SSE Riga Student Research Papers
2017 : 4 (191)

IMPACT OF ECB UNCONVENTIONAL MEASURES ON MONETARY POLICY STANCE

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ISSN 1691-4643
ISBN 978-9984-822-31-0

November 2017
Riga

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Abstract

Ten non-standard monetary policy programmes have been launched by the ECB since 2009. I explore their impact on the monetary policy stance in the Euro Area. Interest rates in the Euro Area are sticky at the effective lower bound and do not reflect the stance of the ECB. I use principal components analysis to estimate the shadow rate – proxy for the monetary policy stance. Next, I establish the impact of the non-standard programmes using ARCH model.

I also assess and compare the programmes' efficiency in terms of the effect on the shadow rate given the amount of euro to be accumulated on the balance sheet of the Eurosystem under these programmes. I conclude that targeted refinancing operations are more efficient in making the monetary policy stance more expansionary given the same euro amount. The Expanded Asset Purchase Programme is on average twice less efficient. Considering the present mix of the programmes, the current contribution to lowering the shadow rate is higher for the Expanded Asset Purchase Programme (0.7%) than for the Second Targeted Longer-Term Refinancing Operations (0.5%).

Previously, the impact of unconventional monetary policy has been studied only in aggregate. I am the first to look into the individual effect of the unconventional programmes.

Keywords: unconventional monetary policy, shadow rate, principal components analysis, effective lower bound, monetary policy stance, ARCH model, Euro Area.

1. Introduction

Since 2002, all major economies experienced optimistic figures of economic growth. It continued up until the beginning of the Great Recession, as the crisis of 2009 was called several years ago. When the economic slowdown became severe, policymakers around the world had to respond accordingly and launch monetary and fiscal stimulus to close the emerged output gap. To make monetary policy more expansionary, interest rates were lowered to stimulate demand in the economy. Already in 2009, in the US, the Euro Area, Japan, Sweden, and Denmark, they reached levels near zero. However, the economic growth did not take off and inflation rates started to fall below zero in several countries of the Euro Area. The increasing deflation threat and the consequent potential vicious cycle of a further shrink of economies due to postponed consumption compelled central banks to come up with some non-standard, also called unconventional, monetary policy measures. The primary objective of this research is to establish how such monetary policy programmes affected the overall monetary policy stance of the European Central Bank (ECB).

Exploring unconventional monetary policy measures has been very topical in the last several years. The usual question that economists try to answer is how these programmes affected economic growth and other key parameters of the real economy. More technical works emphasize that this is the monetary policy stance, i.e. the degree how expansionary monetary policy of a certain central bank is, that can foster economic growth. They study the impact of the unconventional measures on asset prices, interest rates and the overall monetary policy stance. The simple fact that the environment of ultra-loose monetary policy is unprecedented implies that little literature dated prior to 2009 is anyhow related to studying monetary policy when interest rates in the economy are approaching zero.

The research field is new, and I have noticed that the impact of unconventional monetary policy measures is studied only in aggregate. The ECB, however, has a number of programmes intended to make monetary policy in the Euro Area more expansionary. Differences between them, to the best of my knowledge, have not been researched. I formulate the aim of this work as to study the impact of the non-standard monetary policy programmes carried out by the ECB on the overall monetary policy stance. The research question is formulated in the following way.

Research Question: What is the impact of refinancing operations and asset purchase programmes on the overall monetary policy stance in the Euro Area?

Although ten different unconventional monetary policy programmes have been launched by the ECB since 2009, I do not set out to obtain ten different coefficients representing the effectiveness of each monetary policy programme. Such limitation is justified by the fact that several programmes started almost at the same time, were eventually combined by the ECB and implemented as one programme; moreover, not all had monetary policy easing as the primary function.

The research question has substantial importance for central banks to correctly steer monetary policy. In particular, answering it will let them identify by how much a certain unconventional monetary policy programme should be expanded or contracted to match the desired stance of monetary policy in a particular economic environment, for example, to match the policy rate implied by the Taylor rule. Currently, the scope of published papers does not provide clues to how much a certain euro amount of assets accumulated on the balance sheet of a central bank under a certain unconventional program affects monetary policy stance. Obtaining coefficients that answer this question and are easily interpretable is the main contribution of this work.

Three of those coefficients covering six programmes of the ECB's unconventional monetary policy are found in result of this study. Their interpretation is tangible – they represent the change in the policy rate in basis points caused by accumulation of one billion euro of assets on the balance sheet of the Eurosystem that would occur if the effective lower bound did not exist. In this way, I define efficiency of a monetary policy programme: the larger this change caused by the same euro amount of assets accumulated, the more efficient the programme. I provide the coefficients of efficiency for TLTRO, TLTRO-2, and the Extended Asset Purchase Programme, which includes CBPP3, ABSPP, PSPP, and CSPP. I conclude that the latest refinancing operations – TLTRO and TLTRO-2 – are the most efficient in making the monetary policy stance of the ECB more expansionary, with TLTRO-2 being marginally more efficient than TLTRO.

Most studies related to unconventional monetary policy measures examine their impact on either real economy (economic growth rates, inflation, unemployment) or financial markets (asset prices), or, alternatively, study monetary transmission channels. In view of this tendency, I want to clarify from the outset that this study is solely limited to the ECB's non-standard monetary policy measures and their impact on the overall monetary policy stance, represented by the shadow policy rate as argued later in the literature overview section. No other economic variables are considered.

The work is structured as follows. The next section is devoted to description of the research objects – the monetary policy stance in the Euro Area and the ECB's non-standard monetary policy measures. It is followed by the overview of the literature available on the topic with a heavy focus on different models to calculate the shadow rate. Two methodological steps to answer the research question are described in the fourth section. Next, the fifth section comments on sources of data used in this work and delineates transformations of the dataset to make it suitable for this study. The following two sections are devoted to presenting results and robustness checks respectively. Finally, the eighth section contains discussion of the results and outlines implications for further research.

2. Research Object

This study is devoted to establishing the relation between the ECB's non-standard monetary policy measures and the stance of monetary policy in the Euro Area. Since both concepts are quite involved, I describe them in a non-technical style to set up the background for other parts of the paper.

2.1. General description of monetary policy

Monetary policy is one of the main tools how aggregate economic growth can be controlled. The modern monetary theory builds around the empirically proven mechanism of counter-cyclical monetary policy, which should be designed to boost growth in the case of a recession and limit it during excessively buoyant demand periods. Central banks set expansionary monetary policy by lowering interest rates and increasing money supply to spur economic activity and should pursue a monetary contraction to limit money supply in growth periods, prevent overheating, inflation, bubbles on asset markets that can potentially result in sharp recession.

Plenty of monetary policy tools available for central banks to implement expansionary or contractionary monetary policy exist. Therefore, researchers cannot choose one of them to conclude on the degree how expansionary or contractionary a certain monetary policy is disregarding the other policy instruments utilized by a central bank. This degree is called the stance of monetary policy. The range of conventional monetary policy tools includes but is not limited to refinancing operations, setting reserve requirements, repurchase agreements, short-term liquidity provision, and reducing excess liquidity by offering deposits. Different use of all these tools defines monetary policy stance of a central bank. Therefore, the stance is an ordinal rather than cardinal measure: it can be compared to another usage intensity of monetary policy tools as being more contractionary or expansionary, but cannot be formally quantified.

Previously, central banks around the world would target a certain level of money supply. Monetary aggregates M0, M1, M2, and M3 were the best proxies for money supply and the most important variables for assessing the monetary policy stance. Consequently, first research of the monetary policy stance largely focused on monetary aggregates.

Today, central banks target money supply indirectly – they set a certain level of interest rates that changes the amount of money in circulation to the desired level. Therefore, the parameters seen as best proxies for describing the monetary policy stance are interest rates. Usually, the risk-free overnight rate is taken, such as the Federal Funds Rate in the US and the Euro Overnight Index Average (EONIA) in the Euro Area (Damjanovic & Masten, 2015).

The ECB has three policy rates: the main refinancing operations rate (MRO), the deposit facility rate (DFR, the lowest of the three rates) and the lending facility rate (MLFR, the highest). Prior to October 2008, the ECB limited the euro amount of liquidity it provided to the banking system, and MRO represented the minimum bid rate. In result, the larger was the demand for liquidity during a certain tender, the higher the was the rate, thereby MRO served as the equilibrium rate, and the market risk-free interest rates in the Euro Area, EONIA, followed MRO. On 15 October 2008, the ECB started to provide infinite amount of liquidity at the MRO rate set for the tender to solve liquidity crisis. Consequently, market rates ceased to follow MRO and fell further, approaching the deposit facility rate. Therefore, when one speaks of the policy rate in the Euro Area, it stands for MRO before 15 October 2008 and DFR after that date.

2.2. Monetary policy at the lower bound

In the aftermath of the Great Recession, central banks had to lower interest rates to levels close to zero, but it turned to be insufficient to pick up inflation and spur economic growth. Interest rates became sticky at near-zero levels. This made conventional monetary policy inefficient because the main tool of conventional monetary policy, the policy rate, could not be pushed lower. The rationale for interest rates being constrained from below by zero is simple: when offered a negative return for holing assets, one can hold his funds in currency as a physical asset (Krippner, 2013). Therefore, it was believed that interest rates and hence conventional monetary policy was constrained by the zero lower bound (ZLB) when the environment of ultra-low interest rates began.

Even when short-term interest rates are constrained by zero, the monetary policy stance can become more expansionary. To ensure low interest rates and hence low cost of capital for long-term borrowings, which are essential to spur economic activity, a central bank is interested in lowering the market interest rates of longer maturities. Thus, a more expansionary stance is represented by a flatter yield curve with the further end as close to zero as possible.

To reach this objective, the European Central Bank invented a number of non-standard, or unconventional, programmes. They are described in the next subsection.

Quite surprisingly, the reality proved that the level of zero interest imposes no strict floor on interest rates, as could be expected. Keeping money as a physical asset is associated with certain costs, and the modern financial system cannot operate in cash. Considering this aspect, the ECB lowered the deposit facility rate below zero for the first time in June 2014. In March 2016, DFR reached -0.4% (SDW, n.d.). Until now, this is the lowest policy rate for the Euro Area. At the same time, some countries of the European Union like with national currencies have even lower policy rates.

Negative interest rates imply that the zero lower bound is not a strict lower bound for interest rates. At the same time, the evidence suggests that even at levels slightly above zero, conventional monetary policy becomes inefficient. Therefore, it makes sense to speak of the effective lower bound (ELB) instead of ZLB. ELB is defined as the level when conventional policy measures stop working. The definition is very opaque, and it is difficult to say what exactly is the level of ELB at each point of time. However, the latest evidence indicates that when the environment of ultra-loose monetary policy stays for a long time, ELB tends to shift down.

2.3. The ECB's non-standard monetary policy programmes

All non-standard monetary policy programmes can be divided into two groups: refinancing operations that aim at enhanced liquidity provision, and asset purchase programmes. I describe these types in turn.

Long-Term Refinancing Operations (LTRO) were initially a programme of conventional monetary policy. The ECB provided banks with additional liquidity in auctions lending them for up to 3 months at the main refinancing operations rate. In March 2008, the ECB provided liquidity for a period of 6 months for the first time, and extended the lending period up to 12 months since the auction held in June 2009, naming it Longer-Term Refinancing Operations. The period was extended to three years in December 2011 (ECB, 2011).

In summer 2014, the ECB announced the first Targeted Long-Term Refinancing Operations (TLTRO), according to which the funds could be lent to banks for up to four years at record-low interest rate. At the same time, the borrowing banks were required to provide evidence that they will use this funds to provide loans for real economic activity, not including purchases of real estate.

Second Targeted Long-Term Refinancing Operations (TLTRO-2) was announced in summer 2016, it modified TLTRO rules and introduced a changing rate of lending contingent upon banks' success in issuing loans for real economy.

Liquidity provision programmes have different conditions the banks should comply with to be eligible for receiving these longer loans from the central bank at a lower rate (ECB, 2016b). In particular, to be sanctioned for TLTRO borrowings, the bank should prove that it uses the borrowed funds to credit real economy. TLTRO-2 is even more sophisticated: the interest rate under which the loan is offered to the bank is variable upon meeting certain conditions regarding the way the bank credits real economy (ECB, 2016b).

Asset purchase programmes differ by the type of assets that the ECB buys under each of them: these can be securities of the public sector, asset-based securities, or simply covered bonds; on June 10, 2016, the ECB started to buy high-rated corporate debt, but the euro amount of such securities purchased remains small (ECB, 2016a).

The first non-standard asset purchase programme launched by the ECB was Covered Bond Purchase Programme (CBPP1). In fact, it started in July 2009, before interest rates fell close to DFR. Its main objective was to stabilize the market for covered bonds and thus help resolve banks' refinancing problems. Securities Markets Programme (SMP) was not thought as part of monetary policy easing, but it implied purchase of bonds of peripheral countries of the Euro Area to solve liquidity crisis there at the beginning of the Great Recession. The purchased assets still remain on the balance sheet of the Eurosystem. Second Covered Bond Purchase Programme (CBPP2) took place in November 2011 and included €40 billion more stimulus in addition to CBPP1 (ECB, 2011).

Third Covered Bond Purchase Programme (CBPP3) was launched in October 2014 to provide additional stimulus and improve transmission of monetary policy and return inflation rates in the Eurozone to the target level of 2%. Asset-Backed Securities Purchase Programme (ABSPP) was adopted in conjunction with CBPP3 and was intended to solve the remaining problem of insufficient liquidity in asset-backed securities markets after related problems in 2008. Public Sector Purchase Programme (PSPP) started in March 2015 with the main objective to buy public sector bonds and free up funds of investors to direct them to investing in real economy. Finally, Corporate Sector Purchase Programme (CSPP) was a radical step by the ECB in June 2016 and sanctioned purchase of highly-rated debt of the private sector (ECB, 2016a).

On 22 January 2015, CBPP3, ABSPP and PSPP were combined into the Extended Asset Purchase Programme (EAPP) and amounted to € 60 billion of monthly purchases (Draghi, 2015). In April 2016, the span of purchases increased to € 80 billion per month and is expected to be scaled back to € 60 billion per month from April 2017 (ECB, n.d.; ECB, 2017).

There is no doubt that the effect of these programmes is the same as from lowering interest rates. When a central bank cuts the policy rate, it improves the balance sheet of indebted companies and individuals helping to avoid them bankruptcies, induces borrowing, and reduces the cost of capital, thus making investment in real economy more profitable. Lower interest rates force investors to reduce their investment in fixed income that now becomes less profitable and redirect this money to business. Asset purchase programs work in the same way: they are designed to make investors profitable to exit investment in debt and other fixed-income securities that do not contribute to increasing velocity of money in the economy, thus making real-economy investments relatively more attractive. The purpose of longer-term liquidity provision does not differ: its goal is to make money available for banks at a cheaper price and to reduce uncertainty that is normally carried by the financial system – matching obligations on short-term liabilities with much less liquid assets (ECB, 2016b).

3. *Literature review*

3.1. Shadow rate: proxy for monetary policy stance

Once the key policy instrument of central banks is the interest rate of short-term risk-free borrowings, assessment of the monetary policy stance is not a major problem. Albeit the other instruments also have to be taken into account as argued previously, their effect on the extent how much a certain stance is expansionary or contractionary cannot be too distant from that represented by the policy rate.

Ultra-loose monetary policy environment, when interest rates approach ELB, creates a challenge for objective assessment of the monetary policy stance. Short-term interest rates cannot go below zero because there exists the option to invest in physical currency, which is the best risk-free alternative (Krippner, 2012). Consequently, nowadays the short-term risk-free rate set by the central bank or observable on the interbank market cannot be used as a proxy for the monetary policy stance.

The problem is relatively new, and researchers have not yet agreed upon the best and most tractable framework for evaluating monetary policy stance when interest rates are constrained by zero. The return to monetary aggregates as indicators of monetary policy has not been proposed – as follows from evidence on the US, they ceased to be good proxies to evaluate monetary policy stance since 1979 (Estrella & Mishkin, 1997). Another possibility is creating synthetic measures that would represent monetary policy stance, but no one has provided an index of such kind with a practical interpretation.

Undoubtedly, the degree by which monetary policy becomes more expansionary or contractionary when the short-term interest rates are stable near zero is determined by the unconventional monetary policy measures. Interest rates of longer maturities carry information about the degree of loose monetary policy. Therefore, information about the monetary policy stance can be derived from the yield curve. Lower interest rates for securities of long maturities denote that the interest rates are expected to remain at zero for longer, and the actual contribution of the central bank to increase money supply is higher.

