow rate and our findings indicate also significant increase in output and prices after positive central bank asset shock. A change in variable ordering has no substantial effect on our results. We conclude that our findings are robust to using different proxy for unconventional monetary policy and also to use of different ordering.

We find out also significant effect of unconventional monetary policy on market uncertainty. According to impulse responses function we find that negative shadow rate shock decreases the level of implied volatility index. The results obtained with central bank assets as a gauge for unconventional monetary policy of ECB were in contrary with this finding, however, we should interpret them with caution, because the model has problems to converge. We do not find any significant effect of non-standard monetary policy on real effective exchange rates. We can observe only insignificant depreciation of currencies throughout the whole considered period. However, when we look at our individual country estimates, we can see possible reason for this insignificance. There were quite opposite reactions to negative shadow rate shocks obtained in countries with fixed exchange rate regimes and in countries with floating exchange rate regimes. Countries with floating exchange rate regimes observed real exchange rate appreciation at first, however, in countries with fixed exchange rates this appreciation does not occur.

Our results suggest that the unconventional monetary policy measures adopted by ECB during the period 2008-2014 were supportive for economies of CEE countries. These measures have greater and more lasting effect on outputs than on prices in majority of countries. However, these results do not tell us anything about effectiveness of different types of non-standard monetary policies or about their announcement effect. As for future research we recommend to carry out the event study analysis to examine the effects of the announcements of the ECB's Outright Monetary Transactions programme and the Expanded Asset Purchase Programme launched in January 2015 on government sovereign bond yields of Central and Eastern European countries.

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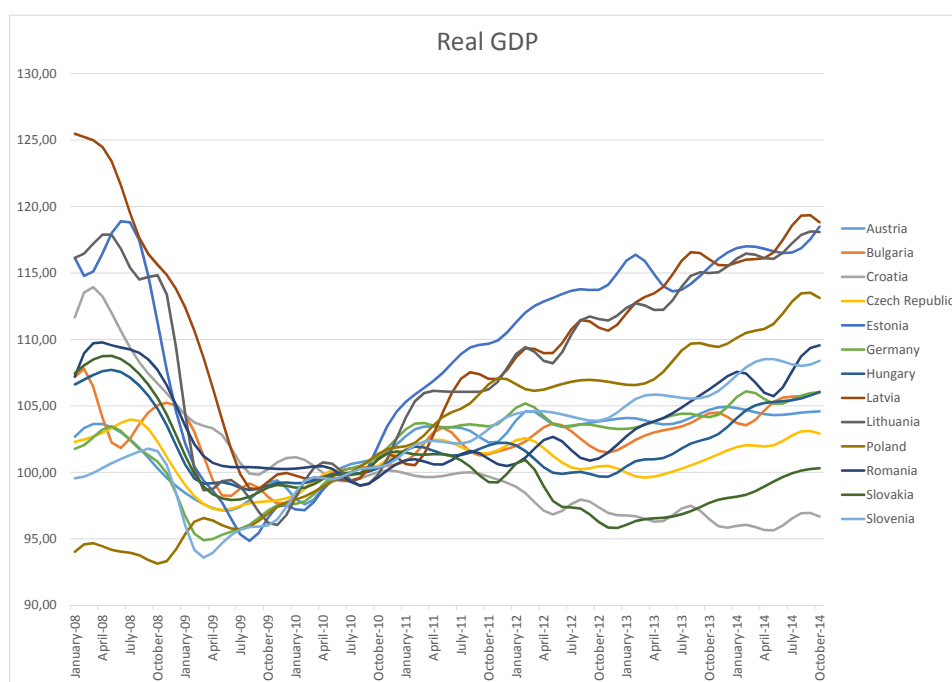
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Appendix A

