



BANK FOR INTERNATIONAL SETTLEMENTS

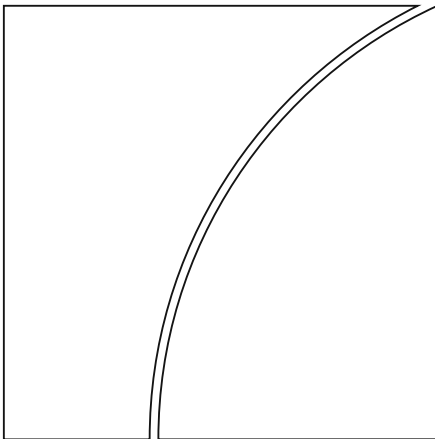
BIS Working Papers No 452

A shadow policy rate to calibrate US monetary policy at the zero lower bound

by Marco Lombardi and Feng Zhu

Monetary and Economic Department

June 2014



JEL classification: E52, E58, C38, C82

Keywords: unconventional monetary policy, zero lower bound, shadow policy rate, federal funds rate, dynamic factor model, monetary VAR

BIS Working Papers are written by members of the Monetary and Economic Department of the Bank for International Settlements, and from time to time by other economists, and are published by the Bank. The papers are on subjects of topical interest and are technical in character. The views expressed in them are those of their authors and not necessarily the views of the BIS.

This publication is available on the BIS website (www.bis.org).

© *Bank for International Settlements 2014. All rights reserved. Brief excerpts may be reproduced or translated provided the source is stated.*

ISSN 1020-0959 (print)

ISSN 1682-7678 (online)

ISBN 978-92-9131-530-7 (print)

ISBN 978-92-9131-531-4 (online)

A shadow policy rate to calibrate US monetary policy at the zero lower bound¹

Marco Lombardi² and Feng Zhu³

Abstract

The recent global financial crisis, the Great Recession and the subsequent implementation of a variety of unconventional policy measures have raised the issue of how to correctly measure the stance of monetary policy when policy interest rates reach the zero lower bound (ZLB). In this paper, we propose a new “shadow policy rate” for the US economy, using a large set of data representing the various facets of the US Federal Reserve’s policy stance. Changes in term premia at various maturities and asset purchases by the Fed are key drivers of this shadow rate.

We document that our shadow policy rate tracks the effective federal funds rate very closely before the recent crisis. More importantly, it provides a reasonable gauge of US monetary policy stance when the ZLB becomes binding. This facilitates the assessment of the policy stance against familiar Taylor rule benchmarks. Finally, we show that in structural vector autoregressive (VAR) models, the shadow policy rate helps identify monetary policy shocks that better reflect the Federal Reserve’s unconventional policy measures.

Keywords: unconventional monetary policy, zero lower bound, shadow policy rate, federal funds rate, dynamic factor model, monetary VAR.

JEL classification: E52, E58, C38, C82.

¹ We thank Leo Krippner, Dubravko Mihaljek, Michele Modugno, Frank Packer, Toshi Sekine, and seminar participants at the Bank for International Settlements (BIS), both in Basel and the Asian Office in Hong Kong, and the European Central Bank for helpful comments and suggestions. Special thanks go to Philip Turner for detailed feedback and guidance. We are indebted to Marta Banbura and Michele Modugno for kindly sharing with us their codes for the estimation of a dynamic factor model on a dataset with missing data. We thank Bilyana Bogdanova and Tracy Chan for data assistance. Views expressed in this paper reflect those of the authors and cannot be attributed to the BIS.

² Corresponding author, BIS, Basel, Switzerland. Email: marco.lombardi@bis.org.

³ BIS Representative Office for Asia and the Pacific, Hong Kong SAR. Email: feng.zhu@bis.org.

I. Introduction

Following the recent global financial crisis and the onset of the Great Recession, central banks of major advanced economies quickly reduced policy rates close to zero and have since implemented a growing variety of unconventional policy measures, referred by some as “quantitative easing” (QE), with the objective of further easing monetary conditions and restoring credit flows.⁴ A main staple of such unorthodox measures have been the large-scale asset purchases, as well as a significant lengthening of the maturity of central bank asset holdings. In the current low-inflation environment and with policy rates practically stuck at the zero lower bound (ZLB) in most major advanced economies, it has become very difficult for central banks and market participants to accurately assess the monetary policy stance. Given the nature and diversity of recent central bank balance sheet policies, no single indicator is seen as a consistent representation of monetary policy stance in both the pre- and post-crisis periods.

In the pre-recession period, there was a growing consensus in both academia and central banking community that a short-term policy rate such as the federal funds rate was a good indicator of US monetary policy stance, as well as the most relevant policy instrument.⁵ Bernanke and Blinder (1992) conclude that the federal funds rate is “extremely informative about future movements of real macroeconomic variables”, it is a “good indicator of monetary policy actions” that is “mostly driven by policy decisions”. Therefore, it became commonplace to use policy rates to proxy monetary policy stance in macroeconomic models, as well as to use shocks to policy rates to study the transmission and the ultimate effects of monetary policy.⁶ But this approach would obviously produce misleading results once the ZLB becomes binding, when policy rates lose their information content and non-standard measures are implemented to provide additional stimulus.

Still, a precise and consistent measure of US monetary policy stance is crucial for analysing the effectiveness of QE measures, ie their impact on economic activity, and for calibrating further measures. As Romer and Romer (2004) suggested, “the accuracy of estimates of the effects of monetary policy depends crucially on the validity of the measure of monetary policy that is used”. This is borne out in recent policy and academic debates: as the transmission channels of unconventional policies are not yet well understood, the lack of one single and consistent policy indicator constitutes a major hurdle.⁷ Also, in the absence of proper quantification of the size of stimulus provided by today’s unconventional policies, it would be hard to answer the question of whether the current policy stance is appropriate, too tight or too loose.

⁴ For ease of exposition, we use the terminologies “quantitative easing”, “central bank balance sheet policy”, “unconventional monetary policy” and “asset purchase programmes” interchangeably wherever the circumstances are clear.

⁵ Earlier discussions on the most appropriate measure of monetary policy focused on monetary aggregates, see, e.g. Havrilesky (1967) and Froyen (1974). However, monetary aggregates are likely to be contaminated by endogenous factors.

⁶ See for example Bernanke and Blinder (1992), Christiano et al (1996) or Kim (1999).

⁷ Woodford (2012) discusses various unconventional policies, including forward guidance and asset purchases. Curdia and Woodford (2011) provide a model-based assessment of the balance sheet of the central bank as an instrument of monetary policy.

Most of the recent attempts to gauge unconventional policies resorted to the impact of announcements and asset purchases on the term structure of interest rates. For example, Meaning and Zhu (2012, 2013) used changes in the size and maturity of the Federal Reserve asset holdings to estimate the impact of central bank asset purchases on the yield curve. Along similar lines, Chadha et al (2013) examined the effects of government debt maturity on long-term interest rates. Such measures may indeed be appropriate to gauge monetary policy and assess its impact during times of unconventional policies. Yet, without an indicator that is consistent over a long period of time, it becomes difficult to quantify the effects of unconventional policies against historical benchmarks. Consequently, almost all recent empirical work has focussed on measuring immediate financial market responses to QE announcements.⁸

Our goal is to provide an intuitive and model-free indicator that can be easily computed in real time and accurately summarise monetary policy stance in different circumstances. More specifically, we estimate a shadow policy rate, i.e. a measure that is directly comparable to the federal funds rate but can be informative of monetary policy stance in the presence of the ZLB on nominal interest rates and unconventional policy interventions.

To construct such a shadow policy rate, we first pool together a comprehensive dataset for variables which could potentially reflect most, if not all, monetary policy actions. These include variables that are closely associated with unconventional policies. We then summarise the information using a dynamic factor model. We interpret the estimated factors as representing different aspects of monetary policy, and finally, we use these factors to reconstruct a shadow policy rate which can assume negative values by treating the federal funds rate as unobserved after it had hit the ZLB. The resulting shadow policy rate can be consistently applied in the pre- and post-ZLB periods.

Using two standard monetary VAR models, we show that it is possible to measure monetary policy shocks with a shadow policy rate which is unconstrained by the ZLB, and to study the impact and transmission of QE measures. More importantly, the shadow rate allows us to examine to what extent various unconventional monetary policy measures have managed to fill the “policy gap” that opened between the federal funds rate when it reached the ZLB, and the levels suggested by the rules of Taylor (1993, 1999), Ball (1999) and Yellen (2012). We find that policymakers have been reasonably successful in trying to achieve the prescribed Taylor rates with QE measures. We also use this approach to evaluate Bullard’s (2012, 2013) assessment of the stance of monetary policy.

The rest of the paper is structured as follows. In the next section, we review the relevant literature and give a detailed account of our empirical strategy, as well as the set of monetary variables we employ. In Section III, we present our shadow policy rate and investigate its properties through several robustness checks. We also examine the evolution of the estimated factors and relate these to different aspects of monetary policy. In Section IV, we evaluate the overall monetary policy stance by comparing the shadow policy rate to the levels of federal funds rate prescribed by Taylor rules, so as to assess the extent to which the policy gap between the actual

⁸ See for example Meaning and Zhu (2011) and references therein. Notable exceptions are Peersman (2011), Chen et al (2012, 2014), and Gamabocorta et al (2014), who attempt to pin down unconventional monetary policy shocks in a structural or global VAR framework.

federal funds rate (constrained by the ZLB since late 2008) and Taylor-rule levels has been filled by unconventional measures, and to. Then we use two standard monetary VAR models to study the properties of monetary policy shocks based on the estimated shadow policy rate in the post-crisis period. Section V concludes.