Based on this relation, researchers have come up with the shadow rate (also called "Short Shadow Rate" and "shadow policy rate"). It is defined in the following way: the shadow rate is the interest rate which equals the overnight risk-free interbank rate when not in the ELB environment, and the estimate of such rate if the ELB did not exist (i.e. there were no option to hold physical currency) when the monetary policy is constrained by the ELB (Krippner, 2012).

3.2. Models for the shadow rate

Wu and Xia (2015) assert that "the shadow rate is a powerful tool to summarize useful information at the ZLB". However, despite the clear interpretation, there exists no precise way to estimate the shadow rate. A number of models has been created to estimate the shadow rate, and none of them can be treated as the perfect one or even the first-best. There are several major classes of such models.

One class is the Gaussian arbitrage-free affine term structure models. Using a model of this class for calculating the policy rate in the ZLB environment was first introduced by Christensen, Diebold, and Rudebusch (2011). Such idea arose from the fact that these models assume a non-zero possibility of interest rates of all maturities being negative. Hamilton and Wu (2012) provide extensive econometric framework on how the shadow rate can be derived from interest yields assuming arbitrage-free risk-averse trading. Christensen & Rudebush (2013) combine it with Krippner's (2012) approach in their paper "Estimating Shadow-Rate Term Structure Models with Near-Zero Yields". A similar approach is undertaken by Chen et al (2012), where he uses corporate bond spreads as a proxy of the policy stance of the Federal Reserve. However, this approach has the same drawback as event study – it can be affected by market sentiments and risks regarding the whole corporate sector that influences corporate bonds and is not related to direct effects of the undertaken monetary policy.

As outlined by Krippner (2013), the major problem of the Gaussian arbitrage-free affine term structure models is the fact that they do not account for the option to hold currency in the physical form. Albeit modelling negative interest rates is possible, such results lose their tractability because interest rates of any maturity can become arbitrarily negative (especially forward rates might tend to minus infinity) and tend to return to the historical mean too fast. In contrast, empirical data shows that interest rates at ELB are stickier and remain near zero for longer periods, whilst are more volatile on other levels (Kortela, 2016).

He tries to solve this issue (Krippner, 2013) by incorporating the proposition of Black (1995) to express an interest rate in form of an option. The intuition behind this idea is that all economic agents have an option to hold currency under the zero interest rate. However, if the interest rate is at the zero lower bound, it may happen that the interest rate rises in the future. Due to the uncertainty about the interest rate in the future, risk-free debt obligations of longer maturities still assume some non-zero return. Thus, the composition of the term yield curve is the main indicator of what the interest rates might have been, should there be no ZLB, i.e. no option to hold money at the zero rate of interest when positive return for savings is not offered.

In this way, Krippner turns to the second class of models for the shadow rate, which assumes that the actual interest rate that persists on financial markets equals the shadow rate when interest rates are above zero and some constant level of ELB otherwise. The shadow rate, in turn, is the function of several factors. Ajevskis (2016) divides them into observable, where he includes the programmes of unconventional monetary policy, since the amount of assets accumulated under them is known, and unobservable, where interest rates are included. In all models of this class, the unobservable factors are assumed to follow a vector-autoregressive process.

In fact, including data from the ECB balance sheet as an observable factor is the novelty of his work. However, he does not discriminate between different programs of the ECB, but aggregates them creating two variables: the amount of assets and their duration (Ajevskis, 2016). Noteworthy, in suggestions for further research he mentions that a perspective way to develop the research is to consider “a more detailed division of the factor of the non-standard policy measures, e.g. by LTROs and the APP”. Despite the infeasibility to follow the same methodology as in Ajevskis (2016), this is exactly the path the author of the current study undertakes.

The most consistent and regularly updated time series of the shadow rate is produced by Wu and Xia (2015). In that paper, they not only discuss the effect of the ultra-loose monetary policy stance of the Federal Reserve, but also explain the mechanics of the three-factor model based on which the shadow rate is estimated. They employ factor-augmented vector autoregression model and show that it produces higher maximum likelihood than Gaussian affine term structure models – mainly because the factor-augmented vector autoregression model is more robust in the ELB environment by accounting for the option to hold currency as mentioned above (Wu & Xia, 2015).

As suggested by the authors of that paper, due to availability of their results, for example, on the website of the Federal Reserve Bank of Atlanta, the shadow rate calculated by Wu & Xia became widely used for assessing monetary policy stance in the US and the Euro Area. However, their model has been demonstrated to be insufficiently robust as well. In his note “A comment on Wu and Xia (2015), and the case for two-factor Shadow Short Rates”, Krippner (2015) suggests that the absolute level of the shadow rate Wu and Xia obtain depends on their assumptions, some of which, the benchmark level of the ELB in particular, are not realistic. He reaches this conclusion by analyzing the same dataset as use by Wu and Xia and afterwards proposes a two-factor arbitrage-free Nelson-Siegel model, demonstrating its superior robustness. In fact, his critic can be extrapolated to all models of this class (the second under classification of the author of this work), because the lack of robustness comes from excess sensitivity of the shadow rate to the level of ELB assumed in model specification.

The main idea of Krippner (2015) is that to be able to evaluate the monetary policy stance correctly, one should come up with the model that produces robust absolute results, not only robust relative results as Wu and Xia suggest, and economic feasibility of changes in the shadow rate is not sufficient to prove that the calculated shadow rate is a powerful tool of summarizing the whole policy.

3.3. Lombardi and Zhu (2014) model for the shadow rate

Lombardi and Zhu (2014) assert that they have managed to create a model that, instead of modelling behavior of interest rates at the lower bound, considers a large variety of variables linked to monetary policy to derive the value of the shadow rate. The advantage relative to other models that are based on Black (1995) is that their model is not so much dependent on market frictions in assessment of the monetary policy stance, because the shadow rate also depends on monetary policy related variables other than interest rates.

Lombardi and Zhu (2014) criticize the models that derive the shadow rate purely from the yield curve for two reasons. The first is the same as argued at the beginning of this section: the monetary policy stance should not be limited to interest rates because interest rates become a less important driver of expansionary monetary policy when ELB is reached and economic agents are therefore willing to exercise the option to hold physical currency. Thus, the omitted variable bias caused by limiting calculation of the monetary policy stance to interest rates gets aggravated in the ELB environment because, once interest rates are sticky at zero, other policy variables matter for the stance more.

The second line of criticism is related to the issue of reliability of shadow rates produced by those models. There exist factors other than monetary policy of the central bank that affect steepness of the yield curve. Interest rates of short maturities are already subject to market sentiments, and those of longer maturities are dependent on markets' expectations even more, simply because longer maturities imply more uncertainty. Consequently, evaluation of the monetary policy stance based on them is less accurate.

To counter this issue, Lombardi and Zhu (2014) suggest process a large number of other variables so as to construct the shadow rate for the US. They collect all data which is anyhow related to monetary policy, dividing it into four blocs: interest rates, monetary aggregates, items on the asset side of the Federal Reserve balance sheet and items on the liabilities' side of the Federal Reserve balance sheet. Further, a dynamic factor model is used to reduce the number of independent variables and avoid collinearity. In fact, Lombardi and Zhu (2014) use the approach similar to the second (as classified in the previous subsection) class of models – they assume the shadow rate equal to the federal funds rate in the above-zero conventional monetary policy situation, specify the model for the best fit, and forecast the shadow rate based on the obtained coefficients. On one hand, such model is potentially subject to the Lucas critique because it implicitly assumes that the coefficients did not change when the ZLB was hit. However, there exists no sufficient evidence that coefficients did change – quite opposite, Altavilla et al (2015) demonstrate the absence of any significant changes in coefficients during the last five years.

Despite the existing discussions regarding the correct construction of the shadow rate, few researchers oppose the consensus that the shadow rate is the most appropriate tool for summarizing monetary policy stance in the ZLB environment. I therefore define the monetary policy stance of the ECB as the value of the shadow rate for the Euro Area and uses it for studying the impact of unconventional monetary policy programmes. Onwards, the monetary policy stance and the shadow rate are used interchangeably.

To conclude the literature overview section, it is interesting to note that all the widely-cited research on the topic described previously discusses the monetary policy of the Federal Reserve in most of the cases; other countries' central banks are mentioned infrequently. Quite paradoxically, targeted longer-term refinancing operations and asset purchasing programmes of the ECB are rarely mentioned in the literature, even though Wu and Xia (2015) calculate the shadow rate also for the Euro Area.

Therefore, I start the practical part of the work by calculating the shadow rate for the Euro Area to subsequently estimate the impact of unconventional monetary policy programmes. As a robustness check, I substitute the shadow rate calculated in this work to that by Wu and Xia (2015) to see how a different shadow rate affects the estimated coefficients and conclusions.

4. *Methodology*

The main objective of this study is to explore the individual impact of unconventional monetary policy programmes on the overall monetary policy stance of the ECB. As discussed in the end of the previous section, the best proxy for this stance is the shadow rate. Consequently, the methodology part is structured as follows: at first, the method for estimating the shadow rate for the Euro Area is described (onwards I call it the first methodological step), and next, the calculation of the unconventional monetary policy programmes' impact on this shadow rate is delineated (respectively, onwards the second methodological step).

4.1. Estimation of the shadow rate

Here the shadow rate serves solely as the indicator for the monetary policy stance, and hence should depict a medium-term position of the ECB. The robustness of the obtained result for the shadow rate to temporary market sentiments is especially important. As follows from the literature overview, an appropriate model to fit this purpose is the one developed by Lombardi and Zhu (2014). I take their methodology as a starting point and adjust it for the needs of this research dedicated to the Euro Area, considering that different data regarding the US and the European monetary systems are available. Lombardi and Zhu (2014) use Kalman filter for estimation of the dynamic factor model. Constructing Kalman filter is a too cumbrous task for this work. For tractability and feasibility purposes, I use a static factor model instead.

The shadow rate calculation process can be intuitively explained as follows. Firstly, all available data that relate to risk-free interest rates in the Euro Area and monetary policy operations of the ECB are collected. Secondly, it must be ensured that variables included in the first methodological step will not cause bias in coefficients to be obtained in the second step. This is a crucial stage because if variables are closely related or directly derived from the euro amount of the unconventional monetary policy programmes analyzed in the second methodological step, the impact of these programmes will be overestimated. Thirdly, all the variables chosen for the purpose of estimating the shadow rate are processed so as to construct several latent factors containing most part of information for the shadow rate estimation. Next, the obtained unobservable factors are regressed on the short-term risk-free rate that best summarizes monetary policy stance for periods when the rates are in the positive zone with no 'stickiness' at near-zero levels.

By following this procedure, I first discover some unobservable factors that are associated with changes in the monetary policy rates and can be derived from a large set of monetary policy related economic variables. In turn, the regression allows to derive coefficients that quantitatively show the relation of the latent factors to the chosen policy-summarizing rate. This regression is meant purely as association – to obtain factors that policy rates can be replaced by; one cannot talk of causality since these factors are synthetic and do not cause changes in the policy rates. Finally, the factors are used to predict the short-term risk-free interest rate in the period when interest rates in the economy approach zero as if there were no lower bound.

The obtained data and the choice of certain variables are explained in the data description section of this work. In this subsection, I focus on the method of processing chosen variables and obtaining the shadow rate from the transformed data.

All of the variables chosen for the estimation of the shadow rate cannot be used outright because of the obvious multicollinearity issue. For example, interest rates of different maturities are highly correlated with each other, with each next maturity adding only little additional information to that available from interest rates of shorter maturities. Similarly, each subsequent monetary aggregate subsumes all previous, and, for example, increase of the narrow money is normally seen in the change of broader aggregates. This is the reason to transform these variables into some latent factors that carry their variance summarized in a smaller number of variables – two to four factors in the optimal case.

There exist two methods of constructing such factors that contain variance of many variables: principal components analysis and factor analysis. These methods have much in common: "both techniques try to explain part of variation in a set of observed variables on the basis of a few underlying dimensions" (Dunteman, 1989, p. 9). However, differences between them have important implications for this work. As outlined by Dunteman (1989, p. 55), principal components analysis decomposes all variance contained in the variables to include it in principal components, whilst factor analysis imposes a certain model on the analyzed data. In particular, this model omits individual variance contained in a certain variable that has no strong correlation with any of the other variables. Consequently, factor analysis can be used only when all variables are expected to be correlated with some other and none of the variables contains economically significant variance unique for this variable. In the case of estimating the shadow rate, however, some variables that describe monetary policy are not expected to be closely correlated to other variables because they carry unique information not contained in the rest. An example of such variable can be the euro amount of repurchase agreements – they are not expected to be closely correlated with monetary aggregates or interest rates of long-term securities, but in themselves can carry variance related to changes in monetary policy. Therefore, choosing factor analysis may lead to omitting information that is actually related to the shadow rate.

Another disadvantage of factor analysis is the big number of assumptions that the statistical model of factor analysis is based on. One of them is the ability to express each variable as a linear combination of two factors: the unobserved variable (the shadow rate in this case) and some factor specific to this particular variable, but not to other variables (Dunteman, 1989, p. 55). This certainly contradicts the reality since monetary aggregates are related to multiple economic variables which can be common for different variables. Principal components analysis, on the contrary to factor analysis, is free of any statistical model and simply decomposes the correlation matrix so as to maximize the variance contained in the first and each consequent component. Considering these arguments and for the sake of being consistent with the idea of Lombardi and Zhu (2014) to construct a model-free shadow rate, I choose principal components analysis to transform the data.

Principal components analysis makes an orthogonal linear transformation by assigning a vector (denote it with a) of variable weights, also called loadings, to the given variables. The variance of a linear composite can be expressed as $a'Ca$, where C is the covariance matrix. In principal components analysis, vector a is chosen in a way to maximize the variance of the first component and considering the constraint

$$a'a = \sum_i a_i^2 = 1 \tag{4.1}$$

where i is the number of variables (Dunteman, 1989, p. 15).

When the transformation is done, the variables that contain the largest variance tend to get higher weights. This can be a source of bias in principal components analysis, especially when variables are in different measurement units – in this case euro amount and interest rates. To eliminate this bias, it is necessary to standardize all variables before the transformation: each observation is reduced by the mean of respective variable and divided by its standard deviation. In this way, a set of standardized variables z_{it} with the mean of zero and unit variance is obtained.

$$z_{it} = \frac{x_{it} - \mu_i}{\sigma_i} \tag{4.2}$$

In result, the correlation matrix equals the covariance matrix. The obtained principal components are free of any statistical model or measurement unit and are calculated by unique transformation of the standardized variables (Dunteman, 1989, p. 56).

$$PC_{it} = a_i \cdot z_{it} \tag{4.3}$$

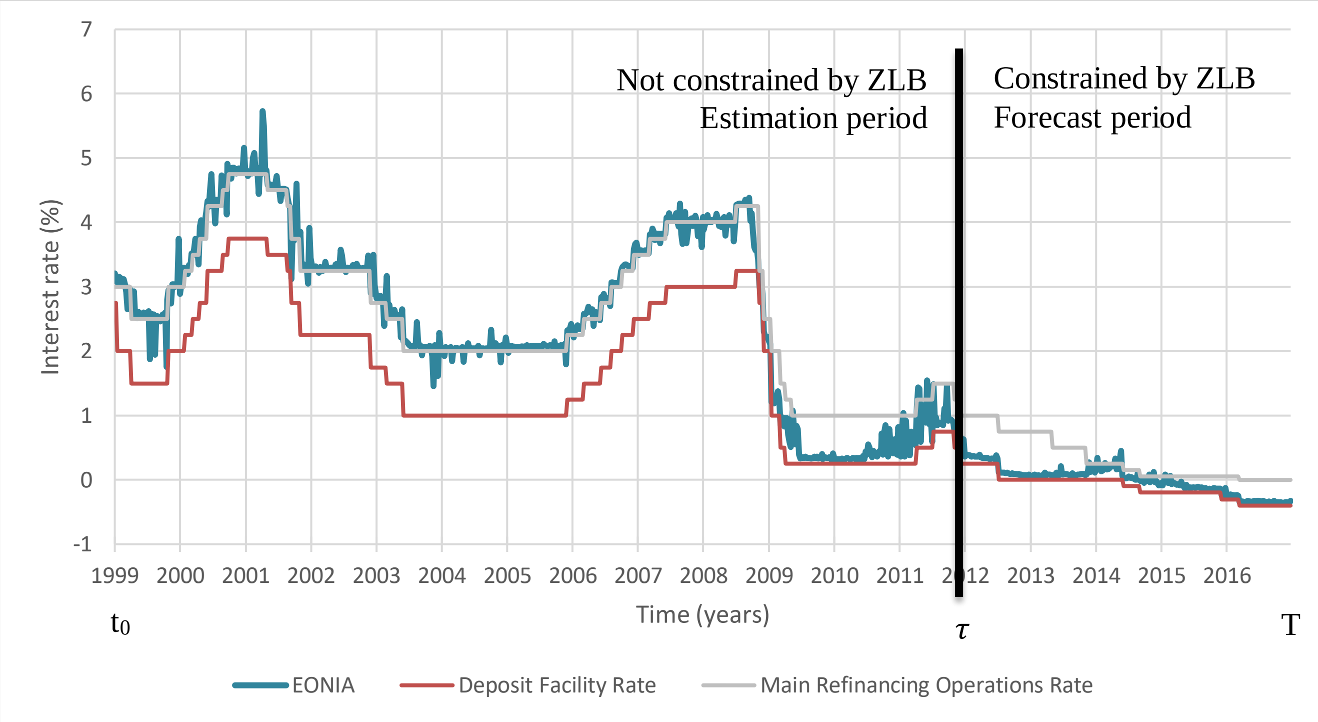
As follows from the equation, the number of obtained principal components equals the number of variables initially in the dataset. Most variance is concentrated in two or three first components: as follows directly from the method of principal components analysis, the first component contains the largest part of the variance, and each next contains less than the previous. Thus, only a small number of first principal components should be chosen and used onwards. A drawback of principal components analysis is the absence of strict rules regarding how many principal components to choose. In fact, this is the problem of any factor analysis as well, and even Lombardi and Zhu (2014) face this problem. They choose the number of dynamic factors according to "the commonly used 90% rule of thumb … of the total variance of the monetary dataset". I decide on the number of components to use after the principal components analysis is done, keeping in mind 90% and 95% thresholds.

