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MASTER THESIS

ECB's Quantitative Easing - What Effects, Through Which Channels?

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

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Prague, July 28, 2016

Signature

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Abstract

The thesis analyzes the wide-economy impacts of the European Central Bank Expanded Asset Purchase Programme (ECB EAPP). The paper investigates the effects of the balance sheet change as well as the latent nature of unconventional policy tools and analyzes the effects by two distinct models, the Structural Vector Autoregressive (S-VAR) and Factor-Augmented VAR (FA-VAR). The paper further discusses the transmission channels of the monetary policy.
The paper finds that the effect on the economy is materialized. The paper shows that the major channel of ECB unconventional policies on the real economy is driven by the response of nominal exchange rate and decline of interest rates.

JEL Classification E20, E27, E30, E43, E47, E52, E58
Keywords Quantitative easing, Unconventional Monetary policy, Euro Area

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Abstrakt

Tato diplomová práce analyzuje efekty působení programu nákupu cenných papírů EAPP Evropské centrální banky. Práce se zaměřuje na efekty plynoucí ze změny velikosti rozvahy centrální banky a sleduje také latentní charakter změny monetární politiky. Analýza využívá dva modely ze skupiny VAR, stukturální VAR (S-VAR) a VAR obohacený o faktory (FA-VAR). Práce dále vysvětluje, jakými kanály monetární šok působí. Analýza ukazuje, že se změna monetární politiky na makroekonomických proměnných projevila. Nejsilnější estimované efekty jsou ve snížení úrokových sazeb a depreciaci domácí měny. Ostatní vlivy na reálné hospodářství se ukazují být spíše zanedbatelné.

Klasifikace JEL E20, E27, E30, E43, E47, E52, E58
Klíčová slova Kvantitativní uvolňování peněz, Nekonvenční monetární politika, Eurozóna

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Acronyms

ABSPP Asset-Backed Securities Purchase Programme

AIC Akaike's Information Criterion

AORD All Ordinaries

AUD Australian Dollar

BoE Bank of England

BoJ Bank of Japan

bp basis point

CAC Cotation Assistée en Continu

CBPP Covered Bond Purchase Programme

CBPP3 Covered Bond Purchase Programme 3

CI Confidence Interval

CISS Composite Indicator of Systemic Stress

CMI Conventional Monetary Indicator

DAX Deutscher Aktien-Index

DSGE Dynamic Stochastic General Equilibrium

EA Euro area

EAPP Expanded Asset Purchase Programme

ECB European Central Bank

EMU European Monetary Union

EONIA Euro Overnight Index Average

ER Exchange Rate

EU European Union

EUR Euro

EURIBOR Euro Interbank Offered Rate

EUROSTAT Statistical office of European Union

FA-VAR Factor-Augmented VAR

FED Federal Reserve System

FEER Fundamental Equilibrium Exchange Rate

FDI Foreign Direct Investment

FPE Final Prediction Error

FRFA Fixed-Rate Full Allotment

IPI Industrial Production Index

GDP Gross Domestic Product

HICP Harmonised Index of Consumer Prices

HIR10y Harmonised Interest Rate on 10 year government bonds

HH Households

HP Hodrick–Prescott

IMF International Monetary Fund

LSAP Large-Scale Asset Purchases

LTRO Long-Term Refinancing Operations

M Million = 10e6

MB Monetary Base

MFI Monetary Financial Institutions

MRO Main Refinancing Operations

NEER Nominal Effective Exchange Rate

NFC Non-Financial Corporations

OECD Organisation for Economic Co-operation and Development

OMO Open Market Operation

OMT Outright Monetary Transactions

pp percentage point

PCA Principal Components Analysis

PPI Producer Price Index

PSPP Public Sector Purchase Programme

QE Quantitative Easing

SMI Synthetic Monetary Indicator

SMP Securities Markets Programme

STOXX EURO STOXX 50 Stock Index

S-VAR Structural Vector Autoregressive

REER Real Effective Exchange Rate

TLTRO Targeted Long-Term Refinancing Operations

UK United Kingdom

UMI Unconventional Monetary Indicator

US United States (of America)

USA United States of America

USD United States Dollar

VAR Vector Autoregressive

T Trillion = 10e12

TVP-VAR Time-Varying Parameter Vector Autoregressive

ZLB Zero Lower Bound

Diploma Thesis Proposal

Author	Daniel Husek
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Proposed topic	ECB's Quantitative Easing - What Effects, Through Which Channels?

Topic characteristics The financial crisis of 2007-09 witnessed unprecedented policy responses from central banks. As a prompt response central banks provided additional liquidity and lowered policy interest rates. However, as the financial crisis spilled over into the real economy, central banks found themselves to be constraint by the nominal interest rate zero-lower-bound and, hence, initiated programmes of unconventional monetary policies to provide additional monetary easing. The programmes included extraordinary measures to provide further liquidity to short-term funding markets (new or expanded credit facilities), as well as expanding central bank balance sheets by large scale purchases of longer-term government bonds and other assets - often referred to as quantitative easing (QE). The aim of these tools is to put direct upward demand pressure on the price of the targeted securities and, therefore, to lower their yields.

The European Central Bank (ECB) pursues an almost symmetric definition of price stability - high inflation is as dangerous to the economy as deflation. Since the interest rate instrument alone has not been sufficient to steer current low inflation closer to 2% target, the ECB followed the steps of other major central banks and used outright asset purchases as part of their monetary policy. The necessary intermediate condition to push inflation upwards is the increase of investment and production. Hence, the asset purchase program promises to promote economic growth consistently with achieving the price stability objective. Since the asset purchase programmes are unprecedented by its magnitude, it is important to investigate their effects on the real economy. This

is important for several reasons. First, the asset purchase programmes could be adjusted in the meantime if the effects show not to match the expectations. Second, the thorough analysis helps the ECB to design the policies involving quantitative easing (QE) in the future.
Large scale asset purchases (LSAPs) could affect the economy through various channels:

- Interest rate channel: Lower yields on government bonds potentially encourage investors to search for the yield elsewhere, and, hence, the increased demand lowers the interest rates in riskier assets. This process is driven by different sub-channels. As summarized by Krishnamurthy and Vissing-Jorgensen (2011) it is duration risk channel, liquidity channel, safety premium channel, prepayment risk premium channel, default risk channel and inflation channel.

- Debt-service channel: Lowering the cost of debt service further stimulates consumption and investment. It also indirectly increases the efficiency of fiscal expansion, as lower interest rates mitigate the crowding out effect.

- Wealth channel: The higher demand for assets increases their prices and thereby wealth of their holders. This consequently supports consumption.

- Exchange rate channel: Lower interest rates in the Euro area put downward pressure on the exchange rate with respect to other currencies and favor demand for domestic products both in foreign and domestic markets.

- Inflation expectations channel: Since the reputation of the European Central Bank is solid and since the policy goal to higher inflation was well communicated with the public, the ECB's actions increases the inflation in expectations and *ceteris paribus* lowers the real interest rates. Low real interest rate environment then supports the investments and consumption.

There is only little guidance from previous experience that could be used to judge the expected impact of unconventional monetary tool by the ECB. Currently, there are analyses of the effects of QE employed by the Federal Reserve System, the Bank of England and the Bank of Japan. They usually focus on the long-term interest rate response and do not try to investigate the full class of effects on real economy or the related channels. Furthermore, one could argue that the reaction in the Euro area context could differ largely. This could be driven by the reliance on the bank-based financial system in the Euro area as opposed to the market-based financial system in the United States and Great Britain.

Hypotheses

- Large scale purchases of government bonds affects the yield curves of highly rated fixed interest rate financial securities but has substantially lower effect on lower rated corporate bonds and mortgages rates.

- Large scale purchases of government bonds lead to a depreciation of Euro currency.

- Large scale purchases of government bonds create controllable inflationary pressures, i.e. through the wealth channel, debt-service channel, exchange rate channel and interest-rate channel they support the consumption and investment, but lower the inflation uncertainty.

Methodology I will use standard statistical and econometric techniques. Next to other tools, I will employ vector autoregression class models. Further, I will use the counterfactual analysis to estimate the development of macroeconomic variables if the QE was not employed among monetary policy tools. To test the first two stated hypothesis I will discuss the output response function generated by the econometric model.

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Chapter 1

Introduction

The monetary policy rules for decades stabilized the economy. Currently, though, it appears that the so-called conventional monetary policies have limitations and that - in the long run - policy makers cannot rely on their availability and efficiency. In this context it is necessary to fully consider the experience of the recent economic recession which forced monetary authorities to think beyond the conventions and initiate so-called unconventional monetary policies. By definition, these instruments are used only when the basket of standard tools has been exhausted. This is why there is only limited empirical and theoretical literature analyzing the impacts of the policy actions considered. The rigorous and comprehensive empirical analysis of effects and pass-through mechanism of the unconventional monetary policy is essential part of understanding our economy. The output of the analysis further forms an important basis to judge and expand the reliability of theoretical models.

This paper analyzes the macroeconomic effects and channels of the Quantitative Easing (QE) applied by the European Central Bank (ECB). The central bank responded to the economic crisis by multiple unconventional policy actions aimed to expand the central bank balance sheet and to influence the long-term bank lending interest rates. The central bank for instance shifted to a fixed rate tender with full allotment, lowered requirements for quality of collateral for refinancing operations and prolonged the maturities on liquidity provided to commercial banks. This paper considers mainly the instruments focused on expanding the stock of broad money in the Euro area economy and refer to it as to QE.

In the pre-crisis period there was a wide consensus among monetary policy researchers that the short-term interest rates provide large part of informa-

tion of monetary policy stance. In the crises the policy rates reached the Zero Lower Bound (ZLB) and the variety of policy actions increased rapidly. Hence, any single measure does not seem to act as the policy variable any longer and the researchers need to control for larger set of effects. This paper analyzes the ECB QE by 2 empirical models. First, we use the S-VAR model to obtain the benchmark results of QE effects on real economy. Second, we employ the two-stage FA-VAR model. In the first stage the Principal Components Analysis (PCA) model is used to reduce the number of relevant variables and ensure the tractability of VAR analysis. The reduced variables – latent factors – are then used in FA-VAR model which controls for the various macroeconomic effects and allows to estimate the impulse response functions for any variable included in the dataset. This paper focus on QE effects on real economy and financial market. The included macroeconomic variables cover the interest rates, the currency exchange rates, the monetary aggregates, borrowing costs, financial stocks and credit creation.
We further consider the impulse responses generated by VAR models and describe the transmission mechanism of the QE.

The next parts of this paper are organized as follows. The chapter 2 summarizes the relevant prior literature. The chapter 3 describes the composition of ECB QE and talks about its intended effects. The chapter 4 describes the data and methodological approach, chapter 5 shows the results of the analysis, the chapter 6 considers the channels and implications of the analysis for the policymakers and chapter 7 concludes our findings.

Chapter 2

Literature review

The financial crisis of 2007-09 saw unprecedented policy responses from central banks. Although the Quantitative Easing (QE) of ECB was initiated with a time delay with respect to other major central banks, one can find only little guidance from previous experience that could be used to judge the expected impact of ECB's unconventional monetary tools. Currently, there are analyses of the effects of quantitative easing (QE) employed by the Federal Reserve System (FED), the Bank of England (BoE) and the Bank of Japan (BoJ). The existing empirical studies of the ECB's QE so far considered almost exclusively the sterilized phase[1] of ECB's balance sheet policies.

From the theoretical perspective the efficiency of the QE is studied by Cúrdia & Woodford (2011). The paper finds that the efficiency depends largely on the perception of substitutability of bank reserves and purchased assets by investors. The larger the distinction the more significant effect on real economy. In extreme case if the bank reserves share the characteristics of the purchased government bonds, the QE is neutral in effect. The key is to create incentives for investors to vary their portfolios. This is why the large set of studies emphasizes the portfolio-balance channel as the active transmission channel of the QE. The mechanism was among others described by Tobin (1961), Tobin (1969) and Brunner & Meltzer (1973). They showed the power of central bank to influence the yields of different assets via affecting the relative supplies of financial assets varying in maturities and liquidity. An important ingredient of the channel is the heterogeneity of investors and credit restrictions. Both ensures that the portfolio balance affects the real economy. The model of Kiyotaki & Moore

[1] In the sterilized phase, until the mid of 2014, the excess liquidity driven by ECB asset purchases were drawn from the system by offsetting operations.

(2012) assumes credit market imperfection and limited participation – both being plausible not only in times of crisis. In the model the financial assets differ in their liquidity and the firms can finance their investment projects only partially by issuing new equity (or debt). Since shares are far from being liquid, the firms sit on stock of high liquid assets – money – in order to be prepared for sudden opportunities. The liquidity shock makes selling shares more difficult and thus the investments shrink. The central bank could ease the distress by buying less liquid assets for money created. The large scale purchases of government bonds by the Eurosystem reduce their available supply. This leads either to a decline in average maturities held by private sector or to reduction of term premium for long-term assets. Equivalently the prices of those assets are likely to rise.

The described mechanism is consistent with the preferred habitat theories of Modigliani & Sutch (1966). In the theoretical economy the investors differ by their preferences over specific segments of the yield curve. Vayanos & Vila (2009) implemented the theory and introduced a model with two types of agents, the investors with preferences for specific maturities and risk-averse arbitrageurs. In such a model the changing supply of bonds affected the yields pattern. In a special case the presented model implies the duration channel, operation of which is also advocated by Gagnon *et al.* (2011). As the purchases of the monetary authority decreases the supply of assets of certain maturity, the investors who prefer to hold such assets are forced to reduce the required premiums or equivalently pay more for the assets.

In the existing empirical literature the portfolio balance channel is sometimes explored as multiple separate channels. The scarcity of asset supply affects the equilibrium safety premium – the transition is known as the safety channel –, and mitigates the duration risk of holding long-term securities – known as the duration channel. Joyce & Tong (2012) used intra-day data on gilt yields and found both of the channels to be operational. On the contrary, the study of Krishnamurthy & Vissing-Jorgensen (2011) explained the effects of QE by the safety channel and found no evidence with respect to the activity of the duration risk channel.

This paper focuses on the evidence captured by data and, thus, it is related to several existing empirical studies. The issue to be tackled before any analysis is the proper formulation of the policy variable. In contrast with the generally accepted key interest rates as the policy variable capturing the conventional monetary policy, there is no single widely accepted policy variable considering unconventional monetary policy. Previous studies used the following four principal analytical approaches.

First, there is literature focusing on the announcements of QE measures by the monetary authorities. This line of research often employs intra-day data to study the immediate responses of financial market to the unexpected elements of QE. The surprise component is then extracted from the futures markets. Among others, this set of literature includes Gagnon *et al.* (2011), Swanson (2011), D'Amico *et al.* (2012), Glick & Leduc (2013) and Weale & Wieladek (2015). It typically finds that domestic interest rates fall upon a QE announcement and the domestic currency weakens against major currencies. The problem with this approach is the limitation to the financial variables. Hence, the study of the operative channels of QE effects on the macroeconomic variables while controlling for the business cycle dynamics is less than ideal.

The second approach relies on the QE's effect on long-term interest rates. The policy variable used is thus either the long-term interest rate or the spread between the long and short-term rates. The paper of Kapetanios *et al.* (2012) analyzes the BoE's QE using the interest rates of UK government bonds (gilts) as a policy variable. The findings show a significant positive impact on Gross Domestic Product (GDP) and inflation. A similar approach was employed by Gilchrist *et al.* (2014) who analyze the US economy. Their findings indicate that a reduction of the two year nominal treasury yield is followed by a significant reduction in real borrowing costs. The paper of Baumeister & Benati (2012) then applies a TVP-VAR model using the spread between short and long interest rates. The paper finds that the unconventional measures applied by the FED and the BoE have avoided a significant output collapse.

The third strand of literature uses the size of balance sheets of the central banks. Gambacorta *et al.* (2014) estimate a panel VAR model consisting of the USA, the Euro area and Japan. QE shocks are identified using sign restrictions requiring, among other things, an immediate increase in the balance sheets following a QE shock. The advantage of this approach is that it allows for the inclusion of macroeconomic variables. In this paper we thus use the adjusted balance sheet size as the policy variable in our benchmark model.

The fourth line of research applies the estimates of a latent variable of monetary policy. The idea of a monetary index variable dates back to Avery (1979) who extracted a single unobserved measure from real and monetary variables. Considering the unconventional monetary policy this approach is among others used by Christensen & Rudebusch (2013) and Wu & Xia (2014) who induce the latent policy variable from the nonlinear term structure models, and by Lombardi & Zhu (2014) who derive the policy variable based on the dynamic factor model of monetary policy indicators. In this paper we will further apply the notion from this strand of literature for several reasons. First, the variable representing a shadow policy rate could be implement as endogenous variable – it is reasonable to believe that the ECB monetary policy reflects the economic environment as well as it is being reflected. Second, because of the complexity of the monetary instruments and European government bond market we consider the index variable to be both appropriate and convenient for the analysis.

Our analysis is also related to the literature assessing the FA-VAR approach for monetary policy analysis. The concept was introduced by Bernanke *et al.* (2004) and among others rigorously discussed by Stock & Watson (2005). The main discussion is placed between the one-step Bayesian likelihood approach or two-step principal component approach of FA-VAR estimation. Soares (2011) adopted the two-step FA-VAR and articulated the base specification of monetary policy analysis for the European case. The inclusion of factors in the VAR allowed the author to depict the monetary policy effects more completely and to achieve responses easier to embrace from the theoretical perspective.

Chapter 3

ECB QE

3.1 What is QE?

The principal modus operandi conventionally used by ECB are the key interest rates – the rate for the deposit facility, the rate for the main refinancing operations and the rate for the marginal lending facility. The main decision making body of ECB – Governing Council – increases them in order to slow down overheating economy and decreases them to support the growth and inflationary pressures. Since the onset of the economic crisis in the Euro area (2009) the Governing Council repeatedly lowered all three rates until reaching the technical zero. Since June 2014 the rate for the deposit facility has been set even negative while other key rates close to zero. Due to the threat of deflation and economic growth below its long-term potential the ECB decided to introduce the programme of unconventional measures – Expanded Asset Purchase Programme (EAPP). It involves the large-scale purchases of various financial securities on the secondary market which increase the quantity of money in the economy and mechanically decrease the supply of purchased securities while affecting their prices and yields. The programmes are usually referred to as QE or Large-Scale Asset Purchases (LSAP). In the next part of this paper we will use the term QE as an abstract variable (which we approximate by various measures) and LSAP for the total purchases by ECB (not only the EAPP phase).

Although the LSAP tool is unconventional in its nature, it is executed through standard tool Open Market Operations (OMOs). One also needs to distinguish the QE from other unconventional monetary policy tools. For instance, the OMT are also proceeded via bond purchases. Nevertheless, the liquidity created is sterilized by offsetting operations[1]. The aim of OMT is to ensure the transmission of monetary policy throughout the Euro area member states, as such, its announcement itself could change the expectations and could be sufficient to generate desired effects. In contrast, the QE is meant to change expectations in the run and the increased money supply needs to precede such an effect (Pacces & Repasi 2015). The sterilization is then the essential difference between the EAPP and the LSAP programmes executed until. Nonetheless, as the full allotment was in place, the sterilization appears to be only a formal step. Therefore, we treat all the LSAP programmes as similar with respect to the impact on liquidity excess.

As indicated above, the EAPP is not the first use of LSAP by ECB. The various policy tools responding to the unstable ground of the Euro area as well as to the liquidity issues of the Euro area banks is summarized in the table 3.1. The Long-Term Refinancing Operations (LTRO) programme had significant effect on the central bank's balance sheet, nevertheless, from its nature it did not intend to increase the broad money in the economy and, thus, it should not be considered a part of the QE. However, in order to answer the question to which extent the composition of total assets increments is important, our analysis includes the total assets measure as well as this value netted of LTRO and MRO – in following parts of the paper we call this variable Net total assets. For complete discussion about the variables see the chapter 4.

Table 3.1: ECB policy tools after 2008

Year	Policy tool
2008	FRFA
2008, 2009, 2011	LTRO (6, 12 and 36 months)
2009, 2011	CBPP1 and CBPP2
2012	announcement of OMT
2013	Forward guidance
2014	TLTRO
2014	ABSPP and CBPP3
2015	EAPP

Source: Constâncio (2015)

[1]The sterilization is decided to be executed via auctions of adequate volumes of one week interest-bearing deposits at ECB which is the same sterilization used as for the SMP programme. Nonetheless, as in April 2016 no securities were purchased under the OMT programme.

3.2 EAPP programmes

This section describes the composition of the last LSAP programme. The EAPP is consisted of three programmes:

- Public Sector Purchase Programme (PSPP)
- Asset-Backed Securities Purchase Programme (ABSPP)
- Covered Bond Purchase Programme 3 (CBPP3)

The PSPP programme was initiated on 9 March 2015 and involved the purchase of the following securities:

- nominal and inflation-linked central government bonds
- bonds issued by recognized agencies, international organizations and multilateral development banks located in the Euro area

The distribution of the programme purchases among countries should on average follow the ECB's capital key, for more details see table A.1. The majority of total purchases, 88%, is said to be allocated among government bonds and securities of recognised agencies and the remaining 12% among securities issued by multilateral development banks and international organizations. In order to enhance market liquidity and collateral availability in the market the securities purchased under the PSPP are further – in a decentralised manner – available for securities lending by a number of Eurosystem central banks (European Central Bank 2015a).

The ABSPP started on 21/11/2014 and is intended to enhance the funding possibilities of banks and consequently to support the lending. The CBPP3 is already the third covered bond purchase programme of ECB. It supports the financing conditions in the Euro area and improves the transmission mechanism of monetary policy.

In total the EAPP involves monthly purchases of public and private sector securities amounting EUR 60 billion (increased to EUR 80 billion since April 2016) and is intended to last until the end of March 2017. In any case the programme will be continued until the Governing Council recognizes a sustained adjustment in the path of inflation which is consistent with its target of "below but close to 2%" in medium term (European Central Bank 2015a).

3.3 Hypothetical channels of ECB QE

The programmes are expected to work through several transmission channels. Let us now briefly discuss their nature.

Portfolio-balance channel: The quantitative easing signals the commitment of the ECB to keep interest rates low in the future. In the opposite case the increased interest rates would decrease the price of bonds held and represented a significant losses for the central bank. Lower yields on government bonds potentially encourage investors to search for the yield elsewhere, and hence the increased demand lowers the interest rates in riskier assets.
This process is driven by different sub-channels. As discussed by Krishnamurthy and Vissing-Jorgensen (2011) the QE potentially affects assets with different maturities via the so-called duration risk channel; since the securities are purchased by the central bank reserves the system acquires additional liquidity and the liquidity premium of the most liquid assets is suppressed – this sub-channel is called the liquidity channel; the scarcity of risk-free securities also affects their safety premium – this sub-channel is known as the safety premium channel; and finally the sub-channel named default risk channel states that the purchased assets could affect the size of default risk of low grade securities as well as its price evaluation.

Debt-service channel: With the exception of the liquidity channel all sub-channels of Portfolio-balance channel predict the decrease of the borrowing costs. Lowering the cost of debt service further stimulates consumption and investment. As the lower interest rates mitigate the crowding out effect, the efficiency of fiscal expansion is increased.

Exchange rate channel: Lower interest rates in the Euro area put downward pressure on the exchange rate with respect to other currencies and favor demand for domestic products both in foreign and domestic markets. This helps domestic producers and service providers, and improves the current account of the European balance of payment.

Credit channel: Even the part of the QE which is effected via non-bank institutions influences the balance sheet of the commercial banks. It increases their deposits and potentially allows them to promote lending. This channel is particularly difficult to estimate because of the identification problem. It is necessary to isolate changes in lending caused by changes in deposits, from changes in deposits caused by new lending (Butt *et al.* 2015). The data requirements therefore limits the rigorous analysis of the channel in this paper.

Wealth channel: The increased demand for assets supports their prices and thereby wealth of their holders. As shown among others by Sousa (2009) the financial wealth is closely related to the consumption levels. Therefore, we expect the QE to support the domestic consumption as the important part of GDP.

Inflation expectations channel: Since the reputation of the European Central Bank seems to stay solid and since the policy goal to higher inflation was well communicated with the public, the ECB's action increases the inflation in expectations and *ceteris paribus* lowers the real interest rates. Low real interest rate environment then supports the investments and consumption.

As well as many researchers the ECB emphasizes the portfolio-balance channel driven by lowering risk-free rate and supported by the preferred-habitat theory. The Bank further stresses the significance of forward guidance (Cœuré 2015). The announcement of EAPP in Euro area on 22/01/2015 was accompanied by a decline in both government and corporate debt yields and the forward interest rates across all maturities dropped as well. The more profound decline in the long-maturity bonds suggests that the duration channel is operational. In France the 10 and 20 year government bond yields dropped by 14 and 19 bp respectively. The corresponding figures for Spain are 17 and 32 bp.

3.4 Stylized facts

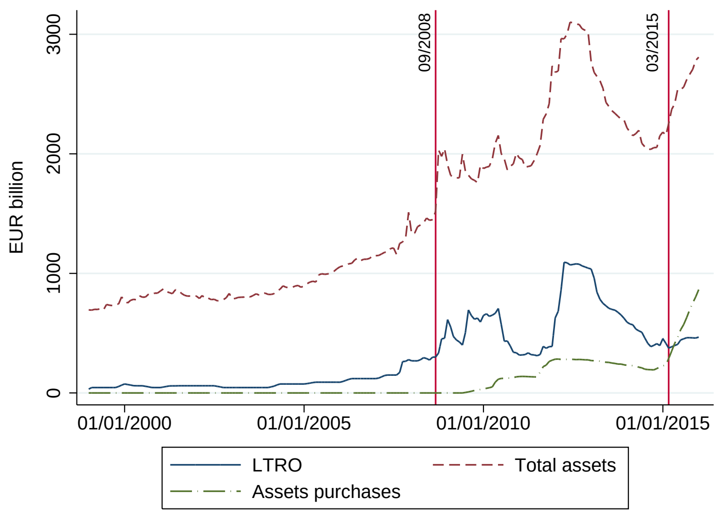
In this section we provide the stylized facts about the effects of the ECB QE on the economy. It is noteworthy that some effects could be the result of complex economic environment and further statistical analysis which we discuss in next chapters is necessary.