II. Measuring monetary policy at the zero lower bound

Measuring monetary policy and estimating its effects on economic activity has been among the most active research topics in macroeconomics. An accurate indicator of monetary policy that can be easily computed in real time is essential for gauging and calibrating current policy stance: is it appropriate or neutral, too tight or too loose, and whether and how much policy adjustment is needed? A good indicator also allows central banks to better measure policy effects on financial markets and real activity, and to better design and implement monetary policy.

II.1 Literature review

Much of the early academic literature emphasised the use of monetary aggregates to gauge the stance of monetary policy. For example, Friedman and Schwartz (1963) and Cagan (1972) stressed the usefulness of broad monetary aggregates such as M1 and M2. Yet money is endogenous and it is difficult to disentangle factors which affect money demand from policies that are aimed to change money supply.

For any monetary aggregate to provide guidance for policy, it needs to display a stable and predictable medium- and long-term relationship with aggregate demand. The US demand function for money became unstable since the “missing money” episode in the mid-1970s. Financial liberalisation and innovations, among other factors, helped weaken the earlier claims of the existence of such a stable relationship. Friedman and Kuttner (1992) do not find evidence of a “close and reliable relationship between money and nonfinancial economic activity”. Estrella and Mishkin (1997) provide evidence that US monetary aggregates failed to perform as information variables since 1979, and claim that they “cannot be used in a straightforward way for monetary policy purposes”. Policymakers have thus shifted attention towards other policy indicators. In particular, Bernanke and Blinder (1992) find that “the interest rate on Federal funds is extremely informative about future movements of real macroeconomic variables” and “the funds rate is a good indicator of monetary policy actions”.

Once an appropriate indicator of monetary policy is identified, it is natural question to examine it against benchmarks such as natural interest rates or rates suggested by “optimal” policy rules, or by simple feedback rules such as those proposed by Taylor (1993, 1999).

Another question is how monetary policy transmits, and what effects it has on real activity. A common approach is to first identify the monetary policy shocks based on the appropriate indicator(s), and then assess the impact of such shocks on various macroeconomic variables. There are two main approaches to the identification of shocks. The first one is narrative, and evaluates evidence derived from historical record. It has evolved from the early work of Friedman and Schwartz (1963), which “traces changes in the stock of money for nearly a century” and “examines the factors that accounted for the changes and analyses the reflex

influence that the stock of money exerted on the course of events". Romer and Romer (1989) propose a test to identify shocks using historical narrative instead of relying on "pure statistical evidence". They find that "demand disturbances are a primary source of post-war economic fluctuations". Romer and Romer (2004) use quantitative and narrative records to infer the Federal Reserve's policy intentions and find that its actions had large and rapid effects on output and inflation. Yet the narrative approach has a strong dose of subjectivity. Moreover, policy decisions are also endogenous and it is not clear that this approach effectively isolates policy shocks from the influence of other factors.

Alternatively, vector autoregressive (VAR) models have been widely used to identify monetary policy shocks, which are interpreted as policy changes. Examples include Bernanke and Blinder (1992), Christiano and Eichenbaum (1992), Sims (1992) and Christiano, Eichenbaum and Evans (1996). While Bernanke and Blinder (1992) use the federal funds rate as the policy indicator, Christiano and Eichenbaum (1992) opt for non-borrowed reserves. VAR studies typically find that monetary policy shocks have modest effects on real activity and they can explain only a small part of output fluctuations. In addition, Bernanke, Gertler and Watson (1997), Sims (1999) and Sims and Zha (2006) analyse the effects of the systematic or endogenous component of monetary policy while imposing more structure on their VAR models.

Both alternatives run into difficulties in the current environment, for two reasons. First, as soon as the zero lower bound (ZLB) is reached, a discontinuity emerges and short-term interest rates cease to convey useful information. As a "liquidity trap" emerges, the public is prepared to hold whatever amount of money supplied, and increases in money supply cannot induce economic agents to hold more bonds so as to reduce interest rates to below zero. Second, the rapid decline of the federal funds rate towards zero was accompanied and then superseded by the implementation of a great variety of unorthodox policy measures ranging from credit programmes to financial institutions, to large-scale asset purchases, to maturity extension and forward guidance. In the absence of a good policy indicator, much of the recent work on the impact of unconventional policies has resorted to event studies by measuring financial market responses to the major announcements of, e.g., large-scale asset purchases.⁹

A key issue is how to design a simple and easy-to-interpret measure of monetary policy that will successfully capture non-interest-rate policy actions at the ZLB and remain consistent when the ZLB is no longer binding. One approach is to exploit the proposition that unconventional measures work to flatten the yield curve. Chen et al (2012) use US term and corporate spreads to proxy the Federal Reserve's policy measures and analyse the global impact of QE.¹⁰ They find significant and diverse cross-border effects. A drawback of this approach is that term and corporate spreads are not monetary instruments *per se* and they fluctuate for many different reasons. Even if they may work well in the post-crisis period with ZLB binding, it is unlikely that they are good indicators of monetary policy over an extended period of time. Meaning and Zhu (2011, 2012) use the Federal Reserve balance sheet information, ie the size and maturity of its Treasury securities holdings and actual asset purchases to evaluate the effects of unconventional

⁹ See for example Meaning and Zhu (2011) and references therein.

¹⁰ Blinder (2010) also suggests that the Federal Reserve's asset purchases work mainly through a reduction in the term and risk or corporate spreads.

measure. But such information does not reflect the true extent of the Federal Reserve's unprecedented monetary easing.

A more sophisticated approach, first suggested in Black's (1995) seminal work, also relies on yield curve information. The idea is to extract shadow rates that can turn negative, driven by the dynamics of the term structure of interest rates. Extending the Black (1995) framework and using an estimated term-structure model, Bomfim (2003) finds that market interest rates during 2002 and early 2003 implied some probability, though very small, of the US economy slipping into a liquidity trap. Gorovoi and Linetsky (2004) model the shadow rate as a Vasicek process and apply it to the Japanese government bonds (JGB) data, reporting a good fit of the Japanese term structure. Ueno, Baba and Sakurai (2006) examine the Bank of Japan's (BOJ) zero interest rate policy during the BOJ quantitative easing between 2001 and 2006. They report a negative estimate of the interest rate throughout the period. More recently, Kim and Singleton (2012) find that their two-factor affine, quadratic-Gaussian, and shadow rate models capture some key features of JGB data and that the shadow rate models outperform other models in terms of the fit to realised excess returns.

Krippner (2012, 2013a) departs from Black (1995) by adding an explicit function of maturity to the shadow rate forward curve; this leads to more tractable models with closed-form solutions. Krippner (2013b) proposes the shadow rate as a monetary policy stance indicator and applies it to Japan's case. Bauer and Rudebusch (2013) suggest that shadow rates models could be more informative on monetary policy expectations than standard dynamic term structure models which ignore the ZLB, and they provide better interest rate fit and forecasts. Wu and Xia (2014) document that the effects of the shadow rate on macroeconomic variables are similar to those of federal funds rate.

Nevertheless, Christensen and Rudebusch (2013) employ a three-factor model for the term structure, and show that estimates of the shadow rate are sensitive to model specifications.¹¹ In addition, while the shadow interest rates estimated à la Black (1995) are unconstrained by the ZLB, they seem to reflect market expectations of very short nominal interest rates. But many factors other than policy changes may affect such expectations, including changes in short-run market sentiments and longer-term growth prospects. As a result, these rates are likely to be a noisy indicator of policy stance, especially in turbulent times when volatility is high, market sentiment shifts frequently, and uncertainties concerning growth prospects are high.

II.2 A dynamic-factor-based shadow rate

To construct a reliable indicator of the overall stance of monetary policy that ideally would work in both conventional and unconventional monetary policy environments, we interpret monetary policy as an unobserved variable, which one can estimate using a variety of methods. This idea is not new and dates back to Avery (1979). He interprets monetary policy as a "single dimensioned unobserved variable" and estimates an "index of monetary policy" by extracting a common

¹¹ For instance, the shadow market rates à la Black (1995) estimated by Krippner (2012, 2013) and Wu and Xia (2014) are significantly different in the period when the zero lower bound on nominal interest rates is binding.

factor out of real and monetary variables. Since then, other synthetic indicators of monetary policy have been proposed. The Divisia index of money proposed by Barnett (1980), for example, weighs different assets by the value of the monetary services they provide. Barnett, Fisher and Serletis (1992) show that the Divisia index predicts GNP at least as well as basic monetary aggregates such as M1 and M2. The Federal Reserve of St. Louis (see eg Thornton and Yue 1992) has developed a monetary services index (MSI) based on such monetary aggregation theory. Rotemberg, Driscoll and Poterba (1995) find that a utility-based currency-equivalent aggregate proposed by Rotemberg (1991) remains valid even as asset characteristics change, and predicts output movements better than conventional monetary aggregates.

Our approach also aims at providing a synthetic indicator of monetary policy. But rather than producing a synthetic index which may be harder to understand, we construct a shadow policy rate that can be directly compared to the federal funds rate. First, we pool together a dataset with variables that are closely associated with different types of monetary policy operations. Second, we estimate a dynamic factor model based on the dataset up until the time when the federal funds rate hits the zero lower bound, and select an optimal model specification. Third, we treat the federal funds rate as missing, and re-run the dynamic factor model to obtain the shadow rate series especially when the ZLB becomes binding. Missing elements are replaced by their best estimates given the evolution of the observed series. In fact, our shadow federal funds rate is a “weighted average” of all monetary information contained in the original dataset, with weights determined on the basis of the historical correlations of the federal funds rate with the other variables. In other words, we map changes in all other monetary policy variables onto a single shadow federal funds rate, based on estimated historical relationships. As such, the shadow rate indicates how the funds rate would have behaved if policymakers could have driven it negative, providing a federal funds rate equivalent for the unconventional measures implemented so far.