The chosen components are treated as unobservable factors that subsume the variance of all important economic variables that are related to monetary policy. They can be interpreted as being closely associated with the policy rate set by the central bank when not constrained by a lower bound. The next step is to choose such rate that best describes monetary policy in ordinary times, i.e. when interest rates are not sticky at a lower bound, and short-term risk-free rates effectively incorporate information about monetary policy. Such rate, as argued by Damjanovic and Masten (2015) and Lemke and Vladu (2014) chosen as the dependent variable, is Euro OverNight Index Average (EONIA). Therefore, I choose it as the dependent variable. For the US, Lombardi and Zhu (2014) use the Federal funds rate, and according to Damjanovic and Masten (2015), EONIA is the equivalent of the Federal funds rate for the Euro Area from the monetary policy perspective.

The chosen several first principal components are used as independent variables. The potential multicollinearity issue is automatically solved because the components are uncorrelated with each other by definition. EONIA is regressed on them to establish the relation between this aggregated variance contained in several unobservable factors and the policy-related rate. As explained previously, the obtained components are some latent factors that can be used to substitute the policy rate when its true value is not observed, like in the lower bound environment. This is just an association, and there is no ground to think that a causal relationship between the policy rate and these components exists. The coefficients linking these latent components to EONIA are found using the ordinary least squares regression to achieve the best fit of the shadow rate estimated from the principal components to the actual short-term risk-free rate in non-ELB environment.

Correctly defining the time dimension for this regression is critical. The intuition behind this part of methodology it that the whole observation period – from January 1999 to December 2016 – consists of two different environments. Approximately until the end of 2011, interest rates were sufficiently above zero, and policy rates served as a good representation of monetary policy stance. Starting 2012, they ceased to be such because they became constrained by the lower bound. The difference in the two periods is clearly seen from Figure 1.

Figure 1. Cutoff date τ is the beginning of the forecast period; the estimation period ends on τ-1.



Source. Thomson Reuters database, Statistical Data Warehouse

The aim of replacing the policy rate by latent factors is to be able to reconstruct the proxy for the monetary policy stance into the period when the policy rate is constrained by a lower bound and ceases to be a proxy for the monetary policy stance. I denote the date when the shadow rate departs from interest rates by τ, and call the period starting τ it the forecast period. To obtain correct coefficients for latent factors, one should look into their link with the policy rate only when it represents monetary policy stance well, i.e. in the estimation period – from the first observation t_0 until τ-1 (the week before the lower bound takes effect). The shadow rate constructed from the principal components using these coefficients closely matches EONIA within the estimation period, and all deviations have the expected mean of zero and are random. In the prediction period, when EONIA is constrained by the effective lower bound and hence ceases to be proxy for the monetary policy stance, the shadow rate keeps fluctuating freely below the bound. Since it was specified for the period when EONIA was representative of the ECB's stance, the shadow rate serves as a good proxy for the monetary policy stance in the lower bound environment (the prediction period).

The short-term risk-free interest rate in the Euro Area has been sticky near zero for a longer time than the deposit facility has fallen to zero, as discussed in the research object description section. This creates a challenge to decide what date to take as τ – the cutoff date of the estimation period and the beginning of the forecast period. As discussed in the literature review, models tend to be sensitive to the choice of the ELB and consequently the date when the short-term risk-free interest rate ceased to objectively reflect the monetary policy stance in the Euro Area. Keeping this in mind, I intentionally leave discussion of the correct date for τ for the robustness check section.

The approach described above can be formalized by the following formulas. First, the coefficients to link the components to the short-term risk-free rate in the Euro Area are estimated using the estimation period as the sample. For t ∈ [t_0, …, τ-1]:

$$EONIA_t = \beta_0 + \beta_1 PC_{1t} + \beta_2 PC_{2t} + \cdots + \varepsilon_t \tag{4.4}$$

Next, the obtained coefficients in front of the components and the constant are used in the next step to calculate the shadow rate. For the estimation period, the shadow rate is defined as being equal to EONIA, and all discrepancies are due to a random error; for the forecast period t ∈ [τ,…,T], the shadow rate is defined in the following way:

$$SR_t = \widehat{\beta_0} + \widehat{\beta_1} PC_{1t} + \widehat{\beta_2} PC_{2t} + \cdots \tag{4.5}$$

Logically, the number of components used to calculate the shadow rate for the forecast period is the same as in regression to estimate their coefficients.

The obtained shadow rate is used to calculate the impact of the unconventional monetary policy programmes in the next step.

4.2. Impact of the unconventional monetary policy programmes

Obviously, in the ELB environment the difference between the actual and the shadow interest rate should be explained by other policy instruments than setting the policy rate. Importantly, it is not assumed that the impact of the conventional monetary policy with the shadow rate in the negative zone equals zero. At the same time, the reason for launching the unconventional monetary policy was exactly the inefficiency of conventional policy measures (Smaghi, 2009). Hence one may conclude that their impact is very small. Moreover, it is realistic to assume that in the ELB environment, measures of conventional monetary policy are set in the most expansionary mode, and therefore the impact of conventional monetary policy is stable. Therefore, including the effect of conventional monetary policy as a constant into the next step is reasonable.

Thus, the gap between the actual rate and the shadow rate can be explained by (1) a constant representing the conventional monetary policy, and (2) other variables representing the unconventional monetary policy measures. Instead of using the actual rate prevailing on the interbank markets to measure this gap, some constant ELB level could be employed. However, evidence suggests that the ELB level is subject to downward changes when liquidity trap continues for a long time (see Kortela, 2016; Lemke & Vladu, 2014). Taking this into account, the first best option would be a rate that reflects the gradually lowering ELB.

The deposit facility rate (DFR) is always lower than EONIA and other interbank rates[1]. Consequently, DFR can be treated as the best proxy for the effective lower bound (ELB). Moreover, it is the main change in the conventional monetary policy measures since 2012, therefore including the rest conventional policy as a constant is even more appropriate. The main regression equation in the following:

$$SR_t - ELB_t = \gamma_0 + \gamma_i P_{it} + \epsilon_t \quad (4.6)$$

DFR_t is used for ELB_t, P_{it} is the matrix of the euro amount of unconventional monetary policy programmes accumulated on the balance sheet of the Eurosystem, and γ_i is the vector of coefficients that show the impact of accumulation of one euro billion of unconventional monetary policy programmes on the balance sheet of the Eurosystem on the difference between the shadow rate and DFR.

One of the limitations that follows from this methodology is the assumption of independence and additivity of the unconventional monetary policy programmes. It is assumed that the impact from some certain euro amount accumulated under one programme is constant irrespective of the amount of assets accumulated under other programmes. Additional implicit assumption is the linear relation of the euro amount to lowering the shadow rate. The proposed regression implies that the impact on lowering the shadow rate due to some fixed euro amount 'printed' for a certain non-standard programme is the same irrespective of how much euro are already accumulated under this programme and what year it is (constant over time). An alternative would be to use a logarithmic or some other function, so that when a programme starts, its effect is stronger, which is more realistic. However, in this case, the results will be very dependent on the chosen functional form. Moreover, it will be much more difficult to interpret the obtained coefficients than when the relation between the euro amounts and the shadow rate is linear.

Another limitation of the chosen methodology is that the estimates are still not protected from noise as in studies by Chen et al (2012) and Meaning and Zhu (2011). Using the factor analysis would not solve this problem either. The main issue lays in the preliminary reaction of markets to new monetary policy measures when they are announced by officials of the central

[1] For commercial banks, the safest option to deposit euro is to put it at the ECB, since this institution that prints euro. Therefore, interbank lending rates cannot be lower than the deposit facility rate, which is -0.4% since 16 March 2016 (ECB, 2016). EONIA generally follows the path of the deposit facility rate since 15 August 2008 (see Figure 1), but is slightly higher; moreover, it contains frequent spikes that cannot be related to ELB changes. Hence, EONIA is clearly inferior to the deposit facility as the proxy for ELB.

bank, not only when they actually take place. Debt markets adjust faster and start partially affecting macroeconomic variables (which are used inter alia to calculate the shadow rate) prior to the actual expansion of the balance sheet of the ECB. To reiterate, the stance of monetary policy is partially determined by central bankers' official promise to carry out a certain unorthodox policy measure if markets believe in it, rather than by the actual euro amount of programs carried out.

To ameliorate this issue, it is worth noting that the effect from market sentiments is not lasting and gets fully reduced after some time, but may persist during more than one period. Therefore, the error term may be divided into a purely stochastic variance and time-dependent variance. In this case, autoregressive conditional heteroscedasticity has economic reasoning. Moreover, interest rates might incorporate the information about anticipated future changes of the shadow rate, and using the autoregressive conditional heteroscedasticity model (ARCH) is justified to ameliorate this omitted variable bias that arises due to inability to include market expectations into regression.

There exists an established practice to employ ARCH models and GARCH, the generalized autoregressive conditional heteroscedasticity models, for financial markets data – the abovementioned short-lived market sentiments imply temporary increased variance, i.e. the variance is heteroscedastic. Per Brooks (2002, p. 445), "it is unlikely in the context of financial time series that the variance of the errors will be constant over time, and hence it makes no sense to consider a model that does not assume that the variance is constant, and which describes how the variance of the errors evolves." The shadow rate is estimated from yields on the German government's debt securities of different maturities, which incorporate market risk subject to market sentiments and therefore potential heteroscedasticity in errors. Consequently, the shadow rate incorporates them as well and an autoregressive conditional heteroscedasticity should be applied to it.

Using Wooldridge (2009, p. 437) as a reference, I present the ARCH model in the conventional way as shown below. The main equation for regression remains the same, but the error term is also specified with its regression equation.

$$\epsilon_t = \sigma_t v_t \tag{4.7}$$

v_t is the stochastic part of the error; σ_t contains the value of several previous errors and the value of the non-stochastic part of the previous errors and can be expressed

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 \epsilon_{t-2}^2 + \cdots \tag{4.8}$$

In this way, the expected variance of the difference between the shadow rate and DFR is explicitly modelled in each next step, taking into account the error in several previous observations. Indeed, if some huge error is observed in a certain observation, it is most probably due to a suddenly increased risk or expectations of some changes, e.g. a launch of a new asset purchase or longer-term refinancing operations programme, or a change in the rate for deposit facility and/or marginal lending facility and/or main refinancing operations – and will possibly last for more than one week.

For GARCH model, the main regression equation and the equation for the error term are the same as for ARCH, but the expected variance incorporates not only the squared errors of several previous observations, but also the expected variances of several previous observations, i.e. not accounting for the random part of the error in previous observations (Enders, 1996, p.54).

$$\sigma_t^2 = \alpha_0 + \alpha_1\epsilon_{t-1}^2 + \alpha_2\epsilon_{t-2}^2 + \cdots + \beta_1\sigma_{t-1}^2 + \beta_2\sigma_{t-2}^2 + \cdots \quad (4.9)$$

Both models need to be specified with respect to the number of lags to be used in estimation of the expected variance for each observation. The number of coefficients α included in the estimation is called q, and the chosen number of coefficients β is called p. It is also worth noting that ARCH is essentially a special case of GARCH when p = 0. To choose the optimal number of lags, a correlogram of residual autocorrelations and partial correlations is considered.

Moreover, the choice of the number of lags is constrained by certain restrictions for the coefficients. An essential restriction is $\forall\, \alpha_i > 0$ and $\forall\, \beta_i > 0$. Otherwise the expected variance might turn to be negative, which has no sense because the variance is always positive. Next, it is important to "ensure the stability of the autoregressive process", i.e. to keep the decreasing effect of previous errors in the future errors (Enders, 1996, p. 55). If the sum of all alphas and betas except for the constant term exceeds 1, the so-called 'non-stationarity in the variance' occurs, the implication of which is that in each next observation, a higher variance than previously is expected, so the variance tends to infinity with time. Obviously, there can be no economic explanation of it, so if the sum of obtained coefficients (except for the constant term) for the variance equation is larger than 1, the model cannot be used in the chosen specification, and some other combination of p and q should be considered.

To conclude the methodology section, I want to recap the benefits of the chosen methodology. Firstly, the obtained coefficients for the impact of unconventional monetary programmes have intuitive interpretation: each shows the effect on the difference between the shadow rate and the deposit facility rate (proxy for the effective lower bound) in result of accumulation of one billion euro on the balance sheet of the Eurosystem under the respective programme. Secondly, by accounting for autoregressive conditional heteroscedasticity, error from the first methodological step that occurs due to market sentiments is partially ameliorated.

5. *Data description*

5.1. Data for Principal Components Analysis

Following the approach of Lombardi and Zhu (2014), all data relevant for monetary policy in the Euro Area is collected for principal component analysis. Appendix A.1 summarizes data for the preliminary analysis.

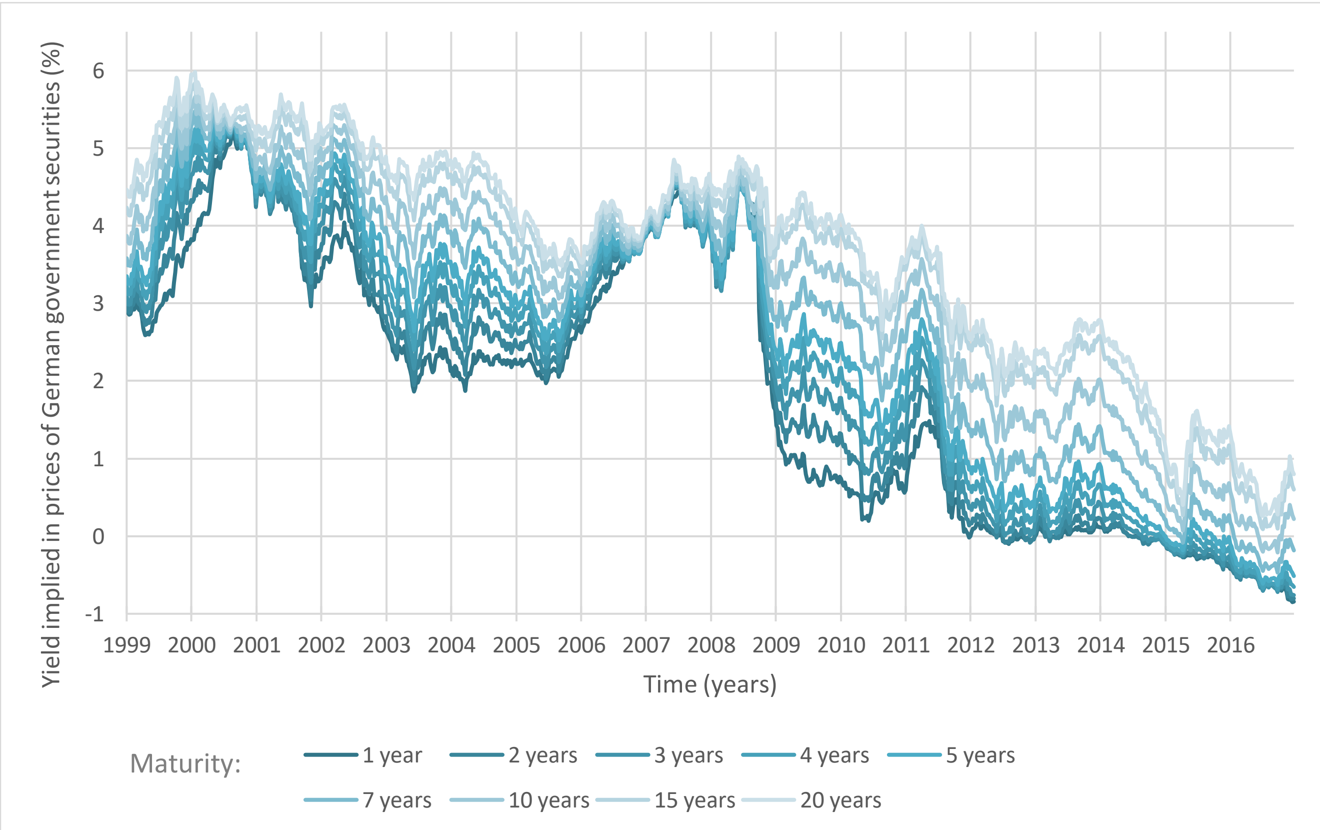
The dataset is constructed from the beginning of 1999 until the end of 2016 with a step of one week. This frequency is chosen to match the second methodological step, as the highest frequency for the data available on the stocks of assets accumulated on the balance sheet of the Eurosystem under certain unconventional monetary policy programmes is one week. Lombardi and Zhu (2014) use monthly observations, whilst most works that derive the shadow rate purely from interest rates work with daily data. For this work, the daily data for asset stocks on the balance sheet of the ECB is unavailable, but the monthly frequency invalidates econometric evaluation of impact of unconventional monetary policy programmes because some of them were launched not long ago, and the number of monthly observations is insufficient.