3.4.1 Twofold increase of total assets

The figure 3.1 indicates that before the crisis the ECB maintained its balance sheet size on a level around EUR 1T with the value of 1.5T in 2008. During the crisis period and until 2014 the level was mostly driven by the level of LTRO. In the mid of 2012 – combined with the initiated asset purchases programmes – it caused the total assets to reach the twofold levels of EUR 3T. The drop of LTRO share in the total assets starting in 2013 seems to be a natural com-

pletion of the LTRO programme. This is the advantage of LTRO in comparison with the LSAP programmes since the gradual termination was set and thus – disregarding the premature repayments – known by the ECB in advance.
From the economical perspective the sudden decrease of liquidity in the system in 2013 could have adverse effects on macroeconomic variables and only strengthened the statement "too little, too late". Nonetheless, from the statistical point of view, this helps the researchers to distinguish the effects of LTRO and LSAP as the major increase of purchases arose after the moderation of LTRO levels.

Figure 3.1: ECB total assets and LTRO

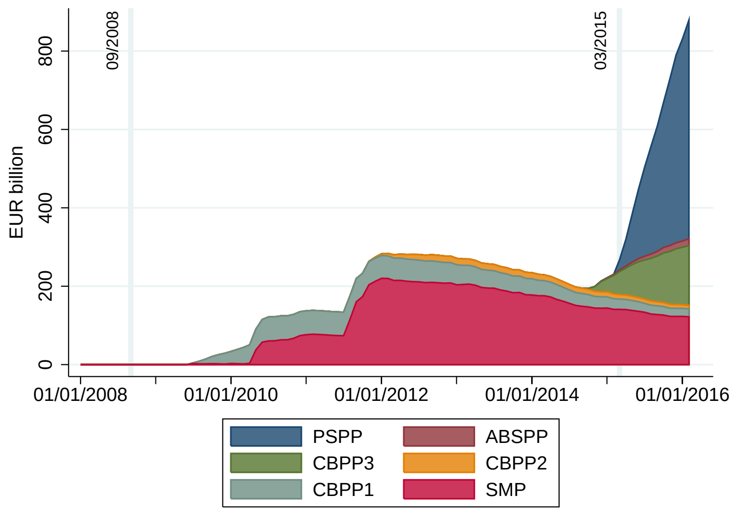


Source: Data from ECB, author's elaboration

3.4.2 PSPP as the most significant LSAP programme

The decomposition of individual EAPPs is portrayed in figure 3.2. It could be seen that the PSPP programme plays the major role in the EAPP and represents the principal channel which the ECB has chosen to increase the money supply. The monthly purchases under PSPP exceeds 80% of the EAPP programme.

Figure 3.2: ECB LSAP decomposition

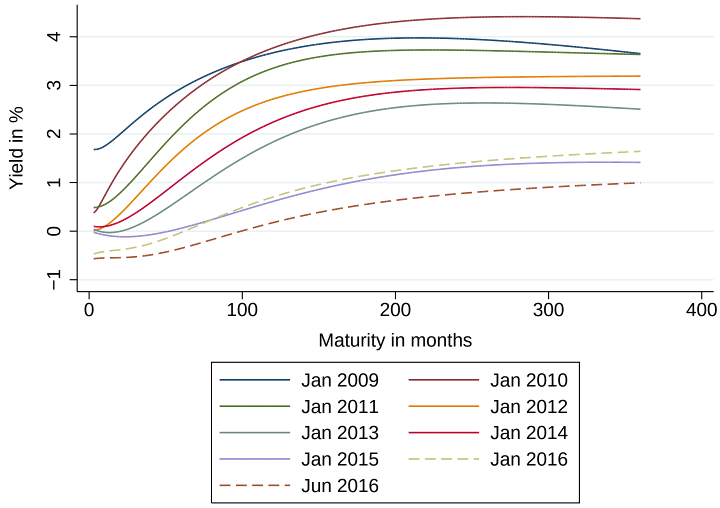


Note: The SMP programme was terminated in 2012 and the volumes held until maturity. The programme was officially replaced by OMT, though, no assets were purchased under this programme and the switch of programmes affected only the expectations.
Source: Data from ECB, author's elaboration

3.4.3 Yield curves of AAA government bonds flatten

The figure 3.3 displays the development of yield curves of EA countries government bonds rated as AAA. It is visible that the decline between the beginning of 2014 and 2015 is greater than the previous movements. This indicates the change of sentiment in the market ahead of the policy change and could be explained by anticipation of the policy action. Next interesting observations is the relatively negligible shift between the beginning of 2015 and 2016 where the influence PSPP programme is expected to be visible. Furthermore, if the notion of anticipation of EAPP programme is valid, one could see that during 2014 the market responded by an important drop of yields of assets with long-term maturities whereas the yields of assets with maturities up to 4 years declined only slightly. On the other hand, they were only the short-term assets which responded immediately to the shock in 2015, the long maturities reacted again, with about a year lag, in 2016. Overall, it seems that the anticipation of QE affects the long-term yields and the additional decline of yields, which comes when the purchases are in place, is uniformly distributed among maturities.

Figure 3.3: Yields of AAA bonds with maturities from 3 months to 30 years



Source: Data from ECB, author's elaboration

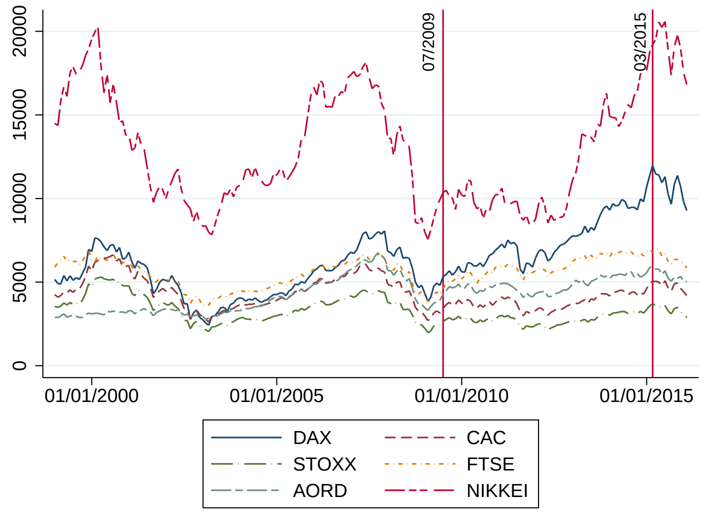
3.4.4 Disputable effect of QE on financial securities

The EAPP programmes potentially affects the financial market through various channels. To indicate the materiality of the effect it is convenient to compare the European stock indexes with the major world index which captures the market sentiment and is not likely to be affected by the QE – the one of ECB nor the own one. This is why we selected the Australian stock index (AORD) to represent the valuable benchmark. The development of ratios of the two principal indexes of European countries – German DAX and French CAC – with respect to AORD is captured in figure 3.5. It seems that after the programme initiation the DAX and CAC to some extent improved the development against the AORD. The volatility of different indexes and volatility of exchange rates though suggests that rigorous analytical approach is needed to evaluate the effect.

3.4.5 Varying response of M1 to LTRO and EAPP

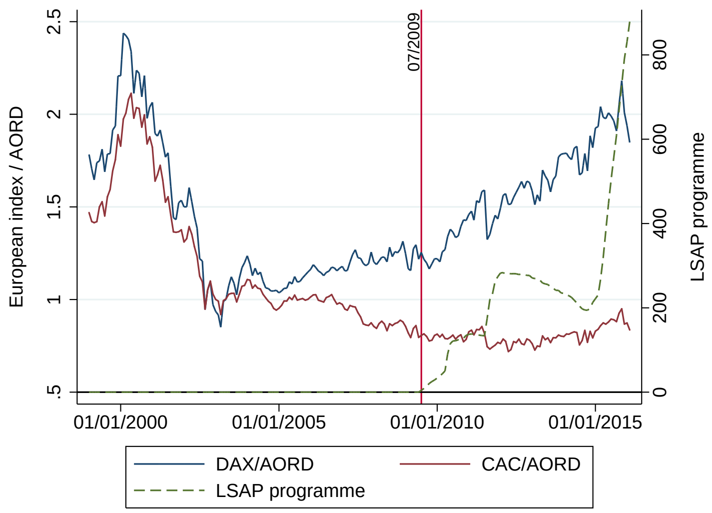
The figure 3.6 shows that during the LTRO programme the monetary base increased importantly. The effect on M1 aggregate is nevertheless lagged and

Figure 3.4: World stocks indexes



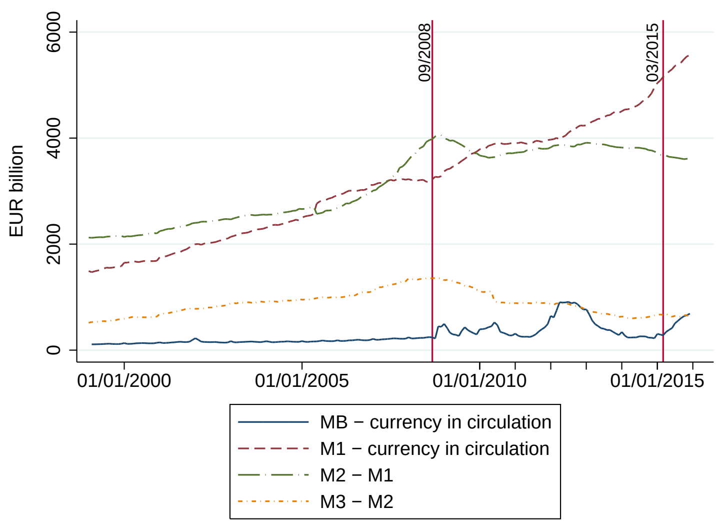
Source: Data from ECB and Yahoo finance, author's elaboration

Figure 3.5: Stock reaction to ECB LSAP



Source: Data from ECB and Yahoo finance, author's elaboration rather limited. This suggests that the commercial banks used the LTRO liquidity dominantly from the precautionary reasons and did not seek for higher yields. The increase of money base in 2015, in contrast, was reflected in the level of M1. This indicates that the EAPP programmes affected the broader notion of money than the LTRO. One needs to consider the fact that the EAPP was created under lower stress posed on banking system than the LTRO and that it can represent the leading force for the perceived difference. The effect on M2 and M3 monetary aggregates than appears to be driven by the M1 increase uniquely as the components specific for these aggregates did respond neither to LTRO nor LSAP.

Figure 3.6: ECB monetary aggregates

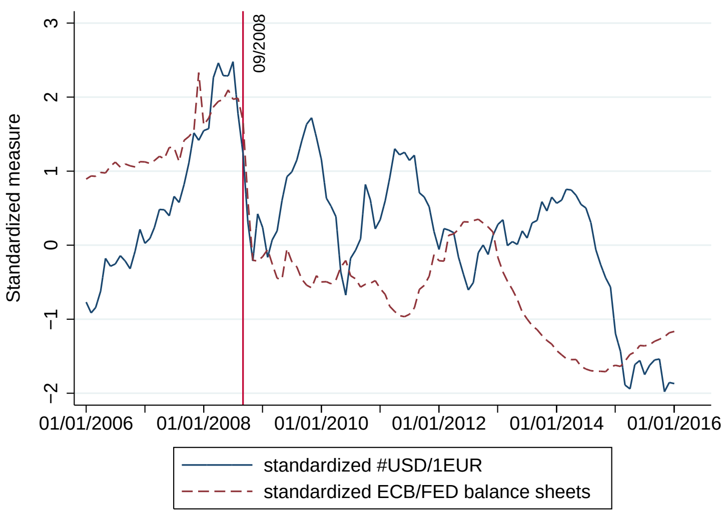


Source: Data from ECB, author's elaboration

3.4.6 ER movements driven by the balance sheet policies

The expectation of inflation associated with the increased money supply is in theory closely related to the variation of nominal exchange rate. We take the relative size of ECB and FED balance sheets and the exchange rate (#USD/1EUR) in standardized representation and display their development in the figure 3.7. The graphics shows that the depreciation of EUR currency due to the relative increase of ECB balance sheet size materialized especially between 2010 and 2015. This response coincides with the theory predictions.

Figure 3.7: ECB & FED relative balance sheet size and ER



Source: Data from ECB, author's elaboration

Chapter 4

Data and Methodology

Our main data source for monetary variables and output-related variables is ECB Statistical Data Warehouse. We also use the Bruegel dataset from World Bank for Real Effective Exchange Rate (REER) and Fundamental Equilibrium Exchange Rate (FEER), Yahoo finance for stock indexes and Reuters Eikon for 12M expected inflation. The dataset has monthly frequency and spans the period from January 1999 to December 2015. Next to the data provided by aforementioned statistical offices we construct a few new variables better suiting our purpose. In order to capture the Euro area (EA) long-term government bond interest rates we construct the harmonized 10 year interest rates as the weighted sum of EA national government bonds interest rates. The weights are assigned based on the capital key of ECB which corresponds to the distribution of PSPP purchases – see Appendix A for details. We further create a variable Net total assets capturing the central bank balance sheet enlargement and affecting the money supply rather than tackling the bank liquidity issues. This measure is constructed by subtracting the main refinancing operations and long-term refinancing operations from the Total assets. The construction of Conventional Monetary Indicator (CMI), Unconventional Monetary Indicator (UMI), Synthetic Monetary Indicator (SMI) and Shadow rate variable is discussed below.

4.1 Conventional Monetary Indicator

It is necessary for us to control the effects of conventional monetary policy tools in the respective VAR models. In the pre-crisis period the main policy tool of ECB was constituted by the key interest rates directly linked to other short interest rates. Nonetheless, it is not convenient to include all the short interest rates to the benchmark autoregressive model and so we constitute the indicator variable. We thus select the Main refinancing operation rate, Deposit facility rate, Marginal lending facility rate, Euro Overnight Index Average (EONIA), and 1,2 and 6-month Euro Interbank Offered Rate (EURIBOR) to constitute the Conventional Monetary Indicator. We intentionally omit to include the monetary aggregates and exchange rate since we want to control and study these variables separately. For the purpose of variable reduction we use the PCA technique on standardized variables and retain the first component which accounts for the most of variation in the data. We further refer to this principal component as the CMI.

4.2 Synthetic and Unconventional Monetary Indicator

The variables constituting the UMI are selected based on their close relationship to the policy actions of ECB. Following Lombardi & Zhu (2014) and Kucharcukova *et al.* (2014) we construct the UMI based on the following four blocks. Block I is consisted of variables affecting the entire yield curve. Block II includes the monetary aggregates which arguably remains relevant instrument of monetary policy. Block III is then consisted of selected ECB balance sheet items which provide important information especially about ECB's LSAP and maturity extension operations. Finally, the Block IV includes the nominal exchange rate of #USD/1EUR.

The indicator is constructed by the Principal Components Analysis (PCA) method and, since the model assumes stationarity of data, except the Block I we use the variables in the year-to-year percentage change form. Furthermore, in order to reflect the appropriate direction of tightening and loosing monetary policy, the variables in the Block II and III are used with the reversed sign. The complete list of variables used for UMI is as follows:

Block I: Interest rates

- Euro Overnight Index Average
- Main refinancing operation rate
- 1M, 3M and 12M EURIBOR

- Harmonized 10-year yields on sovereign bonds of Euro area countries

Block II: Monetary aggregates

- MB, M1, M2 and M3

Block III: Selected ECB balance sheet items

- Total assets
- Large-Scale Asset Purchases
- Long-term refinancing operations
- Liabilities of ECB to Euro area Monetary Financial Institutions related to monetary operations

Block IV: Exchange rates

- Nominal exchange rate of #USD/1EUR.

4.2.1 Principal components analysis

We use the described set of variables as the input to the PCA model and construct the SMI and the Unconventional Monetary Indicator (UMI) from the retained components. The Kaiser's eigenvalue-greater-than-one rule suggests to retain 5 factors whereas the Cattel's Scree test only 3, see figure 4.1. Since the 3 components failed to explain about 80% of principal part of QE – LSAP – we take the Kaiser's test as relevant and retain 5 components. The table 4.1 then displays the unrotated component loadings.

4.2.2 Interpretation

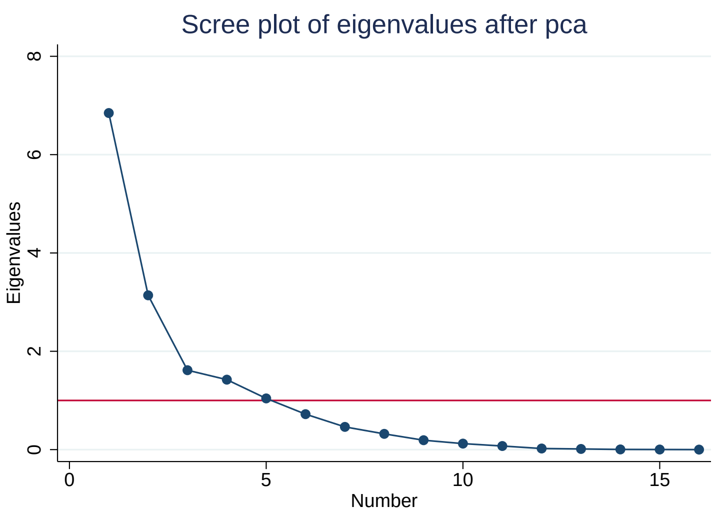
From the table of loadings 4.1 it could be seen that the first component explains mainly the conventional instruments – interest rates and M2, M3 monetary aggregates. The Total assets and money base are explained mostly by the second component. The LSAP and ER are then associated with the fourth and fifth component mainly. Overall, though, apart from the first component it is difficult to associate the component with specific variables which helps to advocate our further aggregation – construction of SMI and UMI indicators. We sum all the five components weighted by their variances to construct the SMI

Table 4.1: PCA loadings

Variable	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Uniqueness
MRO rate	0.3699	0.0806	0.0837	-0.0078	0.1231	0.01543
EONIA	0.3689	0.1086	0.0126	-0.0057	0.1132	0.01737
1M EURIBOR	0.3726	0.095	0.0289	0.0121	0.0996	0.009107
3M EURIBOR	0.3742	0.0744	0.0555	0.0154	0.0928	0.009625
12M EURIBOR	0.3698	0.0576	0.1112	0.0305	0.1078	0.02004
HIR10y	0.2716	0.043	0.4131	0.0829	0.0834	0.1966
- MB yy %Δ	-0.0394	0.5246	0.012	-0.0051	0.055	0.1222
- M1 yy %Δ	0.0477	0.0594	0.5619	0.2803	-0.4253	0.1631
- M2 yy %Δ	-0.2866	0.0648	0.4232	0.1442	0.1706	0.07534
- M3 yy %Δ	-0.3134	0.0425	0.3792	0.1326	0.1604	0.03792
- MRO yy %Δ	0.0375	-0.148	0.1642	-0.6748	-0.1092	0.2177
- LTRO yy %Δ	-0.081	0.4508	-0.2082	0.1963	0.2651	0.1191
- Total assets yy %Δ	-0.1025	0.5055	-0.073	-0.1564	0.0489	0.08014
- LSAP yy %Δ	0.0929	0.0718	-0.2766	0.4345	-0.5806	0.1814
- Liabilities to MFI yy %Δ	-0.1402	0.3568	0.1115	-0.2817	-0.1785	0.2996
ER yy %Δ	-0.0823	-0.2534	-0.0505	0.2971	0.4926	0.3697

Note: We emphasized the loadings greater than 0.25 in absolute value. The only variables where an important part remained unexplained are exchange rate and liabilities for MFI.
Source: Author's elaboration

Figure 4.1: Cattel's Scree Test for number of retained factors



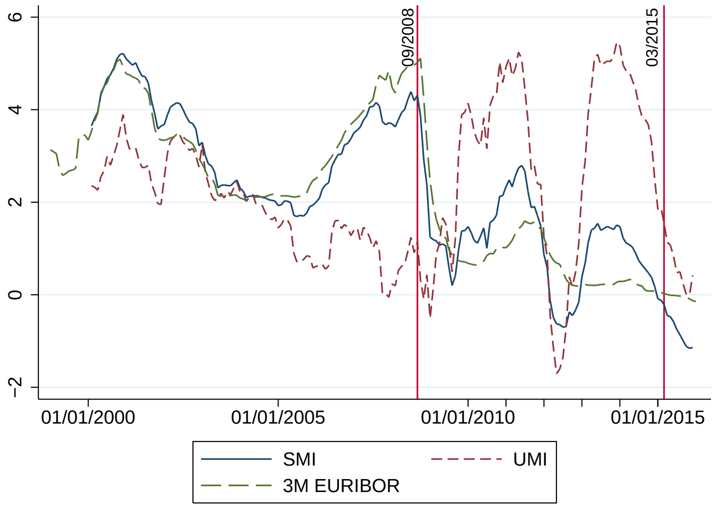
Source: author's elaboration

indicator and all the five but the first to construct the UMI. Next to UMI in further analysis we will also use the first retained component – to capture the conventional monetary policy as orthogonal to the UMI. The SMI, on the other hand, is not used in VAR models and we consider it only for reference.

The figure 4.2 displays the three time series, the 3M EURIBOR, SMI and UMI. It is important to consider the similarity of SMI to the 3M EURIBOR development ahead of the crisis. This suggests that the monetary policy before 2008 is related to the short-term interest rate much more importantly than to the rest of considered variables. The SMI suggests a slightly eased monetary policy after 2007 then the EURIBOR market rate presumed. After 2009, when the LSAP programmes were initiated, the SMI started to reflect the unconventional parts of policies. The figure further pictures the important policy easing in 2011 as a result of LTRO, followed by the policy tightening in 2013 because of LTRO repayments. After 2014 the SMI indicator falls again probably as a result of new LSAP programmes. Since the purchases under the EAPP are designed to increase the balance sheet at linear rate (until April 2016), the year to year percentage change of Total assets decreases rapidly in the end of 2015. This is the main force of the indicated beginning of less expansionary policy driven by its unconventional part at the end of 2015. It is noteworthy that the first component of PCA analysis follows the behavior of the 3M EURIBOR in the whole dataset. One could compare the similarity of 3M EURIBOR, CMI and first retained factor of previous PCA analysis in the figure B.1 of Appendix B.

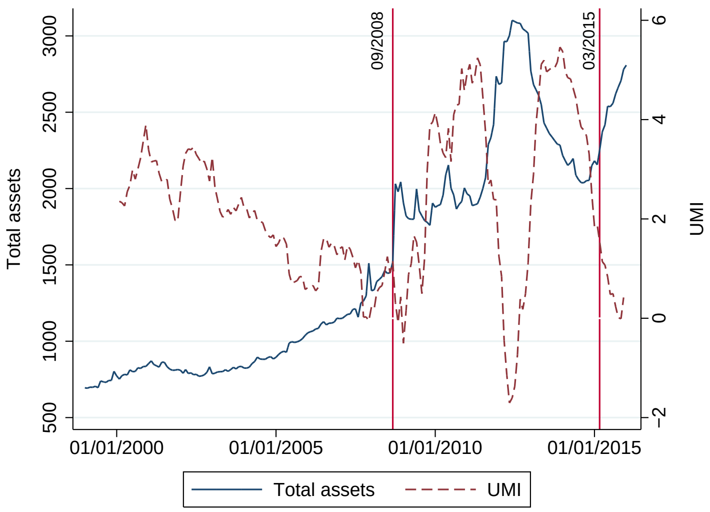
It could be noticed in figure 4.3 that the UMI indicator is closely negatively related to the changes of Total assets. Hence, regarding those two policy variables we expect the estimates of dynamic responses produced by VAR models to be similar in size (and opposite in sign).

Figure 4.2: SMI, UMI and 3M EURIBOR



Source: author's elaboration

Figure 4.3: UMI and Total assets



Source: author's elaboration

4.2.3 Shadow rate

Since the deposit rate decreased to 0.25% in April 2009 and remained stuck to zero until the end of our dataset, we consider the ZLB to be binding in this period. The transmission channel of the key interest rate was well studied for the non-crisis periods where the ZLB is not binding and it is therefore useful to estimate the development of the rate assuming the possibility of negative values. We thus apply the linear regression to estimate the relationship between the Deposit facility rate and the ECB balance sheet size. The model does not intend to find causal relationship but rather correlations. The articulation of the model is as follows:

$$Deposit\ rate = \alpha + \beta_1 * 3M\text{EURIBOR} + \beta_2 * \text{MRO}\ yy\%\Delta + \beta_3 * Total\ assets\ yy\%\Delta + \epsilon \tag{4.1}$$

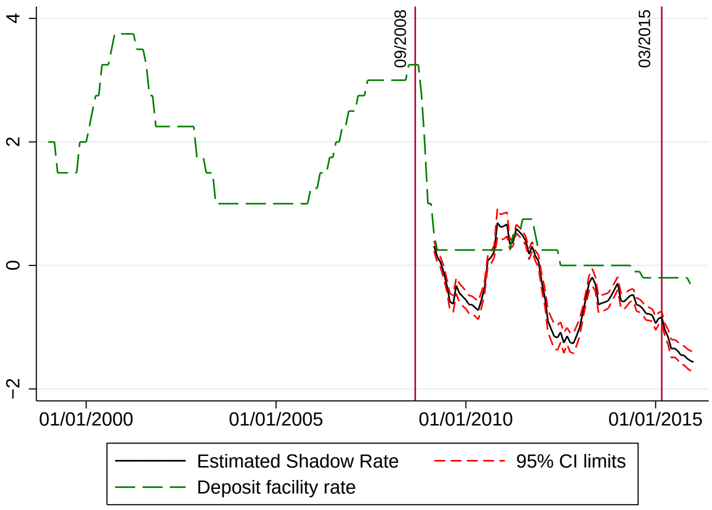
The regression takes the three month EURIBOR, year to year percentage changes of MRO level and year to year percentage changes of ECB Total assets as the independent variables. The coefficients are estimated for the period before the ZLB started to be binding and they are used for in-sample prediction of the Deposit rate development afterwards. The regression is based on rather strong assumption of the balance sheet composition irrelevance. The EURIBOR and Deposit facility rate are not stationary, though, they are cointegrated. Their causal relationship is probably reverse to the modeled one but the creation of Shadow rate does not rely on the correct causality direction. We present the regression results in table 4.2 and prediction in figure 4.4. It is noteworthy that the predictions are similar in size to the predictions from models proposed by Lombardi & Zhu (2014) and Wu & Xia (2014) – as estimated by ČNB Sekce měnová (2015).