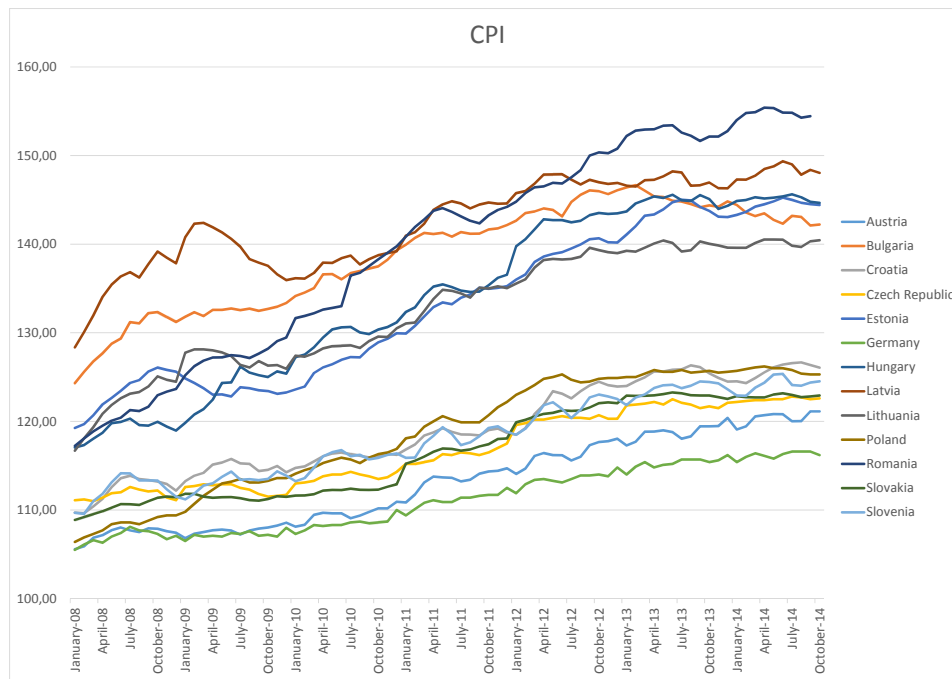
Development Graphs of Time Series

Figure A.1: Development of Real GDP in CEE countries



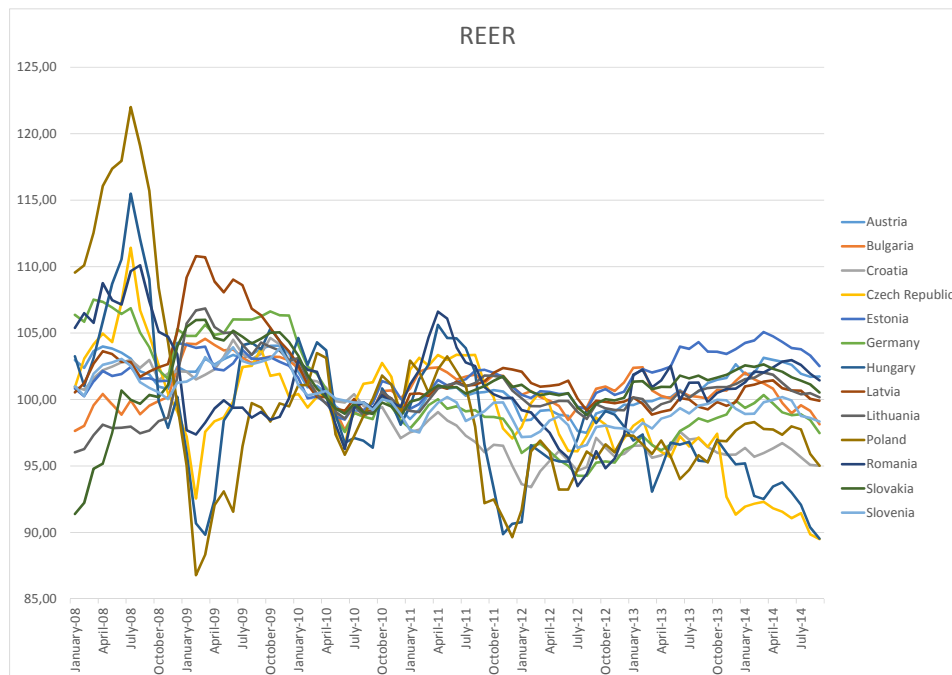
Source: Author. Time is plotted on the horizontal axis.