The factor most closely linked to the shadow rate is the risk-free interest rate for the given currency. Hence the most fundamental variable to estimate the shadow rate in the Euro Area is the rate of no-risk interest for different maturities. All studies for the US work with yields implied in prices for the US Treasury bills and bonds, its alternative for the Euro Area does not exist, since public debt is issued on the country level. The safest euro-denominated debt is issued by the German government – it has the lowest rate of all European countries and extensively used in research as an indicator of risk-free rates.

However, the yield implied in German government securities contains also default risk for Germany. One option can be to separate and subtract this risk. For risky liquid securities, the risk-adjusted rate can be calculated by subtracting the probability of default, which in turn is calculated from the price of credit default swap (CDS) traded on this security. In fact, German bonds contain so little risk that a huge share of price is attributed to mark-up due to illiquidity of these instruments (barely anyone believes Germany will default, hence trading volumes are very low). Consequently, if the risk of default is calculated from prices of CDS on German bonds, it is clearly overestimated.

An alternative solution would be to take a market rate for the euro instead – it is definitely free from any country-specific risk. Several researchers (for example, Ajevskis (2016), Damjanovic & Masten (2015), Kortela (2016)) take the Euro Overnight Index Swap (OIS) for the risk-free rates in the Euro Area. As Kortela (2016) describes it, “In OIS contracts, one counterparty receives a variable payment given by EONIA and the other counterparty receives the fixed OIS rate. Hence, OIS rates in different maturities provide a term structure for EONIA." However, the data for OIS before 2008 are not available, and researchers usually extrapolate it backwards to get a larger amount of observations. This creates an additional source of bias. Moreover, by looking at the data one can clearly see that OIS is an inferior proxy for risk-free rates in the Euro Area relative to the interest rates derived from yields implied in German government securities. The OIS rate follows the path of German government bond yields but is higher on average, hence containing more risk. Instead of the country-specific risk, OIS includes risk of the banking system in the Euro Area. There is a small number of observations where OIS rate is lower, but yields implied in the prices of German government securities are generally a better variable for euro interest rates with as little risk as possible and hence included in principal components analysis to estimate the shadow rate (Figure 2). Respectively, OIS rates are disregarded.

Figure 2. Interest rates derived from yields implied in prices of German government securities.



Source. Thomson Reuters database.

Interest rates of shorter maturities are generally lower (this is not always the case, however). Therefore, when all interest rates are falling, they become constrained by ELB earlier than those of longer maturities. In result, changes in the shadow rate when it is far in the negative zone do not coincide with changes of these short-term rates. Interest rates of a very short term cause an upward bias in the shadow rate if incorporated in the model because they cannot go lower than ELB. This bias is present in rates of longer maturities to a lesser extent. This constraint is visualized in Appendix A.2, showing that EURIBOR rates for maturities less than one year are sticky at ELB since 2012, while there have been some fluctuations in 1-year rate lately. Therefore, only maturities of one year and more are chosen to be included in the principal components analysis, and those of shorter maturities (like EURIBOR, Euro LIBOR) are omitted.

Monetary aggregates and repurchase agreements are given in millions of euro. They are expected to grow with time, which is associated with the real growth of economies of the Euro Area and inflation. The best indicator that captures both real economy growth and inflation is the nominal gross domestic product. Therefore, to measure how contractionary or expansionary monetary policy is, it is more representative to look at the amount of monetary aggregates and repurchase agreements as a ratio to the nominal GDP of the currency area. Following this logic, the euro amount of monetary aggregates and repurchase agreements are divided by nominal GDP of the Euro Area (downloaded from Eurostat, n.d.) and are interpreted in real values (comparing to the size of the economy) without being dependent on the nominal value of the currency. Thus, the relation of the estimation of the shadow rate on growth of the Euro Area economy and changes in the real value of Euro due to inflation is definitely avoided.

The euro amount of assets on the balance sheet of the Eurosystem is also given in millions of euro and should be transformed in the same way. However, including it causes a problem already mentioned in the methodology section: a large share of the total amount of assets is assets accumulated in result of unconventional monetary policy programmes. Indeed, at the end of October 2016, the ECB has € 3.5 trillion assets, and just above € 2 trillion is due to these programmes. If the total amount of assets is used to estimate the shadow rate, the impact of the unconventional monetary policy programmes is expected to be overestimated, because changes in the euro amount of these programmes affect the total amount of ECB’s assets and thus the shadow rate. Therefore, total assets on the balance sheet of the Eurosystem should not be considered for calculation of the shadow rate.

This is not the only variable that cannot be used to estimate the shadow rate. Data on currency in circulation should be dropped because it follows a stable upward trend, historically uncorrelated with the interest rate in the Euro Area. Apparently, it has not been used as a monetary policy tool, and trying to include it in the estimation of the shadow rate could potentially lead to spurious results.

Reserves must be omitted as well. The absolute euro amount of reserves followed the minimum reserve requirements prior to 2012. Therefore, excess reserves cannot be considered to calculate the shadow rate as they were equal to zero or insignificant before ZLB was hit. Starting

2012, the euro amount of excess reserves began to fluctuate severely, which could potentially lead to spurious results of the estimation – the moment when excess reserves become non-zero can be interpreted as a break. Consequently, the total amount of reserves could not be included, too.

The dataset is constructed with a time step of one week, but weekly data for reverse repurchase agreements and monetary aggregates are not collected. These variables are interpolated using the usual linear method, as provided by the following formula:

$$Value(W) = Value(M0) + (Value(M1) - Value(M0)) \times \frac{Date(W) - Date(M0)}{Date(M1) - Date(M0)} \quad (5.1)$$

where W stands for the observation for a certain week ($Date(W)$ is taken for Friday), and M0 and M1 stand for the last date of previous month and the last day of this month respectively; in turn, $Value(M0)$ and $Value(M1)$ stand for values of the interpolated variable on these days.

5.2. Asset Purchase and Longer-Term Refinancing Operation Programmes

As stated in the introduction, the primary objective of this research is to evaluate efficiency of unconventional monetary programmes by estimating how large was an impact of a certain amount of euros issued ('printed') by the ECB on lowering the shadow rate. For the second methodological step, data on euro amount accumulated on the balance sheet of the Eurosystem due to running unconventional monetary policy programmes launched by the ECB are collected, allowing to compare these programmes by size and henceforth take them into account when analyzing their impact.

These data are in open access, but in a highly disaggregated form. Constructing the dataset for the second methodological step (devoted to evaluation of impact of the unconventional monetary policy programmes) requires data transformation and making assumptions, which are discussed in this subsection. As sources of data, I use the ECB official website, the ECB's Statistical Data Warehouse (SDW); some data can be derived only from disaggregated information on auctions, which is available on the ECB website (ECB database, n.d.).

The weekly euro amounts of assets accumulated on the balance sheet of the Eurosystem, expressed in millions of euro, are obtained from the official website of the ECB. I divide the value in each observation by one thousand to obtain euro billions for the sake of more convenient interpretation of results.

A detailed description of each unconventional monetary policy programmes launched by the ECB is provided in subsection 2.3 in the research object description section.

SDW (n.d.) offers only the total amount of liquidity-provision programmes. The euro amount of TLTRO and TLTRO-2 can be derived from the data on auctions available on the ECB website (ECB database, n.d.). For all auctions, the euro amount of assets purchased under each programme and the euro amount of the ECB's lending allotted under each liquidity provision programme is available. The issue with this data is that banks are allowed to repay the money borrowed under longer-term liquidity provision programmes before the loans mature. Unfortunately, no data on early repayments is in open access. To estimate the euro amount of LTRO, TLTRO and TLTRO-2 individually, the following assumptions are made:

1. All amount of LTRO allotted is repaid when it matures;
2. TLTRO-2 are not repaid;
3. TLTRO is repaid to fit the difference between the sum of all LTROs and the sum of LTRO and TLTRO-2.

From the database available on the ECB website one can reconstruct the euro amount of LTRO on the balance sheet of the ECB at each point in time using the information on auctions. The amount of TLTRO is found by subtracting the sum of LTRO and TLTRO-2 as reconstructed from the data on auctions from the sum of all LTROs as provided in SDW (n.d.).

The reason for exactly this set of assumptions is that TLTRO-2 is the most recent of the programmes, and conditions of each commercial bank's borrowing are linked to certain loans issued by it, hence assuming zero repayments of TLTRO-2 is realistic. Since 2013, LTRO was never issued for a term that does not exceed four months, and the historical data shows that early repayments of LTROs of such maturity are rare. Therefore, the assumption that the whole repaid sum should be attributed to TLTRO is realistic – indeed, it was announced before TLTRO-2, and after the start of the latter banks were able to partially requalify their loans so as to fit the new conditions and thus receive better loan service conditions from the ECB.

Formally, the euro amounts of the unconventional monetary policy programmes should also have been scaled following the growth of the nominal GDP for the Euro Area – the more economy grows and the more monetary units are there in economy, the lower is the effect of accumulation of one additional million euro on the shadow rate. However, the author decides to ignore this formality for the convenience of showing the impact of each million of euro of each programme on the shadow rate; otherwise, the programs should be quantified as the share of nominal GDP of the Euro Area. He acknowledges though that ignoring this can provide biased results in the long term, especially when economic growth and inflation go up.

CSPP and TLTRO-2 take non-zero values only in the last several observations and econometric estimation of their impact can yield spurious results. Considering this and the fact that the amount of CSPP is negligible in comparison with PSPP, a new variable is created, which is the sum of PSPP and CSPP, and will observe purchasing programmes of public and corporate sectors together. Most probably, it will not be possible to discern effects of TLTRO-2 and CSPP econometrically and obtain robust results, but one should remember that CSPP is an asset purchase programmes, whilst TLTRO-2 is liquidity provision. Hence one should expect that CSPP has an impact on the shadow rate more similar to other asset purchase programmes than that of TLTRO-2.

Furthermore, it is econometrically impossible to discriminate between CBPP3, ABSPP and PSPP, because CBPP3 and ABSPP were launched simultaneously and the euro amount of assets accumulated on the ECB balance sheet in result of these programmes has been growing almost proportionately. PSPP started 15 weeks later, it is a much larger program, but the amount of assets has been growing almost proportionately to CBPP3 and ABSPP. Moreover, on January 22, 2015, just two weeks after asset purchases under PSPP began, the ECB announced the Expanded Asset Purchase Programme (EAPP), which proclaimed that CBPP3, ABSPP, CSPP, and PSPP would be coordinated together and 60 billion euro per month would be spent on these four programmes in aggregate. Therefore, all four of these asset purchase programmes are included into the second step in form of the sum of their respective euro amounts, because once the programmes are coordinated by a policy institutions, they cease to be independent among each other and cannot be included in more than one variable.

LTRO had only several tenders with extended maturity, whilst 3-month liquidity provision is offered almost every month, which corresponds to conventional monetary policy. Therefore, it is excluded from regression and implicitly included into the constant term. The same is done with SMP, CBPP1 and CBPP2. As explained in the object description section, the primary purpose of SMP was not expansionary monetary policy, but rather to solve liquidity problems in the peripheral countries of the Euro Area. CBPP1 started before interest rates became sticky at ELB, hence if included independently, the coefficient will be biased. CBPP2 was a very small programme with only € 40 billion assets purchased (more than 100 times smaller than EAPP and TLTRO), and econometric estimation of the impact of such a small variance cannot be trustworthy.

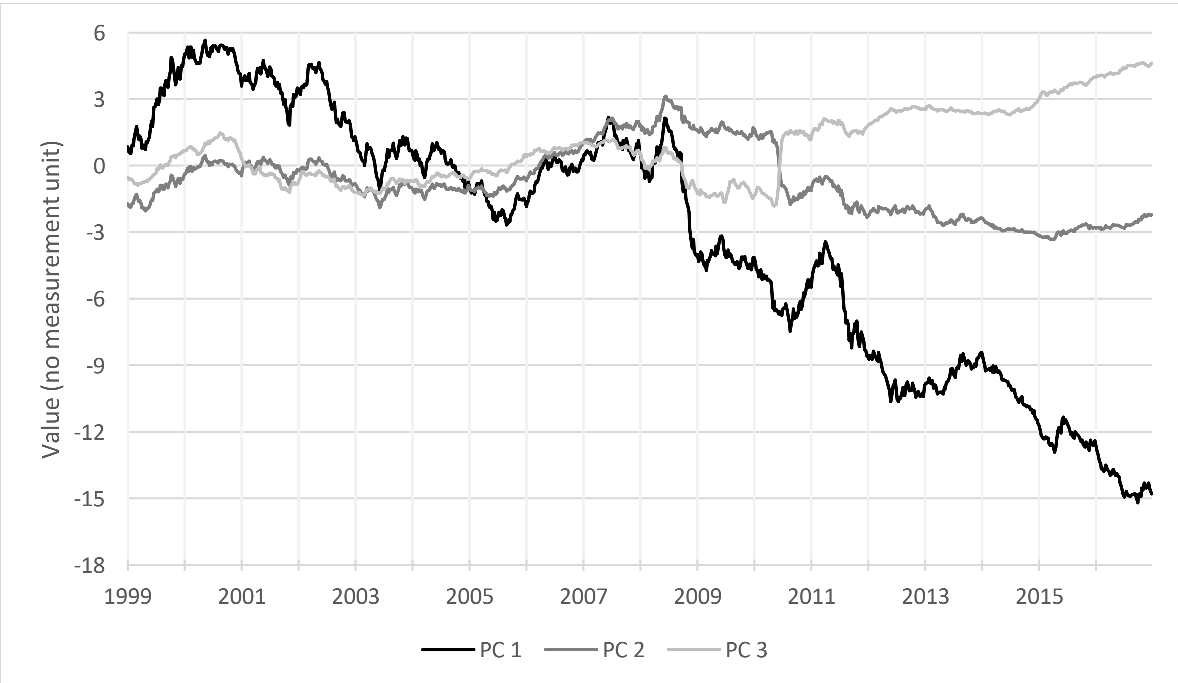
6. *Analysis of results*

6.1. Shadow rate from principal components

The collected data is processed and standardized as described in the methodology part and used for principal components analysis. The date of end of estimation period and the beginning of forecast period for the shadow rate (denoted by τ) is chosen October 7, 2011. On this day, the maturity of LTRO was extended to 12 and 13 months and the launch of CBPP2 was announced. Table 1 (see subsection 7.1) presents the whole set of dates (five in total) that could also be chosen for τ, and discussion about the choice of τ is left for the robustness check section.

The first two components obtained in result of the principal components analysis for the variables chosen to estimate the shadow rate together account for 89.50% of the total variance of the dataset, which is below the common 90% and 95% rules of thumb, and an additional component should be considered. The first three components in aggregate include 95.71% of the total variance, which satisfies both thresholds (Appendix B.1). Therefore, the first three components are chosen as the unobserved factors that monetary policy is linked to and the policy rate should be estimated from, as discussed in the methodology part. Figure 3 presents the values of the three components.