Table 4.2: Shadow rate regression

	Dependent variable:
	Deposit rate
Intercept	-1.067***
	(0.060)
3M EURIBOR	0.949***
	(0.019)
MRO *yy* %Δ	0.158***
	(0.030)
Total assets *yy* %Δ	-0.183***
	(0.026)
Observations	110
R^2	0.9770
Adjusted R^2	0.9763
Residual Std. Error	0.14437 (df = 106)
F Statistic	1202.490** (df = 3; 106)
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: author's elaboration

Figure 4.4: Shadow rate



Source: author's elaboration

4.3 VAR models

4.3.1 S-VAR

The S-VAR econometric model represents a popular tool to analyze the conventional monetary policy, in the European context it was used for instance by Peersman & Smets (2001), and we believe that it also is a convenient tool to estimate the principal effects of QE. This is why we employ S-VAR model for the benchmark estimation. The model includes 7 endogenous variables – they are output measured by the percentage deviation from the Hodrick–Prescott (HP) trend of linearly interpolated quarterly GDP (and monthly IPI for the robustness check), price level expressed as core HICP, the unconventional monetary policy measure, short interest rate factor representing the conventional monetary policy, harmonized 10 year interest rate on EA countries government bonds, #USD/1EUR exchange rate and CISS indicator of systemic stress, and 1 exogenous variable – year to year % change of EA countries government spending. The interest rates are expressed in levels, the CISS variable in log differences and the other variables are explored in logarithms which, as shown by Sims *et al.* (1990), allows for co-integration process.

We use monthly data and evaluate the models both during the whole dataset and during the recession period (since 2008 till the end of 2015). The whole dataset is useful as the VAR models are data demanding whereas the truncated dataset is necessary as the behavior of financial institution, firms and households likely differs from the non-recession time.

In the benchmark specification we use the volume of Total assets net of LTRO and MRO (noted as Net total assets) to measure the quantitative easing and the CMI defined in the previous chapter to reflect the conventional part of applied monetary policy. For the robustness check we employ the ECB Total assets, the volume of purchased assets through LSAP programmes of ECB, UMI, and Shadow rate. In order to capture the financial system condition we include the Composite Indicator of Systemic Stress (CISS). This index is constructed from 15 individual financial stress measures related to financial intermediaries and money, bond, equity and foreign exchange markets. The index captures the instability of financial market in the context of Euro area, for details see Holló *et al.* (2012). As Gambacorta *et al.* (2014) emphasized, disregarding the endogenous part of unconventional monetary response to the economic stress could cause the estimates to be biased and, therefore, the CISS should not be omitted. We also employed the government spending as exogenous variable since the consolidation of public finance during the crisis is arguably pro-cyclical and did not respond endogenously to the macroeconomic conditions.

Identification of S-VAR

To identify the shocks we use the general AB model with the Cholesky restrictions. The model is represented as follows:

$$\begin{aligned} Y &= \Theta(L)Y + \epsilon \\ (I_k - \Theta(L))Y &= \epsilon \\ A(I_k - \Theta(L))Y &= A\epsilon = B\zeta \end{aligned} \tag{4.2}$$

where Y is a vector of k endogenous variables, $\Theta(L)$ a matrix polynomial of the lag operator L, ϵ is vector of innovations, and B represents the contemporaneous impact matrix of the mutually orthogonalized disturbances ζ. The ordering of variables in Y is GDP, HICP, CMI, Net total assets, HIR10y, ER and CISS, and the respective restrictions on A and B are as follows:

$$\begin{aligned} A &= \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ . & 1 & 0 & 0 & 0 & 0 & 0 \\ . & . & 1 & 0 & 0 & 0 & 0 \\ . & . & . & 1 & 0 & 0 & 0 \\ . & . & . & . & 1 & 0 & 0 \\ . & . & . & . & . & 1 & 0 \\ . & . & . & . & . & . & 1 \end{bmatrix} \\ B &= \begin{bmatrix} . & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & . & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & . & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & . & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & . & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & . & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & . \end{bmatrix} \end{aligned} \tag{4.3}$$

The ordering assumes that CISS indicator of systemic stress is the most exogenous (the fastest) variable which responds contemporaneously to all other variables from the model – including the ER. Furthermore, the CISS is restricted not to affect the level of other variables within the period. In contrast, the industrial production is assumed to affect all the other variables within the same period but is not influenced by any. We further assume that the change of price level could affect the interest rates as they involve the nominal component but their change affects the inflation only with a lag.

The tricky part of the ordering assumption lies in the ordering of the triple of short interest rate CMI, long interest rate HIR10y and unconventional measure, and the pair of exchange rate and systemic stress indicator. In the base model ordering we assume that the short interest rate responds to the unconventional measure only with a lag – possibly through the long-term interest rate – but the long-term interest rate could be affected immediately as its change is in the focus of the policy. We also assume that the short-term interest rate could contemporaneously influence the unconventional monetary policy since when the policy is in place, in our opinion, it is plausible to vary the size according to the needs. The short-term interest rate is also allowed to affect the long-term interest rate within the same period. This might be advocated by the notion that in normal times the rates of longer maturities are derived from the rates of shorter maturities which the conventional monetary policy relies on. Nevertheless, we undergo the robust check for the ordering of variables and find qualitatively no perturbation of results, as one could see in section C.3 of Appendix C.

In case of the Shadow rate measure of unconventional monetary policy we do not include the CMI in the model as the Shadow rate itself reflects the conventional policy, the ordering then remains the same as in the base model. In case of the UMI measure, instead of CMI we then use the first component retained from the PCA analysis related to UMI construction. The components are orthogonal which helps the assumption of orthogonality of shocks to be valid.

The FPE and AIC tests for the appropriate number of lags indicated that the 2 lags should be used. As other tests showed 1 or 4 lags to be appropriate we preferred the middle path. All the models satisfy the stability condition. For the tests results see tables C.1 and C.2 in Appendix C.

4.3.2 FA-VAR

The FA-VAR model was first introduced by Bernanke *et al.* (2004) and used for unconventional monetary policy analysis among others by Soares (2011). This approach combines the standard S-VAR analysis with the factor analysis. There are two ways to estimate the FA-VAR model. First approach uses two-step procedure where the first step involves the Principal Components Analysis to generate the estimates of latent factors and the second step applies these as the standard VAR variables. The second approach exploits the Bayesian likelihood method to estimate the VAR and factors at once. The two-step approach is semi-parametric, as opposed to the parametric Bayesian method, which should bring lower dependence on the correct specification of the model. Moreover, according to Bernanke *et al.* (2004) the more burdensome one-step approach does not provide any significant advantage and so we decided to apply the former one – two-step approach. For the estimation we employ the code of Koop & Korobilis (2009).

Let Z be the matrix of K time-series variables, i.e. $Z \in K \times T$. The relationship among those variables could be analyzed by VAR or other approaches. In our base model specification Z includes Unemployment rate, IPI, HICP and the measure of unconventional monetary policy. We believe that this set of variables is missing information important for the analysis. The assumption is that the additional information could be summarized by the matrix F of unobserved factors, where $F \in S \times T$ and S being small. We think of F as representing the variables of latent factors for conventional monetary policy and financial market conditions.

The dynamics of the system could be characterized by:

$$\begin{bmatrix} Z_t \\ F_t \end{bmatrix} = \Theta(L) \times \begin{bmatrix} Z_{t-1} \\ F_{t-1} \end{bmatrix} + \zeta_t, \tag{4.4}$$

where $\Theta(L)$ is a lag polynomial of finite order p which contains the recursive order restrictions. The error term ζ is mean zero with variance-covariance matrix Ω.

Let us denote Y the available information set – N time series. We can further assume that the relation between Y_t and the observed variables Z_t and the factors F_t can be expressed in the following (static) representation of the dynamic factor model:

$$Y_t = \Lambda_F \times F_t + \Lambda_Z \times Z_t + \zeta_t, \tag{4.5}$$

where $\Lambda_F \in N \times S$ matrix of factor loadings, $\Lambda_Z \in N \times K$ and $\zeta_t \in N \times 1$ is vector of error terms which are weakly cross-sectionally and serially correlated and with mean zero.

In general the vector F_t could include the lagged values of factors, nonetheless, the two-step approach does not exploit the dynamic dependence and the static formulation and so does not involve any hidden structure. Since we assume that $K + S << N$, the FA-VAR can proceed noticeably more information than standard VAR models do. In order to calculate the confidence intervals for the impulse response functions which take into account the estimation of factors we use the boot strap method proposed by Kilian (1998).

Identification of FA-VAR

The two-step approach uses the whole available information set Y in the PCA analysis which generates the estimates of $C(F, Z)$, the set of $S+K$ components. It means that it does not use the information about the observability of Z. However, it was shown by Stock & Watson (2002) that, as far as N is large and the $S + K$ is at least the number of true latent factors in the series, the components recover the space of (F_t, Z_t) consistently. Since the $\hat{C}(F_t, Z_t)$ infers with the unconventional monetary policy variable included in Z, the next step is to filter this information from the set of components. The suggested procedure employs the multivariate multiple regression of:

$$\hat{C}(F_t, Z_t) = \beta_1 * \hat{C}(F_t) + \beta_2 * policy\ variable, \tag{4.6}$$

where the $\hat{C}(F_t)$ is obtained from the PCA analysis of variables which are assumed not to be affected by the unconventional monetary policy within the period of shock occurrence. The $\hat{F}_t$, used in the VAR model, is then obtained as the difference between $\hat{C}(F_t, Z_t)$ and the unconventional monetary policy variable multiplied by the regression coefficient. For this purpose we separate the variables of Y_t into two groups, the slow-moving and fast-moving. The former are variable which are supposed not to respond contemporaneously to shocks in monetary policy. On the contrary, the latter are allowed to respond to the policy shocks in the same period. We further follow the methodology of the Bernanke *et al.* (2004) which employs the recursive ordering with the policy variable ordered as last to identify the related VAR model. The list of variables used together with the transformation and assignment into the group of slow-moving variables is displayed in the table 4.3.

Table 4.3: FA-VAR variables ordering and transformation

Variable name	Transformation code	Slow (1 if yes)
Deposit facility rate	2	1
MRO rate	2	1
EONIA	2	0
1M EURIBOR	2	0
12M EURIBOR	2	0
Household borrowing cost	2	0
Corporate borrowing cost	2	0
Long-term borrowing cost	2	0
Short-term borrowing cost	2	0
Households mortgages >10y	2	0
Borrowing cost for big NFC loans <1y	2	0
Borrowing cost for big NFC loans 1-5y	2	0
Borrowing cost for big NFC loans >5y	2	0
MRO	5	0
LTRO	5	0
MB	7	0
M1	7	1
M2	7	1
M3	7	1
Deposits	5	1
Currency in circulation	7	1
Liabilities to MFI	7	1
ER	4	0
REER	4	0
NEER	4	0
PPI	5	1
1Y inflation expectation	1	0
STOXX to AORD	2	0
DAX to AORD	2	0
CAC to AORD	2	0
HIR10y	2	0
Sentiment	5	0
CISS	5	0
Small loans for NFC <1y	1	1
Small loans for NFC 1-5y	1	1
Small loans for NFC >5y	1	1
Big loans for NFC <1y	1	1
Big loans for NFC 1-5y	1	1
Big loans for NFC >5y	1	1
Consumer loans <1y	1	1
Consumer loans 1-5y	1	1
Consumer loans >5y	1	1
AAA yields 1y	2	0
AAA yields 3y	2	0
AAA yields 5y	2	0
AAA yields 10y	2	0
AAA yields 20y	2	0
All yields 1y	2	0
All yields 3y	2	0
All yields 5y	2	0
All yields 10y	2	0
All yields 20y	2	0

Note: Transformation code 1 is the original data, 2 stands for first difference, 4 is the natural logarithm, 5 log first difference and 7 detrend log using 1 sided HP detrending for monthly data. Slow variables are assumed not to be affected by the monetary policy shock in the period when the shock occurs.
Source: Author's elaboration

Chapter 5

Estimation results

The objective of our analysis is to capture the effects of ECB's QE by different analytical approaches and to draw the conclusion based on the commonality of estimates. In this regard we apply 2 different modeling approaches – S-VAR and FA-VAR – as well as 5 different policy variables – Total assets, Net total assets, purchased assets (LSAP), UMI and Shadow rate. For definition of the policy variables see chapter 4. Due to the probable structural break in 2008/2009 we assume the dynamic responses to the policy variable shocks to differ noticeably between the crisis period and whole dataset, and since we consider the crisis period to be more policy- and research-relevant we will put greater weight on the estimates generated from the respective data.

In this chapter we consider the generated impulse response functions and elaborate on their statistical and economic significance.

5.1 S-VAR effects

5.1.1 Crisis period

The impulse response functions generated by our baseline S-VAR models indicate similar dynamics. We are especially interested in the effects of the policy shock on the price level, nominal exchange rate and on the long-term interest rate. The variables are expressed as natural logarithm of core HICP, natural logarithm of #USD/1EUR exchange rate and the weighted sum of interest rates on 10 year government bonds (HIR10y) respectively. The figures of impulse response functions of standardized variables are displayed below the text of this section.

The common effect of all policy variables is the statistically significant increase of the price level and the currency depreciation after the policy easing shock. The increase of price level, though, seems to be economically unimportant. In order to produce the estimated 1% growth of the price level for each 1 standard deviation shock, the estimated response of the standardized HICP variable should be roughly 0.6. The S-VAR estimates, nevertheless, show the responses of about one order of magnitude lower. Moreover, the asset purchases under the QE programme in 2015 do not correspond to the whole 1 standard deviation in the policy variables. In case of the Total assets it represents approximately 1/2 of the standard deviation, for Net total assets it is 1 standard deviation rise, 1/4 of LSAP variable, (-)1/2 standard deviation of UMI and about (-)1/2 standard deviation in case of Shadow rate, for the development of standardized policy variables see figures E.1 and E.2 in Appendix E. Disregarding the fact that the VAR approach models only the response to the unanticipated shocks we take the mentioned changes as the policy shocks and apply them to quantify the counterfactual effects of the policy action. Using the estimates of impulse responses and the transformations described in Appendix F we quantify the QE effect on the economy. The results are presented in the table 5.1.

We estimate the price level to increase by about 9 bp in case of Net total assets. This is the maximum estimate among all S-VAR configurations considered. It is noteworthy that albeit the effect is minor, the significance is robust among policy variables and even such a minor effect is relevant in the crisis period when the economy is struggling and threatened by the possibility of deflation.

In contrast, the estimated response of the nominal exchange rate happens to be more policy relevant. The estimated depreciation varies between insignificant for the LSAP measure to about 1.5% in case of Net total assets. This effect is not stable and diminishes in time, after the period of 12 months it becomes insignificant. We will discuss the possible channels related to the exchange rate in the next chapter.

The principal goal of the QE is to flatten the yield curves. Since the purchases are focused on the government bonds with the maturity longer than 3 years, it is informative to consider the materiality of this effect. This is why we include the HIR10y measure into the model. The policy shock seems to reduce the yields in the long run but the effect is significant only marginally. Furthermore, the dynamics of the response differs among policy variables. In case of the LSAP and UMI the floor occurs about 5 months after the shock and gradually diminishes afterwards. In case of the Total assets and Net total assets shock the negative effect on the long-term yields appears to materialize after about a year. Overall, the LSAP is estimated to have the most important effect on the long-term government yields and reduced them by 7 bp just upon the shock.

The S-VAR model analyzes also the impact on the short-term interest rates as approximated by the CMI. The effect has intuitive direction, the rates decline as the result of the policy shock. The size of the effect is in order of basis points with the largest impact from the Net total assets variable. Since the standard deviation of CMI is almost the same as the one of the EURIBOR 1M, the estimates could be considered as the change of this interbank offered rate.

The effect on the GDP is positive in the first periods in cases of Net total assets, Total assets and LSAP unconventional policy measures. The estimates are 4.2, 1.4 and 1.4 bp respectively. In case of the Shadow rate the effect is positive in the long run and the dynamics follows the usual path of the production response to the short-term interest rate shock. The estimates themselves are nonetheless very limited and suggest that the ECB QE programmes had only minor – if any – effect on the production levels. Furthermore, it is noteworthy that the robust check using the alternative measure of the economic production, IPI, showed insignificant hikes and even significant drops of the production after the shock in the S-VAR model – which only advocates the evidence of insignificant production support.

The final effect measured by the S-VAR analysis is the impact on the financial stress. Counter-intuitively the estimates show the sudden increase in CISS after the policy shock and gradual decrease under the initial level. One would expect the very opposite dynamics. The initial increase is estimated to be 8 pp in maximum and long run effect to be -3 pp the lowest. This could happen due to the varying effects on different segments of the financial market which are aggregated in the CISS measure.

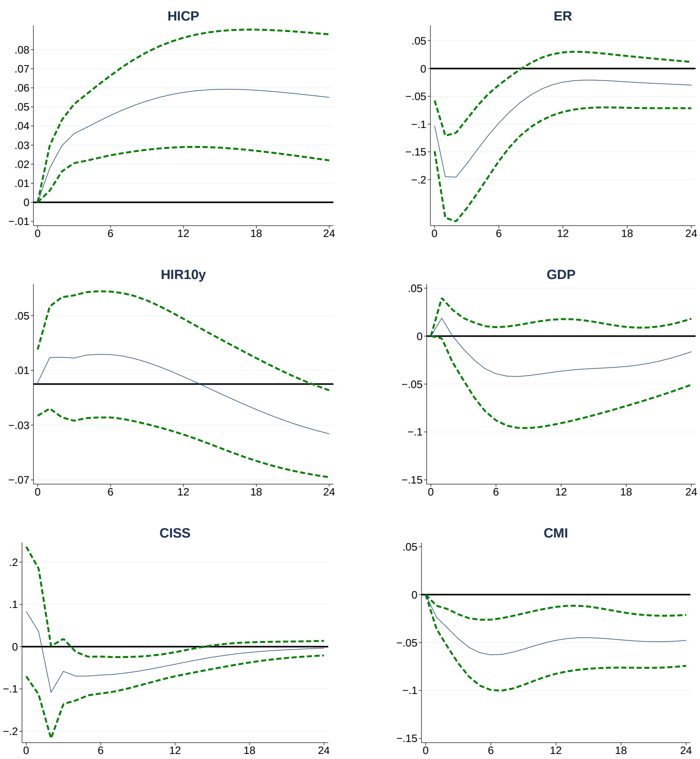
Table 5.1: S-VAR effects (in pp)

S-VAR	HICP	HIR10y beginning	HIR10y end	ER	GDP beginning	GDP end	CISS beginning	CISS end	CMI
Net total assets	0.090	0.022	-0.031	-1.510	0.042	0.000	6.177	-10.252	-0.095
Total assets	0.045	0.011	-0.020	-0.891	0.014	-0.021	1.807	-4.412	-0.041
LSAP	0.009	-0.070	0.000	-0.112	0.014	0.000	-3.403	-1.559	-0.007
UMI	0.023	-0.020	-0.011	-0.802	-0.028	0.000	3.533	-4.412	-0.034
Shadow rate	0.030	0.006	-0.017	-0.357	-0.028	0.035	1.380	-1.559	NA

Note: The rates HIR10y and CMI are expressed in absolute changes, the other variables are expressed in % change from the levels as in December 2014. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F. In case of UMI the Component 1 from SMI PCA analysis is used instead of the CMI.
Source: Author's elaboration

Total assets

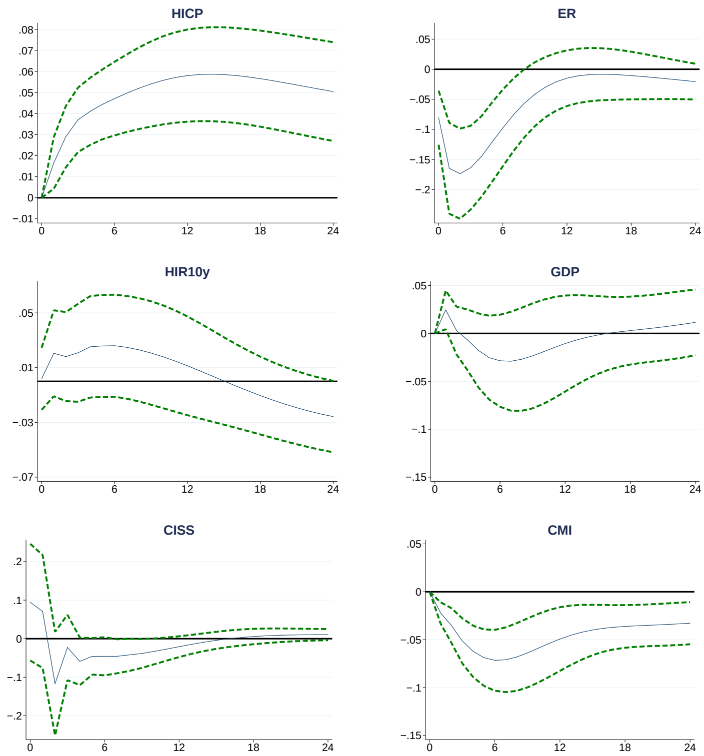
Figure 5.1: S-VAR variables responses to the Total assets shock



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

Net total assets

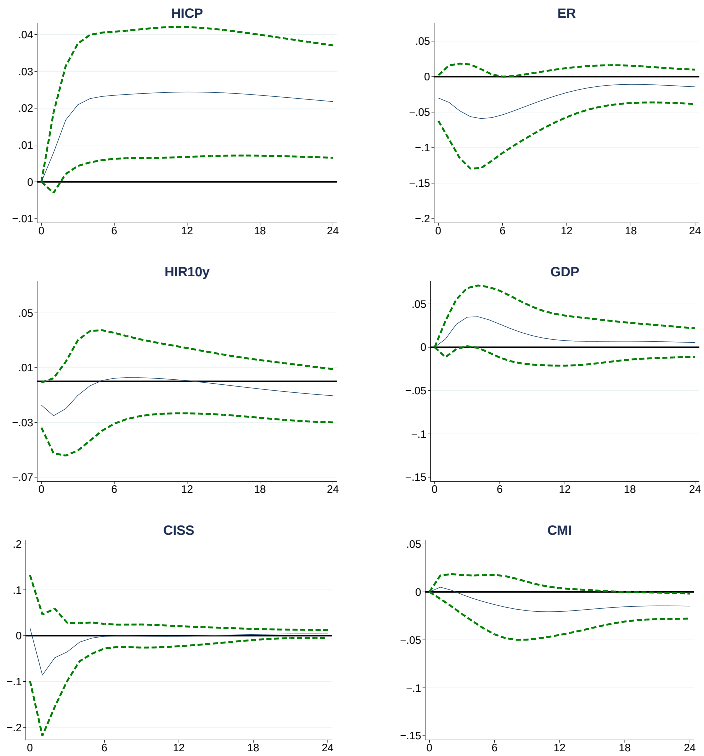
Figure 5.2: S-VAR variables responses to the Net total assets shock



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

LSAP

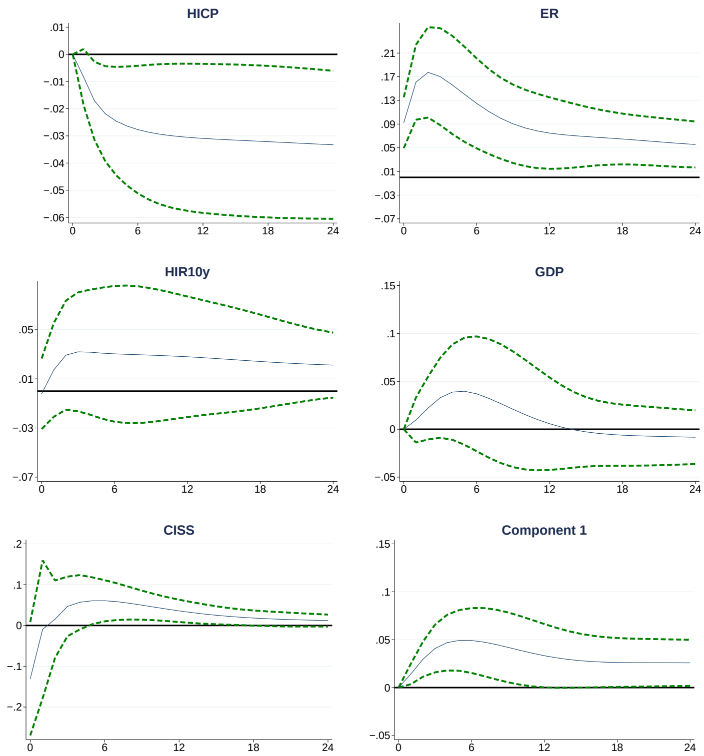
Figure 5.3: S-VAR variables responses to the LSAP shock



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

UMI

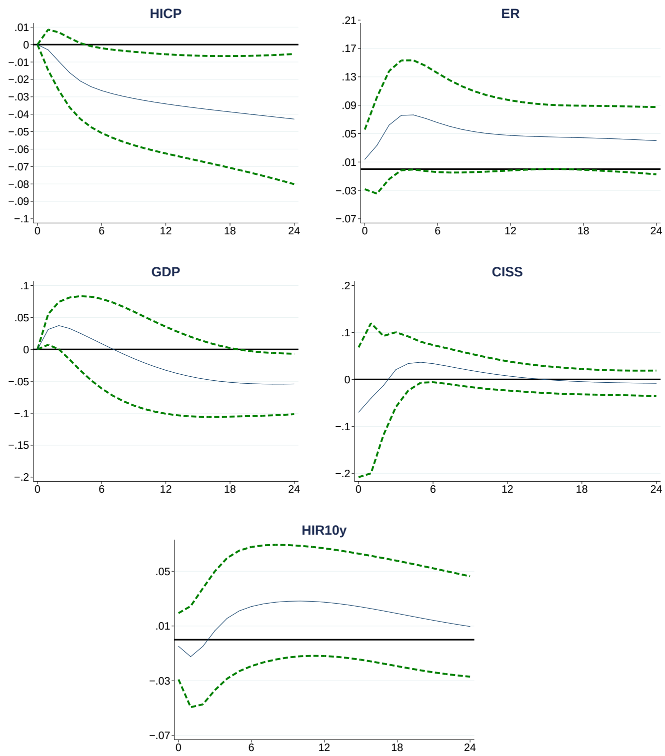
Figure 5.4: S-VAR variables responses to the UMI shock



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

Shadow rate

Figure 5.5: S-VAR variables responses to the Shadow rate shock



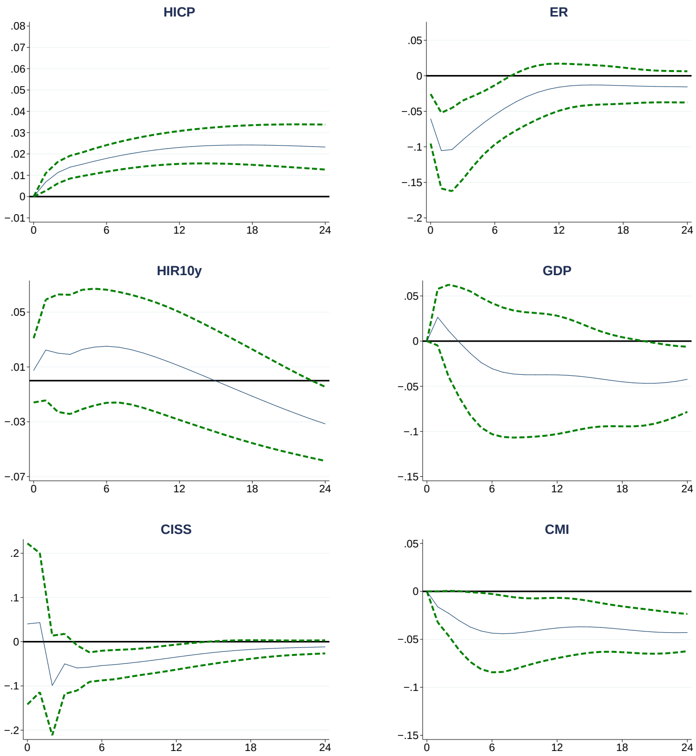
Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

5.1.2 Whole dataset

The impulse response functions produced by the S-VAR model using the whole period of available data are qualitatively very close to the estimates of the crisis period dataset. In comparison the results seem to be less quantitatively important and hence exhibit lower statistical significance.