The approach is not too different, in spirit, from Bernanke and Mihov (1998). They construct a VAR model in which they include the federal funds rate and borrowed and non-borrowed reserves to measure monetary policy. Their indicator of the overall policy stance is a linear combination of these variables, with weights based on the VAR parameter estimates. However, Bernanke and Mihov’s approach cannot be directly employed to account for unconventional measures: the relevant variables would be far too many to be included in a single monetary VAR. Adding variables to a VAR system implies the need to impose extra identifying restrictions which have to rely on a valid theory. Unfortunately we still have too little insights on how unconventional policies work and transmit to devise and justify such restrictions.

Our approach has the advantage of providing a synthetic measure of monetary policy which summarises many different facets of policy and yet remains directly comparable to the federal funds rate, the Federal Reserve’s operational target and instrument of choice. In addition, our approach uses as much information as possible on monetary operations. The resulting shadow policy rate thus reflects information contained in interest rates, monetary aggregates, reserves and the Federal Reserve’s asset holdings. Therefore, our policy indicator works across different policy regimes and remains robust to policy shifts, e.g. from a monetary aggregate to an interest rate target. Given that the shadow rate accounts for information on less conventional measures usually not contained in the interest rates or monetary aggregates, it is an indicator that works in both conventional and

unconventional monetary policy environments. Furthermore, unlike the shadow rates derived from Black (1995), our indicator lets the data speak for itself, and is model-free in the sense that it does not depend on any specific term structure model. Instead of modelling the yield curve, whose evolution may reflect only a subset of unconventional policies, our framework provides a more comprehensive examination of monetary policy stance.

II.3 Data and variables

The first step is to identify an appropriate set of variables that may provide useful information to construct a shadow federal funds rate. The variables are selected based on the fact that they are closely associated with, and accurately reflect the Federal Reserve's policy actions. For instance, the implementation of monetary policy via changes in the federal funds rate and asset purchase programmes would both solicit changes in the size and composition of the Federal Reserve's asset holdings through open market operations. As in Woodford (2012), we start with the basic blocs of interest rates and monetary aggregates, and then include variables that could reflect a wide range of unconventional monetary policy measures.

We construct the monetary policy dataset based on the following four major building blocks.

Bloc I. Interest rates:

- Effective Federal Funds rate (FFR)
- Rates of US Treasury bills with maturities of 1, 3, 6 and 12 months
- Yields of US Treasury bonds with maturities of 1, 2, 3, 5, 7, 10, 20 and 30 years
- Overnight indexed swap – 3 month LIBOR spread

The different interest rates we include in Bloc I reflect the Federal Reserve's policy actions, which affect the future path of the entire yield curve. The OIS spread provides information on the market expectations of the federal funds rate. The interest rate bloc is therefore also likely to contain useful information on the Federal Reserve's forward guidance, broadly defined as the central bank's communications about its future policy intentions.

Bloc II. Monetary aggregates:

- Monetary base or M0
- M1, M2, MZM (Federal Reserve of St. Louis)

Besides the federal funds rate, the various monetary aggregates included in Bloc II are traditional monetary policy indicators. Monetary analysis based on monetary aggregates remains a cornerstone of policymaking in a number of central banks.

Bloc III. Federal Reserve balance sheet (assets):

- Total assets
- Total Federal Reserve securities held outright
 - US Treasury securities
 - Federal agency debt securities

- Mortgage-backed securities
- Average maturity of Federal Reserve securities held outright
- Percentage of long-term US Treasury securities (<5y, <10y, >10y)

Bloc IV. Federal Reserve balance sheet (liabilities):

- Currency in circulation
- Reserves: Total, Non-borrowed, Required and excess reserve balances
- Deposits of depository institutions (other than reserve balances)
- Reverse repurchase agreements

Blocs III and IV focus on the asset and liability sides of the Federal Reserve's balance sheet, which provide important information on a range of central bank's unconventional measures, especially the large-scale asset purchases and maturity extension. While the policy rate can be considered as the price of the reserves commercial banks hold with a central bank, it does not incorporate the information of special lending programmes or the size changes and maturity transformation resulting from the central bank's large-scale asset purchases (and sales), especially at the ZLB. In fact, a central bank's balance sheet contains useful quantity information on almost all monetary operations.

One advantage of our approach is that the dataset used to produce the shadow policy rate can be obtained in real time at monthly or even higher frequencies and the data involved usually do not entail large and frequent revisions as in the case of GDP. This allows the estimated shadow rates to quickly and faithfully reflect ongoing policy changes.

Our sample of monetary data for the United States ranges from January 1970 to December 2013. We use monthly data for our analysis, as we think they better reflect major monetary policy changes. The Federal Reserve holds eight FOMC meetings per calendar year, and some significant changes may also be adopted between these meetings, particularly in a crisis period. A policy stance indicator constructed at quarterly frequency seems to be inadequate and untimely if our intention is to report evolution in monetary policy. On the other hand, historically, we do not observe frequent major policy changes occurring within a month, so weekly or biweekly frequencies are not considered even in cases where data may be available.¹²

II.4 A dynamic factor model with missing observations

Dynamic factor models are useful in the analysis of very large datasets: they reduce the data dimension by extracting a small number of common components out of a large amount of available information. The common components, or factors, are

¹² Decisions on the federal funds rate are usually made by the Federal Open Market Committee (FOMC) in the eight regularly scheduled meetings each year, and policy changes tend to be less frequent in normal times. In the most recent three US recession episodes, the federal funds rate was lowered 14 times from 29 October, 1990 to 20 December, 1991; 11 times from 3 January to 11 December, 2001; and 10 times from 18 September, 2007 to 16 December, 2008. More frequent changes in the funds rate can be found in earlier decades. For example, the federal funds rate was raised seven times between 16 August and 29 September 1978 but this was rare.

chosen in such a way as to maximise the proportion of total variability of the dataset they can explain.

Let $\{X_t, t = 1, \dots, T\}$ be an N -dimensional multiple time series with T observations. We write its factor representation as:

$$X_t = \Lambda F_t + e_t, \quad (1)$$

where F_t is an $r \times 1$ vector of factors, Λ is the $N \times r$ matrix which contains the so-called factor loadings and the errors e_t are idiosyncratic components orthogonal to the factors F_t . The factors F_t are unobserved and must be estimated. We assume that the common factors follow a VAR process of order p :

$$F_t = \sum_{i=1}^p A_i F_{t-i} + u_t, \quad (2)$$

and that the error terms e_t and u_t are both *i.i.d.* and Gaussian, so that the resulting dynamic factor model can be written in the state-space form and estimated using the Kalman filter (see Engle and Watson 1981, Doz et al 2011).¹³

Watson and Engle (1983) first suggested the use of the expectation maximisation (EM) algorithm proposed by Dempster et al (1977) for the estimation of unobservable components models. The EM algorithm works by replacing unobservables with their expected values, conditional on the observed series, and then maximising the likelihood conditional on such expected values. The process is iterated until convergence.

Banbura and Modugno (2014) propose the use of the EM algorithm in the case in which the data series $\{X_t\}_{t=1}^T$ in equation (1) contain an arbitrary pattern of missing entries. They also provide algorithms to deal with serially correlated error terms.

Since the federal funds rate and other short-term interest rates have become practically constrained by the ZLB since late 2008, they have largely lost their information content on monetary policy stance.¹⁴ Other variables, especially those directly related to the implementation of unconventional measures, take up this role. Reflecting this, we treat the short-term interest rates as missing series once they drop to the proximity of the ZLB.

Based on the algorithm by Banbura and Modugno (2014), we estimate a dynamic factor model on the dataset defined in Section II.2. We treat the federal funds rate and the 3-month and the 6-month Treasury bill rates as missing since December 2008, when they hit the lows of 0.16%, 0.03% and 0.26%, respectively. The 1-year and 2-year Treasury bond yields are assumed to be missing since November 2009, when they reached the lows of 0.31% and 0.80%, respectively. For Treasury bonds of 1-year and 2-year maturities, the yields were already low and could be considered to be close to zero for policy purposes taking into account the term and risk premia. To estimate a dynamic factor model, the input series need to

¹³ In practice, the error components may not be orthogonal to each other and can contain residual correlations that are not explained by the factors. However, Doz et al (2012) show that in the presence of weak cross-correlations the estimation of factors is still consistent.

¹⁴ The federal funds rate target was reduced to 0-0.25% on 16 December, 2008, when the effective funds rate dropped to 0.16%. Since then, the effective rate has fluctuated within the target range, and was 0.07% in January 2014.

be stationary. For this reason, we use the year-on-year growth rates for the quantity variables in blocs II, III and IV. Therefore our shadow rate reflects more the rates of change rather than absolute sizes of the balance sheet items.

One critical issue in the estimation of the dynamic factor model is how to correctly select the “optimal” number of factors to adequately represent the underlying dataset. According to the criterion proposed by Hallin and Liska (2007), a total of seven factors appear to be appropriate in our empirical analysis.¹⁵ In fact, these factors can explain 90.8% of the total variance of the monetary dataset, just above the commonly used 90% rule of thumb for lag selection.

We choose the optimal number of lags p in the estimated dynamic factor model according to the well-known Schwarz information criterion (SIC), and obtain two lags. Both the number of factors and the number of lags are selected based on the pre-crisis data sample. This is intended to ensure that the selection of the model structure is based on a sample in which all variables and, consequently, their joint dynamics are observed.