Figure 3. Values for the first three principal components



Note. Created by the author.

Next, the EONIA rate is regressed on these three components for period $t \in [t_0, \ldots, \tau\text{-}1]$. The following regression equation is obtained (t-statistic in parentheses):

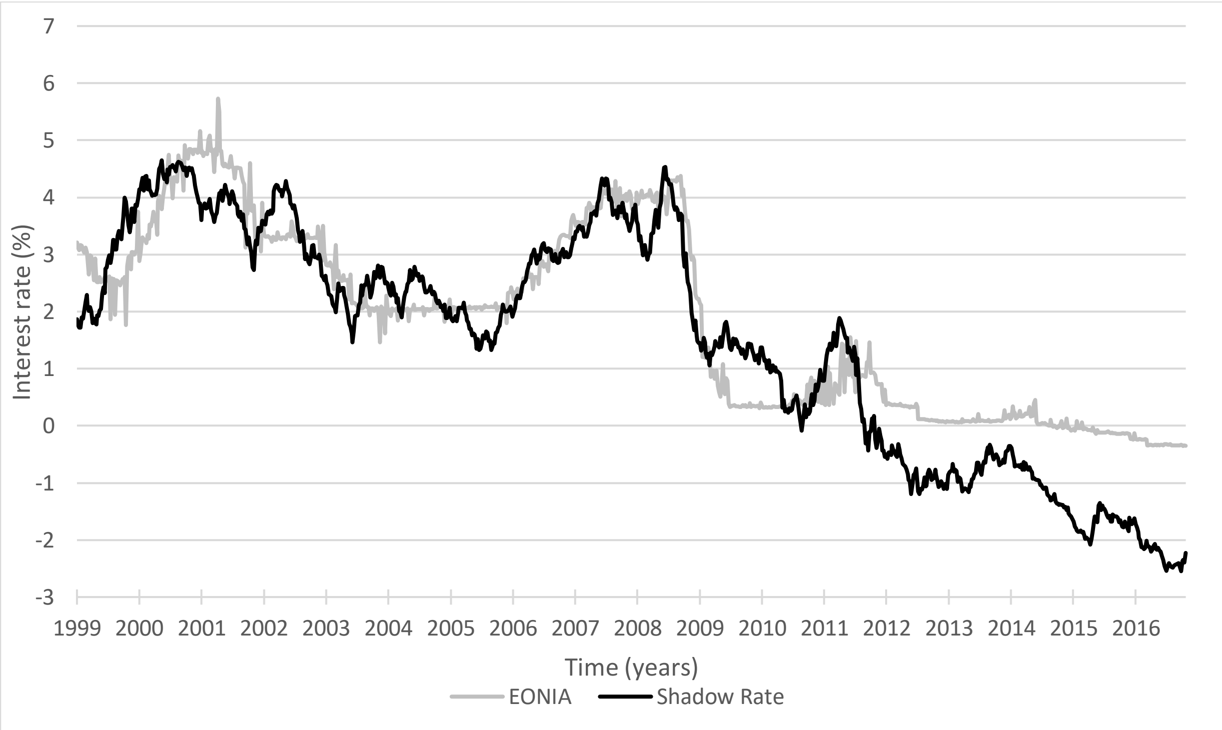
$$SR_t = 2.6120_{(107.28)} + 0.3322_{(40.05)} * PC_{1t} + 0.2498_{(12.23)} * PC_{2t} + 0.2244_{(9.04)} * PC_{3t} + \varepsilon_t \quad (6.1)$$

As explained in the methodology section, in the ELB environment the shadow rate is the proxy for the monetary policy stance. Thus, starting τ, the stance is defined via the shadow rate as follows:

$$SR_t = 2.6120 + 0.3322 * PC_{1t} + 0.2498 * PC_{2t} + 0.2244 * PC_{3t} \quad (6.2)$$

Figure 4 displays the shadow rate, which goes into the negative zone when unconventional monetary policy is implemented. The fit of the model to EONIA is also seen on this graph.

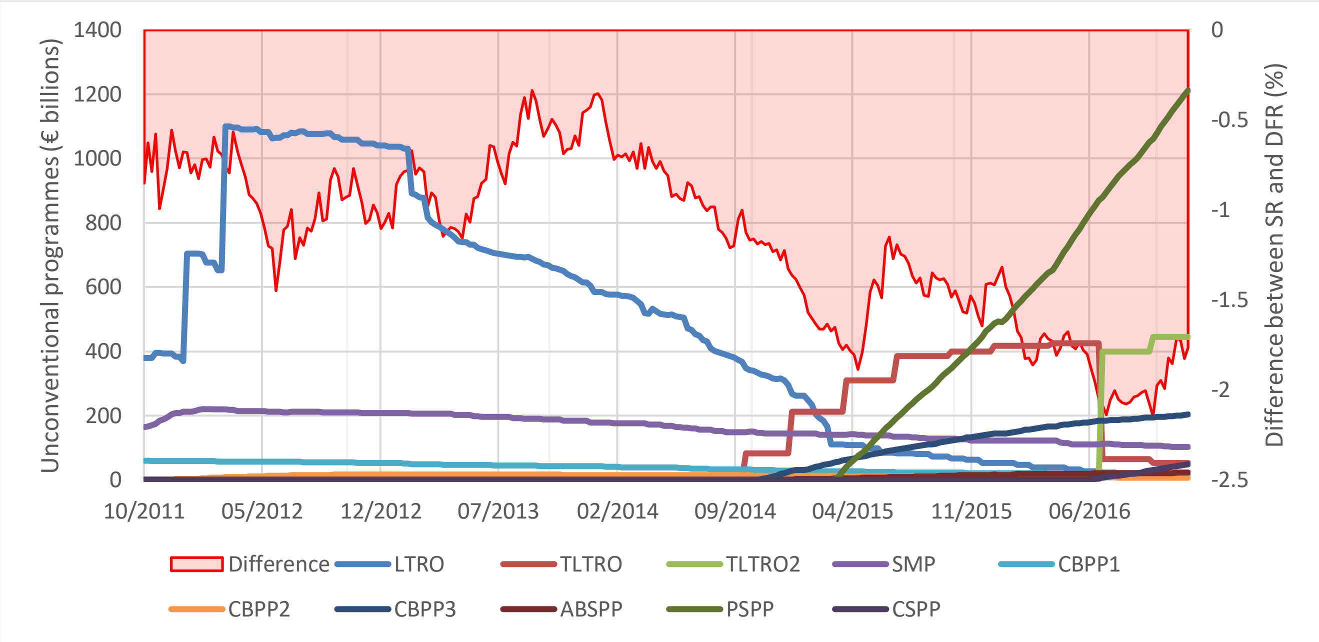
Figure 4. The shadow rate and EONIA



6.2. Factors affecting the shadow rate

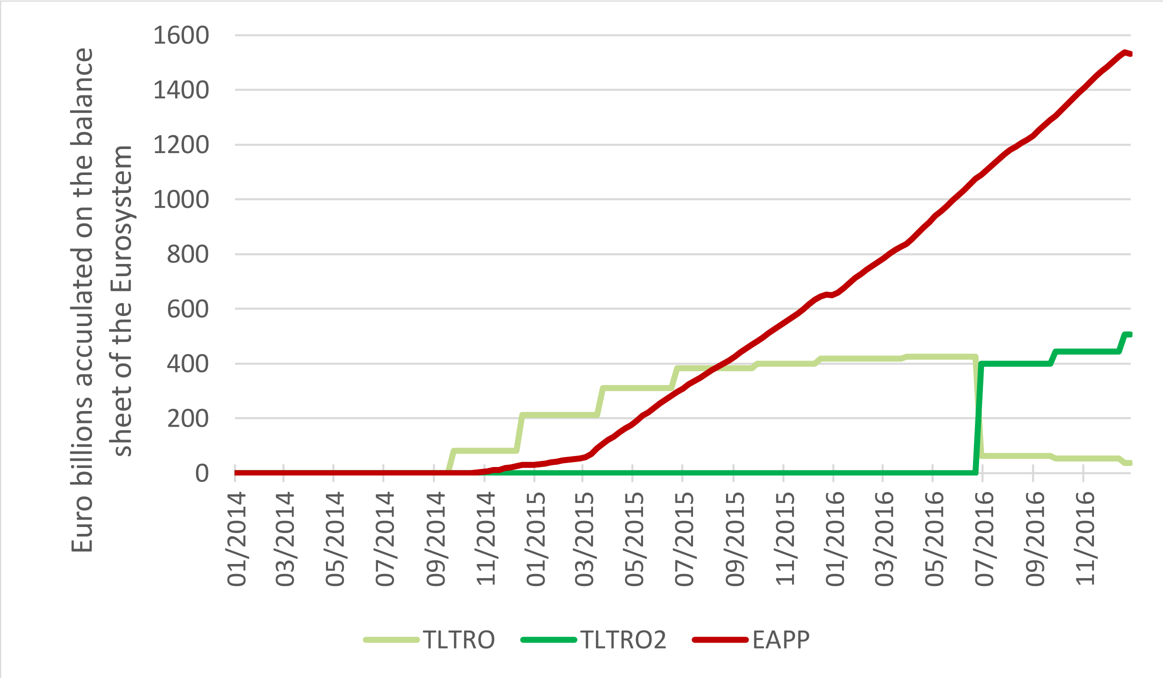
Next, the difference between the shadow rate and the deposit facility rate is calculated. Figure 5 offers a convenient visual representation of the difference between the shadow rate and EONIA and the euro amounts of assets accumulated on the balance sheet of the Eurosystem at each point in time.

Figure 5. Difference between the shadow rate and the deposit facility rate, and euro amount of unconventional monetary policy programmes *(viewed in color only)*



This difference is the variable of interest for the second step because it is mostly due to the impact of unconventional monetary policy, and the role of conventional monetary policy in it is negligible and included into regression in form of a constant, as discussed previously. The euro amounts of unconventional monetary policy programmes are included as factors. As argued previously, CBPP3, ABSPP, PSPP and CSPP are treated as one program – the Extended Asset Purchase Program, as it was called by the ECB. SMP and CBPP1 are omitted because both of them started before the effective lower bound was reached – their effect is included into constant as well. CBPP2 was very small in terms of the euro amount of assets accumulated on the balance sheet of the Eurosystem under his programme (see the orange line in Figure 5). LTRO was initially introduced as a measure of conventional monetary policy, and its primary purpose is liquidity provision rather than directly lowering the shadow rate. This restrains the sample of factors to TLTRO, TLTRO-2, and EAPP. Their euro amounts are presented in Figure 6.

Figure 6. Euro amounts of unconventional monetary policy programmes to be included in the regression as independent variables.



6.3. Data stationarity and cointegration tests

As discussed previously, there exists an irrefutable economic relation between the difference of the shadow rate and DFR and assets accumulated under unconventional monetary policy programmes. However, before running the regression, it should be ensured that for the chosen methodology, the data series are appropriate from the statistical perspective as well.

The minimum requirement to be able to regress variables on each other is their cointegration. This is especially important if the data are not stationary, which is obviously the case for the euro amounts of the unconventional programmes, as the ECB keeps throwing money into economy of the Euro Area by expanding these programmes. The table in Appendix B.2 summarizes the results of Adjusted Dickey-Fuller test, indicating that the variables are non-stationary in levels. The null hypothesis states that they have a unit root. In this subsection, I also report results of the same tests for LTRO, as it will be included into the regression equation in the robustness check section.

To establish cointegration, one must ensure that the variables are integrated with the same order. Appendix B.3 demonstrates that the variables are integrated with order 1, since all of them are stationary in differences if 0.1 critical value is chosen. Therefore, I can proceed to a cointegration test.

Appendix B.4 presents the result of Johansen Cointegration Test. Trace test indicates one cointegrating equation at the 0.01 significance level. Cointegration in the variables allows to conclude the appropriateness of the data for regression.

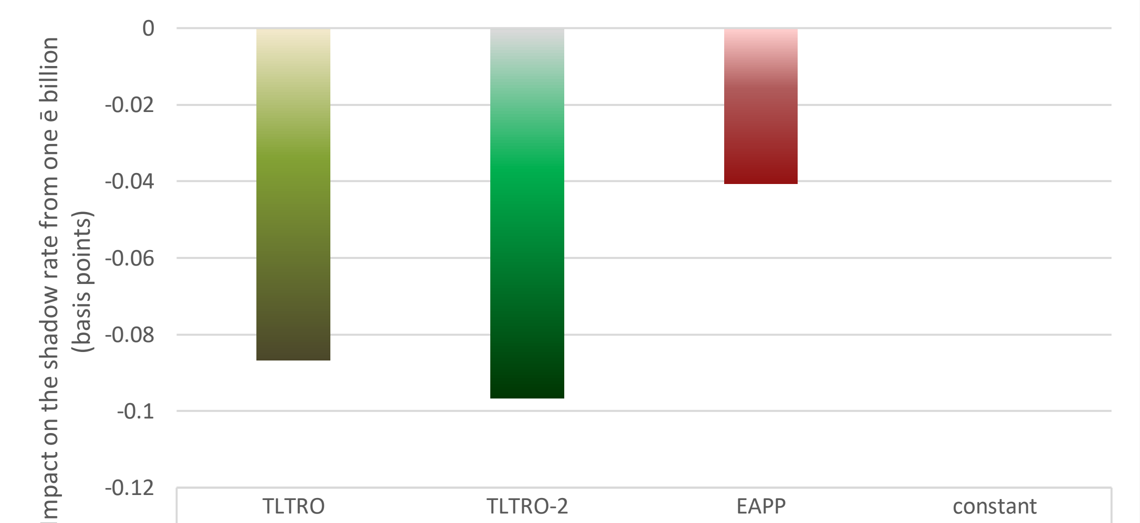
6.4. Results for the baseline specification

The conducted tests allow to proceed with regression in levels. The explanation of the choice of the number of lags is left for the robustness check section (see subsection 7.3), but for now ARCH(1) model is used. The equation system for calculating the impact of the unconventional monetary policy programmes on the difference between the shadow rate and EONIA goes as follows:

$$\begin{cases} (SR - DFR)_t = \gamma_0 + \gamma_1 \cdot TLTRO_t + \gamma_2 \cdot TLTRO2_t + \gamma_3 \cdot EAPP_t + \epsilon_t \\ \epsilon_t = v_t \sigma_t \\ \sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 \end{cases} \tag{6.3}$$

This system of two regression equations is evaluated via maximum likelihood in EViews software (Appendix C.1). Thenceforth, this model specification is called the baseline model.

Figure 7. Results for the baseline model. All the coefficients and the constant significant at 0.01 level.



	TLTRO	TLTRO-2	EAPP	constant
Impact (bp)	-0.0867	-0.0966	-0.0406	-60.46

The obtained results show that without the unconventional monetary policy programmes, the conventional monetary policy in combination with SMP, CBPP1, CBPP2, and LTRO would result in the shadow rate being on average by 60.46 basis points lower than DFR. Putting it into context, less than half of the difference between the shadow rate and DFR can be attributed solely to the three longer-term refinancing operations and the extended asset purchase programme.

Speaking of other coefficients, each euro billion accumulated on the balance sheet of the Eurosystem under TLTRO leads to a decrease in the shadow rate by 0.0867 basis points. Each euro billion accumulated on the balance sheet of the Eurosystem under TLTRO-2 leads to a decrease in the shadow rate by 0.0966 basis points. A billion euro of the Extended Asset Purchase Program is associated with a decrease in the shadow rate by 0.0406 basis points.

7. Robustness checks and alternative model specifications

Both steps of methodology included a number of assumptions made by the author to choose one or another estimation period length, include or exclude some variables, and run ARCH regression in some particular way. Furthermore, it was noted that LTRO may be considered as part of unconventional monetary policy, especially if accounted for the duration of instruments accumulated as assets on the ECB's balance sheet. This section is devoted to looking into alternative model specifications and aims at exploring the robustness of the obtained results depending on some changes in one or another step of the estimation process.

7.1. Robustness to the estimation period cutoff date

As outlined previously, one of the shortcomings of the chosen methodology is the need to define the cutoff date τ – the first date of the forecast period, when EONIA ceases to reflect monetary policy stance and the shadow rate becomes the best proxy. Obviously, this is the case when interest rates are below zero. The deposit facility was first became negative on 11 June 2014, but interest rates had been sticky at zero long before that date. Indeed, as described in the literature review section, there is nothing magical in the zero lower bound, and the effective lower bound should be considered instead. It, in turn, according to plentiful evidence, is subject to downward shifts in the environment of ultra-low rates. Hence, it is impossible to identify τ, and I offer the following list of dates, on each of which an important event for making monetary policy more expansionary took place: a change in rates or announcement of launching new programmes to increase money supply.