Total assets

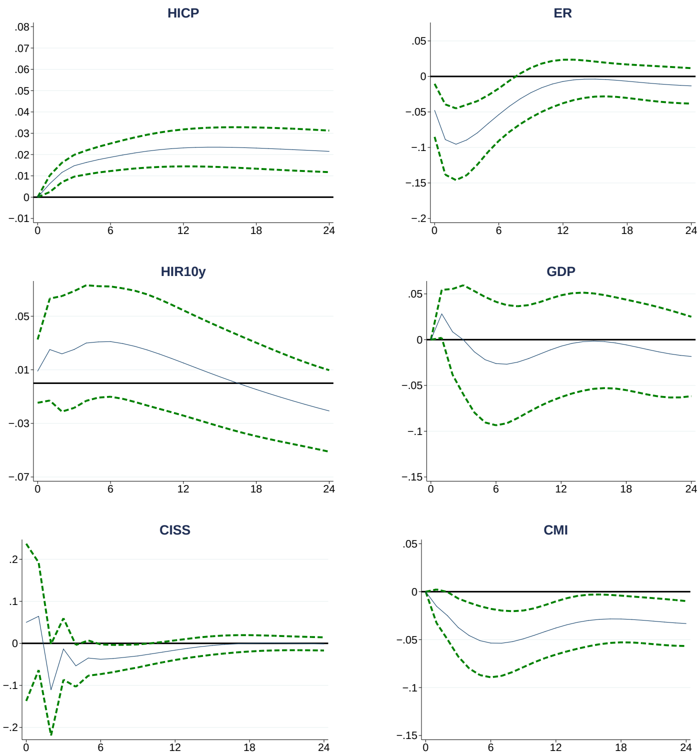
Figure 5.6: S-VAR variables responses to the Total assets shock, 1999-2015 data



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

Net total assets

Figure 5.7: S-VAR variables responses to the Net total assets shock, 1999-2015 data

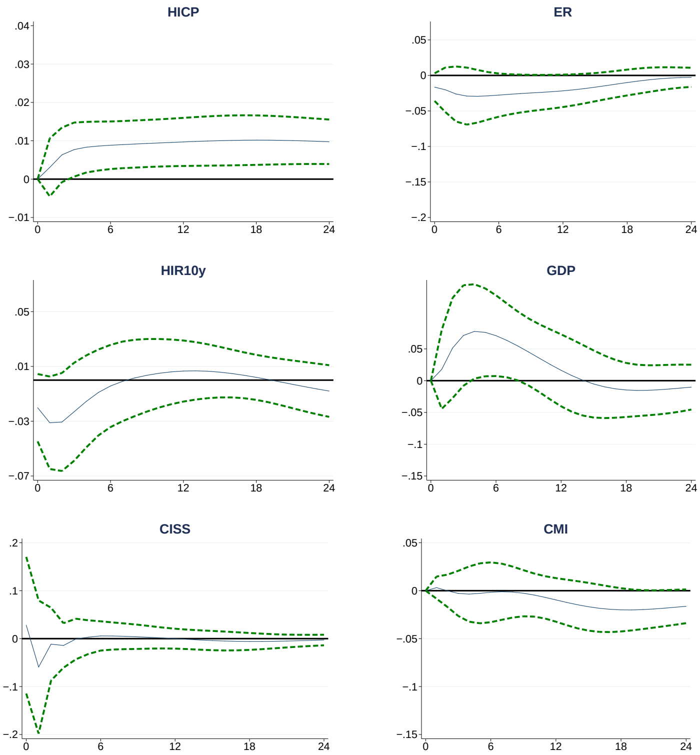


Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.

Source: author's elaboration

LSAP

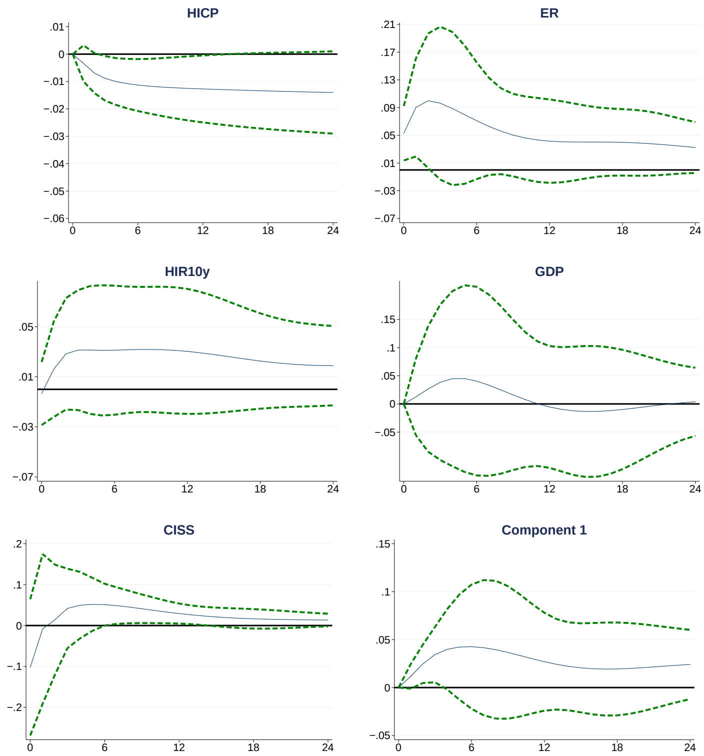
Figure 5.8: S-VAR variables responses to the LSAP shock, 1999-2015 data



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

UMI

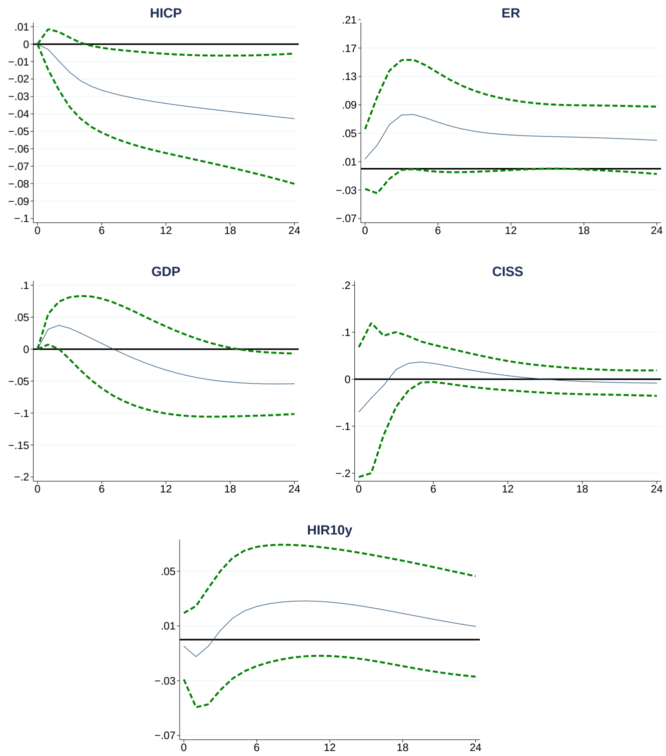
Figure 5.9: S-VAR variables responses to the UMI shock, 1999-2015 data



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

Shadow rate

Figure 5.10: S-VAR variables responses to the Shadow rate shock, 1999-2015 data



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable. The figure displays the 90% confidence intervals.
Source: author's elaboration

5.2 FA-VAR – Crisis period

In this section we discuss the estimates generated by our FA-VAR model. The policy variables are the same as in the S-VAR model with the exception of the LSAP which is now expressed in first difference of log values and treated accordingly. Consistently with the shocks of other variables the shock of LSAP variable is therefore calculated as the cumulative change of the differences occurring after the policy change, it values 1.7 standard deviation of the variable. The remaining variables and the methodology used are described in chapter 4. As well as in the case of S-VAR model all the variables used are standardized. Thus, the change of 0.1 on the graphical representation stands for the change of one tenth of the standard deviation of the respective variable – as a response to the one standard deviation shock of the policy variable. The impulse response functions are displayed below the text of this section, the median impulse responses are depicted with the 10th and 90th quantile for the confidence interval. The estimated responses generated by the whole available dataset could be found in Appendix D.3. Since the wide range of estimated effects in FA-VAR we will center the analysis around the Net total assets variable with reference to the other variables.

The FA-VAR model generally produces results consistent with the S-VAR estimates. The shock of Net total assets induces the long-lasting positive response of the price level and insignificant output response. Furthermore, the price level is driven also by increased expectations about the price level. The response thus suggests that the ECB balance sheet policy stimulated the inflation in a desired direction while the effect on the economic activity has not materialized yet.

The estimated responses of the exchange rates are significant and consistent among our variables. The responses are also important in magnitude and represent the depreciation about 4% from the level in December 2014. This is consistent both with our assumptions and with estimates from S-VAR models.

The effect on CISS differs from the estimates of our S-VAR model. The Total assets, Net total assets and UMI shocks seem to mitigate the systemic stress in the financial market. Nevertheless, despite their important magnitude the effects are either insignificant or significant only marginally. The effects on variables used also in S-VAR model are summarized in table 5.2.

The short-term interest rates are estimated to drop significantly after the shock and the decline continues until the 8th month after the shock. The

Table 5.2: FA-VAR effects (in pp)

FA-VAR	HICP	HIR10y beginning	HIR10y end	ER	GDP beginning	GDP end	CISS beginning	CISS end	1M EURIBOR
Net total assets	0.287	0.077	-0.035	-4.461	0.097	-0.125	-23.498	-29.665	-0.224
Total assets	0.075	0.021	-0.091	-1.774	0.000	-0.208	-9.494	-26.646	-0.158
LSAP	0.026	-0.264	-0.035	-0.304	0.000	0.000	5.731	5.731	-0.094
UMI	0.060	-0.456	-0.035	-2.387	0.035	0.035	-1.559	-94.805	-0.080
Shadow rate	0.128	-0.400	-0.035	-5.227	-0.069	0.242	-2.383	-1.559	-0.102

Note: The rates HIR10y and 1M EURIBOR are expressed in absolute changes, the other variables are expressed in % change from the levels as in December 2014. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F.
Source: Author's elaboration

decrease is economically significant as it surpasses one standard deviation differential. The effect on the 12M EURIBOR is very similar to the response of the 1M EURIBOR, in case of the Total and Net total assets they are virtually the same, in case of the UMI the 12M EURIBOR is more profound whereas Shadow rate indicates the opposite. Thus, the results about the effects on the money market instruments with different maturities are not distinguishable. Considering the responses of the EA government bond yields one can see the different results among policy variables. The LSAP, UMI and Shadow rate shocks drive the yields of bonds with long maturities lower than the short ones. The Total assets and Net total assets estimates nonetheless show the contrasting results as the response of yields generally rises with maturity. This is consistent with the different results related to the HIR10y variable where the yields are weighted according to the expected distribution of QE impacts and closely related to the estimated dynamics from the S-VAR model. Hence, the effects on bonds with different maturities seem to differ but the materiality of the effect is captured differently by each policy variable. We will discuss the reasoning in the next chapter. The results also show that the effect is different for the AAA bond and for the group of all bonds – which next to AAA bonds also includes the bonds of lower ratings. The AAA bonds are generally affected more strongly by the policy shock but the dynamics of responses is very similar. Provided that the bonds of lower quality bear higher yields than AAA bonds the estimates suggest that the yield spread increased upon the shock. Since we do not know the exact composition of the aggregated bond group we cannot quantify the effects on bonds of lower quality in more detail.

The table 5.3 summarizes the estimates of the yield responses.

Table 5.3: FA-VAR effects on yields (in pp)

Yields of AAA bonds	1y	3y	5y	10y	20y
Net total assets	-0.151	-0.094	-0.063	-0.001	0.027
Total assets	-0.087	-0.054	-0.039	0.014	0.014
LSAP	-0.021	-0.026	-0.042	-0.049	-0.038
UMI	-0.024	-0.045	-0.055	-0.064	-0.058
Shadow rate	0.044	-0.032	-0.055	-0.075	-0.061
Yields of all bonds	**1y**	**3y**	**5y**	**10y**	**20y**
Net total assets	-0.161	-0.085	-0.033	0.027	0.030
Total assets	-0.098	-0.046	-0.025	0.012	0.009
LSAP	0.003	-0.027	-0.040	-0.039	-0.024
UMI	-0.035	-0.046	-0.051	-0.060	-0.056
Shadow rate	0.003	-0.016	-0.042	-0.047	-0.050

Note: The variables are expressed in absolute changes of original yields. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F.
Source: Author's elaboration

In accordance with the effects on the interbank rates the borrowing costs drop significantly in the first periods after the shock. The decline continues for about 10 months. Since the variables are expressed in first differences and the rise above the zero level is insignificant, we conclude that the effect on levels is long-lasting. The short-term borrowing costs are against our assumption decreased more rapidly and more importantly than the long-term borrowing costs. Further, the drop of the corporate borrowing costs is also greater to the one of the households. This goes against the assumption that the banking institutions cure their position of low profit margins in low interest rate environment on corporate clients. The quantified effects related to the borrowing costs are summarized in table 5.4.

The main policy goal, though, is the promotion of loans volumes. This is estimated to be rather limited and temporary. We see consistently estimated positive response of short consumer loans and long corporate loans of exposures larger than EUR 1M. The estimates are sizable and suggest that the companies waited with their larger projects for the convenient timing of investment. The estimates are summarized in table 5.5.

The monetary aggregates also behave as assumed. The monetary base is increased immediately after the shock as the increased balance sheet of the central bank is driven by the increased reserves. The M1 then increases grad-

Table 5.4: FA-VAR effects on borrowing costs (in pp)

FA-VAR	Household	Corporate	Long-term	Short-term
Net total assets	-0.064	-0.148	-0.079	-0.150
Total assets	-0.055	-0.102	-0.057	-0.104
LSAP	-0.027	-0.052	-0.025	-0.053
UMI	-0.046	-0.059	-0.042	-0.053
Shadow rate	-0.062	-0.079	-0.056	-0.080

Note: The variables are expressed in absolute changes of the rates from the levels as in December 2014. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F.
Source: Author's elaboration

Table 5.5: FA-VAR effects on loans (in pp)

Loans to NFC	< 1y		1 to 5y		> 5y	
exposure < EUR 1M	beginning	end	beginning	end	beginning	end
Net total assets	0.000	-3.504	2.478	0.000	3.303	0.000
Total assets	1.168	-1.947	0.400	-1.199	-0.826	-3.303
LSAP	0.000	0.000	0.000	0.000	0.000	0.000
UMI	0.487	0.000	0.800	0.000	0.000	0.000
Shadow rate	-3.893	0.000	1.999	1.999	1.651	2.477
Loans to NFC exposure > EUR 1M						
Net total assets	4.591	-3.061	0.000	-6.735	7.013	0.000
Total assets	3.826	-3.061	0.000	-4.490	1.539	-3.421
LSAP	0.000	0.000	0.000	0.000	0.000	0.000
UMI	1.989	0.000	0.000	0.000	0.000	0.000
Shadow rate	-6.121	0.000	-4.490	0.000	1.710	2.566
Loans to HH						
Net total assets	1.502	0.000	2.756	1.102	-6.870	-4.122
Total assets	0.000	-1.126	0.000	-1.323	-4.809	-2.748
LSAP	0.638	0.000	0.000	0.000	0.000	0.000
UMI	0.000	0.000	0.000	0.000	-1.374	0.000
Shadow rate	1.689	2.628	3.031	3.031	5.496	2.748

Note: The variables are expressed in % change as the original time-series are available only in the form of the y-y % change. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F.
Source: Author's elaboration

ually with the peak estimated to be around 7th month after the shock. It is noteworthy that the estimates show the rapid increase of broader monetary aggregates indicating that the financial institutions started to provide liabilities of lower liquidity. Since the bank usually try to match the maturities of assets and liabilities it is plausible that the banks also started to hold the assets of longer maturities. The estimates of Net total assets shock show that the M2 and M3 monetary aggregates increased more readily than the M1 aggregate. This supports the evidence that the liquidity issue was overcome and the banks search for the yields again. The increase of the monetary aggregates in response to the policy shock is only transitory as it follows the temporary nature of the policy shock itself. Complete effects of monetary aggregates are summarized in table 5.6.

Table 5.6: FA-VAR effects on monetary aggregates (in pp)

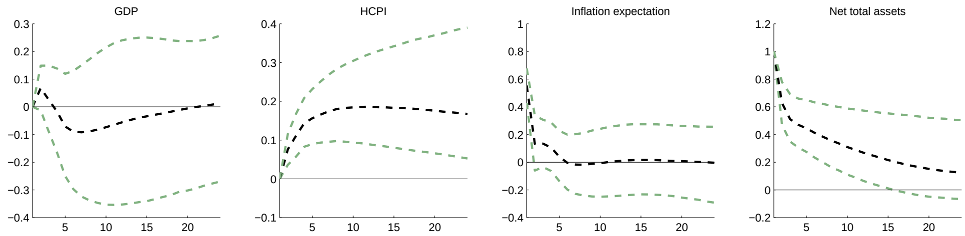
FA-VAR	MB	M1	M2	M3
Net total assets	18.973	1.385	1.000	1.100
Total assets	10.888	0.687	0.641	0.592
LSAP	1.692	0.690	0.305	0.164
UMI	9.338	0.813	0.478	0.397
Shadow rate	9.492	2.040	0.433	0.320

Note: The variables are expressed in % change from the levels as in December 2014. The process of back-transformation of effects on the VAR variables into the original time-series is described in Appendix F.
Source: Author's elaboration

The effects on the stock markets is positive only in the cases of balance sheet policy variables, i.e. Total assets, Net total assets and LSAP, and it is statistically significant only in the LSAP case. We therefore conclude that the effect of QE on the stock markets is unimportant.

Net total assets

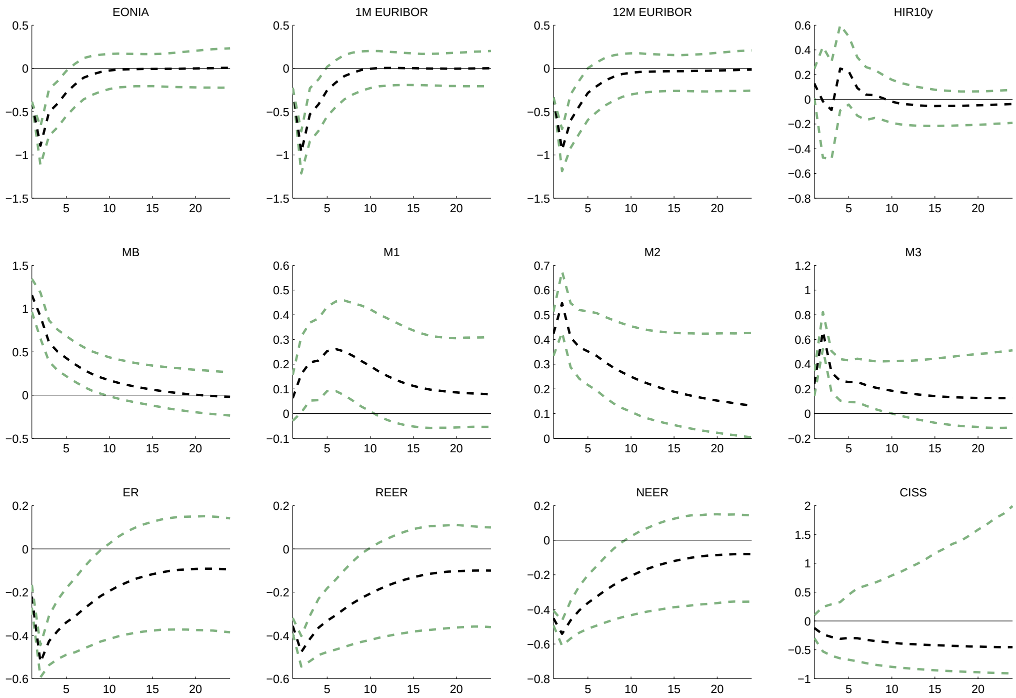
Figure 5.11: FA-VAR impulse responses of macro variables to Net total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

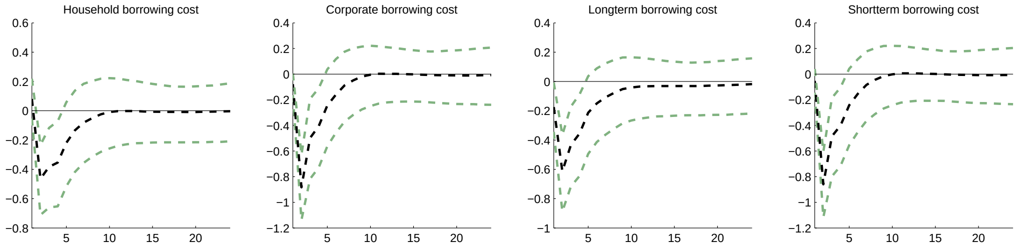
Figure 5.12: FA-VAR impulse responses of selected variables to Net total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

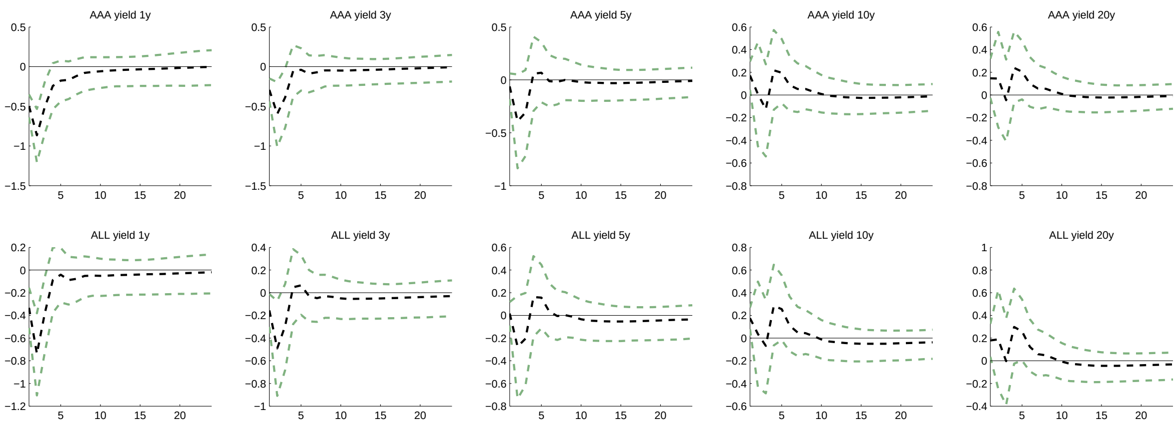
Figure 5.13: FA-VAR impulse responses of borrowing costs to Net total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

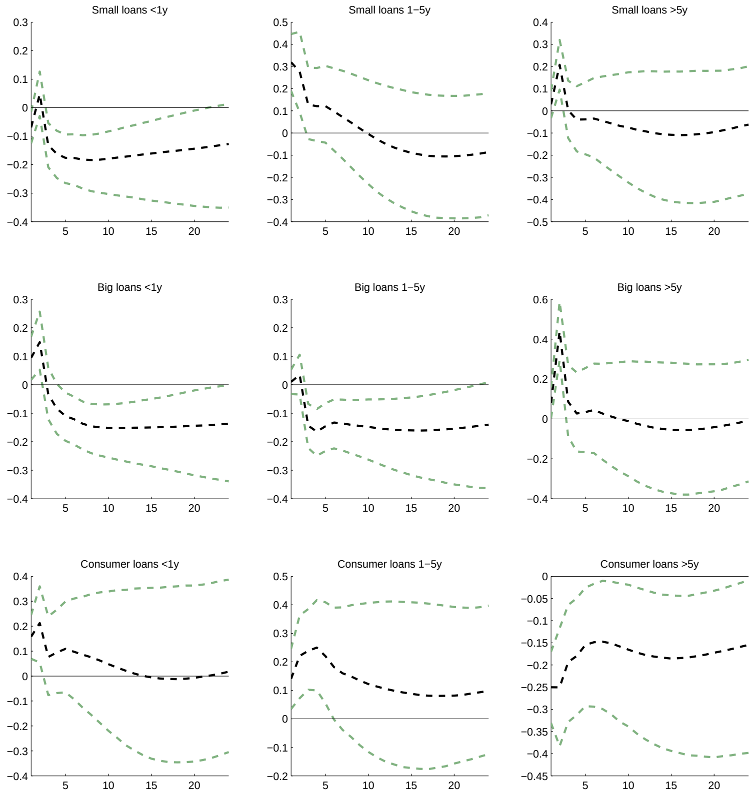
Figure 5.14: FA-VAR impulse responses of bond yields to Net total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

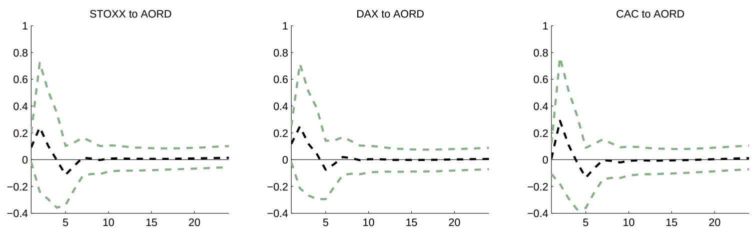
Figure 5.15: FA-VAR impulse responses of loans volume to Net total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure 5.16: FA-VAR impulse responses of stock indexes to Net total assets shock