Figure A.2: Development of CPI in CEE countries



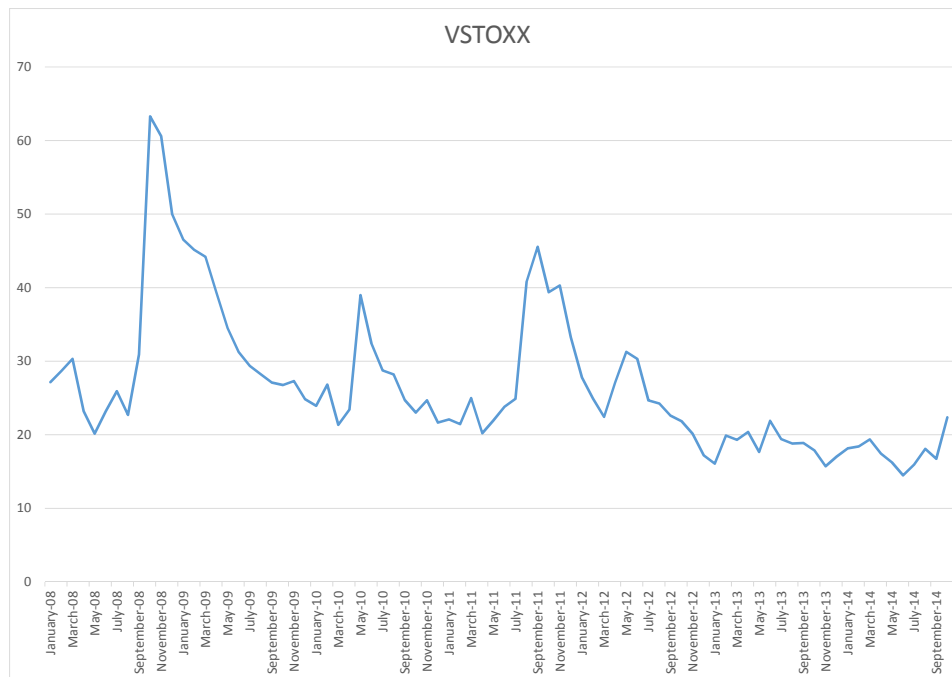
Source: Author. Time is plotted on the horizontal axis.

Figure A.3: Development of REER in CEE countries



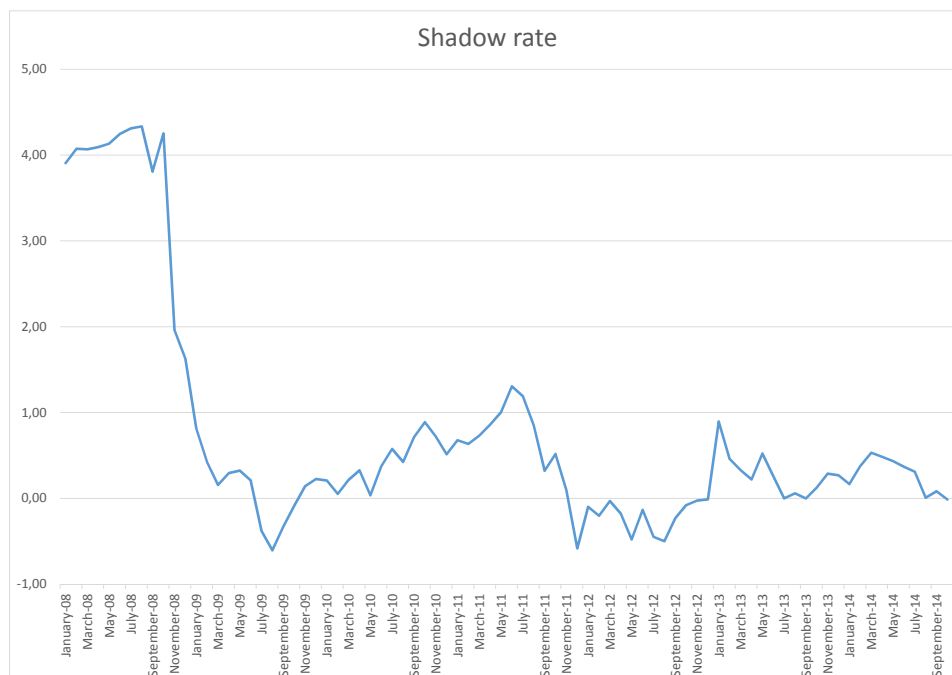
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Figure A.4: Development of VSTOXX