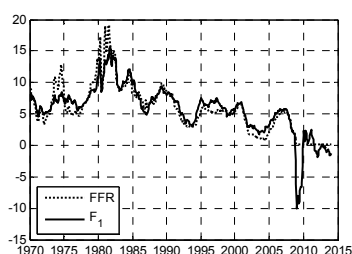
Once dynamic factors are estimated, we investigate how they evolve and correlate with variables that can best reflect the Federal Reserve’s policy actions. The findings are interesting. In Graph 1, we present the first three factors, which taken together account more than 70% of the total variance of the monetary dataset. The first factor, which alone explains about 39% of the total variance, is strongly connected with the federal funds rate until the time when the funds rate effectively hit the ZLB (Graph 1, left-hand panel). The second factor, which explains around 20% of the total variance, appears instead to be mainly driven by monetary aggregates, especially since 1990. In fact, this factor is highly correlated with monetary base in the post-crisis period (Graph 1, centre panel). The third factor, which accounts for around 11% of variance, is highly correlated with the growth rate of the Federal Reserve’s outright Treasury securities holdings (Graph 1, right-hand panel). This factor adds additional information on unconventional measures associated with changes in the size and composition of the central bank’s securities holdings, which is especially useful in present circumstances.

Factors and observed variables

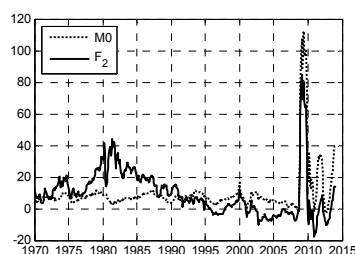
In per cent

Graph 1

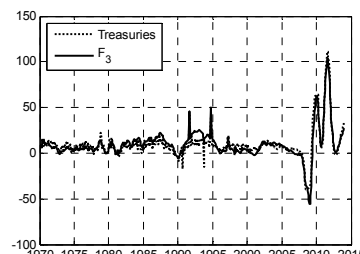
Factor 1¹ and the federal funds rate



Factor 2¹ and monetary base²



Factor 3¹ and securities held³



¹ The factors are rescaled (and in the case of factors 2 and 3, multiplied by -1) to match observed series. ² Year-on-year rate of growth. ³ Year-on-year rate of growth of the outstanding amount of treasuries held by the Fed.

Sources: Federal Reserve, authors’ calculations.

¹⁵ We analyse and discuss the robustness of our results to alternative selection criteria for the optimal number of factors as well as the lag order in Section IV.1.

III. Filling the gap: the shadow federal funds rate

The dynamic factor model presented above has the advantage of providing a reconstruction of missing values for key variables based on the expectation maximisation (EM) algorithm. The EM-based estimates of missing values are driven by the evolution of the fully observed series, and historical patterns of their correlations with the series with missing observations. This is essential to our approach to constructing a shadow federal funds rate, which reflects changes in alternative monetary policy gauges once the ZLB becomes binding. In other words, we retrieve a shadow federal funds rate that maps the changes in other indicators of monetary policy onto it. As such, it can be interpreted as an estimate of how the federal funds rate would have behaved had the ZLB not been binding, based on the evolution of a variety of other indicators of unconventional policy actions.

One significant advantage of using the estimated shadow federal funds rate to gauge the overall monetary policy stance is that it preserves continuity and consistency. As noted in the literature review, the bulk of the empirical literature of the last few decades has focused on the federal funds rate as the most important indicator of monetary policy. Having a shadow rate that behaves in an almost identical manner in normal times, and yet continues to work in the ZLB environment is useful in that respect. The shadow policy rate can be easily plugged into the existing quantitative models for monetary policy analysis. We will elaborate on this and provide two examples in Section IV.

We report both the actual and the estimated shadow federal funds rates in Graph 2. The first striking feature is how well the shadow rate tracked the actual effective federal funds rate before the ZLB became binding. This suggests that in the pre-crisis period, when the ZLB had no material impact, the shadow policy rate would be as good an indicator of the overall policy stance as the federal funds rate. In a few cases when there was a discernable deviation of the shadow rate from the effective federal funds rate, ie in 1974-75 and 1982, when the federal funds rate was much higher than the historical average. The episodes were preceded by recessions and monetary policy appeared to have been looser than what the actual rate would suggest. This indicates that the federal funds rate might not accurately reflect the full extent of policy actions at times of high monetary policy activism.

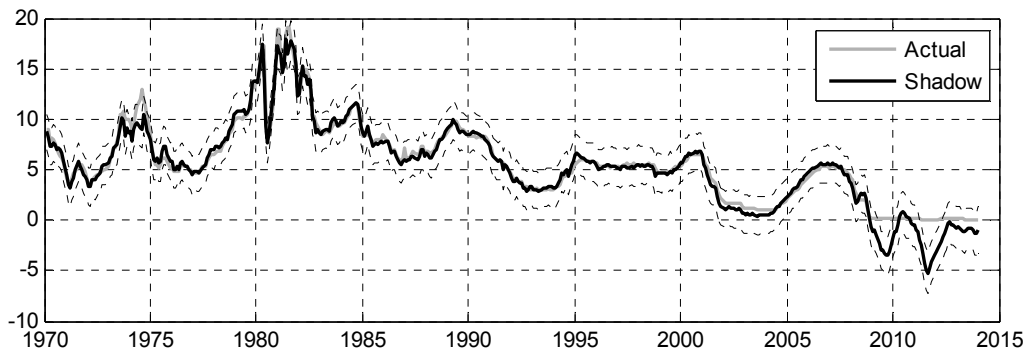
Second, following the crisis, when the actual federal funds rate declined to close to zero by the end of 2008, the shadow policy rate turned negative reflecting further monetary stimulus provided by unconventional measures. In particular, the shadow rate picked up the two waves of balance sheet policy measures: the first phase of the large-scale asset purchase programme (LSAP1) announced in November 2008 and reinforced with purchases of longer-term Treasury securities in March 2009; and the LSAP2 put in place in November 2010, followed by the maturity extension program (MEP) announced in September 2011 (see Table 1).¹⁶

¹⁶ For further details on the Federal Reserve's asset purchase programmes, see Meaning and Zhu (2011, 2012).

Shadow¹ and actual federal funds rate²

In per cent

Graph 2



¹ Solid black line; the dotted lines represent the 95% confidence interval. ² Grey line.

Sources: Federal Reserve, authors' calculations.

Third, the shadow policy rate suggests that the overall policy stance became less easy following the completion of the LSAP1 in March 2010. The shadow rate gradually edged back to around zero before a second dip associated with LSAP2 in November 2010. After the LSAP2 was terminated in mid-2011, the overall impact on the shadow rate of the halt in the Federal Reserve's outright asset purchases was not sufficiently addressed by the maturity extension via the subsequent MEP, also known as the Operation Twist.¹⁷ But the Federal Reserve's September 2012 decision to add purchases of Agency mortgage-backed securities at a pace of \$40 billion per month via its LSAP3, and the December decision to continue to purchase longer-term Treasury bonds at a rate of \$45 billion per month upon the completion of the MEP, helped drive the shadow rate lower. The LSAP3 provided additional stimulus throughout the first half of 2013, but had a much smaller impact compared to LSAP2.

Shadow federal funds rate

In per cent

Table 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2008	3.1	2.3	1.7	1.9	2.3	2.7	2.6	2.6	2.1	1.2	0.2	-0.7	1.8
2009	-1.2	-1.0	-1.4	-2.2	-3.0	-3.0	-3.3	-3.4	-3.5	-3.1	-2.5	-1.8	-2.4
2010	-1.2	-1.1	-0.5	0.4	0.7	0.8	0.6	0.3	0.2	-0.3	-0.5	-0.5	-0.1
2011	-1.0	-1.2	-2.0	-2.5	-3.3	-4.3	-4.9	-5.2	-4.7	-4.1	-3.8	-3.4	-3.4
2012	-3.1	-2.8	-2.1	-1.7	-1.3	-0.8	-0.3	-0.2	-0.4	-0.4	-0.6	-0.7	-1.2
2013	-0.6	-0.7	-1.0	-1.2	-1.2	-0.9	-0.8	-0.9	-1.0	-1.4	-1.3	-1.0	-1.0

Source: authors' calculations.

¹⁷ Indeed, Chen et al (2014) find that the impact on US and global asset prices of MEP announcements differed markedly from that of LSAP announcements, but it was quite similar to the tightening effects of the Federal Reserve's Tapering announcements in 2013.

To a large extent, the smaller LSAP3 impact can be explained by the timing, size and pace of the Federal Reserve’s large-scale asset purchase policy, which is reflected in the shadow rate. This becomes clear when we examine the first two estimated dynamic factors which explain about 60% of the total variance (Graph 3). First, we notice that factor 1 declined in the first half of 2012, in line with a decline in the 10-year Treasury bond yield which might be attributed to the MEP implementation (Graph 3, left-hand panel). Yet such a decline did not drive down the shadow federal funds rate, as it was more than compensated by a continued deceleration and eventual decline in the Federal Reserve’s asset holdings (Graph 3, right-hand panel). So, as outright asset purchases were halted, the shadow rate drifted towards zero. The rise in the shadow rate was only reverted following the implementation of LSAP3 announced in September 2012, which exerted strong downward pressures on the shadow rate. But as long-term yields started to increase with tapering discussions in the second quarter of 2013, the fall in the shadow rate was mitigated.