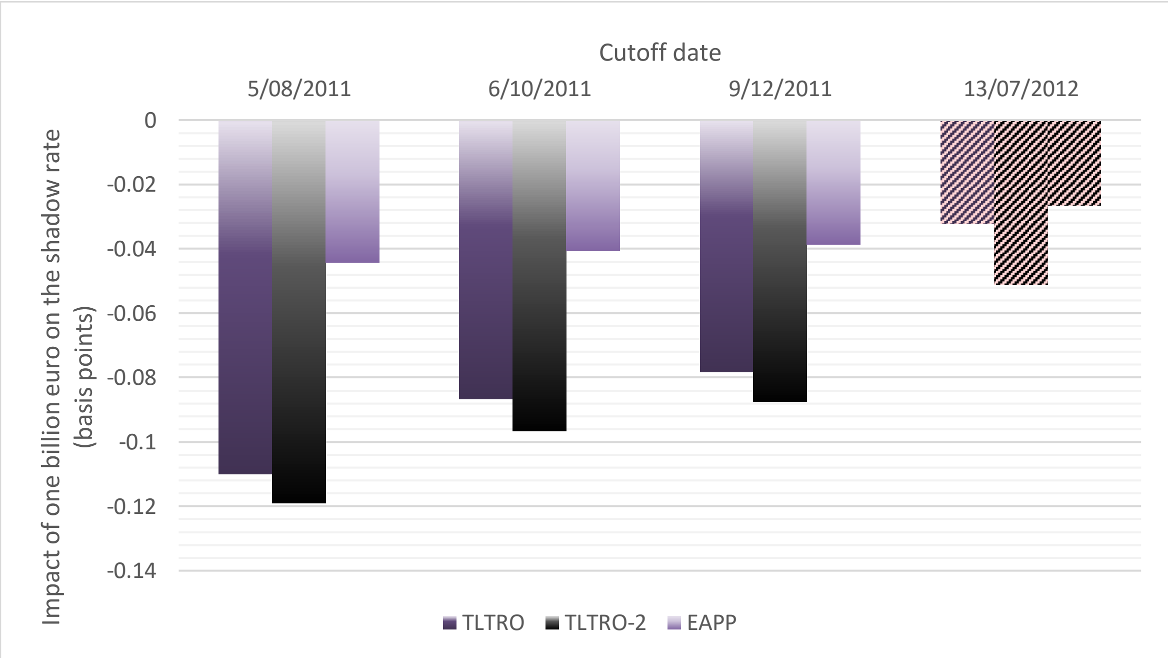
Table 1. Important events that might indicate the beginning of the ELB constraint

Cutoff date (τ) (end of the week)	DFR	Event during that week
26 June 2009	0.25%	Technical details of CBPP1 to be launched in two weeks published, EONIA fell to around 0.4% and its volatility dropped since then
5 August 2011	0.75%	LTRO maturity extended to 6 months
7 October 2011	0.75%	LTRO maturity extended to 12 months, CBPP2 announced; EONIA became sticky at no more than 0.5% above DFR
9 December 2011	0.25%	The ECB announced lowering DFR to 0.25%, lowering reserve requirements to 1%, two upcoming auctions for LTRO with 3-year maturity and significant increase in collateral availability
13 July 2012	0%	DFR lowered to 0%

Source: Falagiarda et al (2015), ECB (2011)

I go through the whole process described in the methodology several more times, each time choosing different cutoff date. Taking an earlier date shortens the period in which the variables chosen for principal components analysis and standardized, reduces the number of observations for principal components analysis and respectively for the regression EONIA on the components. Accordingly, the forecast period, in which the shadow rate serves as proxy for the monetary policy stance, gets longer (starts earlier – on the cutoff date), and the number of observations for the ARCH regression of the difference between the shadow rate and DFR on the chosen unconventional programmes is larger.

Figure 8. Robustness check for the cutoff date



Source. Created by the author

For all dates between August and December 2011, the coefficient in front of TLTRO is between -0.07 and -0.11, the coefficient in front of TLTRO-2 is between -0.08 and -0.12, and the coefficient in front of EAPP is between -0.038 and -0.045; all of them are significant at 0.01 significance level (Appendix C.2).

The result when τ is set 26 June 2009 is not depicted on the diagram (Figure 8). The reason is that the coefficient in front of EAPP is positive and insignificant at 0.1 level. This makes no economic sense as it implies contractionary effect on the shadow rate due to accumulating assets on the balance sheet of the Eurosystem under the Expended Asset Purchase programme, which is not true for sure. The positive constant term also does not make sense indicating that CBPP1, CBPP2, SMP and LTRO had contractionary effect as well. All these facts lead to conclusion that the model produces wrong results if 26 June 2009 is chosen as the cutoff date, hence this is not the date when the ELB environment began.

For τ set on 13 July 2012, the model produces considerably smaller results for all coefficients (due to a higher level of the shadow rate obtained in the first methodological step), but cannot be treated as valid. For ARCH(1) specification, GARCH(1,1) and any other reasonably small amount of lags for variance the sum of coefficients in front of these lags (α's and β's in equation 3.4) is larger than 1 – this means that the variance is non-stationary and the model cannot be used. The ordinary least squares regression shows a positive coefficient in front of EAPP, which makes no economic sense as argued earlier; the ARCH test clearly rejects the null hypothesis about conditional homoscedasticity, which implies conditional heteroscedasticity and the need for ARCH or GARCH. The conclusion is that for this model (τ set on 13 June 2012), the estimation of the shadow rate is incorrect. Therefore, this date is too late for the cutoff date, which indicates that the ELB began to constrain interest rates prior to July 2012.

Considering both conclusions, one can be quite certain that ELB was hit some time in the second half of 2011. This becomes even more obvious considering the fact that no expansionary steps were made by the ECB in the first part of 2012, but prior to the middle of 2011, monetary policy stance was contracting, which is reflected in gradually increasing EONIA (Figure 1). All three models with τ set on August, October and December 2011 are trustworthy, and the one for October has been chosen as the baseline.

7.2. Including other unconventional monetary policy programmes in the model

As explained in subsection 5.2, some unconventional programmes have been omitted and implicitly included in the constant term. In this subsection, I try alternative model specifications, where some of these programmes are brought to the regression equation explicitly.

From the beginning, it is clear that for CBPP1 and SMP trustworthy coefficients cannot be obtained. Not only did SMP serve other purpose than making monetary policy stance more expansionary (it solved liquidity problems in the peripheral countries of the Euro Area), but also they both started before the ELB environment was established. Before October 2011, the difference between the shadow rate and the deposit facility is estimated as positive, whereby it loses its interpretation. Consequently, it makes no sense to try to include SMP or CBPP1. I limit myself to testing whether CBPP2 and LTRO can be included as independent factors explaining the shadow rate. Table 2 summarizes results for different model specifications.

Table 2. Results of the model extended by additional factors

Additional factor	DURLTRO	LTRO	CBPP2	TLTRO	TLTRO-2	EAPP	constant
No (baseline)	not included	not included	not included	-0.0867***	-0.0966***	-0.0406***	-60.46***
CBPP2 (€)	not included	not included	-0.540***	-0.0669***	-0.0813***	-0.0419***	-62.82***
LTRO (€)	not included	0.0066***	not included	-0.0767***	-0.0871***	-0.041***	-64.5***
LTRO (€×dur)	0.0000292*	not included	not included	-0.0835***	-0.0933***	-0.0408***	-61.6***

Note. Significance: ***: 0.01 level, **: 0.05 level, *: 0.1 level

7.2.1. CBPP2

CBPP2, in contrast to CBPP1 and SMP, was launched in the second half of 2011. In fact, the only reason for excluding it was the negligible euro amount of assets bought under this programme – more than a hundred times less than under EAPP. I modify the baseline model by including the euro amount of assets accumulated on the balance sheet of the Eurosystem under CBPP2 as a fourth factor to explain the difference between the shadow rate and the deposit facility rate (Table 2).

This implies that CBPP2 has been much more efficient in terms of making the monetary stance more expansionary (lowering the shadow rate) than TLTRO and TLTRO-2, and more than 10 times more efficient than EAPP. This result is not trustworthy, because CBPP2 and EAPP are expected to have comparable coefficients since both are asset purchase programmes. Although no constraints are breached from econometrical point of view, CBPP2 is excluded from the baseline model – indeed, it was expected in advance that the coefficient in front of CBPP2 will be hard to estimate due to the small size of the programme. After all, thanks to its small size the whole model should not be invalidated when CBPP2 is included in the constant term.

7.2.2. The euro amount of LTRO

LTRO was introduced long before the Great Recession as a conventional monetary policy measure with the main purpose to provide commercial banks liquidity for periods longer than seven days. When interest rates approached zero and the ECB experienced a shortage of policy measures to make monetary policy more expansionary, it prolonged the duration of loans to commercial banks under LTRO up to 3 months, then up to 6 months, and next to 12 months. Finally, two auctions offering 3-year LTRO took place. According to ECB (non-standard list), LTRO qualifies as a non-standard policy measure. Therefore, it makes sense to include it into the regression as a separate factor. It is reasonable to expect a weaker (less negative) coefficient compared to other programmes, as 'enhanced lending support' rather than lowering the shadow rate is the primary purpose of LTRO.

A positive coefficient in front of LTRO is obtained (Table 2). It has no economic meaning because the effect of LTRO could not have been contractionary. The model cannot be used since it produces an economically impossible result. Consequently, the impact of accumulating assets under this programme cannot be established using the chosen methodology.

7.2.3. The weighted average duration of LTRO

Since LTRO was changed several times, a variable that would depict changes of how LTRO was conducted that relate to its efficiency can be included in the regression. Such variable is the duration of lendings issued to commercial banks under this programme. Per Ajevskis (2016), the two variables that represent the scale of unconventional monetary policy are the euro amount of assets accumulated on the Eurosystem's balance sheet and the weighted average duration of these assets. Following this argumentation, I create a variable '*duration'* that shows the weighted[2] average time in days left until repayment of borrowings allotted via LTRO. Since both an increased euro amount and a longer duration should make LTRO more efficient, the obtained *duration* is included as an interaction term with the euro amount of LTRO.

The obtained coefficient in front of this interaction term is positive (Table 2), which makes no economic sense – LTRO cannot be making monetary policy stance more contractionary. Therefore, this model is misspecified and cannot be considered.

7.3. The number of lags for GARCH

In the baseline, the model is specified ARCH(1), which is the same as GARCH(0,1) – a special case of GARCH with zero lags for the expected variance. The optimal number of lags to consider for GARCH model should not exceed the number of significant autocorrelations of squared residuals. However, if a huge number of lags is considered for the estimation, some of the constraints described in the methodology part can potentially be breached.

To decide on the optimal number of lags to be used in the model, I look at the correlogram of autocorrelations and partial correlations of squared residuals of an ordinary least squares regression with the same factors and the dependent variable (Appendix C.3). It clearly indicates

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[2] Weighting of maturity is done considering the euro amount of assets initially allotted rather than the present value of assets at each point in time, but the discrepancy should be minimal because the rate of interest on these borrowings is very low.

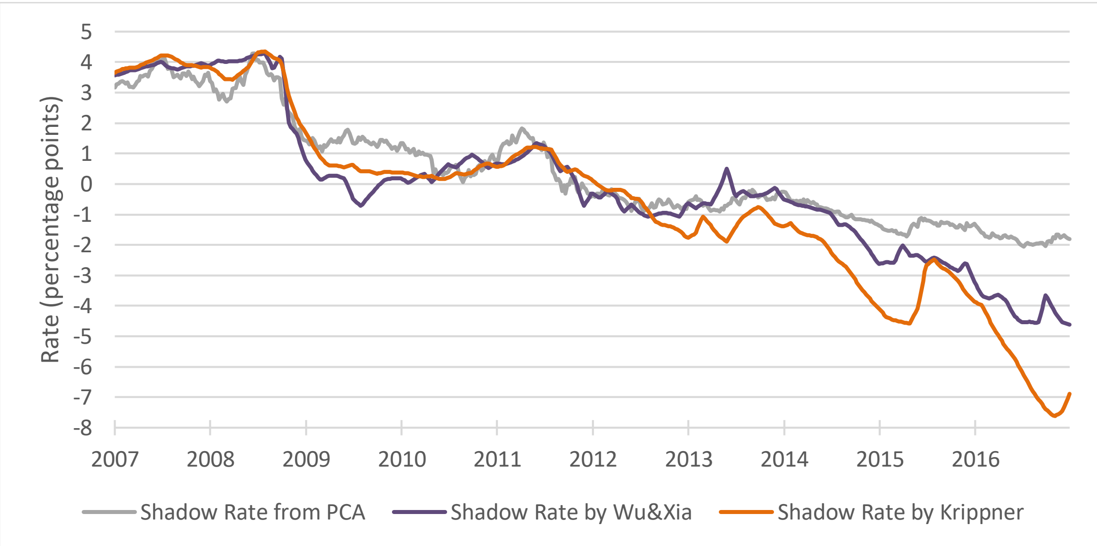
one significant ARCH term (q coefficient in GARCH specification is associated with the number of significant partial correlations). I further check other specifications of GARCH with p > 0 and/or q > 1. They all have an inferior Swartz information criterion to GARCH(0,1). Moreover, in the variance equation all coefficients α after the first and all coefficients β are insignificant. This clearly leads to conclusion that ARCH(1) specification is the best, as used in the baseline.

7.4. Estimation of impact using the shadow rate by Wu & Xia and Krippner

To estimate the impact of unconventional monetary policy programmes, I use the shadow rate for the Euro Area calculated by myself. To recall, the most objective model that accounts for large amount of monetary policy related variables is chosen and adopted for the data available for the Euro Area instead of the US. However, some researchers have calculated the shadow rate for the Euro Area. This subsection is devoted to comparing the results obtained using the shadow rate obtained in this work as the variable for *SR* on the left-hand side of equation 6.3 with a shadow rate calculated using some other methodology in order to find out whether the results are robust to model specification.

Wu & Xia (2017) describe their methodology of constructing the shadow rate for the case of the US, but also use the same method to estimate that in the Euro Area without explicit theoretical explanations. Krippner (2017) also provides a time series of his own estimates of the shadow rate in the Euro Area. These two are arguably the most consistent and widely referred shadow rate time series. The shadow rate for the Euro Area calculated by Wu and Xia is presented in Figure 9 presents these shadow rates together with the one calculated in this work.

Figure 9. Comparison of the shadow rate used in this work with that of Wu & Xia and Krippner

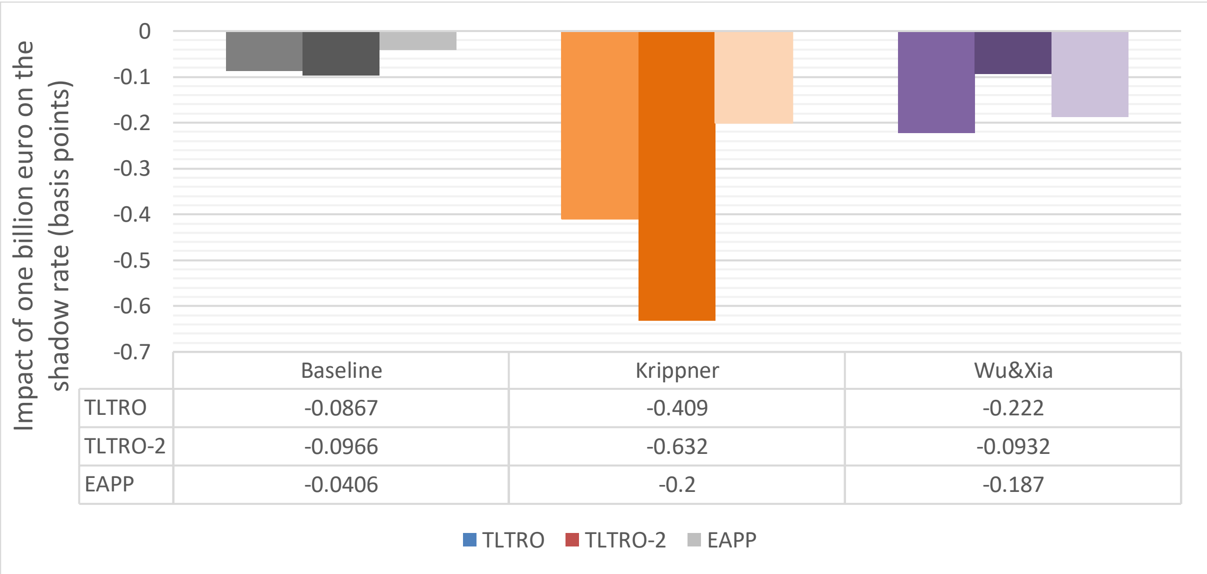


Source: Created by the author using the shadow rate time series estimated by him and the series provided by Wu & Xia (2017) and Krippner (2017)

As I argue during the explanation of data selection, it is important to maintain that the euro amounts of unconventional monetary policy programmes are not used for calculation of the shadow rate, because otherwise the estimation of the programmes' impact might be overestimated. Wu & Xia and Krippner do not face such limitation because they estimate the shadow rate not with purpose to calculate the impacts of non-standard policy measures. Consequently, it is reasonable to expect that the results for the impact obtained using their shadow rate are higher.