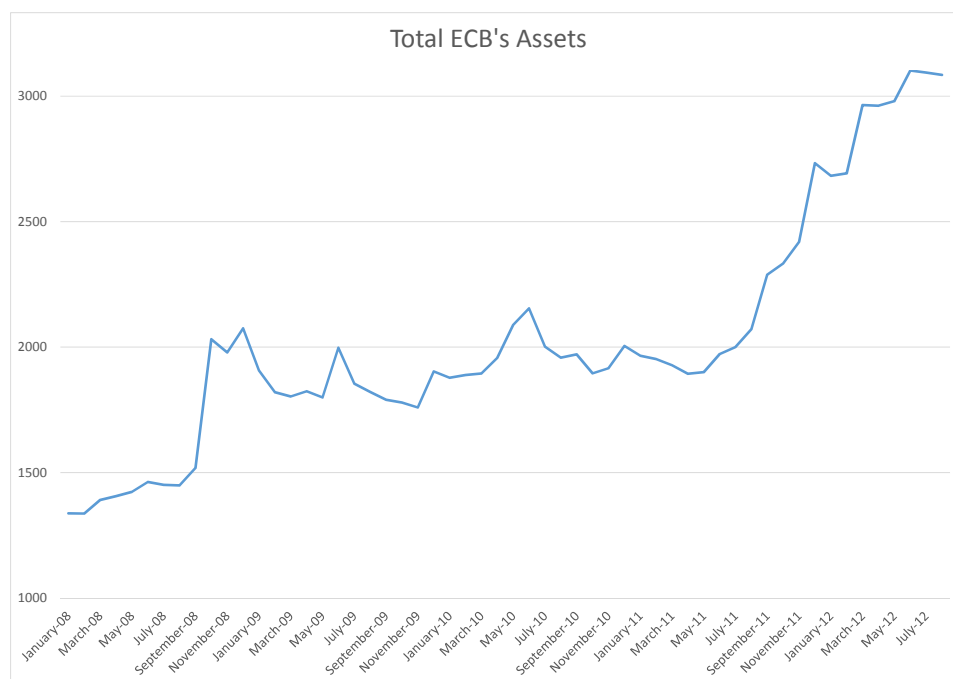
Source: Author. Time is plotted on the horizontal axis.

Figure A.5: Development of shadow policy rate of ECB



Source: Author. Time is plotted on the horizontal axis.

Figure A.6: Development of European Central Bank assets

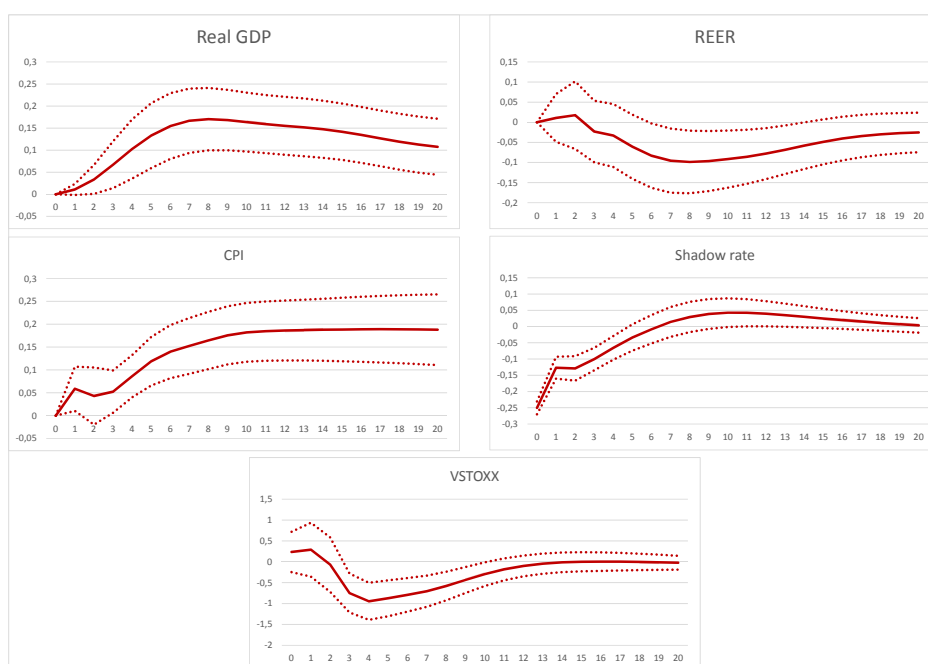


Source: Author. Time is plotted on the horizontal axis.

Appendix B

Impulse Responses to Shadow Rate Shock: Individual Country Results

Figure B.1: Austria



Source: Author. The solid line shows the impulse responses. The dashed lines indicate 68% confidence interval.