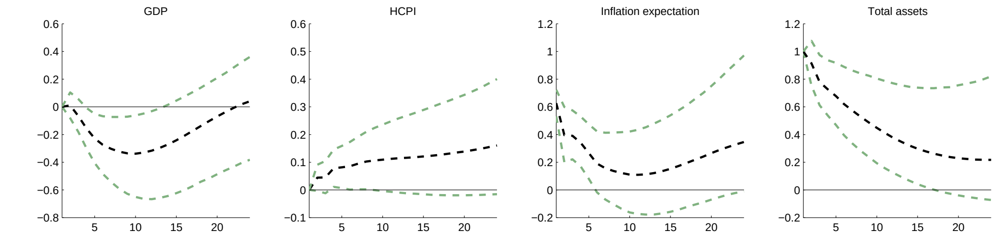


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Total assets

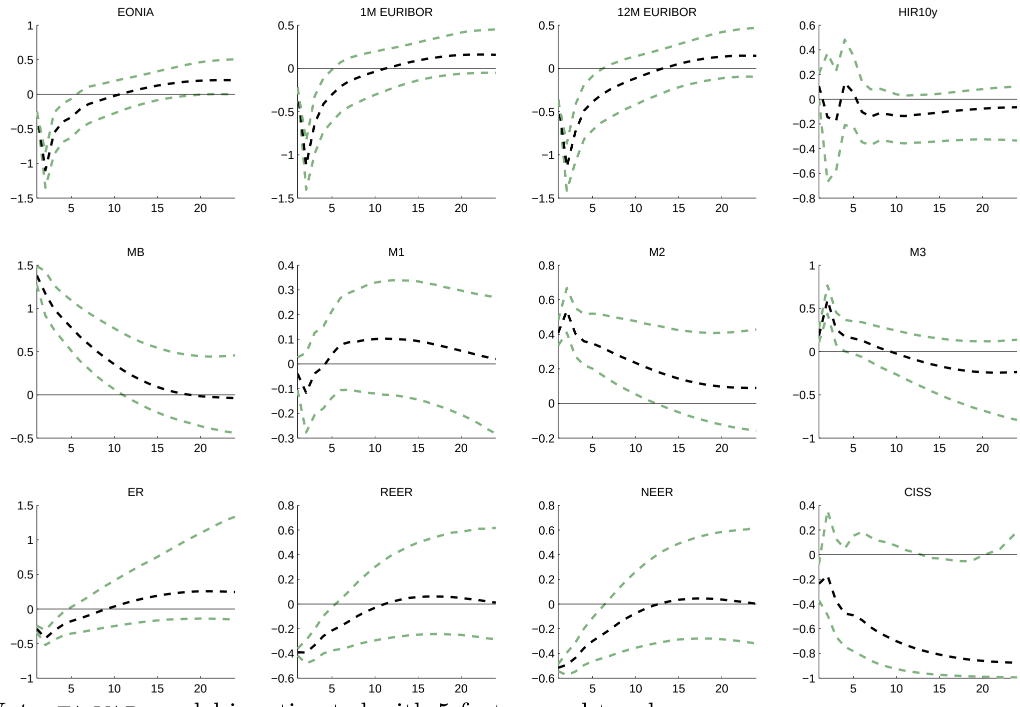
Figure 5.17: FA-VAR impulse responses of macro variables to Total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

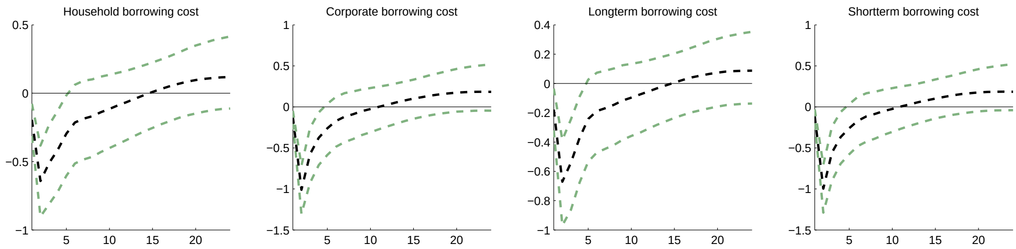
Figure 5.18: FA-VAR impulse responses of selected variables to Total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

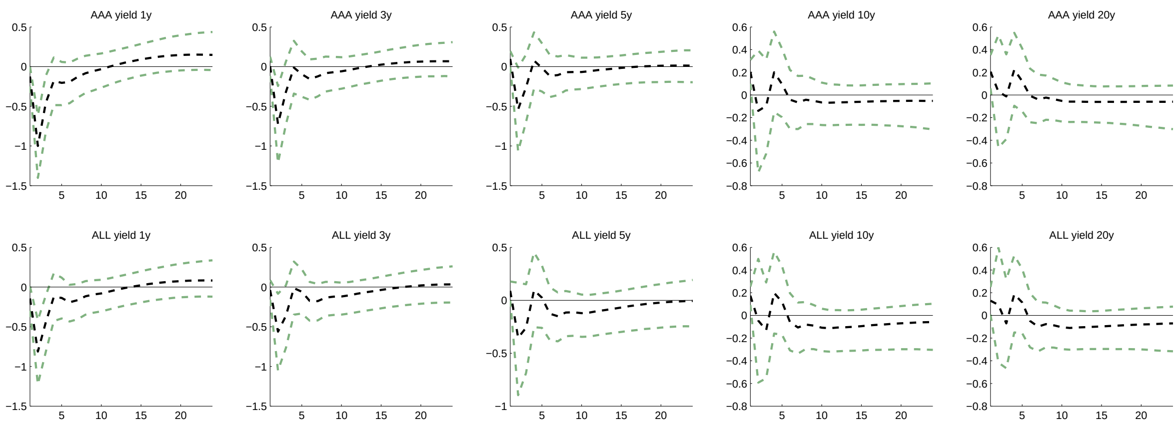
Figure 5.19: FA-VAR impulse responses of borrowing costs to Total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

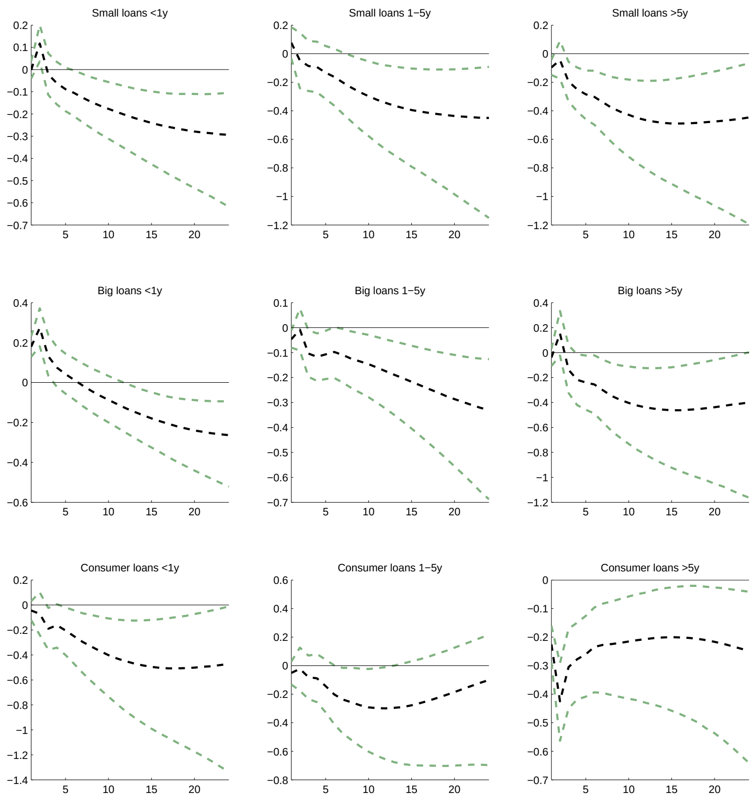
Figure 5.20: FA-VAR impulse responses of bond yields to Total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

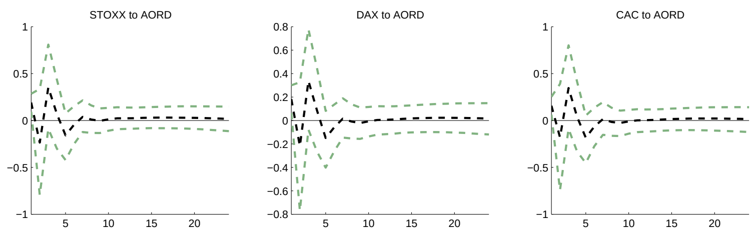
Figure 5.21: FA-VAR impulse responses of loans volume to Total assets shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure 5.22: FA-VAR impulse responses of stock indexes to Total assets shock

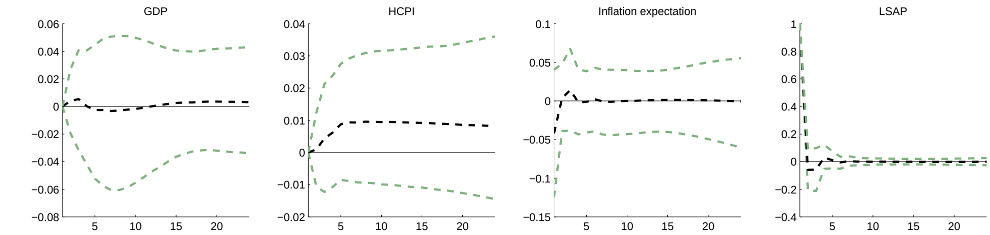


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

LSAP

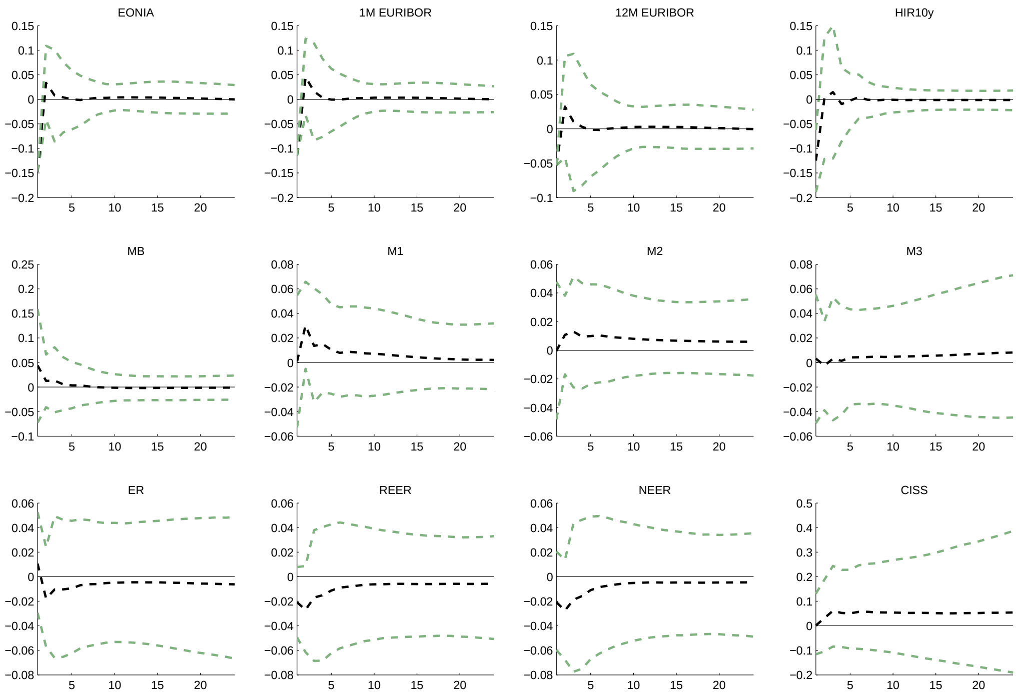
Figure 5.23: FA-VAR impulse responses of macro variables to LSAP shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

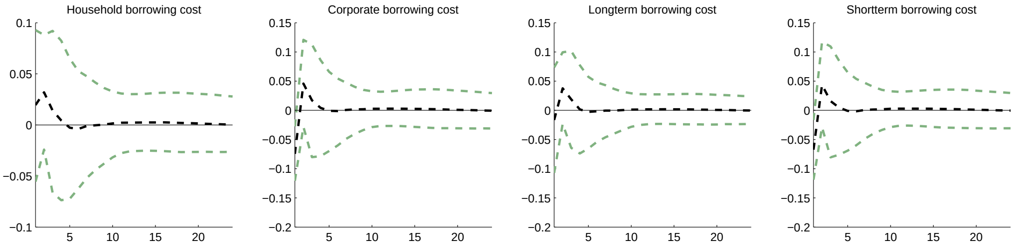
Figure 5.24: FA-VAR impulse responses of selected variables to LSAP shock



Note: FA-VAR model is estimated with 5 factors and two lags.

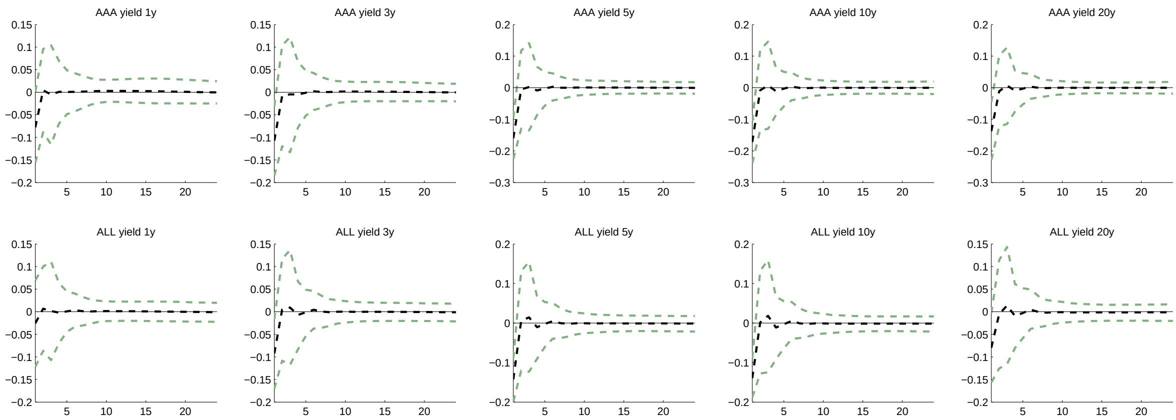
Source: author's elaboration

Figure 5.25: FA-VAR impulse responses of borrowing costs to LSAP shock



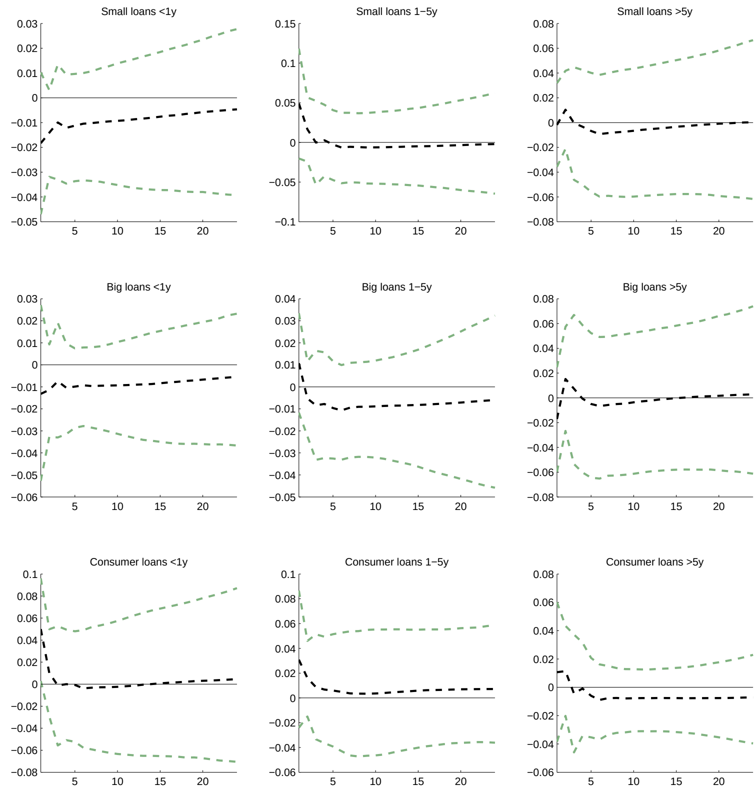
Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

Figure 5.26: FA-VAR impulse responses bond yields to LSAP shock



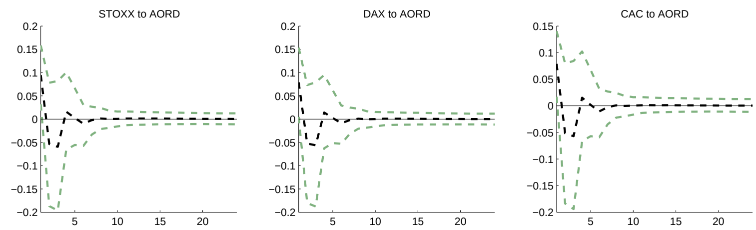
Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

Figure 5.27: FA-VAR impulse responses of loans volume to LSAP shock



Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

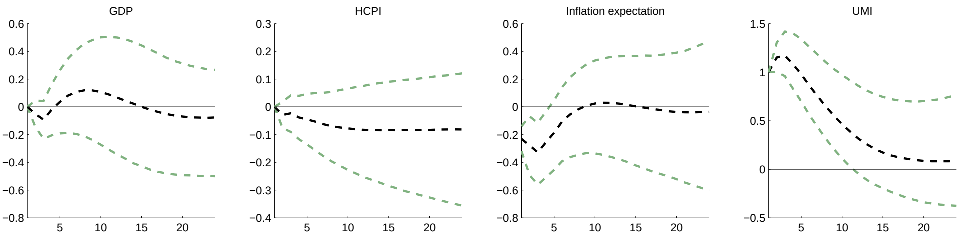
Figure 5.28: FA-VAR impulse responses of stock indexes to LSAP shock



Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

UMI

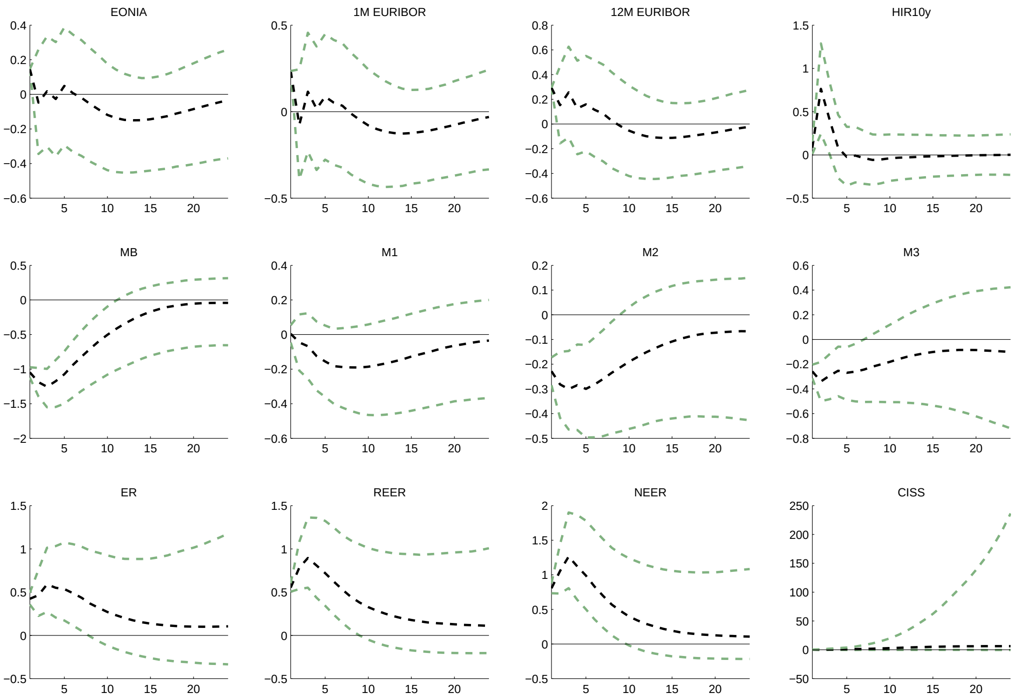
Figure 5.29: FA-VAR impulse responses of macro variables to UMI shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

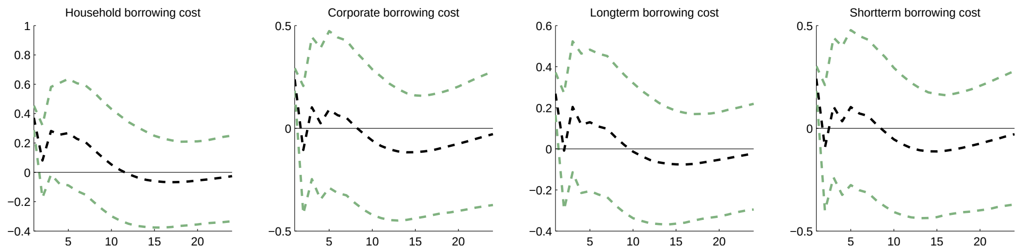
Figure 5.30: FA-VAR impulse responses of selected variables to UMI shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

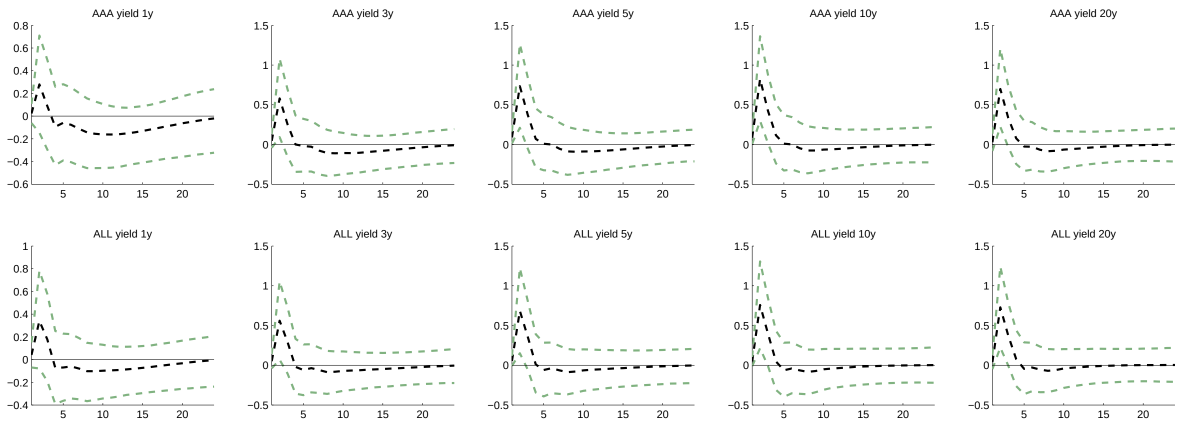
Figure 5.31: FA-VAR impulse responses of borrowing costs to UMI shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

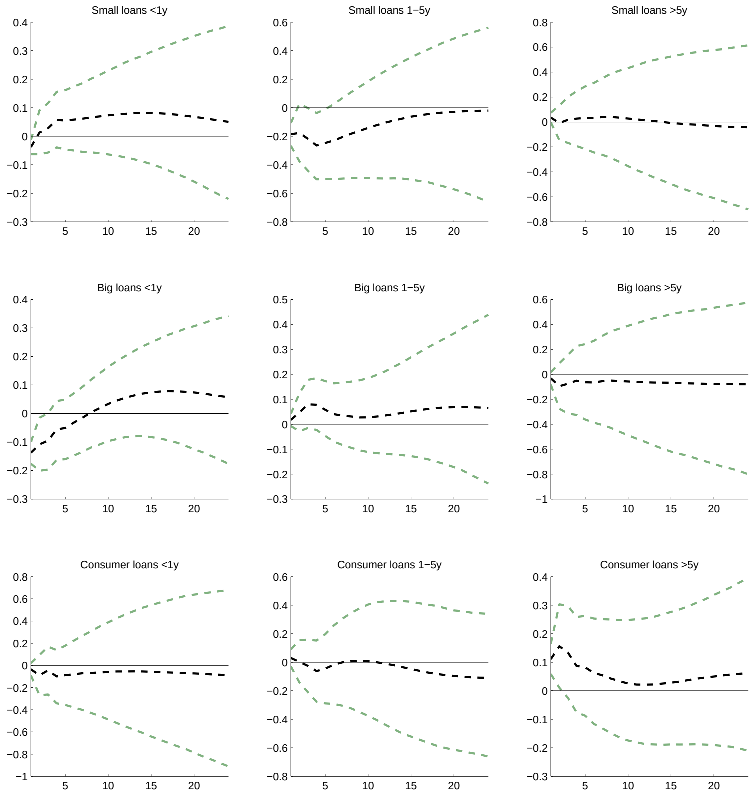
Figure 5.32: FA-VAR impulse responses of bond yields to UMI shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

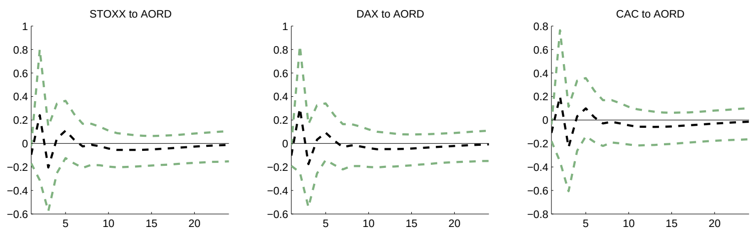
Figure 5.33: FA-VAR impulse responses of loans volume to UMI shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure 5.34: FA-VAR impulse responses of stock indexes to UMI shock