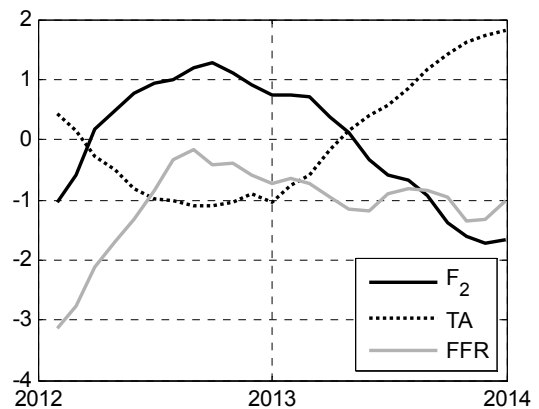
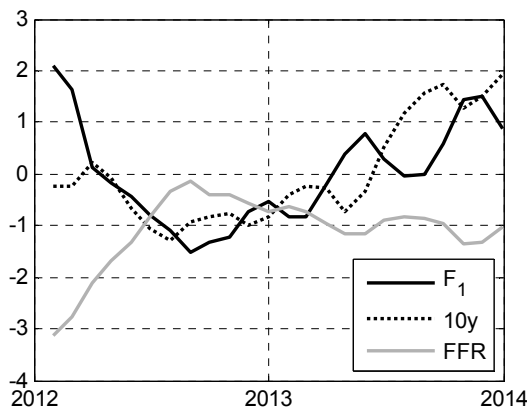
Shadow FFR and the first two dynamic factors since 2012¹

In per cent

Graph 3

Factor 1 and 10-year US Treasury yield²

Factor 2 and growth in Fed’s total assets³



¹ The vertical dotted line corresponds to January 2013. ² The solid black line refers to the first dynamic factor (an increase corresponds to a policy tightening); the dotted line is the yield on 10-year Treasury bills and the grey line is the estimated shadow rate. ³ The solid black line refers to the second dynamic factor (an increase corresponds to a policy tightening); the dotted line is the year-on-year growth of Fed’s total assets and the grey line is the estimated shadow rate.

Source: Authors’ calculations.

Nevertheless, the confidence interval for the estimated shadow rate includes zero as the rate approaches zero in mid-2012 and stays statistically insignificant after that. There are two important additional caveats: first, we have not used the information on the sizes of different balance sheet items in the estimation of the shadow policy rate (as they are non-stationary), but rather their rates of change. There is a possibility that we miss out some important information contained in the levels; second, in estimating the shadow rate, we have not attempted to distinguish and isolate changes in the interest rates which are driven by monetary policy from those by non-monetary factors, such as changes in investors’ appetite for US

Treasury securities, often treated as a unique safe asset.¹⁸ Nevertheless, it is important to include interest rates, especially the long-term yields in the estimation of the shadow policy rate, since it helps capture, eg effects arising from the Federal Reserve’s forward guidance. In fact, such announcements in August 2011 and September 2012 correspond to sizeable drops in the shadow rate (see Table 1).

III.1 Robustness analysis

In this sub-section, we conduct a number of robustness checks to examine whether the estimated shadow federal funds rate remains a good indicator if the model specification changes. Indeed, in the context of their work on a shadow market rate à la Black (1995), Christensen and Rudebusch (2013) find that the sensitivity to model specifications is of particular concern. We test the robustness of our approach in three dimensions: the number of lags in the dynamic factor model; the number of factors; and the inclusion or exclusion of certain monetary variables from the underlying dataset.

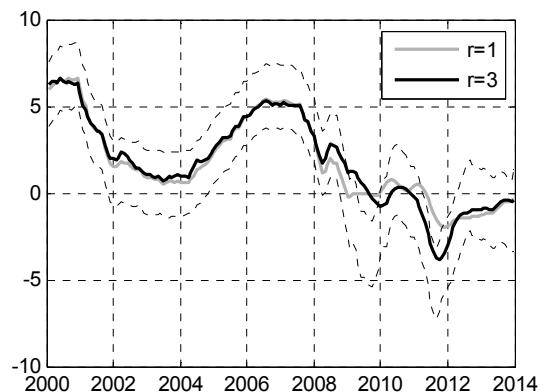
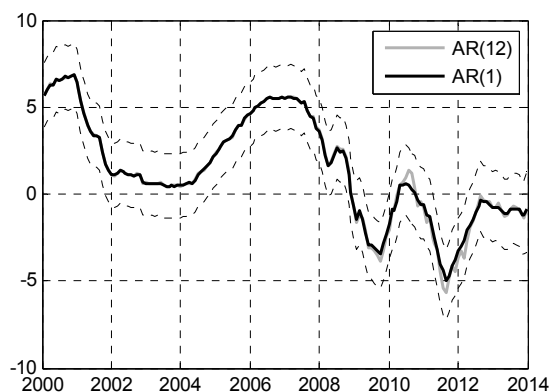
Robustness of the shadow FFR to model specification¹

In per cent

Graph 4

Lag order²

Number of factors³



¹ The dotted lines represent the 95% confidence interval of the baseline specification (2 lags, 8 factors). ² The solid black line refers to one lag, the grey line to three lags. ³ Black line refers to three factors, as per Bai and Ng (2007) criterion, grey line to one factor.

Source: Authors’ calculations.

Correctly choosing the lag order is essential to the estimation of any time series model. In our baseline dynamic factor model we select the lag order based on the well-known Schwarz information criterion (SIC), which suggest an optimal two-lag structure.¹⁹ Using a different lag order does not seem to significantly affect the results. Indeed, the shadow federal funds rates estimated with one or twelve lags (instead of two) still fall within the 95%-confidence band of the baseline two-lag

¹⁸ Chadha, Turner and Zampolli (2013) suggest that this may have been a key factor in keeping long-term yields at extremely low levels.

¹⁹ The Akaike information criterion points to the same number of lags.

specification (Graph 4, left-hand panel). All three shadow rate estimates show a very similar dynamics over time and the quantitative differences are small.

Second, choosing the right number of factors is a crucial step in the estimation of any dynamic factor model. The Hallin-Liska criterion, on which we rely, suggests seven factors as “optimal”. This result is clearly in line with the usual rule of thumb of retaining as many factors as possible to explain at least 90% of the total variance of the underlying dataset. Alternatively, the Bai-Ng (2007) criterion suggests three factors, which would account for around 70% of the total variance. Graph 4 (right-hand panel) reports two shadow federal funds rate series, one based on three factors, and the other on just one factor. Apparently, shadow rate estimates based on a smaller number of factors turn out to miss the significant stimulus from LSAP1 as the estimates stay above the upper limit of the confidence band in much of 2009. Yet such estimates manage to account for the stimulus provided by LSAP2 in 2011.

Last but not the least, a key element for the success of any monetary policy stance indicator is the proper selection of the variables to be included. Essentially, the information content of the shadow rate is limited by the data on which the dynamic factor model is estimated. Whether the shadow policy rate reflects the full range of the Federal Reserve monetary policy operations – but nothing more than that – depends on the quality of the underlying monetary dataset we put together in the first place. As we argue in Section II.2, our choice of variables is based on sound economic reasoning: we try to be comprehensive and make sure that our data represent all different aspects of monetary policy measures over the entire sample period, which include post-crisis unconventional policies. Yet what would happen had we left out some important elements?

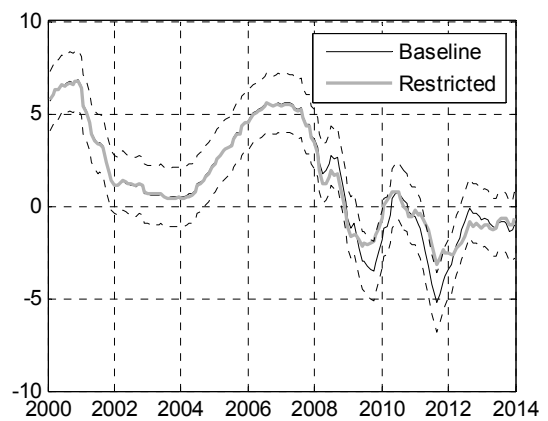
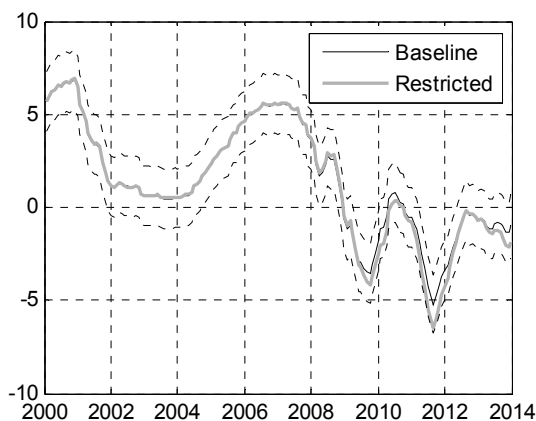
Robustness of the shadow FFR to data selection¹

In per cent

Graph 5

Excluding maturity structure of government bonds²

Excluding balance sheet items³



¹ The black lines refer to the baseline specification on the full dataset, together with 95% confidence bands. ² The grey line refers to a restricted dataset, from which we exclude the series on the maturity composition of the Fed’s holdings of government bonds. ³ The grey line refers to a restricted dataset from which we exclude the series on the maturity composition of the Fed’s holdings of government bonds, as well as all balance sheet items.

Source: Authors’ calculations.

To answer this question, we re-estimate the dynamic factor model using two “reduced” datasets. In the first exercise, we exclude the series related to the maturity

composition of the Federal Reserve's holdings of Treasury bonds. In the second exercise, we further exclude all information on the Federal Reserve's balance sheet, so that the shadow funds rate is effectively constructed using only the yield curve and monetary aggregates.²⁰

The results are reported in Graph 5, together with the baseline shadow rate and its confidence band. In fact, the exclusion of potentially relevant and informative series does not appear to alter results in a dramatic way. Excluding information on the maturity composition of the Federal Reserve's asset holdings (Graph 5, left-hand panel) yields a pattern very similar to that of the baseline shadow rate. Yet excluding information on the Federal Reserve's balance sheet, unsurprisingly, downplays the extent of stimulus provided by both the Federal Reserve's LSAP1 and LSAP2 asset purchase programmes (Graph 5, right-hand panel), since this constrained shadow rate estimate can only provide information on non-standard measures to the extent that US yield curve and monetary aggregates are affected by these. But in both cases, the "restricted" shadow rate estimates remain inside the confidence band for the baseline estimate.