Figure B.2: Bulgaria



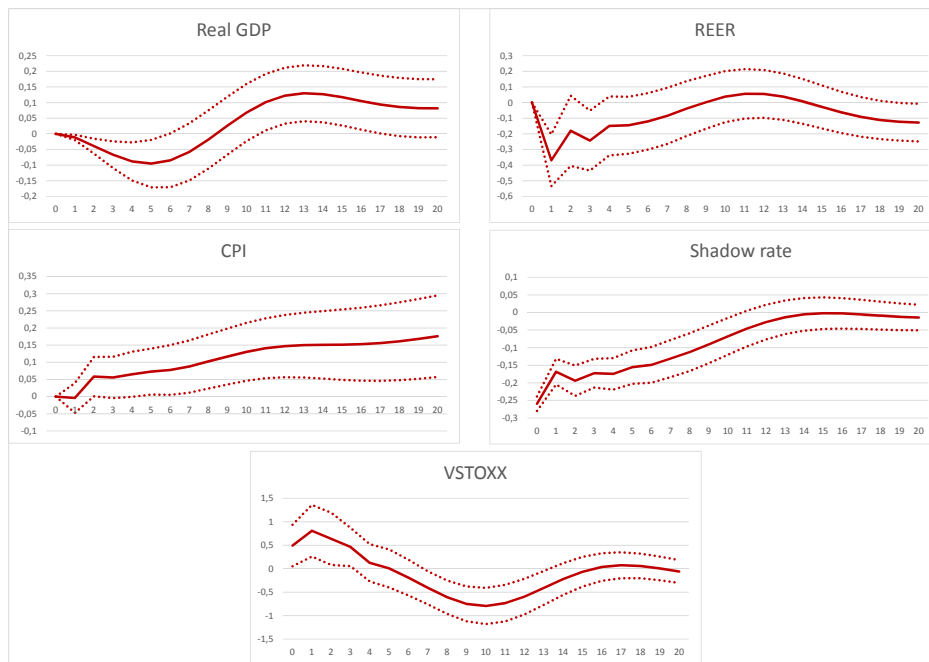
Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.3: Croatia



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.4: Czech Republic



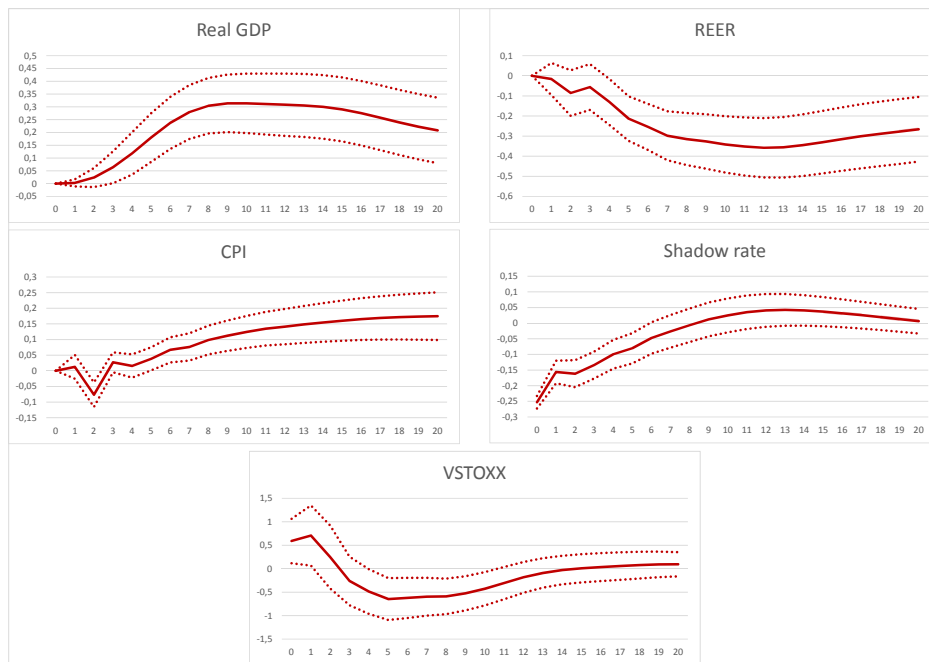
Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.5: Estonia