The diagram in Figure 10 presents the results. The obtained coefficients can be interpreted in the same way as described in subsection 6.4.

Figure 10. Comparison of impact of unconventional monetary policy programmes using different shadow rates



Source: Created by the author

The shadow rate by Krippner (2017), despite going much further into the negative zone, results in approximately the same relative value of the coefficients for individual impact of the programmes as using the shadow rate calculated in this work – TLTRO2 has the largest effect from the same amount of euro accumulated on the balance sheet of the Eurosystem on the shadow rate, TLTRO is slightly weaker, and the impact of EAPP, despite being the largest programme in terms of euro 'printed' under this programme, is lower than that of the longer-term refinancing operations.

If we switch to the shadow rate calculated by Wu and Xia (2017), the impact of each euro 'printed' for TLTRO is still slightly higher than that of EAPP, which is in line with our previous results. The effect of TLTRO2, however, is lower. This is a quite contradictory result. Let us recall that TLTRO2 is just an improved version of TLTRO, so that commercial banks in the Euro Area which get this liquidity provision are not only obliged to comply with certain requirements of passing this credits on to consumers and firms to boost real economy, but also eligible for certain discount (a form of variable rate) if they issue even more credits. Therefore, it is hard to believe that TLTRO2 is less efficient than TLTRO. This makes us recall the critics of Wu and Xia methodology by Krippner (2015), who argues that their estimation of the zero lower bound is too high and unrealistic (Note, however, that the respective discussion is mainly around ZLB in the US, but the shadow rate for the Euro Area is calculated by a similar methodology). Indeed, TLTRO2 auctions took place when ELB started already shifting down below zero. It might be the case that Wu and Xia do not sufficiently account for this phenomenon, which makes their results of the shadow rate biased starting 2015 – the period of TLTRO2. Consequently, it is quite probable that the impact coefficients obtained using the shadow rate by Wu and Xia are less accurate.

Overall, the coefficients obtained using different shadow rate are quite different in levels, but similar in relative terms. The difference in level is because the other two shadow rates go much further into the negative zone. My shadow rate might be underestimated (too close to zero) because even yields of longer maturities become sticky at the lower bound when monetary policy is ultra-loose. In other words, the relation of the shadow rate to longer-term yields becomes non-linear when they approach zero, but principal components analysis assumes linear construction of factors, and OLS regression implies linear relation between these latent factors and the shadow rate. The true relation, however, is most probably non-linear, which is a limitation of the methodology proposed in this work. On the other hand, this shadow rate is not constructed from euro amounts of the unconventional monetary policy programmes – the shadow rates by Krippner and Wu & Xia do not have such restriction, hence may produce an overestimated result when used to measure the impact of the programmes. Consequently, it is reasonable to believe that the true value of the coefficients lays somewhere between the coefficients obtained using the shadow rate proposed in this work and using that by Krippner.

8. *Discussion of Results*

8.1. General inferences from the results

The first thing to note in the results is the negative coefficients in front of all non-standard monetary policy measures included as factors and the constant term, which subsumes all other unconventional and conventional measures. Since all programmes definitely have expansionary effect on the monetary policy stance, this is the primary requirement to conclude that the model is trustworthy.

Overall, the model has high explanatory power – all coefficients are significant at 0.01 level and the R-squared is 0.628 (Appendix C.1). The obtained result shows not only an association, but rather a direct causality: the unconventional monetary policy programmes are the only tool to push the shadow rate below the effective lower bound (as argued throughout the work, the impact of the conventional policy is negligible). Therefore, the obtained coefficients show the causal effect of accumulation of one billion euro assets on the balance sheet of the Eurosystem on the difference between the shadow rate and the effective lower bound proxied by the deposit facility rate.

A large amount of information about monetary policy events and relations is unknown at the outset of this study, in particular, when exactly interest rates became significantly constrained by the effective lower bound. Respectively, the level of the effective lower bound is not known either. Learning more about ELB has important implications for monetary policy because it indicates at what level of interest rates monetary policy becomes inefficient and some non-standard policy measures should be launched. The conducted robustness check suggests that 2009, when interest rates in the Euro Area fell below 0.5% for the first time, was not the time when the effective lower bound started to significantly constrain interest rates. The model does not allow to reject that ELB might have affected interest rates for a short period in 2009, but one can clearly say that thereafter, when monetary policy was contracted, there was no ELB-constrained environment. Only the beginning of the next monetary expansion in the second half of 2011 was strong enough to make interest rates sticky at a lower bound permanently. This also reveals the level of ELB when it took effect. Rather than being equal to zero, it is as high as 0.75% – the value of the deposit facility rate at the beginning of the forecast period. Afterwards, it fell to -0.4% in 2016, which is in line with the literature suggesting that ELB is subject to downward changes when interest rates are low for a long time.

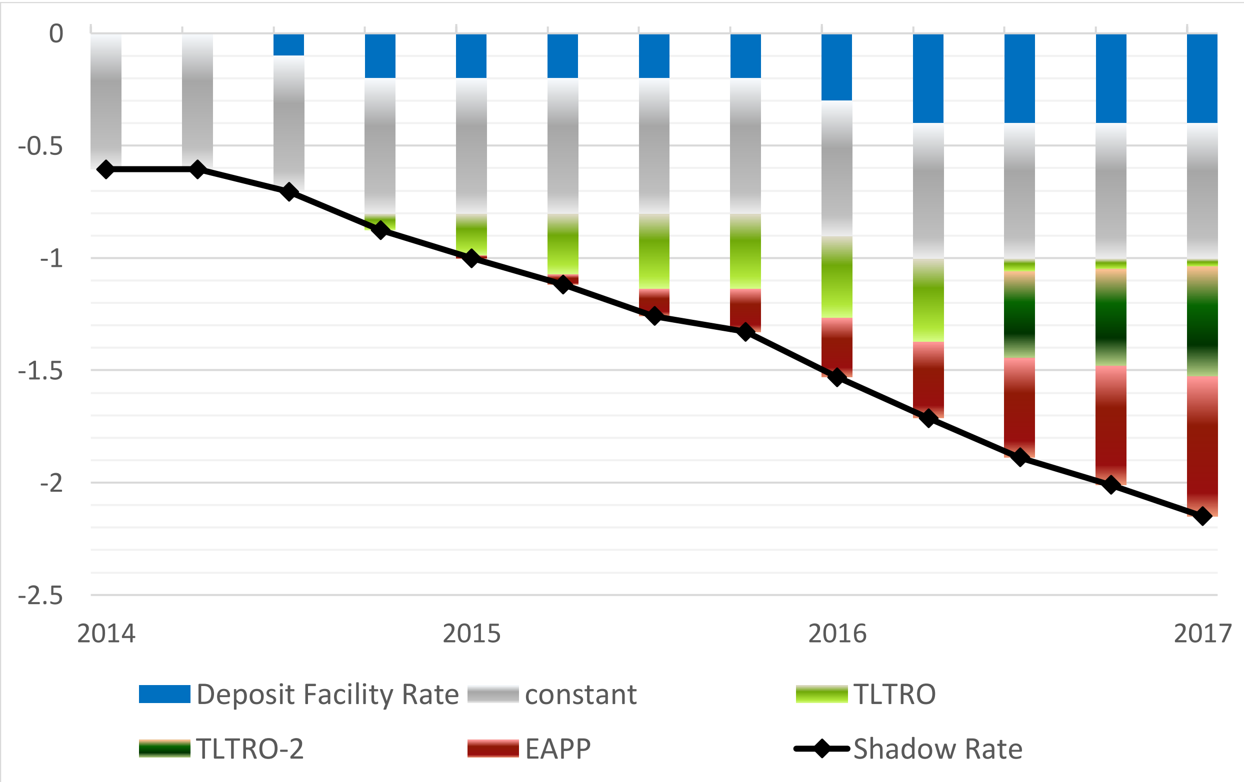
8.2. Assessment of programmes' impact

The primary objective of this work has been to assess efficiency of the programmes in terms of lowering the shadow rate. As discovered in the robustness check section, each billion euro accumulated on the balance sheet of the Eurosystem under TLTRO causes a decrease in the shadow rate relative to the deposit facility of 0.07 to 0.11 basis points. If TLTRO-2 is expanded by an additional euro billion, the shadow rate is expected to fall from 0.08 to 0.12 basis points. In turn, each additional euro billion spent on asset purchases under EAPP leads to a decrease in the shadow rate between 0.038 and 0.045 basis points.

Putting it into context, the ECB has set to purchase € 80 billion assets under EAPP starting 1 April 2016 (ECB, 2016a). This implies that each month, the shadow rate is expected to become lower by around 3.25 basis points in result of asset purchases. Consequently, the result of continuing this scale of purchases for a year until March 2017 is expected to be a shadow rate lower by approximately 39 basis points (0.39%).

The constant term is also negative. It implies that the aggregate effect of SMP, CBPP1, CBPP2, LTRO and conventional monetary policy pushed the shadow rate down. The total contribution of these programmes on the difference between the shadow rate and the deposit facility rate is expected to lie approximately between -0.4% and -0.85%. This is a very realistic result: not all of them had lowering the shadow rate in the Euro Area as the primary objective of their launch, but all increased money supply and thus contributed to contractionary monetary policy.

Figure 11. Decomposition of the negative shadow rate by the unconventional monetary policy programmes and other factors.



Source. Created by the author

Figure 11 shows programmes' individual impact at the end of 2016. The monetary policy stance in the Euro Area is represented by a shadow rate of -1.8%. The ECB has been able to push it so far below zero thanks to the negative deposit facility (-0.4%, assumed to represent ELB), TLTRO, which is mostly paid back at that date (-0.01%), TLTRO-2 (-0.49%), EAPP (-0.69%) and other unconventional and conventional monetary policy measures. For these other measures, only their average contribution throughout the whole ELB-environment period is estimated, which is -0.6%. In 2016, LTRO was reduced to minimum and all the other programmes included in the constant term had been terminated previously and their contribution to the shadow rate of -1.8% is expected to be lower. Indeed, the sum of all factors of the shadow rate depicted in Figure 11 results in a shadow rate of -2.2%, and it is reasonable to expect that the contribution of other 'measures' at the end of 2016 was only 0.2%.

8.3. Comparison of the non-standard monetary policy programmes

To compare the efficiency of the non-standard programmes, the Chi-squared test is run comparing the obtained coefficients in front of the two TLTRO programmes between each other and then each against the coefficient for the extended asset purchase programme. The null hypothesis states that the respective programmes have equal impact of the same amount of euro accumulated under them on the shadow rate.

Table 3. Chi^2-test results for comparison of the non-standard programmes

	TLTRO – TLTRO-2	TLTRO – EAPP	TLTRO-2 – EAPP
Chi^2-statistic	0.93	9.56	5.79
p-value	0.3349	0.0020	0.0161

Results in Table 3 show that the hypothesis that TLTRO and TLTRO-2 are equally efficient cannot be rejected. Indeed, TLTRO-2 is in effect an enhanced form of the first TLTRO: it allows banks to get a lower rate considering loans they issue to the real economy. The relative size of the coefficients in front of TLTRO and TLTRO-2 is in line with theory, as TLTRO-2 has a slightly higher impact on lowering the shadow rate (i.e. making monetary policy stance more expansionary) per euro accumulated on the balance sheet. Logically, the enhanced programme is expected to be more efficient.

Comparing EAPP with both TLTRO programmes, one can claim a significant difference in the coefficients with at least 95% certainty. Therefore, although the extended asset purchase programme is undoubtedly an effective tool at disposal of the ECB, the four asset purchase programmes that constitute EAPP are on average less efficient in making monetary policy more expansionary than the targeted longer-term refinancing operations.

Targeted longer-term refinancing operations stimulate banks to issue more loans to qualify for a lower borrowing rate, thus motivating banks with refinancing more profitable for them. The programme is designed to directly influence the amount of loans issued and hence money supply. With asset purchase programmmes, monetary policy is made more expansionary by making smaller the universe of low-risk assets that banks in the Euro Area can purchase. Thus, banks are required to make the additional freed funds work, i.e. issue loans, or bear with a negative interest rate. This is an indirect method of forcing banks to credit real economy, but it directly targets interest rates in the Euro Area. The results of this study lead to conclusion that the former approach is more efficient.

8.4. Limitations

In spite of the extensive robustness check section, there remains a considerable number of limitations. They are due to estimation errors, data constraints, and imperfections of the models in both methodological steps.

The shadow rate, being a proxy for monetary policy stance, is estimated only from those economic variables related to monetary policy that are in public access. To objectively assess the stance of the ECB, one should go beyond the universe of publicly available data. Moreover, the shadow rate is estimated from yields implied in prices of German government securities. Even if OIS rates were taken, the result would still be subject to market sentiments, be it country and liquidity risk in the first case or the risk implied in the financial system in the second. One cannot clearly derive the direction of bias in either of the two cases, but there is no evidence that it should be substantial.

What causes a more significant problem is the fact that interest rates become sticky when they approach ELB. In other words, the relation between the shadow rate and interest rates included in the principal components analysis becomes non-linear at levels close to ELB – a small downward move of interest rates is associated with a bigger expansion of monetary policy, compared to the case when interest rates freely fluctuate in the positive zone. Since the principal components (which are calculated linearly from the chosen monetary policy related variables) are regressed on the shadow rate in the non-ELB period, an upward bias in the shadow rate is expected when interest rates are close to the deposit facility rate – interest rates simply cannot go much lower, while the monetary policy stance can become much more expansionary.

As obvious from Figure 2, in 2016 interest rates of almost all maturities became less volatile as they approached ELB. The upward bias in the shadow rate from the first methodological step implies that when the unconventional programmes are regressed on the difference between the shadow rate and DFR in the second methodological step, the impact of these programmes is underestimated. Hence one can expect that the programme launched the latest, which is TLTRO-2, will have the most underestimated coefficient. The obtained results suggest that EAPP is twice less efficient in terms of making monetary policy stance more expansionary with the same amount of euro is created comparing to TLTRO-2. In reality, this ratio can be even bigger, which supports the conclusions.

The fact that the coefficient are underestimated is also corroborated by the fact that if a shadow rate estimated by other researchers, like Krippner (2017) or Wu and Xia (2017), is used instead of that estimated in this work, the coefficients for impact are larger (more negative).

At the same time, the second step also leads to a bias. The rationale under the main regression equation in the second step is the causal relationship between the euro amounts of unconventional monetary programmes accumulated on the balance sheet of the Eurosystem and monetary policy stance. However, the stance is also formed by promises of central bankers to launch and carry out certain non-standard measures in the future. These expectations are incorporated in interest rates and respectively the shadow rate before monetary policy programmes are launched. In result, coefficients in front of programmes that had been anticipated for a long time before they were launched are underestimated. In our case, TLTRO and TLTRO-2 were not announced in advance, but EAPP, especially its largest part PSPP, was intimated by Draghi more than half a year before it was launched. This justifies why CBPP2, which took place before EAPP, was estimated to be so efficient – these were expectations of the upcoming launch of EAPP that affected the shadow rate. This omitted variable bias is extremely difficult to solve, since there exists no variable that quantifies market expectations about the upcoming new policy measures. Alternatively, it can be partially solved econometrically – the model can be modified so that the equation for the variance incorporates not only lags, but also leads of the variance to account for growing errors up until moments when new programmes start. Obviously, this substantially complicates the mathematical form of the model.

On balance, neither a very complicated mathematical model nor publicly unavailable data about the balance sheet of the Eurosystem is available within the scope of this study. Therefore, despite the outlined limitations, the chosen methodology is the best available option to study the impact of the non-standard monetary policy measures.