IV. Filling the gap: effectiveness of unconventional policies

In this section, we provide some substantive analysis to demonstrate how one can employ our shadow federal funds rate in a standard monetary policy analysis.

First, we check if unconventional monetary policy measures, which include various central bank lending facilities, large-scale asset purchases, maturity extension, and forward guidance, would nudge the shadow policy rate closer to the levels prescribed by standard Taylor rules.²¹ In other words, have the non-standard measures managed to fill the policy gap opened when the federal funds rate practically hit the zero lower bound, while Taylor Rules suggested negative values? We then examine, in canonical monetary VAR models, whether our shadow policy rate provides a better description of the underlying shocks to monetary policy in the post-ZLB period. The exercises are intended to validate our dynamic factor model-based shadow policy rate procedure, and to gauge the overall monetary stance, especially the effectiveness of unconventional monetary policies in the aftermath of the global financial crisis.

IV.1 The shadow federal funds rate and Taylor Rules

One critical issue in the design and implementation of the vast arsenal of unconventional monetary policy measures is to what extent such measures are effective and have eventually eliminated, or at least reduced, the policy gap that emerged since the zero lower bound on short interest rates set in. Due to the sharp

²⁰ In both cases, the number of factors and the lag order are chosen according to the same criteria as in the baseline case.

²¹ We also compared our shadow federal funds estimates to the updated series of the Laubach-Williams (2003) natural interest rate. The Laubach-Williams rate, by definition an equilibrium real rate and a useful benchmark for policy, is naturally very smooth over the sample period compared to the various nominal rates we use in this section.

economic downturn during the Great Recession, Taylor Rules would suggest a very loose policy stance with negative nominal federal funds rates. To check whether this has been the case, one needs to summarise the non-standard measures in terms of the federal funds rate. In other words, if, for instance, the Federal Reserve's purchases of \$600 billion of longer-term Treasury bonds during the LSAP2 were equivalent to a reduction of the federal funds rate by 50 basis points, would these purchases have been sufficient for the "implicit" shadow federal funds rate to become negative enough to attain the levels suggested by standard Taylor rules?

We answer this question with a simple exercise.²² We first compute the levels of federal funds rates recommended by simple Taylor Rules, and then compare the estimated shadow funds rate to the Taylor benchmark rates. The Taylor rates are computed based on the latest US data as follows:

$$i = \pi + 0.5y + 0.5(\pi - 2) + 2, \quad (3)$$

where i is the federal funds rate, π is the current rate of inflation, y is a measure of output gap. The inflation target or equilibrium rate of inflation is set to be 2, so is the equilibrium real interest rate. The parameterisation of this rule follows Taylor (1993), who shows that the rule closely tracked the effective federal funds rate movements in his original sample period from 1987 to 1990. A second rule, analysed by Taylor (1999) and recommended by Ball (1999) and by Yellen (2012), who renamed it as the "balanced-approach rule", takes a slightly different parameterisation:

$$i = \pi + y + 0.5(\pi - 2) + 2. \quad (4)$$

In this case the central bank respond more aggressively to movements in the output gap. The Taylor Rules are simple and straightforward and are known to provide a good description of the Federal Reserve's behaviour in much of the post-war era, including the period when the Federal Reserve targeted monetary aggregates.

We compute the Taylor (1993, 1999) benchmark rates using inflation rates based on CPI, PCE and the GDP deflator, and measures of economic slack based on the output gap and unemployment gap. We use three distinct gap measures: the first one is based on the Hodrick-Prescott filter, the second uses the difference between the actual and potential real GDP in levels and growth rates using updated output gap and potential growth series based on Laubach and Williams (2003), and the third is derived from US Congressional Budget Office's (CBO) estimates of potential output and long-term NAIRU. All have known deficiencies, and the Hodrick-Prescott filtered series behave especially poorly towards the end of the sample. The shadow federal funds rate is averaged to the quarterly frequency, and the rates derived from Taylor rules (1993, 1999) are based on the latest data.²³

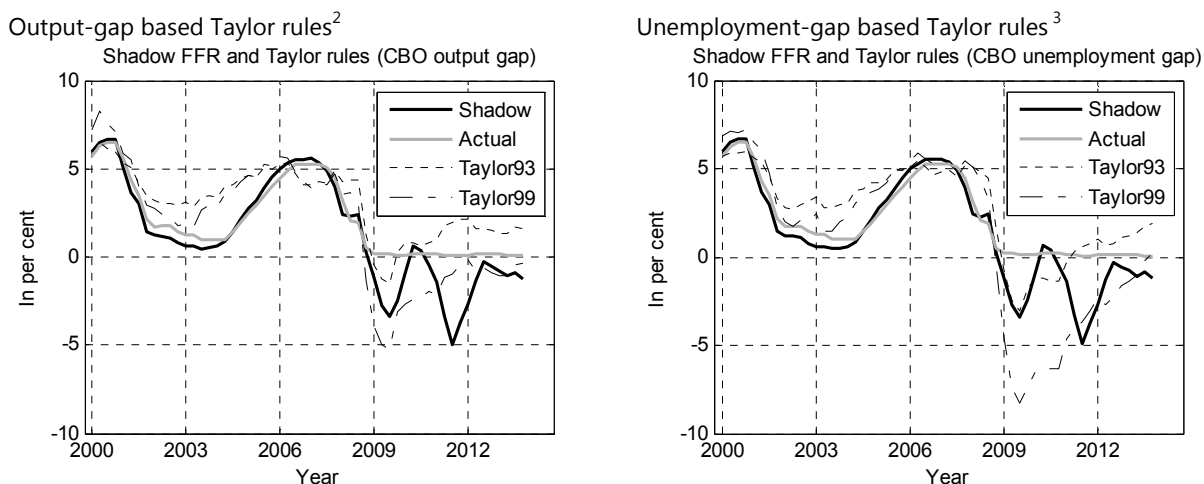
²² Note that we do not address here the issue of whether central banks target both macroeconomic and financial stability, nor the possible implications of an extended period of low interest rates for financial stability.

²³ The estimated Taylor-rule (1993, 1999) rates based on the latest data can be different from previous estimates due to significant data revisions in the past. This can lead to different implications for monetary policy. Orphanides (2003) and Kahn (2012) compared Taylor rules estimated using different vintages of data and uncovered substantial differences among these, even within the original sample period of Taylor (1993)

Shadow FFR and Taylor rule prescriptions¹

In per cent

Graph 6



¹The black lines refer to the estimated shadow federal funds rate and the grey line refers to the actual effective federal funds rate. Numbers on the horizontal scale are placed to indicate the start of the year. ² The comparison is made against Taylor (1993) and Taylor (1999) rules based on CBO estimates of potential output. ³ The comparison is made against Taylor (1993) and Taylor (1999) rules based on CBO estimates of long-term NAIRU.

Source: Authors' calculations.

The results based on CBO estimates are displayed in Graph 6. They suggest that monetary policy stance, as indicated by both the shadow and actual federal funds rates, was too loose or expansionary between 2001 and 2006.²⁴ As the crisis neared, monetary policy did not react fast enough and remained tight in much of 2007. Once the federal funds rate was rapidly cut to near zero, unconventional measures provided additional monetary stimulus and the shadow rate turned negative in early 2009, but not as rapidly as Taylor (1999) rules based on CBO measures would indicate. Yet the LSAP1 was effective in lowering the shadow rate to below -3.5% in September 2009, effectively covering half to over two-thirds of the maximum policy gaps derived from the CBO output- and unemployment-gap-based Taylor (1999) rules and more than covering the maximum policy gaps derived from the Taylor (1993) rules. Notably, policy rates suggested by Taylor (1993) rules appear to be much higher than those implied by Taylor (1999) rules from late 2008 on, as one would expect.

However, the shadow federal funds rate rebounded quickly to above zero in May 2010 as the LSAP1 was wrapped up, well above the levels suggested by Taylor (1999) rules although it was below the level suggested by the output-gap based Taylor (1993) rule. On this measure, then, the monetary policy stance became less accommodative through much of 2010, until it was loosened sharply with the implementation of LSAP2, which was announced in November 2010. However, judged against the Taylor benchmarks, the monetary policy stance was rather loose in 2011. Interestingly, the MEP, announced in September 2011, appeared not to have had much of an impact in further easing the policy stance. Indeed, the shadow

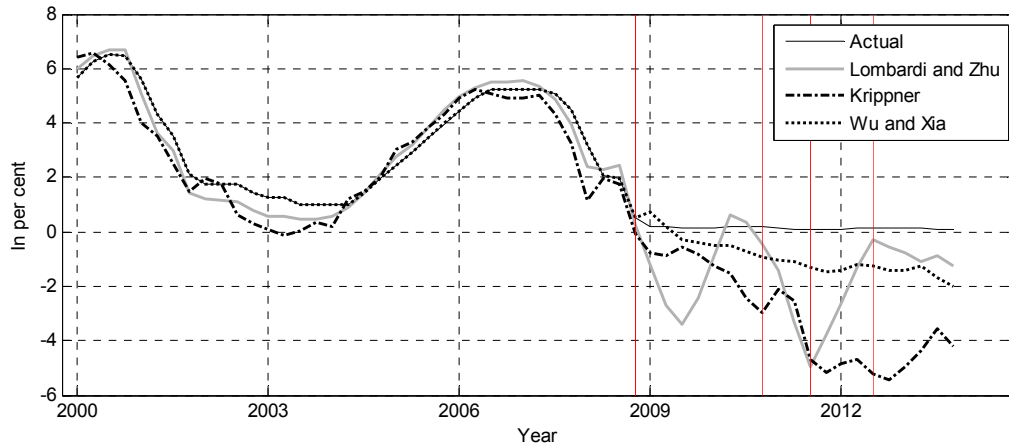
²⁴ Taylor (2007) suggests that US monetary policy could have been too loose from 2000 to 2006, when the actual federal funds rate is compared to a counterfactual scenario based on a Taylor rule.

rate suggests that the policy stance became less expansionary since August 2011, rising to a level more consistent with the output-gap-based Taylor (1999) rule by mid-2012. But the stance would be still considered loose judging by Taylor (1993) rules.