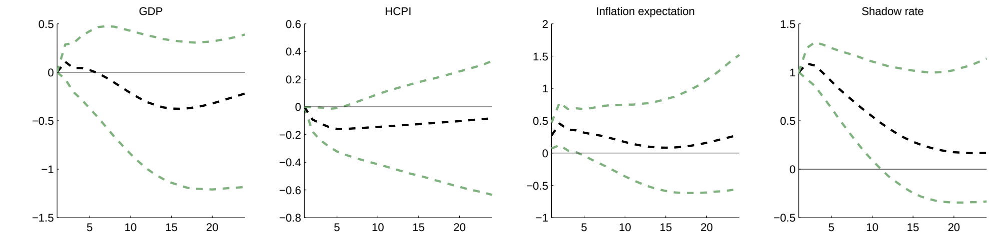


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Shadow rate

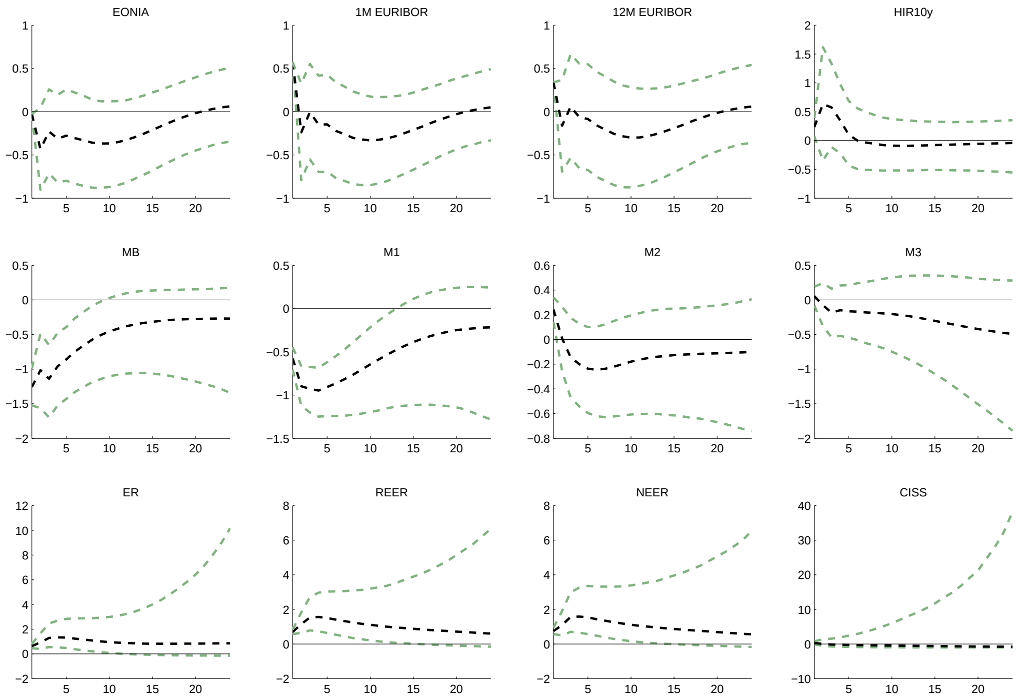
Figure 5.35: FA-VAR impulse responses of macro variables to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

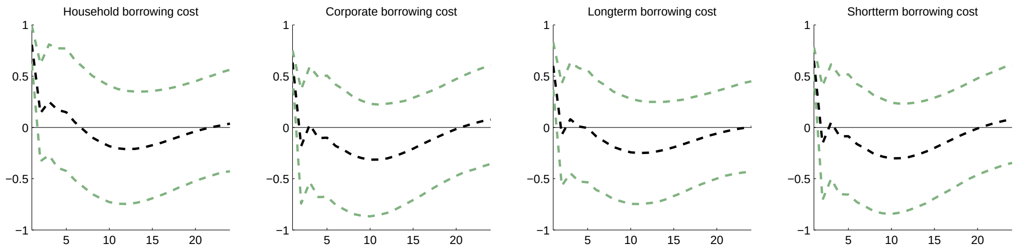
Figure 5.36: FA-VAR impulse responses of selected variables to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

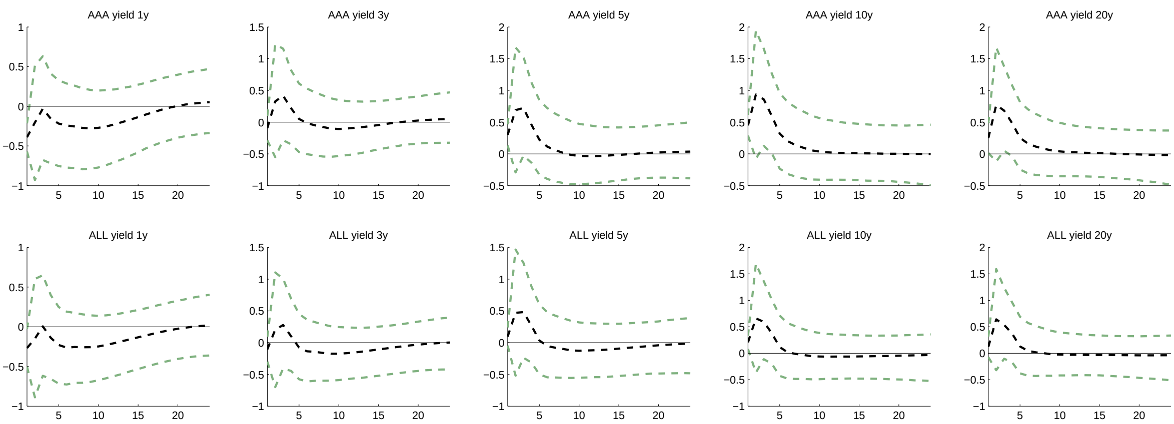
Figure 5.37: FA-VAR impulse responses of borrowing costs to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

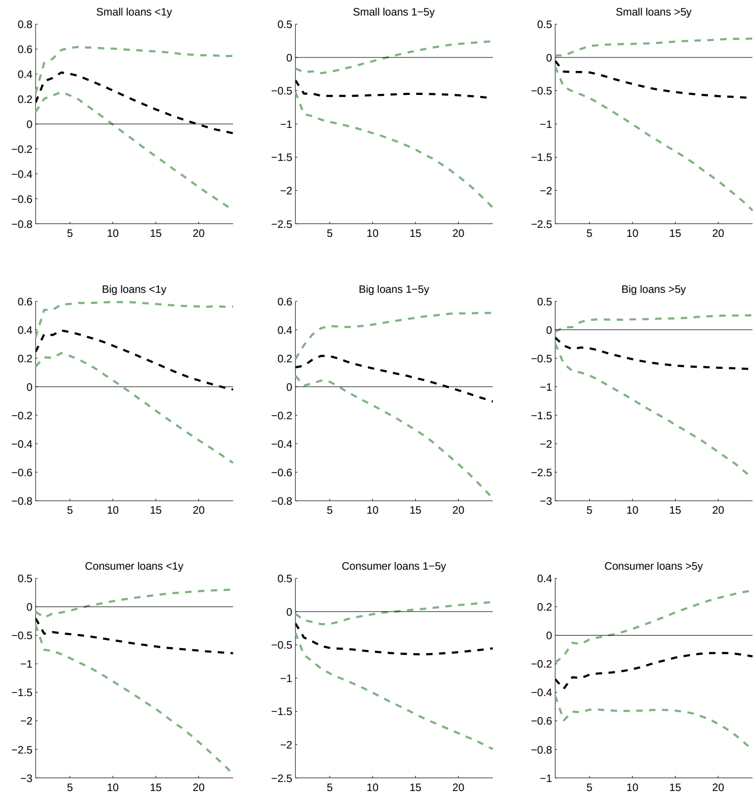
Figure 5.38: FA-VAR impulse responses of bond yields to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

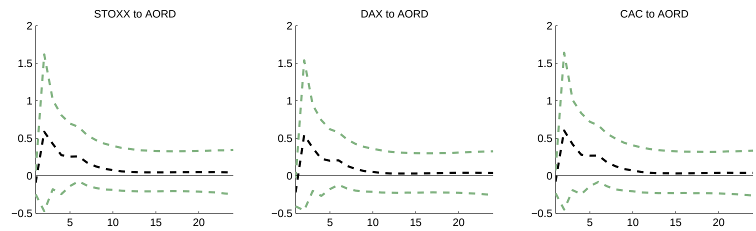
Figure 5.39: FA-VAR impulse responses of loans volume to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure 5.40: FA-VAR impulse responses of stock indexes to Shadow rate shock



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Chapter 6

Identified policy shock channels

In this section we will discuss the relationship among effects described in chapter 5 and elaborate on the causalities.

6.1 Channel of Interest and Exchange rates

The most important effects identified in the analysis are the depreciation of Euro currency and the decline in interest rates. In most scenarios we find that the currency depreciation follows the U shape and is estimated to return back to its initial levels. In contrast the interest rates decline gradually and appear to stay below their initial levels. The two variables probably exert mutually influence.

The fast response of the exchange rate and lagged response of the interest rates suggest that it is the exchange rate which influences the interest rates. In theory, provided that the market anticipates the effect on the Euro currency value to be temporary and calculates with its future appreciation, the currently lower value of currency *ceteris paribus* increases the yields of newly purchased assets from the foreign investors. Since the exchange rate increases back to the initial levels it is intuitive to draw conclusions about the increased demand for the currency from abroad particularly for the investment purposes. The delayed decline of interest rates – potentially driven by the covered interest rate parity – than offsets the initial benefits for incoming investors and the economy stabilizes with the lowered interest rates and virtually unchanged exchange rate.

The prevailing direction of causality between the interest rates and exchange rate though is probably the opposite. Since the market assumes the yields to be suppressed by the QE policy, the European assets become less attractive and demand for the domestic currency follows the declined demand for the assets. Furthermore, the covered interest rate parity suggests the appreciation of the currency to come and the market thus tend to overshoot the initial depreciation to allow for the future appreciation. The usual regressive formulation of expectation then explains the U shape dynamics of the exchange rate response.

Overall, we believe that both the directions of influence are in place and the dynamics is driven by expectations.

6.2 Channel of Exchange rate, Inflation

The paper finds significant increase of price level with the limited magnitude. Since the effect on economic activity is disputable the inflation is probably not driven by increased production and consumption. On the other hand, it is plausible that the true channel of increased price level is caused by the currency depreciation. Since markets of goods and services in EA are not heavily open to the rest of the world – the share of trade exchange (imports + exports) is about 80% of GDP – and since the depreciation is not estimated to be very sizable, the limited increase of price level is related mostly to the exchange rate variation.

The story goes like this, once the monetary authority purchases assets it increases the amount of money in the financial system and, provided that the sellers of assets do not sit on the cash, it starts the process of increasing amount of money in circulation. The economic agents therefore anticipate the future increase of the price level. This explains the estimated initial hike in inflation expectation. Further, the currency exchange market reacts to the expected inflation and the value of currency declines accordingly. The depreciation equivalently rises the price of imports while the volumes of imports react with a lag. This leads to the gradually increased domestic price level in the EA. The general market equilibrium is achieved consistently with the Dornbusch (1976) overshooting model as the exchange rate depreciation is the most important at the beginning and than gradually diminishes as the price level varies.

6.3 Channel of Inflation and Interest rate

The policy makers are mostly interested in the real interest rates as opposed to the nominal rates. Here is where the inflation usually plays important role. As the inflation is very close to zero and the variation of the price level due to the policy shock is negligible, the change of nominal interest rate is approximately one to one with the change of the real rate. The transition of real interest rates on the economy is mostly through the investments, as the long-term corporate loans increased their volumes the effect appears to materialize.

The hypothesis that the Shadow rate drives the change of interest rates from the shorter maturities to the longer ones while the UMI, i.e. the policy variable related mostly to the remaining monetary variables without the direct inclusion of interest rates, drives the interest rates from the longer maturities was not confirmed. On the contrary considering the impacts on the AAA government bond yields the reaction is qualitatively similar between the two. The estimates of mentioned policy variables together with the estimates of LSAP variable represent a supportive evidence that the QE programmes flatten the yield curves and are consistent with the notion of the effect of the key interest rates on the real economy. The reason why the Total assets and Net total assets show the inconsistent results in this regard is possibly caused by different relation with the expectations as we shown earlier in the section 3.4 about stylized facts that the yield curve flattened closely before the change of the quantitative measures.

6.4 Financial markets and Wealth Channel

The unexpected rise of financial asset prices is closely related to the perceived wealth of the asset holders. Furthermore, the financial wealth size influences the consumption levels (Sousa 2009) and can represent the relevant support for the real economy. Our estimates show that the stock market did not react extensively to the monetary policy shock, nevertheless, the purchases of government bonds decreased the yields while increasing the bond prices. Since the lowered yields are received by the monetary authority and the inflated prices are enjoyed by the investors in secondary markets, it is plausible to believe that the financial wealth increased. Thus, even though we do not expect the wealth channel to be important, we believe it is operational.

Chapter 7

Conclusion

In this paper we analyze the QE program used by the European Central Bank (ECB) and its impact on the real economy. The literature focusing on the broad topic of the QE effects is still narrow. Moreover, the former estimations considering effects of policies governed by the Federal Reserve System, Bank of England or Bank of Japan are only of a limited use in the context of the European Monetary Union. This is why this empirical study is relevant for the future policy decisions as well as for calibration of theoretical models.

This paper ensures the robustness of the estimated effects by applying two different model techniques as well as 5 different measures of the QE. Among those there are three balance sheet measures – the size of European Central Bank balance sheet, this measure netted of the Long-Term Refinancing Operations and the Main Refinancing Operations and the volume of Large-Scale Asset Purchases, and two measures constructed by statistical models – Unconventional Monetary Indicator by principal components analysis and Shadow rate by in-sample prediction of time-series linear regression model. These variables are then used in the Structural Vector Autoregressive (S-VAR) and Factor-Augmented Vector Autoregressive (FA-VAR) models.

When constructing the UMI we created also the Synthetic Monetary Indicator which involves both the unconventional and conventional part of the monetary policy. The development of this synthetic measure advocates the notion about the policy change in the crisis as the indicator is driven by the interest rates ahead of the crisis and by the balance sheet measures during the crisis.

We analyzed the dynamics of the QE effects for the datasets covering the crisis period 2008 to 2015 and also on the whole available dataset, and we quantified the effect of the balance sheet policies initiated at the beginning of 2015. The results consistent with the theoretical assumptions include the negative effect on the short-term interest rates together with the drop of borrowing costs, the positive effect on the price level and the depreciation of Euro currency. We estimated the EURIBOR rates to decrease by about 14 bp in case of FA-VAR which is consistent with the results of prior literature and the Shadow rate modeling. Furthermore, the decline in rates is long-lasting. The estimates of the increased price level is statistically significant but of rather minor size. The estimates show the increase by less than 30 bp with the average of about 10 bp. Even though the effect is low one should not forget about its relevance in the crisis period.

The consistent also appears to be the decline of the value of Euro currency. The models show that the depreciation happens just after the policy shock. The value of currency than declines within the next 3 months and gradually returns back to its initial levels afterwards. The magnitude of the effect is estimated to be approximately 4% in its peak.

There is only one result which differs greatly between our two VAR model techniques. The models vary in the estimated response of the systemic stress in the financial market as measured by Composite Indicator of Systemic Stress variable. The S-VAR model displays sudden hike in the stress and only gradual decrease below the original level which just offsets the initial rise but the FA-VAR model overall shows the decline in the first periods and long-lasting effect. Thus, we could only predict that the long-term shock of the policy have positive effect on the financial environment but the dynamics is uncertain.

The models are consistent in the estimated response of the economic output. For the economic performance proxies we used the percentage deviation from the HP trend both of the linearly interpolated quarterly data of the real Gross Domestic Product (GDP) measure and of the monthly data of real Industrial Production Index (IPI). All the model specifications used show mostly insignificant effect on the production activity.

Since the S-VAR approach is restricted by the degrees of freedom problem, we estimated several variables only within the FA-VAR. We included another proxy of economic output – unemployment rate together with variables of monetary aggregates, financial market indexes, borrowing costs and loan volumes to better understand the propagation of the QE monetary policy. The effect on unemployment is insignificant and consistent with the effect on the economic output and we conclude that the effect on the real economy is limited and has not fully materialized yet.

The borrowing costs are estimated to drop significantly and the size of the effect is comparable to the interbank borrowing rates EURIBOR. The estimates vary between 4 to 15 bp and are generally more important for the short-term borrowing costs as opposed to the long-term rates and for Non-Financial Corporations (NFC) costs as opposed to the Households (HH) costs.

Overall the effect on the credit creation seems to be positive but the effect varies among different types of loans. We used the division of the loans into the HH and to the NFC with the differentiation according to the maturity as "up to 1 year", "1 to 5 years" and "more than 5 years". In the case of NFC loans we also distinguished the loans according to the exposure volume as by the threshold of EUR 1M. We find the positive response of the long-maturity (more than 5 years) loans with the exposures above the threshold and of the short-maturity (up to 5 years) consumer loans for HH.

Overall, the responses are probably affected by the relatively short data collected in the period after the last policy easing as it intuitively requires longer time for transition then conventional monetary policies in non-crises periods. We believe though that the variety of policy measures partly compensates for the data deficiency.

The complete effects and their channels could be further analyzed with updated datasets as well as by different than proposed models. One could use sign restriction for S-VAR models for the benchmark estimates and Bayesian S-VAR model as substitute to the FA-VAR. The Bayesian model provides similar benefits to the FA-VAR model considering the possible size of dataset. Next to the analysis of truly applied QE the researchers could also analyze the announcements of the policies and focus on the expectation changes. In this regard it could be useful to consider the Qual VAR as the analytical tool.

The next logical step we plan to pursue is to build a theoretical model which satisfies the estimates from this empirical work. The model will be from the Dynamic Stochastic General Equilibrium group of models with agents covering the financial sector, production sector, households and monetary authority.

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Appendix A

ECB QE statistics

Table A.1: PSPP breakdown according to the ECB's capital key

Country	Monthly net purchases (EUR M)	Cumulative monthly net purchases (EUR M)	National purchases (%)	Key for subscription of ECB capital (%)	Key for subscription of ECB capital (EA %)	Weighted average remaining maturity (years)
Austria	1411	11486	2.55	1.96	2.79	8.25
Belgium	1764	14450	3.21	2.48	3.52	9.62
Cyprus	97	285	0.06	0.15	0.21	5.91
Estonia	7	48	0.01	0.19	0.27	2.63
Finland	909	7352	1.63	1.26	1.78	7.61
France	10221	83500	18.53	14.18	20.14	7.81
Germany	12903	105182	23.34	18.00	25.57	7.02
Greece	-	-	-	2.03	2.89	-
Ireland	840	6899	1.53	1.16	1.65	9.34
Italy	8876	7228	1.60	12.31	17.49	9.28
Latvia	31	661	0.15	0.28	0.40	5.88
Lithuania	117	13	0.00	0.41	0.59	5.64
Luxembourg	30	173	0.04	0.20	0.29	6.13
Malta	2	275	0.06	0.06	0.09	9.6
Netherlands	2883	23421	5.20	4.00	5.69	6.59
Portugal	1248	10202	2.26	1.74	2.48	10.57
Slovakia	533	4345	0.96	0.77	1.10	8.54
Slovenia	248	231	0.05	0.35	0.49	8.13
Spain	6334	51680	11.47	8.84	12.56	9.74
Supranationals	6650	54701	12.14	-	-	7.05
Total	55,105	450621	100.00	70.39	100	8.06

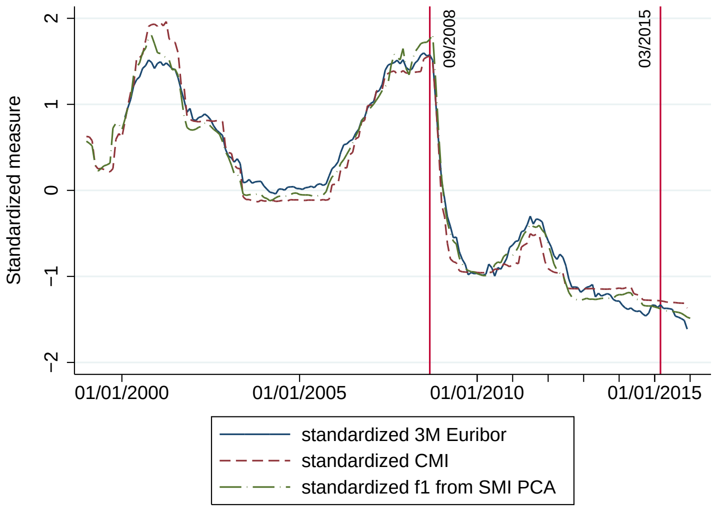
Note: Data are actual to 30/11/2015 and expressed in the book value.

Source: European Central Bank (2015a) and European Central Bank (2015b)

Appendix B

Short-term interest measures

Figure B.1: 3M EURIBOR, CMI and first component from SMI PCA



Source: author's elaboration

Appendix C

S-VAR analysis

C.1 Tests for number of lags

Table C.1: S-VAR testing the number of lags

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-575.217				0.00074	12.6569	12.7343	12.8488
1	292.935	1736.3	49	0	1.40E-11	-5.15076	-4.53122*	-3.61576*
2	362.226	138.58	49	0	9.0E-12*	-5.59187*	-4.43023	-2.71374
3	397.96	71.469	49	0.02	1.30E-11	-5.30348	-3.59975	-1.08223
4	440.018	84.115*	49	0.001	1.60E-11	-5.15256	-2.90672	0.411825

Note: The asterisks indicate the optimal lag length estimated by the corresponding test. This particular table is related to the S-VAR of crisis period with total assets as the unconventional monetary variable. The test results are very similar also for other unconventional variables used.
Source: Author's elaboration

C.2 Test for system stability

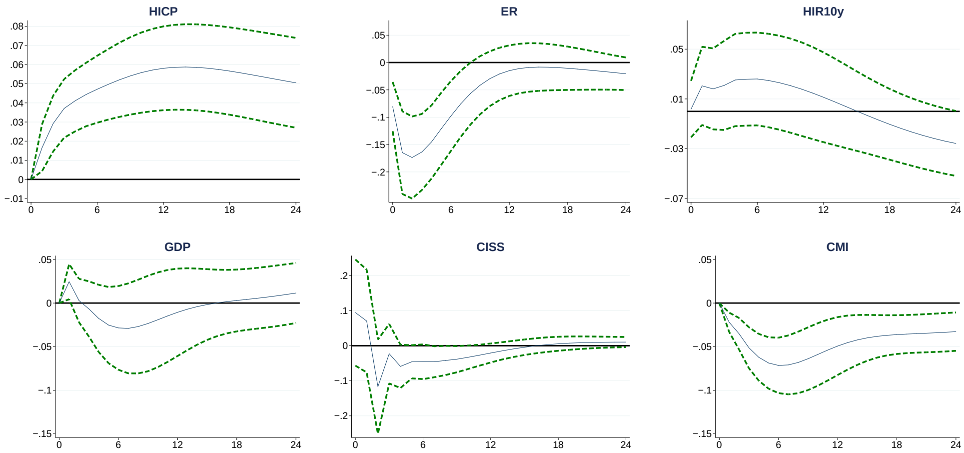
Table C.2: S-VAR testing the system stability

Eigenvalue			Modulus
0.99292			0.992919
0.931378	+	.07957722i	0.934771
0.931378	-	.07957722i	0.934771
0.804521	+	.3058878i	0.860709
0.804521	-	.3058878i	0.860709
0.84319	+	.09144411i	0.848134
0.84319	-	.09144411i	0.848134
0.326243	+	.2889015i	0.435774
0.326243	-	.2889015i	0.435774
0.09717	+	.3834496i	0.39557
0.09717	-	.3834496i	0.39557
-0.19835			0.198353
-0.13579	+	.06680426i	0.151333
-0.13579	-	.06680426i	0.151333

Note: All the eigenvalues lie in the unit circle and thus the system satisfies the stability condition. This particular table is related to the S-VAR of crisis period with total assets as the unconventional monetary variable. The test results are very similar also for other unconventional variables used.
Source: Author's elaboration

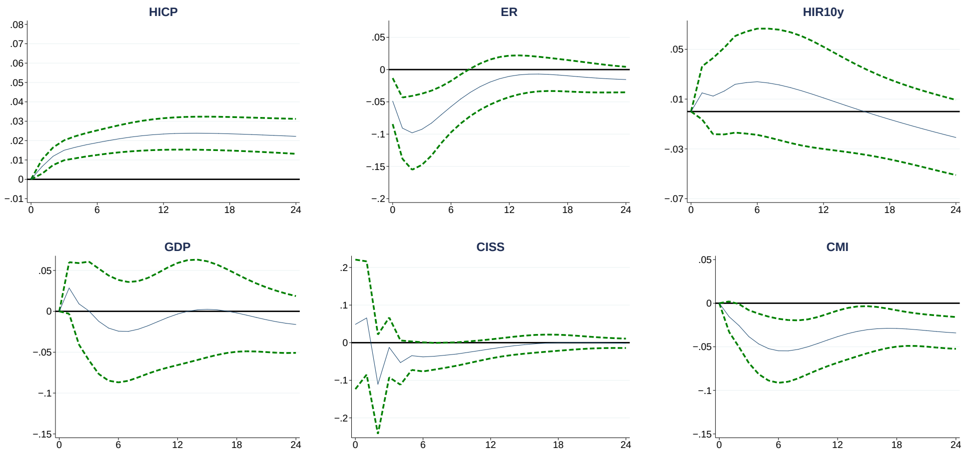
C.3 Robust analysis for identification assumptions

Figure C.1: S-VAR variables responses to the Net total assets with change of ER and CISS ordering



Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable.
Source: author's elaboration

Figure C.2: S-VAR variables responses to the Net total assets with change of HIR10y and Net total assets ordering



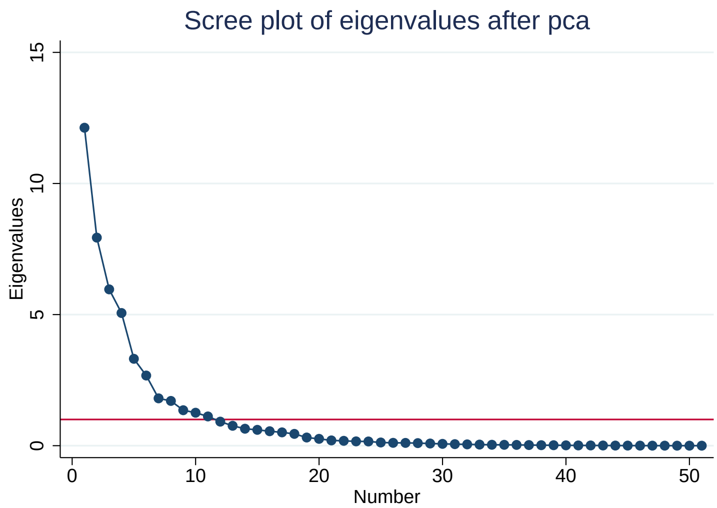
Note: S-VAR model is estimated with 2 lags and EA countries government deficit as exogenous variable.
Source: author's elaboration

Appendix D

FA-VAR analysis

D.1 Cattel's Scree Test for number of retained factors

Figure D.1: Scree plot for FA-VAR first step



Note: Cattel's Scree Test indicates 5 to 7 principal components to be retained, we find the model to be robust to the variation of number of factors and use 5 in the benchmark model.
Source: author's elaboration

D.2 Tests for number of lags

Table D.1: FA-VAR testing the number of lags

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-492.457				5.60E-07	11.1435	11.2443	11.3935
1	369.675	1724.3	81	0	1.60E-14	-6.21501	-5.20694*	-3.7152*
2	462.933	186.51	81	0	1.3e-14*	-6.48739	-4.57206	-1.73776
3	544.04	162.22	81	0	1.50E-14	-6.48979*	-3.66719	0.509679
4	613.834	139.59*	81	0	2.50E-14	-6.24076	-2.5109	3.00853

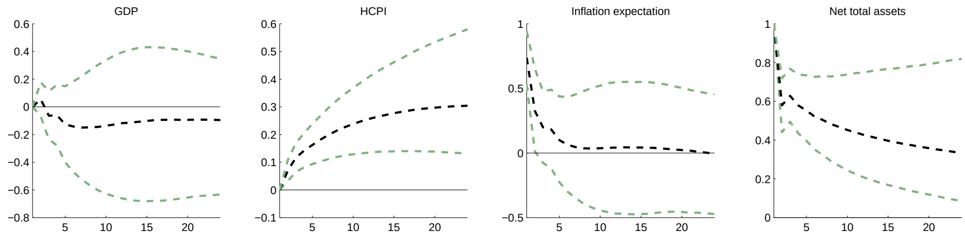
Note: The asterisks indicate the optimal lag length of estimated by the corresponding test. This particular table is related to the FA-VAR of crisis period with Net total assets as the unconventional monetary variable. The test results are very similar also for other unconventional variables used.
Source: Author's elaboration

D.3 FA-VAR – whole dataset

The estimates of FA-VAR model produces the impulse response functions very close to those of generated using the crisis period only. The dynamics and the size of effects generally differ only for the monetary aggregates. Furthermore, especially in the case of UMI policy shock this particular group of variables behaves counter-intuitively. This could be caused by the fact that the monetary aggregates did not vary importantly before the crisis and the identification of relationship in data is thus difficult. The figures of impulse response functions follow.