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.6: Germany



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.7: Hungary



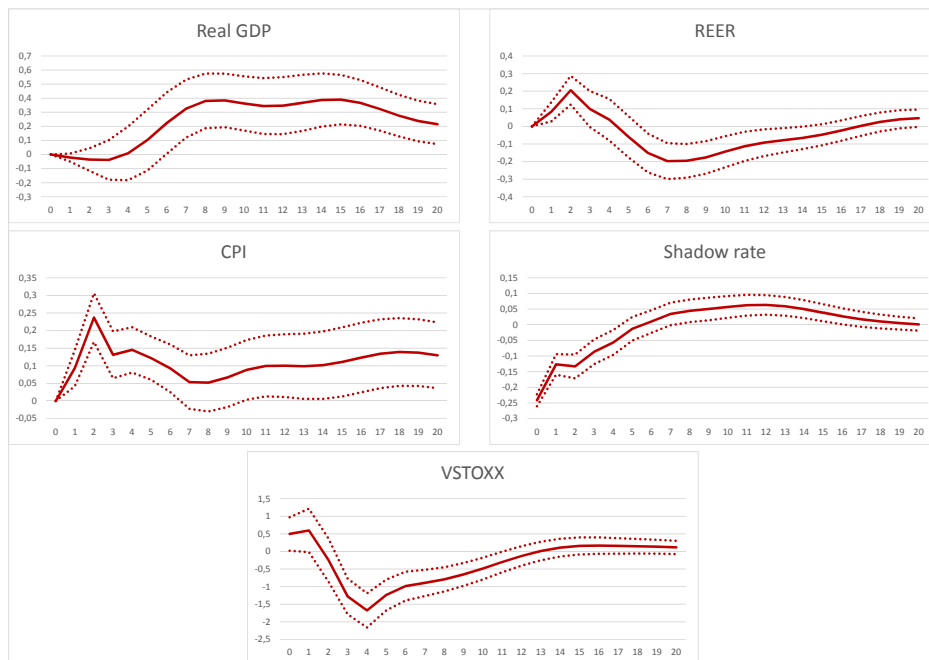
Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.8: Latvia



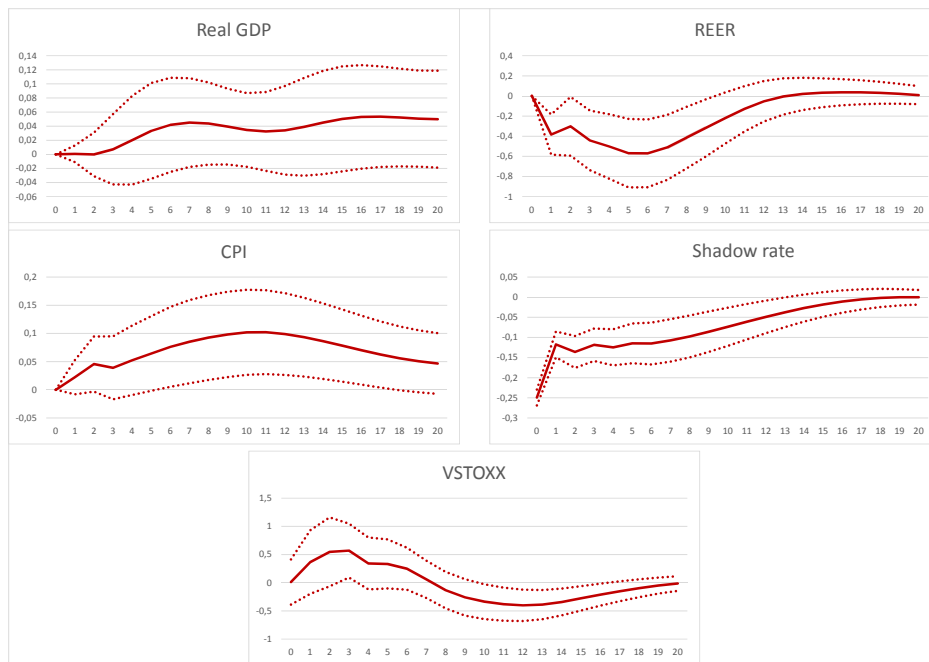
Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.9: Lithuania