9. Conclusions

The main objective of the research has been to study the impact of the non-standard monetary policy programmes carried out by the ECB on the overall monetary policy stance. It has been achieved using a two-step methodology: the shadow rate reflecting the stance of monetary policy has been estimated by principal components analysis, and the individual impact of TLTRO, TLTRO-2 and EAPP has been established using linear regression with ARCH.

The effect of CBPP1, CBPP2, SMP and LTRO has been evaluated in aggregate. The coefficients obtained for TLTRO, TLTRO-2 and EAPP have enabled to compare these non-standard monetary policy programmes from two perspectives: (1) their efficiency in terms of basis point decrease of the shadow rate in result of accumulation of the same euro amount of assets under each respective programme, and (2) their individual contribution to the negative shadow rate. Thereby, the research question has been answered.

Regarding efficiency, both targeted longer-term refinancing operations programmes have the highest impact of accumulation of assets on the balance sheet of the Eurosystem under these programmes, with TLTRO-2 being slightly more efficient than TLTRO; EAPP, which subsumes different asset purchase programmes, is less efficient. If the assumptions and limitations of this work are considered reasonable, the result leads to a general conclusion that to make monetary policy more expansionary by printing a given amount of euro, the ECB has to issue them using targeted refinancing operations, i.e. provide commercial banks with cheaper loans upon condition that a certain portion of these loans is used to credit the real economy. Expanding the monetary base simply to purchase financial assets from banks to increase their currency reserves has been estimated to lower the shadow rate two times less given the same amount of newly issued euros.

Speaking of the total individual effect, EAPP has contributed to lowering the shadow rate the most – around 0.7%, since almost as much as € 1.6 trillion assets has been accumulated under this programme. The cumulative impact of TLTRO-2 auctions is comparable – approximately 0.5%, although only half a trillion euro of assets has been accumulated on the balance sheet of the Eurosystem under this programme.

The obtained conclusions for efficiency of the programmes is the main contribution of this work to all research devoted to unconventional monetary policy. I am the first to offer the coefficients that quantify the causal link between the amount of euros ‘printed’ under each of the three largest programmes of unconventional monetary policy launched by the ECB and the decrease in the shadow rate for the Euro Area, which represents a more expansionary monetary policy stance.

As outlined at the very beginning, any links to real macroeconomic variables such as inflation or GDP growth are beyond the scope of this work. However, already at this stage the work has important implications for monetary policymakers, suggesting that to run unconventional monetary policy more efficiently, more money should be created using a targeted longer-term refinancing operations programme instead of asset purchase programmes. Economic consequences of these implications cannot be underestimated – they show how to make monetary policy more expansionary, thus boosting economic growth.

Therefore, acknowledging the limitations of this study, the non-standard monetary policy measures must continue being researched. To obtain more trustworthy results, a better estimation of the shadow rate accounting for non-linearity in the coefficients due to the effective lower bound should be produced in the first place. Incorporating market expectations as an independent variable into the main equation in the second methodological step is another potential significant improvement of the model.

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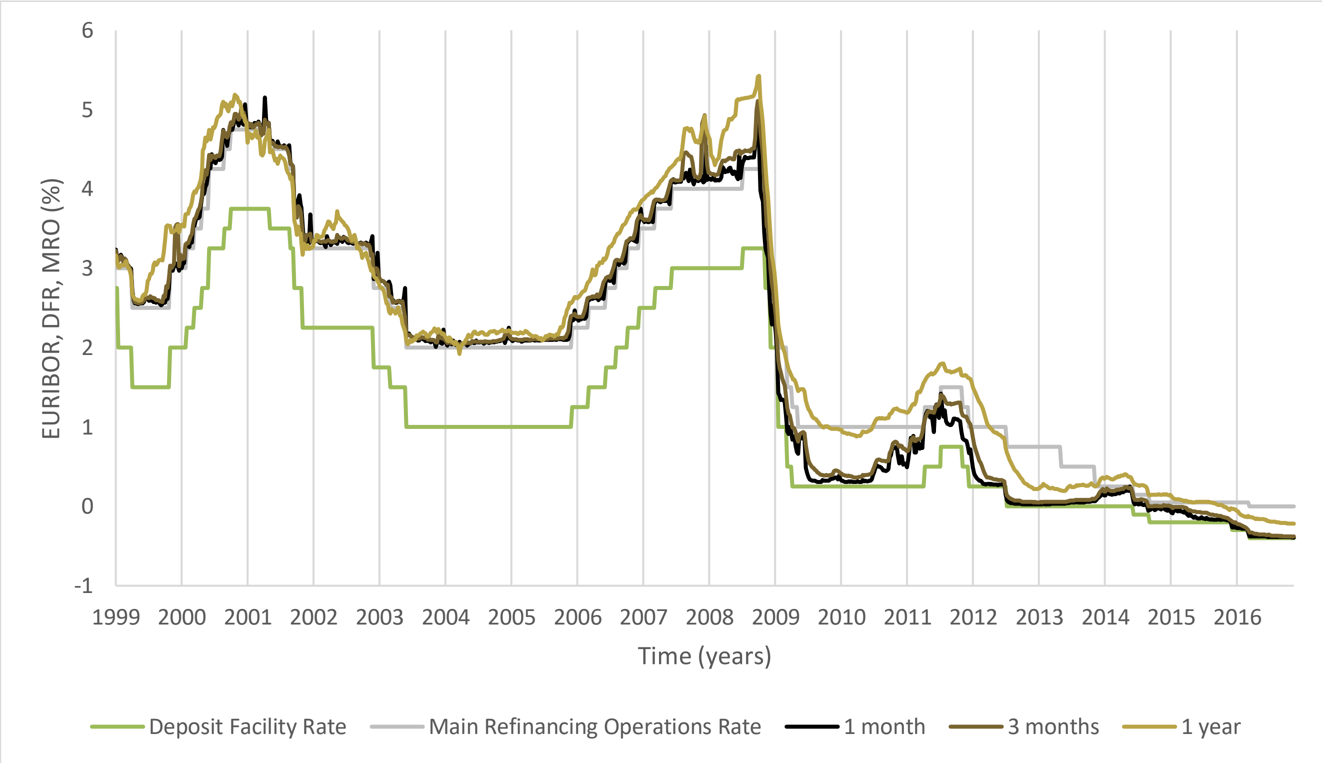
11.Appendices

Appendix A. Monetary policy descriptive variables

Table A.1. Summary of variables used to estimate the shadow rate

Variable	Maturity/date	Frequency	Source	Included	Name of the variable / Reason for omitting
Euro Overnight Index Average (EONIA)	overnight	daily	Thomson Reuters Datastream	Yes	**eonia**
Euro Interbank Offered Rate (EURIBOR)	1 week, 1, 3, 6, 9, 12 months	daily	Deutsche Bundesbank	No	Interest rates of short maturities are sticky at ELB – cause upward bias in the shadow rate when it is far in the negative zone
Implied yield of German government securities	1, 2, 3, 4, 5, 7, 10, 15, 20 years	daily	Deutsche Bundesbank	Yes	**y1, y2, y3, y4, y5, y7, y10, y15, y20**
Euro Overnight Index Swap (OIS)	1, 2, 3, 4, 5, 7, 10, 15, 20 years	daily	Thomson Reuters Datastream	No	Produces an inferior measure of risk-free rates in the Euro Area because has generally higher value than German government securities (hence more risk)
Repurchase agreements on the BS of the Eurosystem	End of month	monthly	ECB website	Yes	**repo**
Monetary aggregates	End of month	monthly	ECB website	Yes	**m0, m1, m2, m3**
Required and excess reserves of the Euro Area banks	End of month	monthly	Statistical Data Warehouse	No	Obvious structural break in August 2012 – excess reserves rose dramatically due to liquidity trap, but were negligible before
Currency in circulation	End of month	monthly	Statistical Data Warehouse	No	Follows linear upward trend – contains no useful information
Assets on the balance sheet of the Eurosystem	End of week	weekly	Statistical Data Warehouse	No	Cannot be included since the programmes used in the second methodology step are part of this sum – may cause upward (more negative) bias in coefficients for the programmes' impact

Figure A.2. Short-term interest rates and effective lower bound



Interest rates of maturities smaller than one year always closely follow the policy rate (which is MRO until August 2008 and DFR since then). Once the policy rate is constrained by ELB, short-term interest rates become sticky as well and hence cannot be used for estimation of the shadow rate. Interest rates of 1-year maturity and above (which are higher than the 1-year rate and not shown on this graph) are not too close to the ELB and keep fluctuating, therefore can be used for the estimation.

Appendix B. Interim results and tests

Table B.1. Results of principal components analysis

```
Principal components/correlation                  Number of obs    =       665
                                                  Number of comp.  =        12
                                                  Trace            =        14
    Rotation: (unrotated = principal)             Rho              =    1.0000
```

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	11.0544	9.57846	0.7896	0.7896
Comp2	1.47596	.607592	0.1054	0.8950
Comp3	.868366	.388255	0.0620	0.9571
Comp4	.480111	.412363	0.0343	0.9913
Comp5	.067748	.0306598	0.0048	0.9962
Comp6	.0370881	.0255306	0.0026	0.9988
Comp7	.0115575	.00905601	0.0008	0.9997
Comp8	.00250154	.000712814	0.0002	0.9998
Comp9	.00178872	.00140818	0.0001	1.0000
Comp10	.000380543	.000326098	0.0000	1.0000
Comp11	.0000544449	.0000401871	0.0000	1.0000
Comp12	.0000142578	5.98699e-06	0.0000	1.0000
Comp13	8.27079e-06	7.47076e-07	0.0000	1.0000
Comp14	7.52372e-06	.	0.0000	1.0000

Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9	Comp10	Comp11	Comp12
st_scm0	-0.2575	0.3221	0.1720	0.2969	-0.8110	0.1995	0.0061	-0.0516	0.1094	0.0056	-0.0026	0.0000
st_scm1	-0.2693	0.2826	0.2562	0.0567	0.3875	0.4377	0.6436	0.1283	0.0772	-0.0191	-0.0029	-0.0013
st_scm2	-0.2612	0.3610	0.1681	0.2162	0.1547	-0.3000	-0.1941	0.1994	-0.7307	0.0234	0.0245	0.0058
st_scm3	-0.2525	0.4249	0.1000	0.1199	0.3223	-0.3422	-0.3245	-0.2480	0.5858	0.0110	-0.0138	-0.0032
st_screpo	0.0239	0.5565	-0.7447	-0.3363	-0.0513	0.1082	0.0502	0.0320	-0.0644	-0.0038	0.0019	0.0001
st_y1	0.2679	0.2022	0.2869	-0.3589	-0.1770	-0.4742	0.4462	-0.2983	-0.0747	0.2966	-0.1764	0.0626
st_y2	0.2781	0.1977	0.2615	-0.2381	-0.0741	-0.0977	-0.0011	0.1925	0.0642	-0.4845	0.5082	-0.2765
st_y3	0.2852	0.1837	0.2179	-0.1342	-0.0066	0.1034	-0.1803	0.3035	0.0775	-0.2441	-0.1005	0.2229
st_y4	0.2899	0.1679	0.1721	-0.0450	0.0387	0.2119	-0.2269	0.2075	0.0367	0.1140	-0.3497	0.2738
st_y5	0.2928	0.1526	0.1278	0.0331	0.0690	0.2624	-0.2149	0.0334	-0.0135	0.3419	-0.2076	-0.1380
st_y7	0.2943	0.1267	0.0480	0.1642	0.0967	0.2587	-0.1149	-0.3128	-0.1069	0.3253	0.3104	-0.5075
st_y10	0.2910	0.0976	-0.0493	0.3096	0.0893	0.1229	0.0481	-0.5033	-0.1502	-0.2195	0.2733	0.6043
st_y15	0.2824	0.0626	-0.1516	0.4355	0.0289	-0.1466	0.1967	-0.0816	-0.0200	-0.4626	-0.5335	-0.3696
st_y20	0.2782	0.0323	-0.2003	0.4640	-0.0200	-0.2956	0.2380	0.5084	0.2218	0.3446	0.2803	0.1288

Table B.2. Augmented Dickey-Fuller test for levels of the variables

	Difference	LTRO	TLTRO	TLTRO2	EAPP
p-value	0.6051	0.9146	0.6240	0.9864	1.0000
t-statistic	-1.3531	-0.3464	-1.3133	0.4969	23.8560

Critical values: -3.4542 at 0.01 level, -2.8719 at 0.05 level, -2.5724 at 0.1 level

*Table B.3.*Augmented Dickey-Fuller test for differences of the variables

	Difference	LTRO	TLTRO	TLTRO2	EAPP
p-value	0.0000	0.0000	0.0000	0.0000	0.0528
t-statistic	-19.0860	-16.3468	-16.4322	-16.5263	-3.4047

Critical values: -3.4542 at 0.01 level, -2.8719 at 0.05 level, -2.5724 at 0.1 level

Table B.4. Johansen Cointegration Test

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.863000	584.3373	69.81889	0.0001
At most 1	0.070450	41.67506	47.85613	0.1680
At most 2	0.055088	21.73101	29.79707	0.3137
At most 3	0.020785	6.261823	15.49471	0.6646
At most 4	0.001931	0.527626	3.841466	0.4676

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Appendix C. The baseline specification and robustness checks

Table C.1. Output for the baseline model

Dependent Variable: DIFF
Method: ML - ARCH (Marquardt) - Normal distribution
Date: 04/06/17 Time: 10:20
Sample: 10/07/2011 12/30/2016
Included observations: 274
Convergence achieved after 110 iterations
Presample variance: backcast (parameter = 0.7)
GARCH = C(5) + C(6)*RESID(-1)^2

Variable	Coefficient	Std. Error	z-Statistic	Prob.
TLTRO	-8.67E-07	9.30E-08	-9.323503	0.0000
TLTRO2	-9.66E-07	1.75E-07	-5.518491	0.0000
EAPP	-4.06E-07	6.02E-08	-6.733212	0.0000
C	-0.604555	0.006508	-92.89347	0.0000
Variance Equation				
C	0.004001	0.000843	4.747599	0.0000
RESID(-1)^2	0.960010	0.206349	4.652365	0.0000

R-squared	0.627380	Mean dependent var	-0.913177
Adjusted R-squared	0.623240	S.D. dependent var	0.362974
S.E. of regression	0.222796	Akaike info criterion	-0.926775
Sum squared resid	13.40228	Schwarz criterion	-0.847655
Log likelihood	132.9682	Hannan-Quinn criter.	-0.895018
Durbin-Watson stat	0.139878		

Note. The coefficients in front of the non-standard programmes show the impact **in percentage points** of accumulation of one **million** euro on the balance sheet of the Eurosystem under the respective programmes. To obtain the effect of an additional **billion** euro in **basis points**, the coefficients must be **multiplied by** $\mathbf{10^5}$.

The constant term is also expressed in **percentage points**. The constant effect of the ultra-loose monetary policy on the shadow rate not accounted for TLTRO, TLTRO-2 and EAPP is the reported constant term **multiplied by** $\mathbf{10^2}$.

Table C.2. Impact of unconventional monetary programmes estimated by models with different cutoff dates τ

Cutoff date	TLTRO	TLTRO-2	EAPP	constant
26/06/2009	-0.208***	*-0.254**	*0.0584*	66.85***
5/08/2011	-0.110***	-0.119***	-0.0442***	-80.64***
7/10/2011	-0.0867***	-0.0966***	-0.0406***	-60.46***
9/12/2011	-0.0783***	-0.0875***	-0.0387***	-43.97***
13/07/2012	-0.0323***	-0.0513***	-0.0265***	-23.85***

Note. Significance: ***: 0.01 level, **: 0.05 level, *: 0.1 level
The coefficients in front of TLTRO, TLTRO-2 and EAPP show change (in basis points) in the difference between the shadow rate and DFR in result of accumulation of one billion of assets under the respective programme. The constant is expressed in basis points.

Table C.3. Autocorrelations and partial correlation for the OLS regression of the difference between the shadow rate and the deposit facility rate on the euro amounts of TLTRO, TLTRO-2 and EAPP

Date: 04/06/17 Time: 20:32
Sample: 10/07/2011 12/30/2016
Included observations: 274

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.707	0.707	138.30	0.000
		2	0.531	0.064	216.81	0.000
		3	0.374	-0.046	255.79	0.000
		4	0.225	-0.082	269.99	0.000
		5	0.147	0.027	276.05	0.000
		6	0.052	-0.073	276.82	0.000
		7	0.020	0.033	276.94	0.000
		8	-0.005	-0.008	276.95	0.000
		9	-0.017	0.004	277.03	0.000
		10	-0.025	-0.018	277.21	0.000
		11	0.020	0.100	277.32	0.000
		12	0.029	-0.024	277.55	0.000