Net total assets

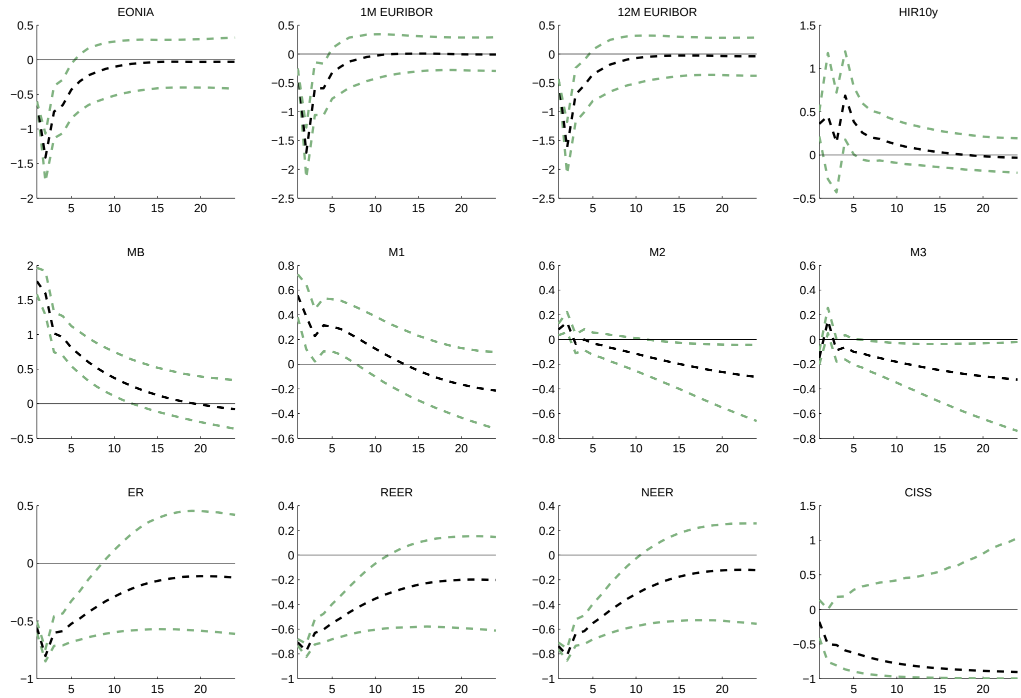
Figure D.2: FA-VAR impulse responses of macro variables to Net total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

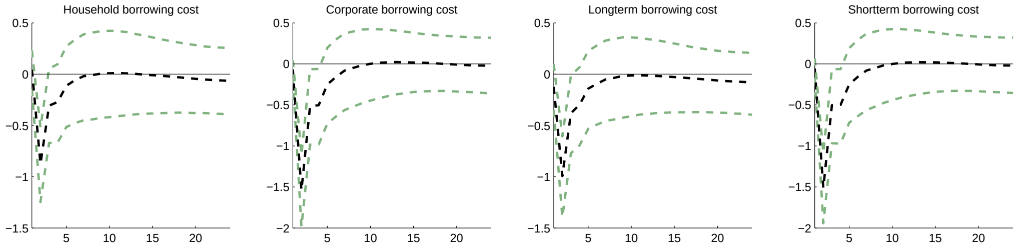
Figure D.3: FA-VAR impulse responses of selected variables to Net total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

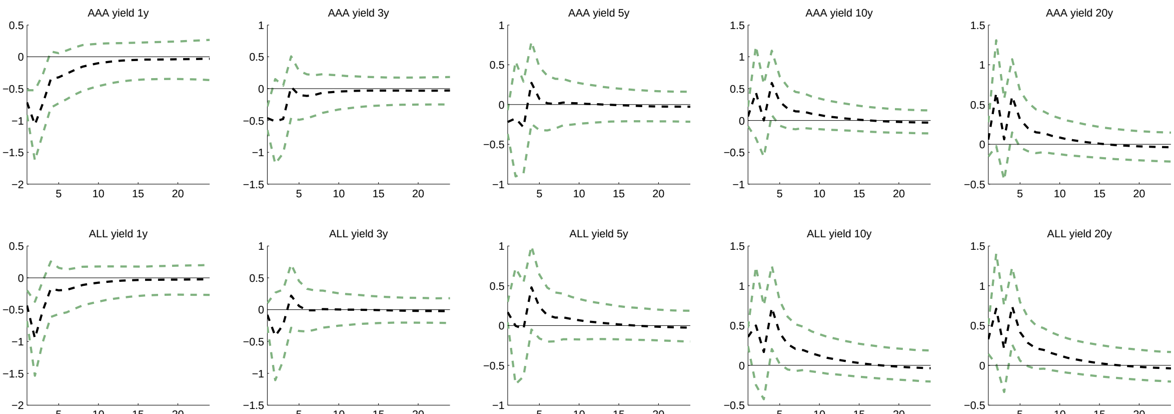
Figure D.4: FA-VAR impulse responses of borrowing costs to Net total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

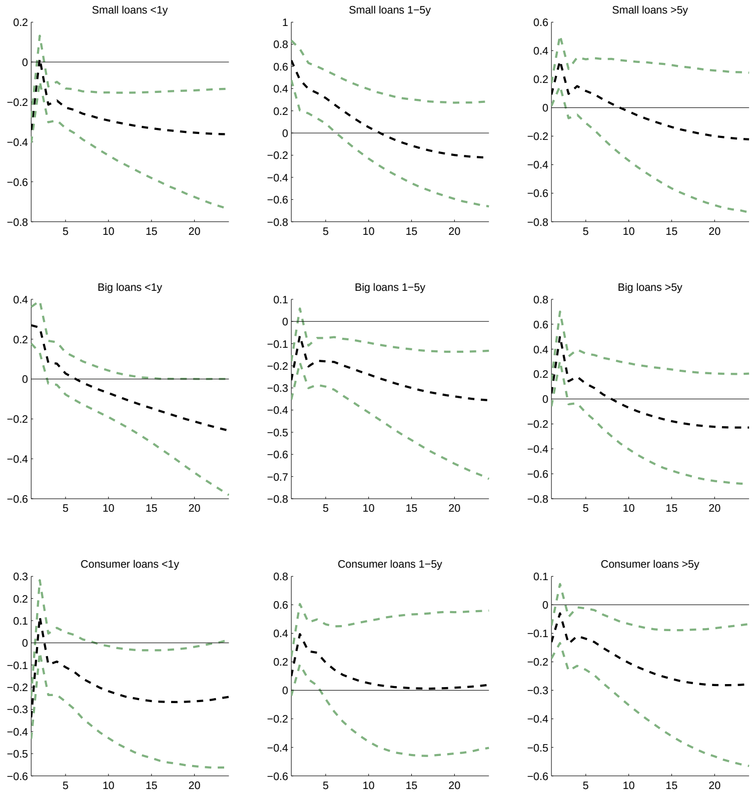
Figure D.5: FA-VAR impulse responses of bond yields to Net total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

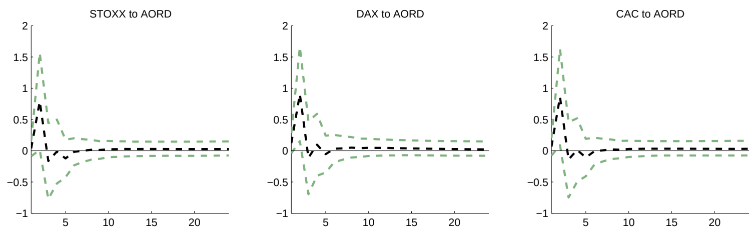
Figure D.6: FA-VAR impulse responses of loans volume to Net total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure D.7: FA-VAR impulse responses of stock indexes to Net total assets shock, 2003-2015 data

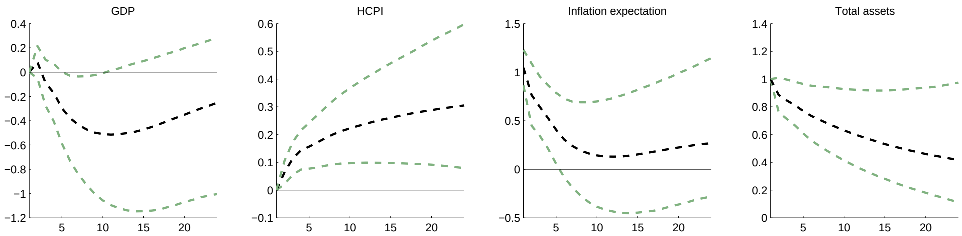


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Total assets

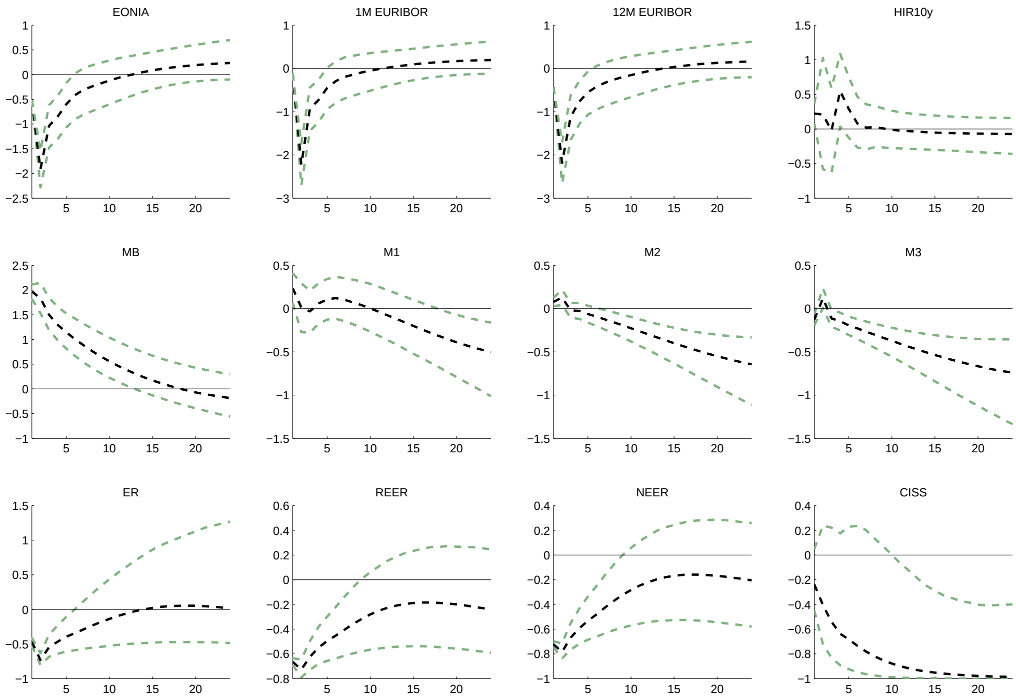
Figure D.8: FA-VAR impulse responses of macro variables to Total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

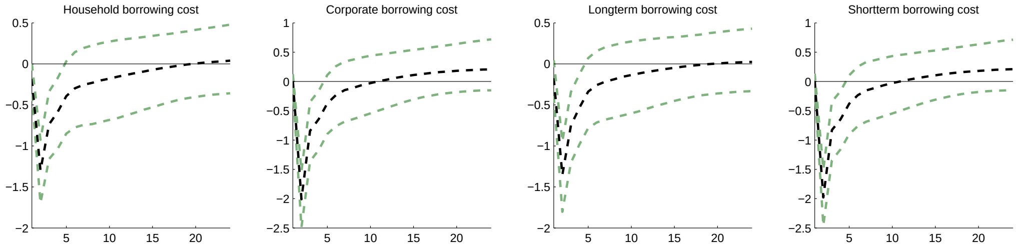
Figure D.9: FA-VAR impulse responses of selected variables to Total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

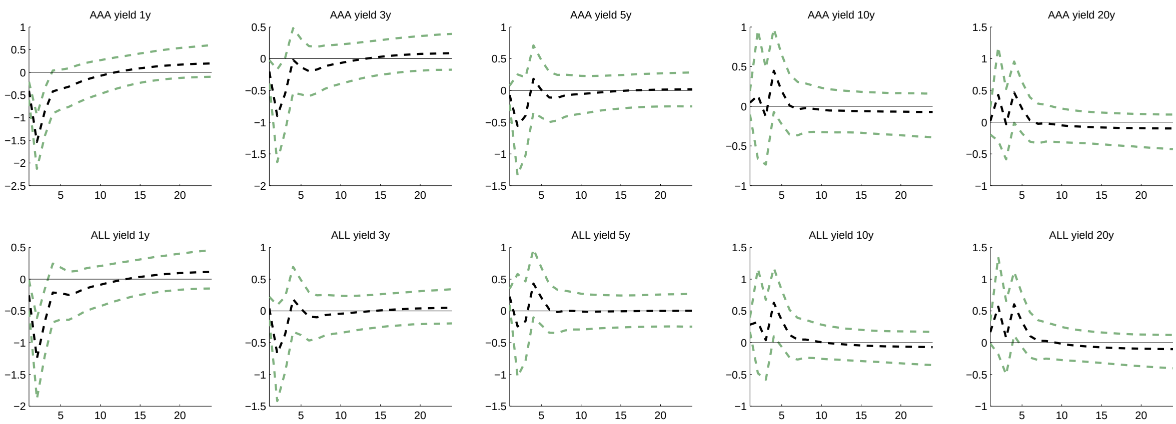
Figure D.10: FA-VAR impulse responses of borrowing costs to Total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

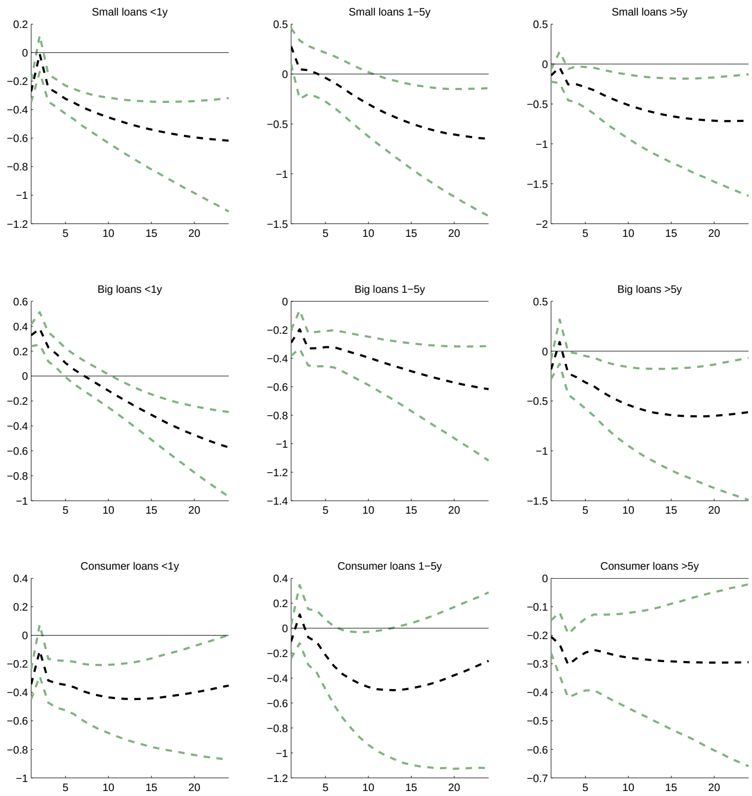
Figure D.11: FA-VAR impulse responses of bond yields to Total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

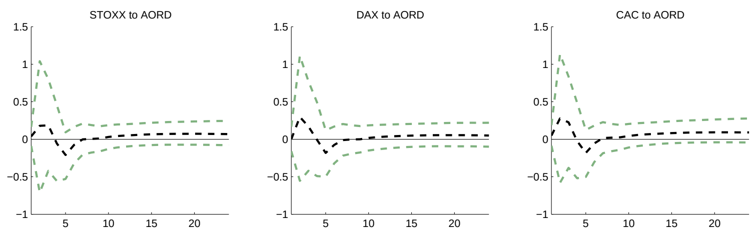
Figure D.12: FA-VAR impulse responses of loans volume to Total assets shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure D.13: FA-VAR impulse responses of stock indexes to Total assets shock, 2003-2015 data

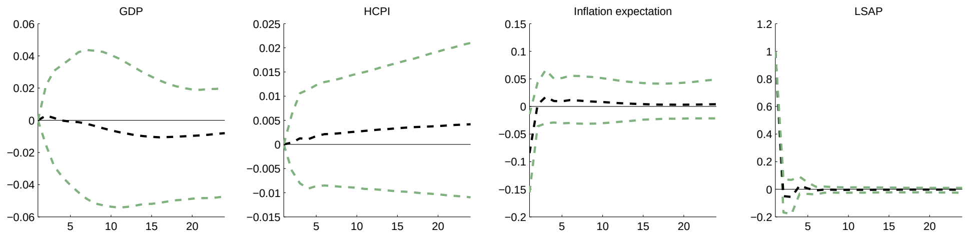


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

LSAP

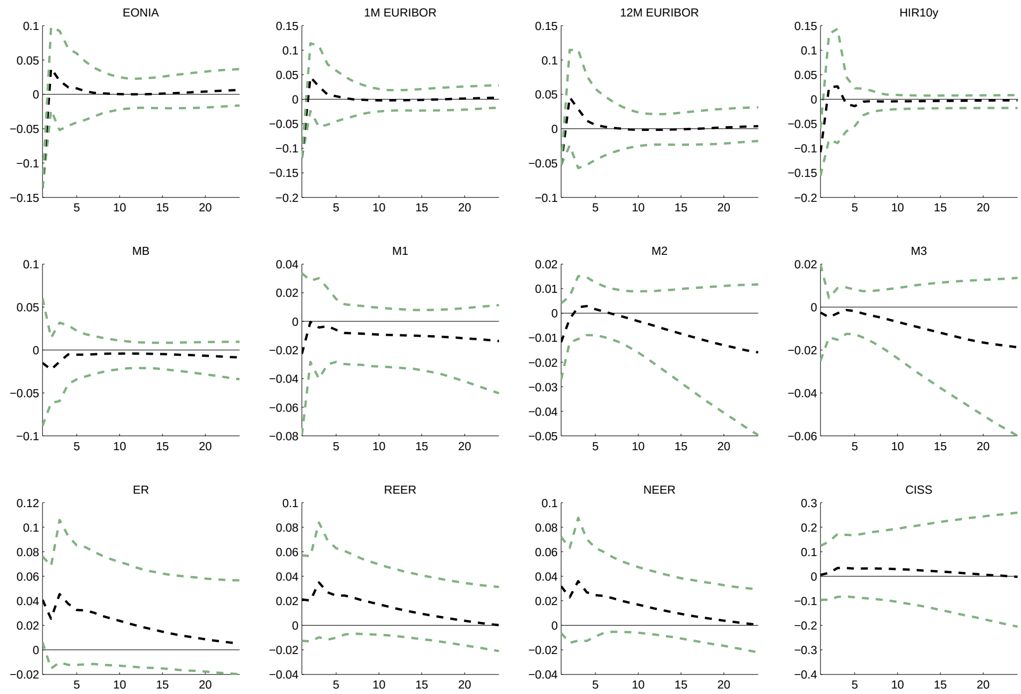
Figure D.14: FA-VAR impulse responses of macro variables to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

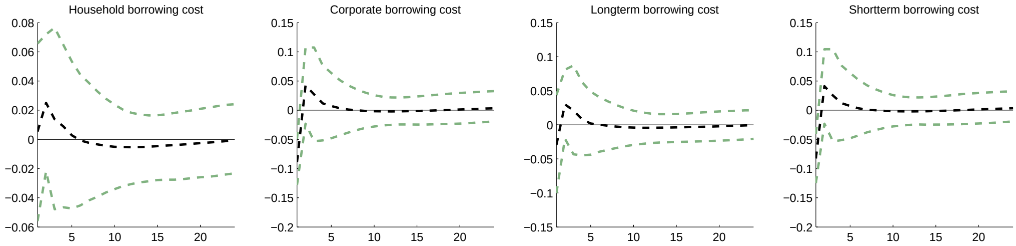
Figure D.15: FA-VAR impulse responses of selected variables to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

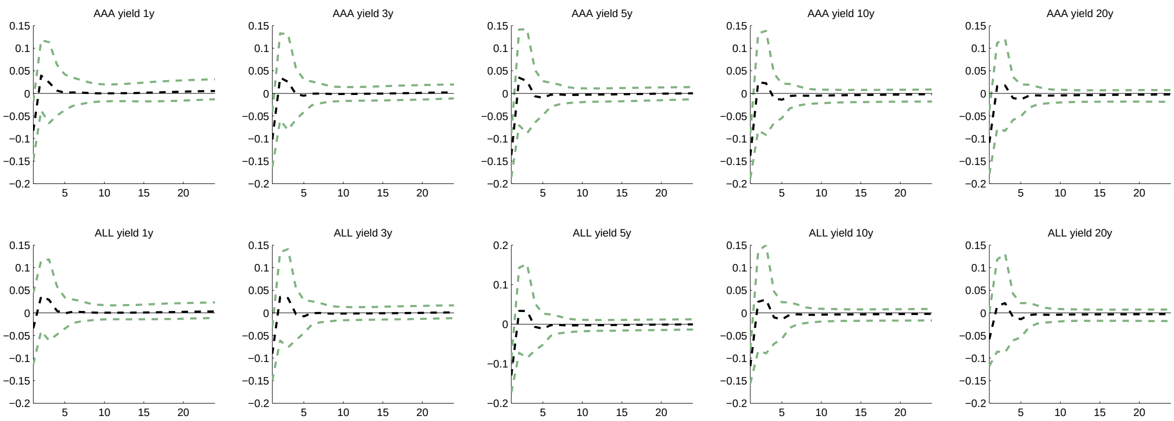
Figure D.16: FA-VAR impulse responses of borrowing costs to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

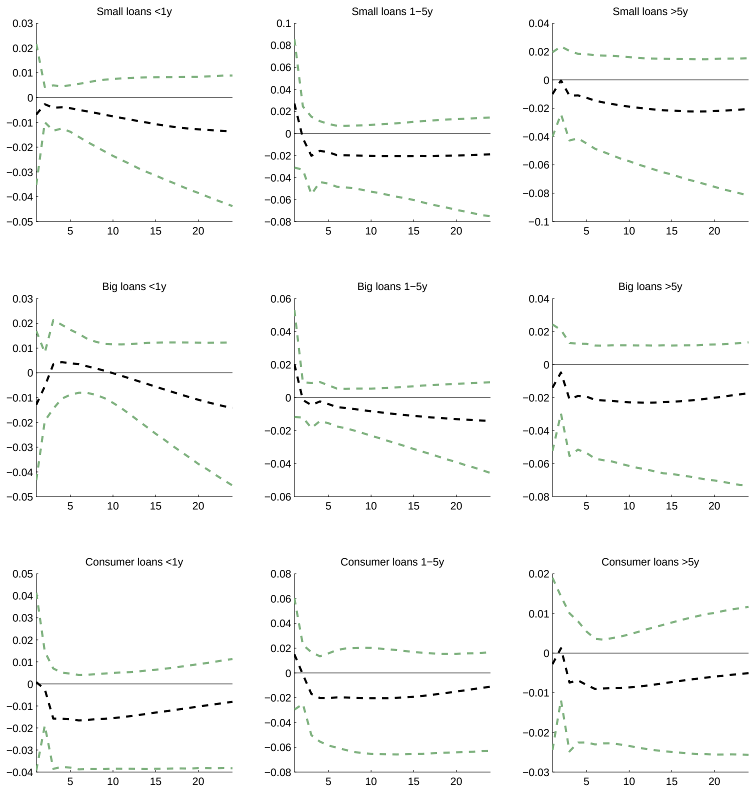
Figure D.17: FA-VAR impulse responses bond yields to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

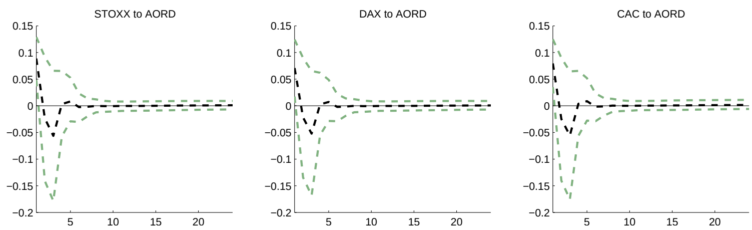
Source: author's elaboration

Figure D.18: FA-VAR impulse responses of loans volume to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