Alternative estimates of the shadow federal funds rate¹

In per cent

Graph 7



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

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

This last finding raises some questions on Bullard's (2012, 2013) claim, based on Krippner's (2012) shadow market rate, that the Federal Reserve's policy stance became excessively loose in 2012. In Graph 7, we report two alternative estimates of the shadow rate which extend the Black (1995) intuition of interest rates as options, one provided by Krippner (2013a) and the other by Wu and Xia (2014). While the first estimates provided by Krippner (2012) dropped to below -9% in August 2011, indeed suggesting an overly loose monetary policy stance, the more recent estimates based on Krippner (2013a) suggest levels that are more consistent with our shadow policy rate estimates towards mid-2011, and suggesting a less expansionary US monetary policy stance by the end of 2012. On the other hand, the Wu-Xia estimate never dropped to below -2% until late 2013, but has continued to decline (to -2.9% in April 2014) despite a recent rise in long-term interest rates and the Federal Reserve's successive decisions to taper asset purchases since December 2013. Indeed the Wu-Xia rate implies that US monetary policy was very tight especially in the earlier years when the zero lower bound on interest rates began to bind, and became rather loose in recent quarters.

IV.2 Shadow funds rate, policy shocks and monetary VARs

In this section, we discuss the use of the shadow federal funds rate in standard VAR models for monetary policy analysis, focusing on the use of interest rate shocks to

measure monetary policy.²⁵ Applying these models mechanically to samples that include periods when the ZLB is binding and policy rates are stuck at close to zero exposes researchers to the risk of grossly underestimating the true extent of policy stimulus provided by a central bank engaged in non-standard measures. We make the point by applying the shadow funds rate in monetary policy analysis using two canonical VAR models, and we show that the shadow rate provides a more appropriate measure of the post-ZLB unconventional stimulus.

We focus on two standard model specifications, the VAR model of Bernanke and Blinder (1992) and a more complex monetary VAR of Christiano, Eichenbaum and Evans (1996). The model by Bernanke and Blinder (1992) consists of three key macro variables: the log of real GDP, the log of the real GDP deflator, and the federal funds rate. The identification of the structural shocks is based on a recursive Choleski identification scheme: real GDP is postulated to react only with a lag to inflation and monetary policy, and inflation reacts only with a lag to monetary policy shocks.

We estimate both VAR systems using data ranging from January 1970 to December 2013, using four lags in this exercise, as is common practice.²⁶ We then extract, in two separate exercises, two monetary policy shocks, one based on the actual federal funds rate, another based on our estimated shadow federal funds rate. The results suggest that the use of the actual federal funds rate would lead a researcher to conclude wrongly that too little monetary stimulus was provided since late 2008, as shocks to the actual funds rate were rather small and only mildly negative (Graph 8, left panel). In contrast, monetary shocks estimated using our shadow funds rate series clearly indicate sizeable easing, its timing corresponding to the implementation of LSAP1, LSAP2 and LSAP3. The shocks suggest that the LSAP2 provided unprecedented easing to the economy.

The Christiano, Eichenbaum and Evans (1996) VAR model is more elaborate in that it contemplates various measures of money policy, which include total reserves, non-borrowed reserves and the federal funds rate. They also include in their model an index of sensitive commodity prices to control for possible price puzzles and for endogenous policy responses to such price movements.²⁷ Specifically, the model features the log of real GDP, the log of the GDP deflator, the log of a commodity price index, the log of non-borrowed reserves, the federal funds rate, and the log of total reserves. As in Bernanke and Blinder (1992), the identification of structural shocks is based on a recursive Choleski ordering.

²⁵ Unlike monetary analysis based on policy rules, i.e. the anticipated or endogenous part of policy, Bernanke and Mihov (1998) point out the importance of studying innovations to the federal funds rate as it enables one to assess monetary policy effects with “minimal identifying assumptions”.

²⁶ This exercise is of course subject to a number of caveats, in particular that the macroeconomy and monetary policy may both have been subject to a structural break in the aftermath of the Great Recession. However, our objective here is not to pin down the most appropriate VAR model for post-crisis monetary policy, but rather to illustrate how the results differ based on the FFR series one employs.

²⁷ See Sims (1992) for further details on the price puzzle.

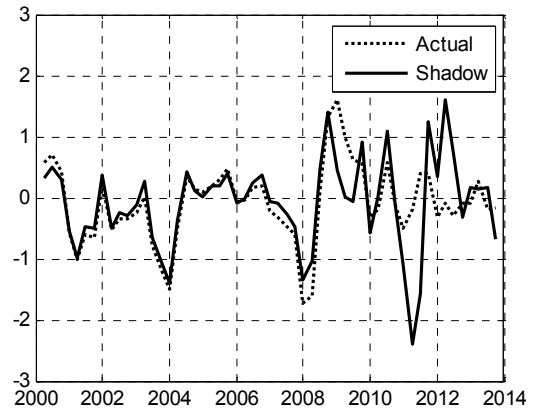
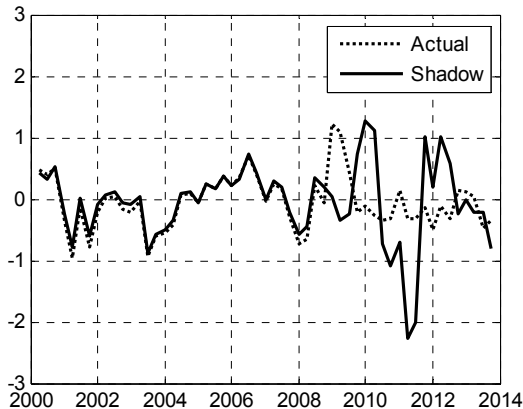
Monetary policy shocks¹

In per cent

Graph 8

Bernanke and Blinder (1992)²

Christiano, Eichenbaum and Evans (1996)³



¹ Structural shocks are extracted using recursive Choleski schemes; estimation is based on data from January 1970 until December 2012. The dashed line corresponds to a model estimated with actual FFR, while the solid line refers to the shadow FFR series. ² The model features (in order) the log of real GDP, the log of the GDP deflator and the FFR. ³ The model features (in order) the log of real GDP, the log of the GDP deflator, the log of commodity prices, the log of non-borrowed reserves, the FFR and the log of total reserves.

Source: Authors' calculations.

The estimated monetary policy shocks based on both the shadow and actual federal funds rates are presented in the right-hand panel of Graph 8. Given that this model includes, in addition to the federal funds rate, two monetary aggregates that are potentially more revealing of unconventional measures (i.e. total and non-borrowed reserves), it is not surprising that the difference between monetary policy shocks based on the actual and the shadow federal funds rates becomes less pronounced over much of the sample period. Nevertheless, the benefits from a policy indicator based on more comprehensive monetary information become clear in the post-crisis period, when unconventional policies are the norm. In fact, shocks to our shadow funds rate again reveal sizeable monetary stimulus with the implementation of the LSAP2 in late 2010, while the stimulus appears to be minor if we assess monetary policy based on shocks to the actual federal funds rate constrained by the ZLB. Monetary policy shocks estimated in the standard way would therefore severely understate the true extent of monetary expansion afforded by non-standard policy measures implemented after the breakout of the financial crisis.

V. Concluding remarks

This paper introduces an intuitive and, we believe, easy-to-use measure of the US monetary policy stance that incorporates the effects of changes in the Federal Reserve's balance sheet. As Friedman (2014) suggests, central bank balance sheet policies are likely to remain relevant for some years to come. If so, the effective stance of monetary policy could not be gauged accurately by only looking at policy rates.

Our measure is based on a comprehensive set of information on monetary policy operations, and comes in the form of a shadow federal funds rate that has the advantage of being unaffected by the zero lower bound on nominal interest rates. Unlike shadow market rates estimated à la Black (1995), which may include information over and above a central bank's policy actions, our indicator directly measures US monetary policy, in that it is derived solely from the data closely linked to the Federal Reserve's monetary operations. Being estimated using data readily available to the Federal Reserve and the public at a high frequency, the shadow federal funds rate can be computed in real time.

We showed that our shadow policy rate is robust to different specifications, and works well both before the crisis and after the zero lower bound became binding. It does not suffer from the problem of shadow rates estimated à la Black (1995), which are very sensitive to the underlying term structure model. The single policy indicator gives a good representation of unconventional policies. In fact, our measure can be used across different monetary policy regimes as it includes information on monetary aggregates, interest rates and crucially, the Federal Reserve's balance sheet.

Furthermore, our analysis with the shadow federal funds rate suggests that the unconventional policies were able to fill in a substantial portion of the policy gap between the ZLB and Taylor rule rates. Monetary policy provided the greatest stimulus over 2011, with the shadow policy rate dropping to below -5% in August, but it became less accommodative since then, before loosening again starting in October 2012. We also applied the shadow funds rate in standard VAR models, and we found that monetary policy shocks estimated this way provided a far more realistic picture of US monetary policy in the post-crisis period than those based on the actual federal funds rate.