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.10: Poland



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.11: Romania



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.12: Slovakia



Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Figure B.13: Slovenia

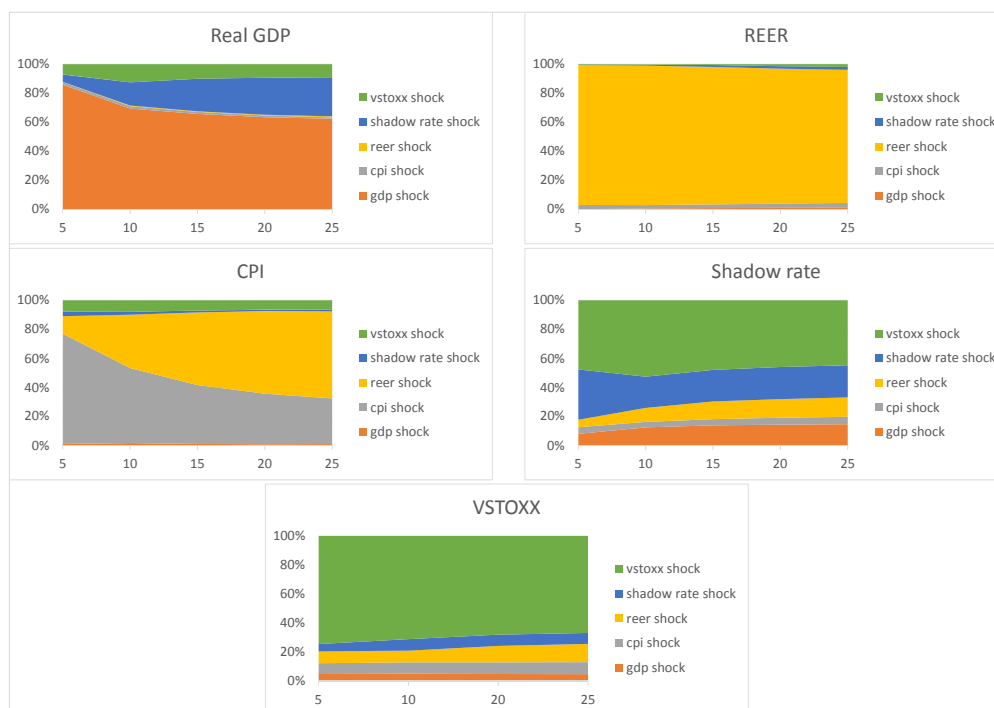


Source: Author. The solid line shows the impulse responses. The dashed line indicates 68% confidence interval.

Appendix C

Results of Variance Decompositions

Figure C.1: Forecast error variance decompositions



Source: Author .

Table C.1: VAR forecast error variance decomposition: Proportions of forecast error in GDP

Proportions of forecast error in GDP accounted for by:					
<i>forecast horizon</i>	GDP	CPI	REER	Shadow rate	VSTOXX
5	86%	2%	0%	5%	7%
10	69%	2%	1%	16%	13%
15	66%	1%	0%	22%	10%
20	63%	1%	0%	26%	9%
25	62%	1%	1%	27%	9%

Source: Author.

Table C.2: VAR forecast error variance decomposition: Proportions of forecast error in CPI

Proportions of forecast error in CPI accounted for by:					
<i>forecast horizon</i>	GDP	CPI	REER	Shadow rate	VSTOXX
5	1%	76%	12%	3%	8%
10	2%	52%	37%	2%	8%
15	1%	41%	50%	1%	7%
20	1%	35%	57%	1%	7%
25	1%	32%	60%	1%	7%

Source: Author.

Table C.3: VAR forecast error variance decomposition: Proportions of forecast error in REER

Proportions of forecast error in REER accounted for by:					
<i>forecast horizon</i>	GDP	CPI	REER	Shadow rate	VSTOXX
5	0%	3%	96%	0%	0%
10	0%	2%	96%	1%	0%
15	1%	3%	95%	1%	1%
20	1%	3%	93%	2%	1%
25	1%	3%	92%	2%	2%

Source: Author.

Table C.4: VAR forecast error variance decomposition: Proportions of forecast error in shadow rate

Proportions of forecast error in shadow rate accounted for by:					
<i>forecast horizon</i>	GDP	CPI	REER	Shadow rate	VSTOXX
5	8%	5%	5%	35%	48%
10	12%	4%	10%	22%	53%
15	14%	4%	12%	22%	48%
20	14%	5%	13%	22%	46%
25	15%	5%	13%	22%	45%

Source: Author.

Table C.5: VAR forecast error variance decomposition: Proportions of forecast error in VSTOXX

Proportions of forecast error in VSTOXX accounted for by:					
<i>forecast horizon</i>	GDP	CPI	REER	Shadow rate	VSTOXX
5	5%	7%	8%	5%	75%
10	5%	8%	8%	8%	71%
15	5%	8%	10%	8%	70%
20	5%	8%	11%	8%	68%
25	5%	8%	13%	8%	67%

Source: Author.