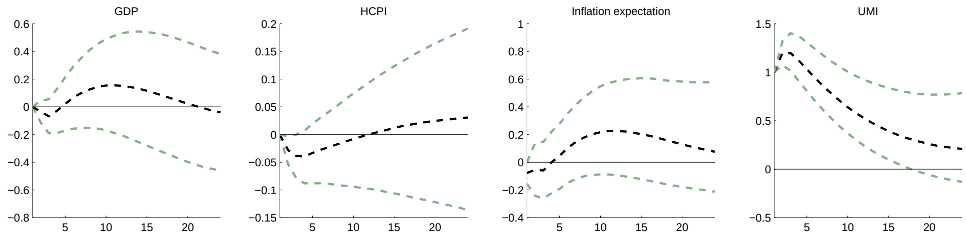
Figure D.19: FA-VAR impulse responses of stock indexes to LSAP shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.
Source: author's elaboration

UMI

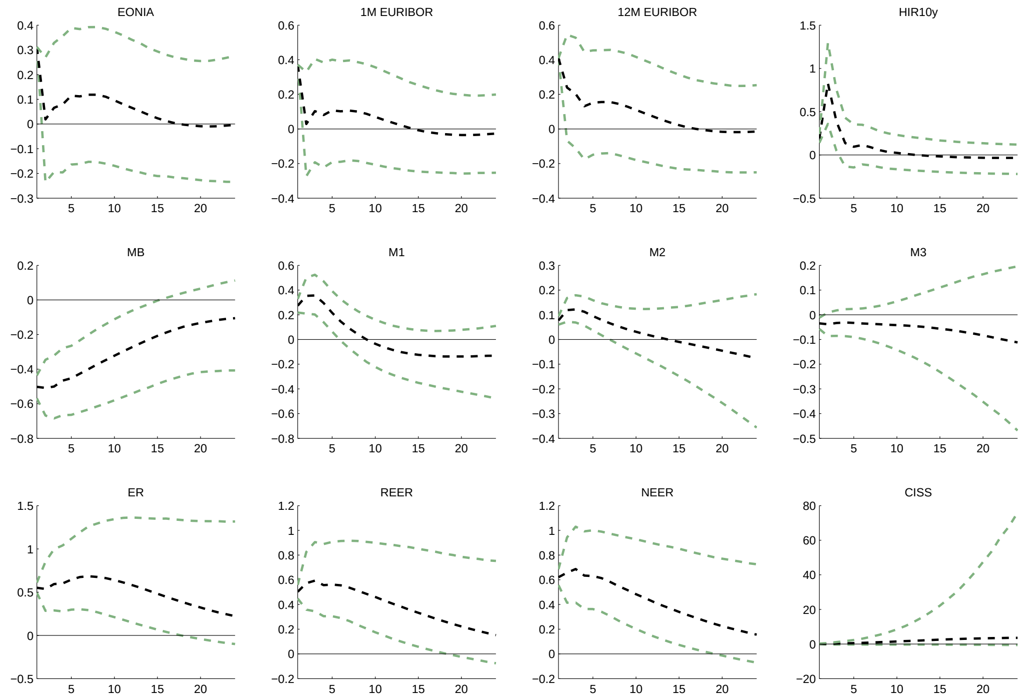
Figure D.20: FA-VAR impulse responses of macro variables to UMI shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

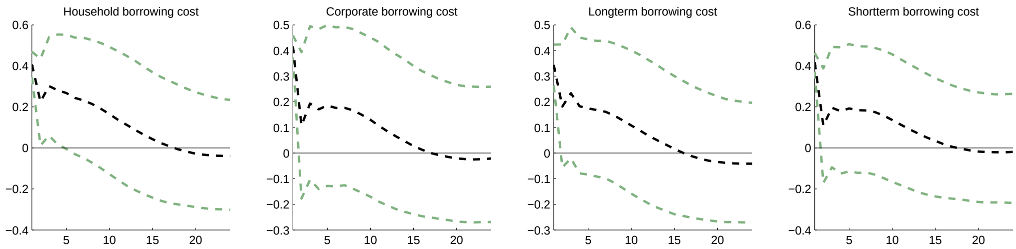
Figure D.21: FA-VAR impulse responses of selected variables to UMI shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

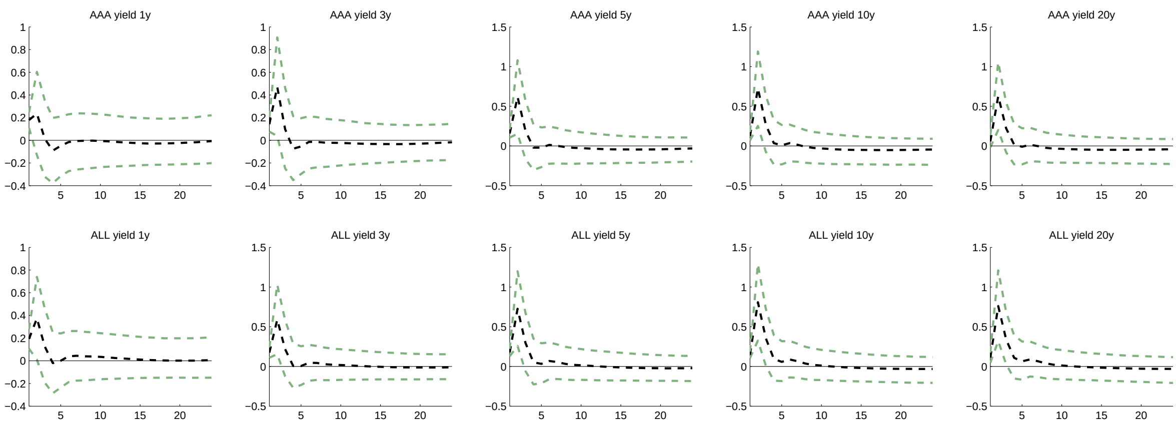
Figure D.22: FA-VAR impulse responses of borrowing costs to UMI shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

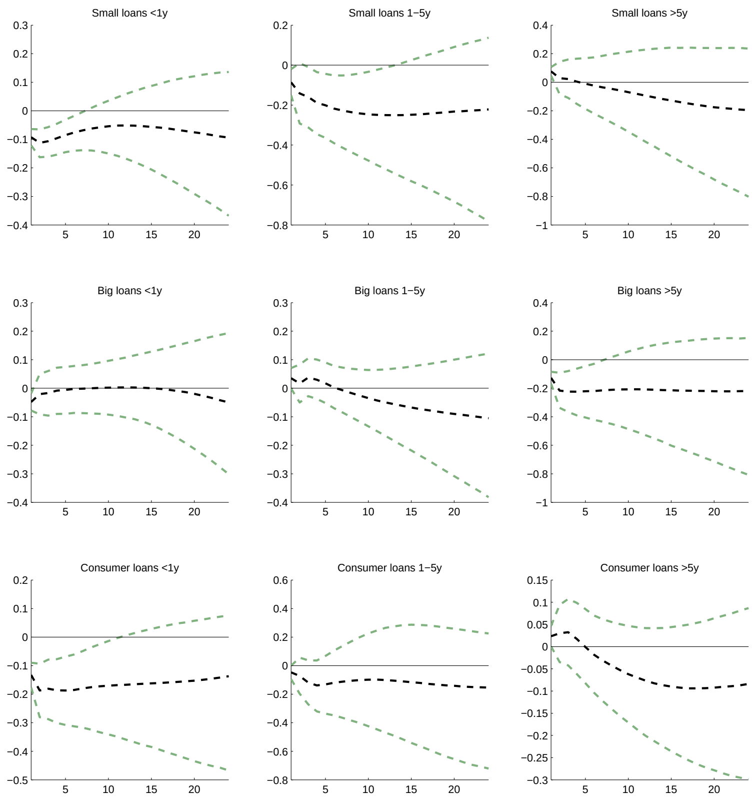
Figure D.23: FA-VAR impulse responses of bond yields to UMI shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

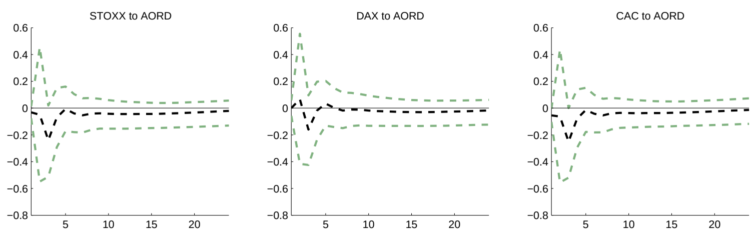
Figure D.24: FA-VAR impulse responses of loans volume to UMI shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure D.25: FA-VAR impulse responses of stock indexes to UMI shock, 2003-2015 data

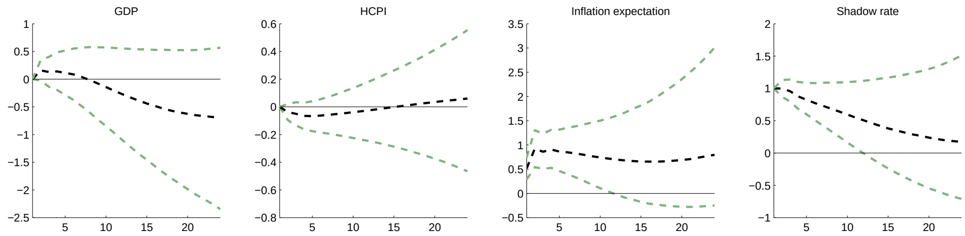


Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Shadow rate

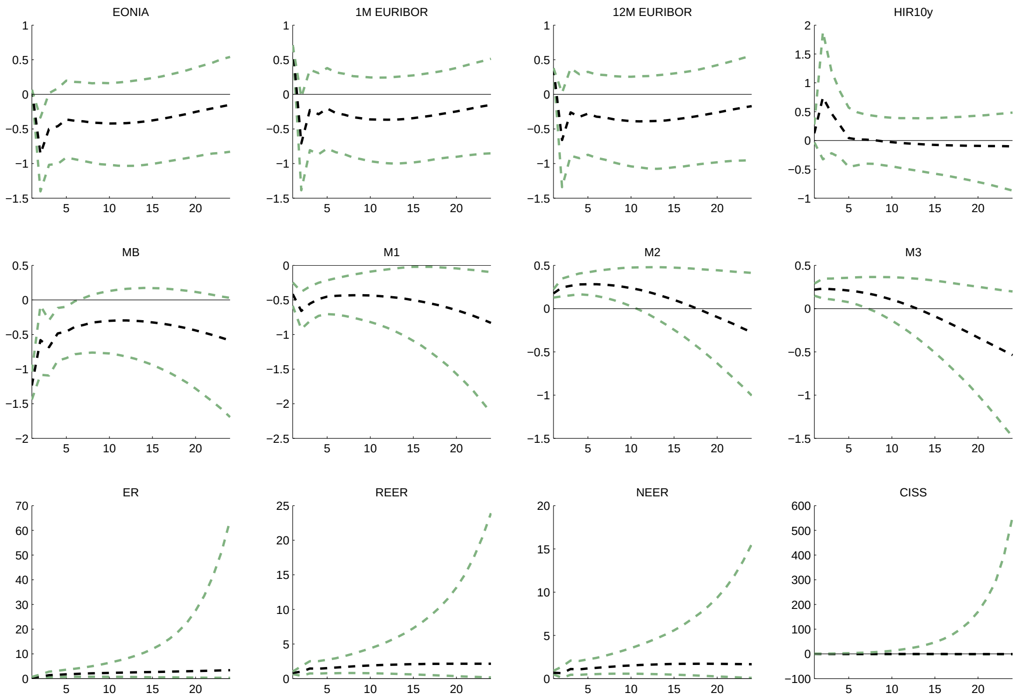
Figure D.26: FA-VAR impulse responses of macro variables to Shadow rate shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

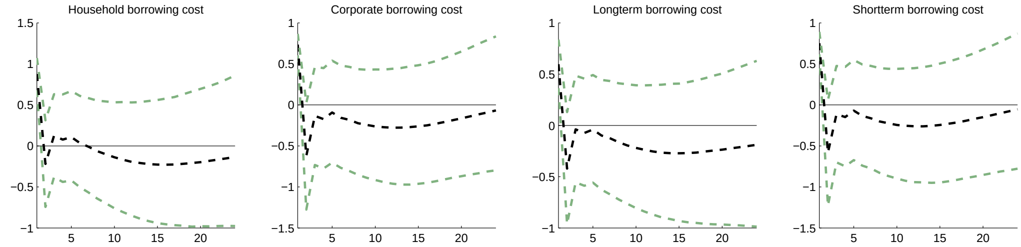
Figure D.27: FA-VAR impulse responses of selected variables to Shadow rate shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

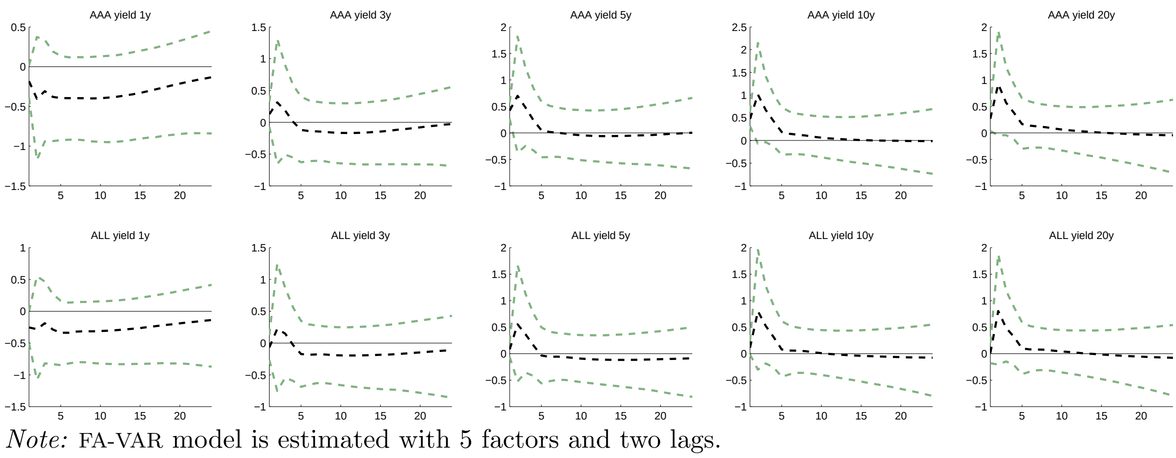
Figure D.28: FA-VAR impulse responses of borrowing costs to Shadow rate shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

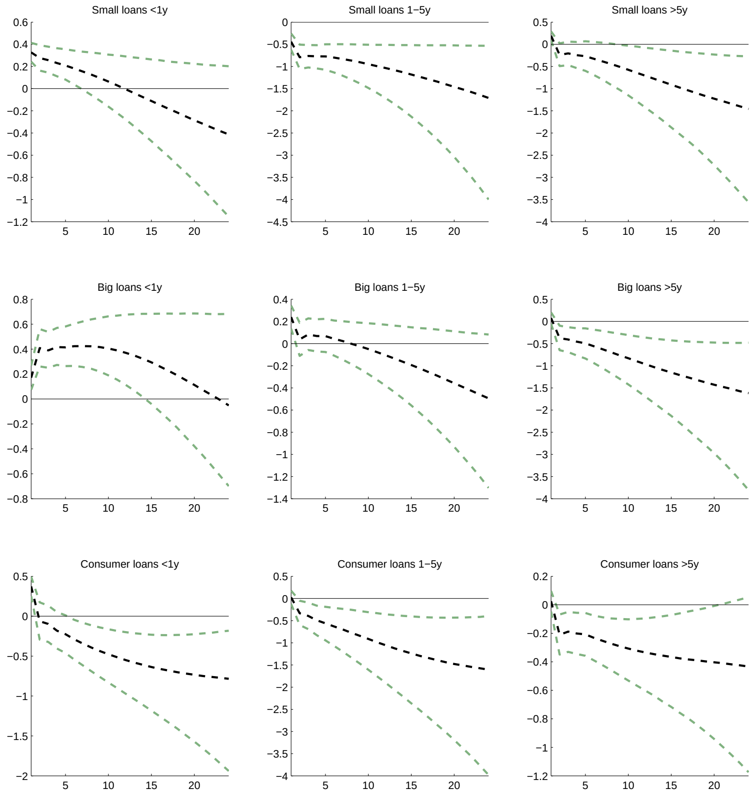
Figure D.29: FA-VAR impulse responses of bond yields to Shadow rate shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

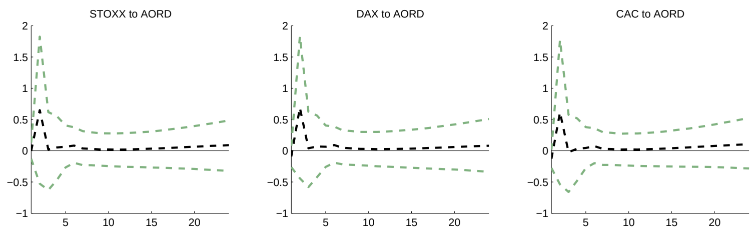
Figure D.30: FA-VAR impulse responses of loans volume to Shadow rate shock, 2003-2015 data



Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Figure D.31: FA-VAR impulse responses of stock indexes to Shadow rate shock, 2003-2015 data



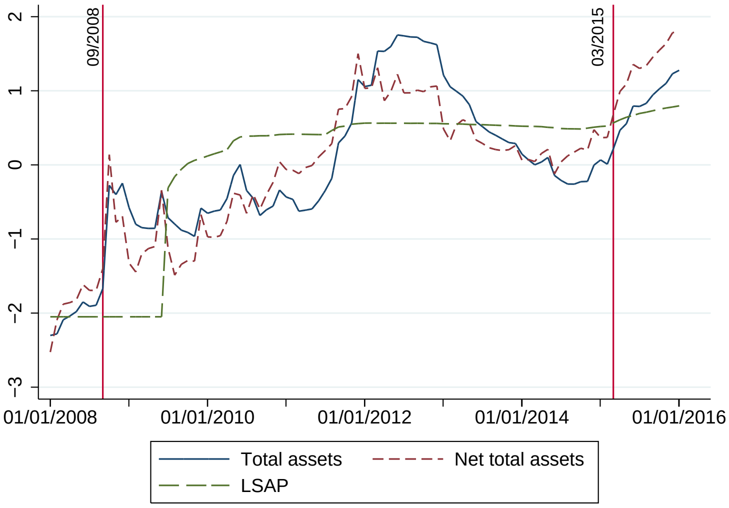
Note: FA-VAR model is estimated with 5 factors and two lags.

Source: author's elaboration

Appendix E

Policy variables

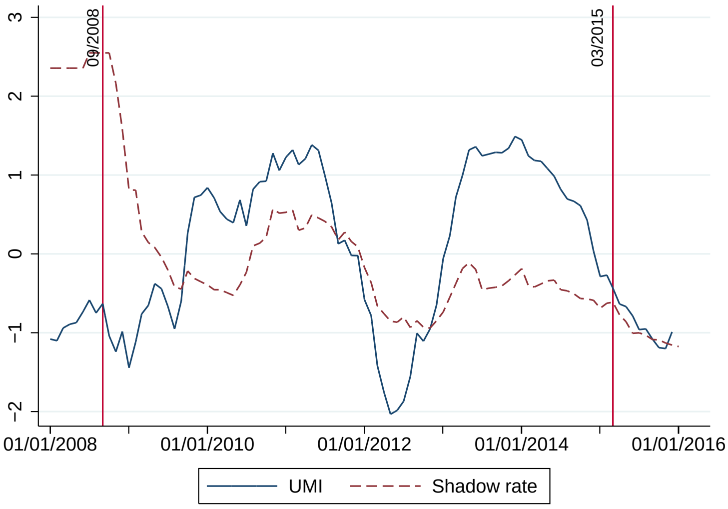
Figure E.1: Policy variables based on balance sheet data



Note: The variables are standardized.

Source: author's elaboration

Figure E.2: Constructed policy variables



Note: The variables are standardized.

Source: author's elaboration

Appendix F

Transformation of VAR estimates

In this section the transformation mechanism of estimated effects on VAR variables into the effects on original time-series is presented. This includes three steps. First, it is the quantification of the effect of the unconventional monetary policy from the beginning of 2015 on the variables as they are formulated in VAR analysis. Second, it is the quantification of the size of the effects on the non-standardized form of the variables as equivalent to the effects expressed in the first step. And third, in case the variables are presented in logarithms, first differences or deviations from the trend the equivalent effects on the variables in levels is calculated.

F.1 Effect on standardized variables

The effect of the policy change on the variable used in the VAR model is expressed as follows:

$$\Delta_{Stand} = N_{StDev} * IR, \tag{F.1}$$

where:

- Δ_{Stand} is the unknown absolute change of the standardized variable,
- N_{StDev} represents the size of the policy variable change after the policy change in 2015 expressed as a number of its standard deviations, and
- IR represents the estimated impulse response of the VAR variable to the policy variable shock of 1 standard deviation.

F.2 Effect on non-standardized variables

The absolute and relative changes of the non-standardized variable are expressed as follows:

$$\begin{aligned}
\Delta_{Stand} &= \frac{V_t - \bar{V}}{std(V)} - \frac{V_{t-1} - \bar{V}}{std(V)} \\
&= \frac{V_t - V_{t-1}}{std(V)} \\
&= \frac{\Delta_{NonStand}}{std(V)} \\
\Delta_{NonStand} &= \Delta_{Stand} * std(V) \\
\%\Delta_{NonStand} &= \frac{\Delta_{NonStand}}{|V_{t-1}|},
\end{aligned} \tag{F.2}$$

where:

- $\Delta_{NonStand}$ is the unknown absolute change of the non-standardized variable V,
- $\%\Delta_{NonStand}$ is the unknown relative change of the non-standardized variable V,
- Δ_{Stand} represents the absolute change of the standardized variable calculated in equation F.1,
- $|\cdot|$ represents the absolute value,
- V_{t-1} represents the value of the non-standardized variable V in 12/2014, i.e. before the policy change,
- $\bar{V}$ represents the mean value of the non-standardized variable V, and
- $std(V)$ is the standard deviation of the non-standardized variable V.

F.3 Effect on variables in levels

F.3.1 Variables in logarithm

In case the non-standardized variable is expressed in logarithm of the original time-series, the following back transformation is used to express the relative response of the original time-series in levels:

$$\begin{aligned}\Delta_{NonStand} &= ln(V_t^{Level}) - ln(V_{t-1}^{Level}) \\ &= ln(1 + \frac{V_t^{Level} - V_{t-1}^{Level}}{V_{t-1}^{Level}}) \\ &= ln(1+p) \\ p &= exp(\Delta_{NonStand}) - 1,\end{aligned} \tag{F.3}$$

where:

- p is the unknown relative change of the non-standardized variable V in levels,
- $\Delta_{NonStand}$ represents the absolute change of the standardized variable calculated in equation F.2,
- $ln(\cdot)$ represents the natural logarithm,
- $exp(\cdot)$ represents the exponential function, and
- V_{t-1}^{Level} represents the value of the non-standardized variable V before the log transformation in 12/2014, i.e. before the policy change.

F.3.2 Variables in first difference

In case the non-standardized variable is expressed in first difference of the original time-series, the following back transformation is used to express the response of the original time-series in levels:

$$\begin{aligned}\Delta_{NonStand} &= V_t - V_{t-1} \\ \Delta_{NonStand} &= (V_t^{Level} - V_{t-1}^{Level}) - (V_{t-1}^{Level} - V_{t-2}^{Level}) \\ &= \Delta_{Level} - (V_{t-1}^{Level} - V_{t-2}^{Level}) \\ \Delta_{Level} &= \Delta_{NonStand} + (V_{t-1}^{Level} - V_{t-2}^{Level}) \\ &\approx \Delta_{NonStand} + \frac{\sum_{k=1}^{t}(V_k^{Level} - V_{k-1}^{Level})}{t},\end{aligned} \tag{F.4}$$

where:

- Δ_{Level} is the unknown absolute change of the non-standardized variable V in level,

- $\Delta_{NonStand}$ represents the absolute change of the non-standardized variable V calculated in equation F.2,
- V_{t-1} represents the value of the non-standardized variable V in 12/2014, i.e. before the policy change, and
- V_{t-1}^{Level} represents the value of the non-standardized variable V before the first difference transformation in 12/2014, i.e. before the policy change.

F.3.3 Variables in % deviation from the trend

In case the non-standardized variable is expressed in % deviation from the trend of the original time-series, the following back transformation is used to express the response of the original time-series in levels:

$$\%\Delta_{Level} = \frac{\Delta_{NonStand} * |V_{t-1}^{Level-Trend}|}{|V_{t-1}^{Level}|}, \tag{F.5}$$

where:

- $\%\Delta_{Level}$ is the unknown relative change of the non-standardized variable V in levels,
- $\Delta_{NonStand}$ represents the absolute change of the non-standardized variable V calculated in equation F.2,
- $|\cdot|$ represents the absolute value,
- $V_{t-1}^{Level-Trend}$ represents the value of the trend of non-standardized variable V before the deviation transformation evaluated in 12/2014, i.e. before the policy change, and
- V_{t-1}^{Level} represents the value of the non-standardized variable V before the deviation transformation in 12/2014, i.e. before the policy change.

F.3.4 Variables in logarithm and detrended

In case the non-standardized variable is expressed in detrended log-value of the original time-series, the following back transformation is used to express the response of the original time-series in levels:

$$
\begin{aligned}
\Delta_{NonStand} &= V_t - V_{t-1} \\
&= [ln(V_t^{Level}) - V_t^{Log-Trend}] - [ln(V_{t-1}^{Level}) - V_{t-1}^{Log-Trend}] \\
&= ln(1 + \frac{V_t^{Level} - V_{t-1}^{Level}}{V_{t-1}^{Level}}) - (V_t^{Log-Trend} - V_{t-1}^{Log-Trend}) \\
&\approx ln(1+r) - \frac{\sum_{k=1}^{t}(V_k^{Log-Trend} - V_{k-1}^{Log-Trend})}{t} \\
r &= exp[\Delta_{NonStand} + \frac{\sum_{k=1}^{t}(V_k^{Log-Trend} - V_{k-1}^{Log-Trend})}{t}] - 1
\end{aligned}
\tag{F.6}
$$

where:

- r is the relative change of the non-standardized variable V in levels,
- $\Delta_{NonStand}$ represents the relative change of the non-standardized variable V calculated in equation F.2,
- V_{t-1} represents the value of the non-standardized variable V in 12/2014, i.e. before the policy change,
- $V_{t-1}^{Log-Trend}$ represents the trend value of the non-standardized variable V in 12/2014, i.e. before the policy change,
- V_{t-1}^{Level} represents the value of the non-standardized variable V before the deviation transformation in 12/2014, i.e. before the policy change,
- $ln(\cdot)$ represents the natural logarithm, and
- $exp(\cdot)$ represents the exponential function.