References

- Avery R (1979): "Modeling monetary policy as an unobserved variable", *Journal of Econometrics*, 10, pp 291–311.
- Bai, J and S Ng (2007): "Determining the number of primitive shocks in factor models", *Journal of Business and Economic Statistics*, 25, pp 52–60.
- Ball, L (1999): "Efficient rules for monetary policy", *International Finance*, 2, pp 63–83.
- Banbura, M and M Modugno (2014): "Maximum likelihood estimation of factor models on datasets with arbitrary pattern of missing data", *Journal of Applied Econometrics*, 29, pp 133–160.
- Barnett, W (1980): "Economic Monetary Aggregates: An Application of Index Number and Aggregation Theory", *Journal of Econometrics*, 14, pp 11-48.
- Barnett, W, D Fisher and A Serletis (1992): "Consumer theory and the demand for money", *Journal of Economic Literature*, 30, pp 2086–2119.
- Bauer M and G Rudebusch (2013): "Monetary policy expectations at the zero lower bound", *FRBSF Working Paper*, 2013-18.
- Bernanke, B and A Blinder (1992): "The federal funds rate and the channels of monetary transmission", *American Economic Review*, 82, pp 901–921.

- Bernanke, B, M Gertler and M Watson (1997): "Systematic monetary policy and the effects of oil price shocks", *Brookings Papers on Economic Activity*, 1, pp 91–142.
- Bernanke, B and I Mihov (1998): "Measuring monetary policy", *Quarterly Journal of Economics*, 113, pp 869–902.
- Black, F (1995): "Interest rates as options", *Journal of Finance*, 50, pp 1371–1376.
- Bomfim, A (2003): "'Interest rates as options:' Assessing the markets' view of the liquidity trap", *Federal Reserve Board Finance and Economics Discussion Series*, 2003-45.
- Bullard, J (2012): "Shadow interest rates and the stance of U.S. monetary policy", speech at the Annual Corporate Finance Conference, Olin Business School, Washington University in St. Louis, November 8.
- Bullard, J (2013): "Perspectives on the current stance of monetary policy", speech at the NYU Stern Center for Global Economy and Business, New York, February 21.
- Chadha, JS, P Turner and F Zampolli (2013): "The interest rate effects of government debt maturity", *BIS Working Papers*, 415.
- Chen, Q, A Filardo, D He and F Zhu (2012): "International spillovers of central bank balance sheet policies", *BIS Papers*, 66, pp 220–64.
- Chen, Q, A Filardo, D He and F Zhu (2014): "Financial crisis, unconventional monetary policy and international spillovers", *manuscript*.
- Christensen J and G Rudebusch (2013): "Estimating shadow-rate term structure models with near-zero yields", *FRBSF Working Paper*, 2013-07.
- Christiano, L, M Eichenbaum and C Evans (1996): "The effects of monetary policy shocks: evidence from the flow of funds", *Review of Economics and Statistics*, 78, pp 16–34.
- Curdia, V and M Woodford (2011): "The central-bank balance sheet as an instrument of monetary policy", *Journal of Monetary Economics*, 58, pp 54–79.
- Dempster A, N Laird and D Rubin (1977): "Maximum likelihood estimation from incomplete data", *Journal of the Royal Statistical Society B*, 39, pp 1–38.
- Doz, C, D Giannone and L Reichlin (2011): "A two-step estimator for large approximate dynamic factor models based on Kalman filtering", *Journal of Econometrics*, 164, pp 188–205.
- Doz, C, D Giannone and L Reichlin (2012): "A quasi-maximum likelihood approach for large approximate dynamic factor models", *Review of Economics and Statistics*, 94, pp 1014–1024.
- Engle, R and M Watson (1981): "A one-factor multivariate time series model of metropolitan wage rates", *Journal of the American Statistical Association*, 76, pp 774–781.
- Estrella, A and F Mishkin (1997): "Is there a role for monetary aggregates in the conduct of monetary policy?", *Journal of Monetary Economics*, 40, pp 279–304.
- Friedman, B and K Kuttner (1992): "Money, income, prices, and interest rates", *American Economic Review*, 82, pp 472–492.
- Friedman, B (2014): "Has the financial crisis permanently changed the practice of monetary policy? Has it changed the theory of monetary policy?", lecture at the

Royal Economic Society Conference on Monetary Analysis and Monetary Policy Frameworks, Heriot-Watt University, Edinburgh, April 9.

Friedman, M and A Schwartz (1963): "A monetary history of the United States 1867–1960", Princeton University Press, Princeton, NJ.

Froyen, R (1974): "A test of the endogeneity of monetary policy", *Journal of Econometrics*, 2, pp 175–188.

Gambacorta, L, B Hofmann and G Peersman (2014): "Effectiveness of unconventional monetary policy at the zero lower bound: a cross-country analysis", *Journal of Money, Credit and Banking*, forthcoming.

Gorovoi, V and V Linetsky (2004): "Black's model of interest rates as options, eigenfunction expansions, and Japanese interest rates", *Mathematical Finance*, 14, pp 49–78.

Hallin, M and R Liska (2007): "Determining the number of factors in the general dynamic factor model", *Journal of the American Statistical Association*, 102, pp 603–617.

Havrilesky, T (1967): "A test of monetary policy action", *Journal of Political Economy*, 75, pp 299–304.

Kahn, G (2012): "Estimated rules for monetary policy", *Federal Reserve Bank of Kansas City Economic Review*.

Kim, D and K Singleton (2012): "Term structure models and the zero bound: an empirical investigation of Japanese yields", *Journal of Econometrics*, 170, pp 32–49.

Kim, S (1999): "Do monetary shocks matter in the G-7 countries? Using common identifying assumptions about monetary policy across countries", *Journal of International Economics*, 48, pp 387–175.

Krippner, L (2012): "Modifying Gaussian term structure models when interest rates are near the zero lower bound", *Reserve Bank of New Zealand Discussion Paper*.

Krippner, L (2013a): "A tractable framework for zero-lower-bound Gaussian term structure models", *Reserve Bank of New Zealand Discussion Paper*.

Krippner, L (2013b): "Measuring the stance of monetary policy in zero lower bound environments", *Economic Letters*, 118, pp 135–138.

Laubach, T and J Williams (2003): "Measuring the natural rate of interest", *Review of Economics and Statistics*, November, pp 1063–1070.

Meaning, J and F Zhu (2011): "The impact of recent central bank asset purchase programmes", *BIS Quarterly Review*, December, pp 73–83.

Meaning, J and F Zhu (2012): "The impact of Federal Reserve asset purchase programmes: another twist", *BIS Quarterly Review*, March, pp 23–32.

Orphanides, A (2003): "Historical monetary policy analysis and the Taylor rule", *Journal of Monetary Economics*, 50, pp 983–1022.

Romer, C and P Romer (1989): "Does monetary policy matter?: A new test in the spirit of Friedman and Schwartz", *NBER Macroeconomics Annual*, NBER, Cambridge, MA.

Romer, C and P Romer (2000): "Federal Reserve Information and the Behavior of Interest Rates", *American Economic Review*, 90, pp 429–57.

- Romer, C and P Romer (2004): "A new measure of monetary shocks: derivation and implications", *American Economic Review*, 94, pp 1055–84.
- Rotemberg, J (1991): "Monetary aggregates and their uses", in *Monetary Policy on the 75th Anniversary of the Federal Reserve System*, ed. M Belongia, Kluwer Academic Press, pp 224–232.
- Rotemberg, J, J Driscoll and J Poterba (1995): "Money, output, and prices: Evidence from a new monetary aggregate," *Journal of Business & Economic Statistics*, 13, pp 67–83.
- Peersman, G (2011): "Macroeconomic effects of unconventional monetary policy in the Euro area", *ECB Working Paper*, 1397.
- Sims, C (1992): "Interpreting the macroeconomic time series facts: the effects of monetary policy", *European Economic Review* 36, pp 975–1000.
- Sims, C (1998): "Role of interest rate policy in the generation and propagation of business cycles: what has changed since the '30s?," *Federal Reserve Bank of Boston Conference Proceedings*, pp 121–175.
- Sims, C and T Zha (2006): "Does monetary policy generate recessions?," *Macroeconomic Dynamics*, 10, pp 231–272.
- Taylor, J (1993): "Discretion versus policy rules in practice", *Carnegie Rochester Conference Series on Public Policy*, 39, pp 195–214.
- Taylor, J (1999): "A historical analysis of monetary policy rules", in *Monetary Policy Rules*, ed. J Taylor, National Bureau of Economic Research, University of Chicago Press, pp 319–348.
- Taylor, J (2007): "Housing and monetary policy", *Federal Reserve Bank of Kansas City, Proceedings*, pp 463–476.
- Thornton, DL and P Yue (1992): "An extended series of Divisia monetary aggregates", *Federal Reserve Bank of St. Louis Review*, 74, pp 35–52.
- Watson, MW and RF Engle (1983): "Alternative algorithms for the estimation of dynamic factor, mimic and varying coefficient regression models", *Journal of Econometrics*, 23, pp 385–400.
- Woodford, M (2012): "Methods of policy accommodation at the interest-rate lower bound", *Presented at the 2012 Jackson Hole symposium*.
- Wu, J and F Xia (2014): "Measuring the macroeconomic impact of monetary policy at the Zero Lower Bound", *NBER Working Paper*, 20117.
- Ueno, Y, N Baba and Y Sakurai (2006): "The use of the black model of interest rates as options for monitoring the JGB market expectations", *Bank of Japan Working Paper*, 2006-E-15.
- Yellen, J (2012): "Perspectives on monetary policy", speech at the Boston Economic Club Dinner, Boston, Massachusetts, June 6.